

PERCEPTION

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Abstracts

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Twenty-seventh European Conference on Visual Perception

Budapest, Hungary

22 – 26 September 2004

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ECVP '04 Abstracts

SUNDAY

HUNGARIAN SYMPOSIUM

HUNGARIANS IN VISUAL SCIENCE AND ART

◆ **Adolf von Szily (1848 – 1920) and visual science**

N J Wade, B Gillam¶, W H Ehrenstein§, G Kovács#, Z Vidnyánszky‡ (Department of Psychology, University of Dundee, Perth Road, Dundee DD1 4HN, Scotland, UK; ¶ School of Psychology, University of New South Wales, Sydney, NSW 2052, Australia; § Institut für Arbeitsphysiologie, Universität Dortmund, Ardeystrasse 67, D 44139 Dortmund, Germany; # Center for Cognitive Sciences, Budapest Technical University, Műegyetem-rkp. 3-9, H 1111 Budapest, Hungary; ‡ Neurobiology Research Group, Hungarian Academy of Sciences, Semmelweis University, H 1094 Budapest, Hungary; e-mail: n.j.wade@dundee.ac.uk)

Adolf von Szily was born in Budapest, studied medicine in Vienna, and returned to Budapest to practice ophthalmology. In addition to his ophthalmological research, he explored a range of topics in visual science, including motion aftereffects, fluttering hearts, and stereoscopic depth perception. He demonstrated that a physically stationary pattern that appears to move as a consequence of surround motion yields a motion aftereffect when the surround motion ceases. This close relationship between simultaneous and successive motion contrast has assumed considerable theoretical significance. He explored interactions between colour, space, and motion in the fluttering-hearts phenomenon. His paper on stereoscopic depth, first given in 1894 at a conference in Vienna, was published posthumously by his son, Aurel (an even more famous ophthalmologist). It described a novel stereoscopic technique using all-black figures (silhouettes) with certain monocular appendages; they form subjective contours in front of the binocular shape or amodal completions behind it. This technique anticipated a number of modern findings and the recent interest in Da Vinci stereopsis. Despite these farsighted investigations, von Szily's work has been sadly neglected within visual science.

◆ **Lajos Kardos: outstanding Hungarian Gestaltist**

A Gilchrist (Department of Psychology, Rutgers University, 101 Warren Street, Newark, NJ 07102, USA; e-mail: alan@psychology.rutgers.edu)

Though little known today, Lajos Kardos was a brilliant Gestalt psychologist. His work in lightness, advanced even by today's standards, is captured in his 1934 monograph *Object and Shadow*, recently translated into English. He was the first to clearly demonstrate the influence of depth perception on lightness. He emphasised the relational determination of lightness and the role of illumination frames of reference, addressing the crucial question of what proximal factors allow the segmentation of such frames. He worked with 'inumbra' or hidden shadows, including the Kardos illusion, the inverse of the Gelb effect that is known in limited circles. His most important theoretical contribution was the concept of co-determination. Kardos argued that the lightness of an object is never computed exclusively relative to its own frame of reference, but rather shows an influence from foreign, or adjacent fields of illumination as well. Here, we find the most developed theory of lightness-constancy failures. Kardos also made distinguished contributions in animal learning and economics.

◆ **Dennis Gabor's holography and its consequences for the arts**

D Jung (Academy of Media Arts, Peter-Welter Platz 2, D 50676 Cologne, Germany; e-mail: jungdie@web.de)

The quest for new forms of expression and aesthetic light effects in colour and space constitutes one of the most fascinating phenomena in the history of art. Light art, kinetic art, and the manifold sphere of holography are brought into a broader dialogue context, revealing interrelationships between them at many different levels in what can only be described as a multi-media, kaleidoscopic, spatial enigma. Cross-genre interpretations of old and new realities and the orientation these offer for the future are explored. Since the late 60s, painters, photographers, sculptors, light artists, musicians, and dancers have been producing remarkable holographic works of art in collaboration with scientists and technicians. Drifting into this form of art from conventional genres, artists from all corners of the globe and diverse cultures have discovered in holography common ground and a congenial medium for polyphonic expression in alternation

Sunday

with their own particular art form. Art is presented here as an experience in the context of individual artistic competence through contraposition of matter and material, surface and space, transparent and solid, static and interactive. The horizontal and vertical lines that chart the intricate patterns of the real world resonate with the transparency and deception of spatial illusion devoid of a vanishing point.

◆ **Victor Vasarely's monster pictures**

A Pierre (Département d'Histoire de l'Art, Université de Grenoble II, 7 rue de la Santé, F 75013 Paris, France; e-mail: avpierre@pop3.club-internet.fr)

Although part of the Constructivist lineage, Victor Vasarely's work can also be seen as a perversion of that very lineage insofar as it opens onto a world of meaning very different from that of 'classic' Constructivism. In the latter, the artist strives to achieve total mastery of the world via consciousness according to a reasoned and calculated plan, making clear-cut and literal use of plastic elements. Vasarely, on the other hand, uses an astonishingly inventive range of illusionistic processes, originated directly from the visual patterns used in the psychology of vision, to underscore the impossibility of capturing appearances, the pitfalls of vision, and the endless metamorphosis of a visible world in a state of constant flux. It might be said that never since the Mannerist and Baroque periods had such trickery been devised. Vasarely called his compositions 'monster pictures', and they are indeed proof that it is not just the sleep of reason but also its excesses, or certain logical processes taken to absurd extremes, which produce monsters. Vasarely's work likewise produces a fundamental sense of doubt vis-à-vis the appearances of the world, a doubt that rests on scientific knowledge and imagination from which it is no longer possible to obtain anything but unstable, intangible, mobile, and multi-dimensional images.

THE PERCEPTION LECTURE

◆ **Perceiving objects and locating them in space**

M Morrone (Università 'Vita-Salute' San Raffaele, via Olgettina 58, I 20132 Milan, and Istituto di Neuroscienze, CNR, via Moruzzi 1, I 56100 Pisa, Italy; e-mail: concetta.morrone@hsr.it)

The visual system is faced with many difficult tasks, including segmenting the retinal image into meaningful objects, and localising those objects stably in space in the face of continual movements of the eyes. I briefly review the current knowledge on these two processes, from theories of spatial filters to the recent concepts of spatially invariant receptive fields that encode and classify objects; and from labelled-line theories to recent discoveries of neural mechanisms that create spatial maps anchored to the external world rather than the retina. The physiological properties of the ventral stream in human and monkey allow it to segment images and to classify their content, while the dorsal stream takes advantage of efference copy and eye-position signals to create a world-centred spatial representation. In this talk I attempt to bring together the seemingly separate problems of segmentation and spatial localisation within a single, biologically plausible model.

MONDAY
ORAL PRESENTATIONS**EYE MOVEMENTS**

◆ **How smooth pursuit eye movements affect the perceived direction and speed of moving objects**

J L Souman, I T C Hooge, A H Wertheim (Helmholtz Institute, Department of Psychonomics, Utrecht University, Heidelberglaan 2, NL 3584 CS Utrecht, The Netherlands; e-mail: j.l.souman@fss.uu.nl)

Most studies concerned with motion perception during smooth pursuit eye movements have focused on the perception of collinear object motion. Usually, the dependent variable in those studies is the perceived speed of the object. In contrast, in the few studies addressing non-collinear object motion, it is perceived motion direction that has been measured. This makes the two classes of studies hard to compare. To address this issue, we developed a method to measure both perceived motion direction and speed at the same time. A random-dot kinematogram (RDK; direction ranging between 180° and 360°) was first presented during smooth pursuit and in a second interval during fixation. Observers had to match speed and direction in the second interval to the perceived velocity in the first one. The results show that the eye movements affected only the horizontal component of the perceived velocity. This component was shifted against the pursuit direction, with the shift being approximately constant across RDK motion directions. Interpreted in terms of a linear model of perceived velocity (perceived velocity equals estimated retinal velocity plus estimated eye velocity) these results suggest that the errors in perceived velocity are mainly due to underestimation of the eye velocity, not to overestimation of the retinal image velocity.

◆ **Eye movements, corollary discharge, and perceptual coherence**

Z M Hafed, R J Krauzlis (Systems Neurobiology Laboratory, Salk Institute for Biological Studies, 10010 North Torrey Pines Road, La Jolla, CA 92037, USA; e-mail: zhafed@salk.edu)

Perception can guide eye movements, but the influence of eye movements on perception has received less attention. We hypothesised that corollary discharge from eye movements helps resolve the ambiguity of retinal images and thereby promotes perceptual coherence. To test this, we compared three conditions with different eye movements but the same retinal stimulus. The stimulus consisted of two vertical apertures that revealed four line segments, consistent with a chevron whose vertices were occluded. In one condition (fixation), subjects ($n = 3$) fixated a central spot while the chevron translated along a circular trajectory. In the other conditions, the spot and occluder translated sinusoidally in a horizontal (orthogonal to the apertures) or vertical (parallel) direction, while the chevron moved sinusoidally along the complementary axis; subjects tracked the spot, producing the same retinal stimulus as in the fixation condition. Subjects reported whether or not the lines cohered as one object. Tracking increased coherence (65% versus 32% for fixation). This increase was larger for orthogonal (+50%) than parallel (+15%) tracking, showing that the benefit was specific to movements providing directional information that resolves the ambiguous motion in the apertures. These findings argue that corollary discharge from eye movements constrains the perceptual interpretation of ambiguous inputs.

◆ **Parafoveal processing during reading**

E Richter, R Engbert (Department of Psychology, University of Potsdam, PO Box 601553, D 14415 Potsdam, Germany; e-mail: richtere@rz.uni-potsdam.de)

Experimental tests for models of gaze control in reading are especially relevant, if they extend their scope beyond the situation of normal reading. Here, a modified version of the SWIFT model (Engbert et al, 2002 *Vision Research* **42** 621–636) has been tested for a situation of degraded visual perception. Sentences of the Potsdam-Corpus (Kliegl et al, 2004 *European Journal of Cognitive Psychology* **16** 262–284) were presented with four kinds of gaze-contingent degradation (normal fovea, no foveal benefit, no fovea, inverted fovea) in a within-subjects design. In a first step, fixation measures (durations, frequencies, landing zone distributions) and oculomotor behaviour (saccade lengths) have been analysed and yielded substantial and, in particular, dramatic effects. In a second step, the SWIFT model was extended by adding the ideas of a spatial processing gradient, delayed inhibition, and decaying activations. We fitted this model separately to the four conditions by means of a genetic algorithm. The gradient parameters reacted in support of the model. In addition, the preferred mean rate of saccade initiation and the foveal inhibition parameter showed systematic responses to the strength of degradation. Some concluding remarks about the plausibility of modifying the model in the light of the data are presented.

Monday

- ◆ **Seeing into the future by going with the flow: The role of gaze and optic flow in steering**
 E E Kadar, S D Rogers, A Costall (Department of Psychology, University of Portsmouth, King Henry Building, Portsmouth PO1 2DY, UK; e-mail: endre.kadar@port.ac.uk)
 Driving round a bend in the road consists of two closely related visually controlled tasks: moving forward by controlling speed, and keeping the car on the road by accurate steering. Previous eye-movement studies have failed to provide an adequate account of these apparently complex tasks (Shinar et al, 1977 *Human Factors* **19** 63–71; Serafin, 1993, Technical Report No. UMTRI-93-29, University of Michigan Transport Research Institute, Michigan, MI; Land and Lee, 1994 *Nature* **369** 742–744). The present simulator study shows that there are two fundamental gaze patterns in curve negotiation and their use depends on the circumstances. Drivers consistently direct their gaze at the tangent point when driving close to the inside contour, and at the outside boundary when driving close to the outside contour. In both cases, speed and accuracy could be controlled by the two basic properties of the optic flow field: the flow rate and the centre of optic expansion [Gibson, 1979 *The Ecological Approach to Visual Perception* (Hillsdale, NJ: Lawrence Erlbaum Associates); Lee, 1976 *Perception* **5** 437–469]. These ideas are compatible with recent neurophysiological findings (Siegal and Read, 1997 *Cerebral Cortex* **7** 327–346; Anderson and Siegal, 1999 *Journal of Neuroscience* **19** 2681–2692).
- ◆ **Event-related fMRI during saccadic gap and overlap paradigms: Neural correlates of express saccades**
 J Özyurt, R M Rutschmann¶, I Vallines¶, M W Greenlee¶ (Institute of Cognitive Science, University of Oldenburg, Ammerländer Heerstrasse 114, D 26129 Oldenburg, Germany; ¶University of Regensburg, Universitätsstrasse 31, D 93053 Regensburg, Germany; e-mail: jale.ozyurt@uni-oldenburg.de)
 Saccadic reaction times can be reduced dramatically when a short temporal gap (~200 ms) is induced between fixation point offset and onset of a peripheral target. These ‘express’ saccades (< 130 ms) are thought to reflect endogenous processes related to the prior release of attention, thereby enhancing a rapid lateral shift to the saccadic target. Whereas the contribution of the superior colliculi to express saccade performance has been examined in several electrophysiological studies, little is known about the role of other cortical and subcortical areas. We used an event-related paradigm to study haemodynamic correlates of saccade control in the gap paradigm (70% express saccades) and the overlap paradigm (5% express saccades). Random-effect analyses (SPM) on nine subjects reveal more activation bilaterally in dorsolateral prefrontal, premotor (FEF), posterior parietal, superior temporal, and posterior cingulate cortex in the overlap paradigm compared to the gap paradigm. The right putamen of the basal ganglia is the only area showing more activation in the gap compared to the overlap task. The findings suggest that express saccades are associated with less cortical and more subcortical activation.

ATTENTION: MECHANISMS

- ◆ **Transcranial magnetic stimulation of the left human frontal eye fields eliminates the cost of invalid endogenous cues**
 D Smith, S R Jackson, C Rorden (School of Psychology, University of Nottingham, University Park, Nottingham NG7 2RD, UK; e-mail: lpxdts@psychology.nottingham.ac.uk)
 There is mounting evidence that covert shifts of attention may activate many of the same brain regions involved when executing eye movements. For example, functional magnetic resonance imaging (fMRI) studies show that the oculomotor regions known as the frontal eye fields (FEF) are involved with shifts of attention. However, it remains possible that the activations seen in these studies result from active inhibition of eye movements rather than modulation of perceptual processing. Here, we provide direct evidence for the role of this region in endogenously driven spatial attention. We show that briefly disrupting the left frontal eye fields with transcranial magnetic stimulation eliminated the slow response times associated with invalid strategic cues when the target appeared in the right visual field. Our findings appear to contradict the null results reported by Grosbras and Paus (2003 *Journal of Cognitive Neuroscience* **14** 1109–1120), and we suggest this is likely due to design differences. Specifically, we disrupted the FEF at the time of cue onset, rather than target onset. Taken together with the findings of Grosbras and Paus, our findings suggest that the FEF plays an early role in the inhibition of perceptual information.

◆ **Transient attention increases performance and neuronal activity in an orientation discrimination task**

M Carrasco, T Liu, F Pestilli (Department of Psychology and Center for Neural Science, New York University, 6 Washington Place, New York, NY 10003, USA; e-mail: Marisa.carrasco@nyu.edu)

Transient attention has been characterised psychophysically—by precueing a target location—and shown to improve performance on early visual tasks, eg contrast sensitivity and spatial resolution. It has been postulated that these effects may depend on striate and extra-striate areas, which are capable of carrying out the necessary computations. To test this hypothesis, we investigated the effects of precueing on brain activity in the striate and extra-striate cortex using rapid event-related fMRI. On each trial, two Gabor patches were presented simultaneously for 150 ms, 4° to the left and right of fixation—one tilted and one vertical. Five observers performed an orientation discrimination task on the tilted stimulus. This display was either preceded or followed by a peripheral cue that was either valid (above the tilted stimulus) or invalid (above the vertical stimulus). The cue and stimulus were positioned at a distance that enabled us to differentiate their cortical activity. Independent localiser scans and retinotopic mapping were also performed to obtain the cortical representation of the Gabor stimulus in early visual areas. For each observer, the valid precue improved accuracy and speed. Correspondingly, we found a progressively greater attentional effect from striate to extra-striate areas (V1, V2, V3, and V3a).

◆ **Measuring the efficiency of attentional filtering**

G Sperling, S A Wurst¶, Z-L Lu§ (Department of Cognitive Sciences and Neurobiology and Behavior, and Institute of Mathematical Behavioral Sciences, University of California at Irvine, Social Sciences Plaza, Building A-3, Irvine, CA 92697, USA; ¶ Department of Psychology, State University of New York at Oswego, NY 13126, USA; § Department of Psychology and Neuroscience Graduate Program, University of Southern California, Los Angeles, CA 90089-1061, USA; e-mail: sperling@uci.edu)

Consider stimuli composed of two classes of items: A-items to which an observer must attend and B-items which the observer must ignore. To measure the efficiency of human observers in excluding information from the unattended B-items, we compared performance with three types of stimuli: AB, the mixed stimulus composed of both A-items and B-items; A–, the B-items are entirely removed, only A-items remain; AA, the feature B is changed to A so that all items contain A and no feature-distinction is possible. Various performance indices are computed, eg $[P(A-) - P(AB)]/[P(A-) - P(AA)]$ gives the fraction of total possible benefit (physically excluding the ignored feature) achieved by attentional exclusion. This index includes a stimulus differentiation benefit in the AB stimuli, so a more complex, pure attentional-exclusion ratio was defined. Performance was measured in a character stream (10 items s⁻¹) with a repetition-judgment task that largely involves perceptual attentional filtering. Various A–B feature-pairs were tested: red–green, LARGE–small, black–white, 45°–135° slant, high-versus-low spatial frequency, and two feature combinations: LARGE–black versus small-white and LARGE–high versus small–low spatial frequency. There are great individual differences; 60% efficiencies were achieved by some subjects for red–green, spatial bandpass, and both feature combinations.

◆ **Common characteristics for attention-induced suppression of motion and disparity information**

A Sahraie, M Milders, M Niedeggen¶ (Vision Research Laboratories, School of Psychology, University of Aberdeen, Aberdeen AB24 2UB, Scotland, UK; ¶ Institute of Experimental Psychology, Heinrich Heine University, Universitätsstrasse 1, D 40225 Düsseldorf, Germany; e-mail: a.sahraie@abdn.ac.uk)

We have previously reported a paradigm in which attentional capacity was modulated in the temporal domain by using two synchronised rapid serial visual presentation (RSVP) streams. A red fixation in one stream was the 'cue' to switch attention to the surrounding global stream. This switch between streams evoked a transient deficit in visual motion perception (Sahraie et al, 2001 *Vision Research* 41 1613–1617) and in detection of a change in disparity. We have proposed that the impairment was due to the active suppression of the distractor events. Here we report on the effect of distractors in activating the suppression mechanism for motion and disparity distractor events. Each subject ($n = 10$) carried out two experiments: a motion discrimination and a detection of disparity. The percentage of distractor events varied between 0%, 20%, and 80%. For both features, performance deteriorated with increasing number of distractors. Furthermore, the extent of the deterioration was similar for motion and disparity, which may indicate that both features are equally affected by the top–down modulation. We propose that the suppression of distractor stimuli is a general effect which takes place at a central rather than sensory level.

Monday

◆ **Unfocused spatial attention underlies the crowding effect in indirect form vision**

H Strasburger ¶ (Generation Research Program, Human Science Centre, University of Munich, Goethestrasse 31, D 80336 Munich, Germany; ¶ now also with Institute of Medical Psychology, University of Göttingen, Waldstrasse 37, D 37073 Göttingen, Germany; e-mail: strasburger@uni-muenchen.de)

Mechanisms underlying the crowding effect in indirect form vision were studied by measuring recognition contrast sensitivity of a character with flankers to the left and right. Attentional and featural contributions to the effect can be separated by a new paradigm that distinguishes pattern location errors from pattern recognition errors, and further by manipulating the focusing of spatial attention through a positional cue, appearing 150 ms before the target. Measurements were on the horizontal meridian, at 1°, 2°, and 4° eccentricity, and a range of flankers distances was used. The results show that, in normal indirect view, the impairment of character recognition by crowding is—in particular at intermediate flanker distances—caused by spatially imprecise focusing of attention. In contrast, the enhancement of performance by a transient positional cue seems mediated through a separate attentional mechanism such that attentional locus and focus are controlled independently. The results, furthermore, lend psychophysical support to a separate coding of ‘what’ and ‘where’ in pattern recognition.

SACCADES

◆ **Perceptual visual space is not compressed before saccades**

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In recent years, a group of studies has purported to show that, in the brief period before saccades, perceptual visual space is compressed toward the target of the saccade. These findings have been speculatively linked to issues of perceptual stability and to observed visual receptive-field shifts in parietal cortex and superior colliculus. These studies have focused on errors in judgments of the location of isolated, brief pre-saccadic flashes or bars, inferring an instantaneous distortion in the shape of visual space from the spatial distribution of their mislocalisations. Some have claimed to bridge the gap between these judgments about isolated points and the overall structure of visual space by showing that both the width and the number of a set of pre-saccadically presented objects are underestimated. We show that this results from the failure to perceive peripheral objects in the set, an event whose probability increases with stimulus width. We thus show that visual space, whether judged by the distance between edges of single objects or by distributed sets of objects, is not compressed before saccades. This demonstrates the need for a new understanding of how pre-saccadic perceptual mislocalisations and the structure of visual space are related.

◆ **Anticipating the three-dimensional consequences of saccades**

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Ocular saccades give rise to sudden enormous changes in optic information arriving at the eye. How the world nonetheless appears stable is known as the problem of spatial constancy. While two-dimensional direction constancy—how the spatial directions of individual points appear stable despite uniform shifts on the retina—has received extensive study, three-dimensional (3-D) spatial constancy has been neglected. For example, when the gaze moves from one surface patch to another on the same plane, the surface in the eye-centred frame undergoes a rotation in depth; instead of perceiving this rotation, however, we perceive the two surfaces as coplanar in space. Using stimuli with ambiguous 3-D structure and motion, I show that, even before the eyes begin to move, the visual system anticipates 3-D rotations due to saccades. Because this anticipation is absent when subjects fixate while experiencing optically simulated saccades, it must be evoked by extraretinal signals. Such anticipation could provide a simple mechanism for 3-D spatial constancy and trans-saccadic integration of depth information.

◆ **Coordination of saccadic and pursuit eye movements during shifts in attention**

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Switching fixation from one target to another requires that eye movement control systems are disengaged from the current target and engaged to the new one. The current opinion is that disengagement precedes engagement and that both neural states are mediated by the process of visual attention. We studied the smooth pursuit eye movements made before and after shifts in fixation between targets moving in random directions. Comparison of pursuit changes occurring

at fixational shifts with those induced by unexpected changes in the direction of target motion showed that (i) the timings of pursuit changes and saccades were highly correlated during shifts in fixation, whereas they were uncorrelated after sudden changes in target direction, and (ii) pursuit changes were completed within the saccadic shifts of fixation that took less than 50 ms, whereas induced pursuit changes took 150 ms or longer to complete. A single model of pursuit and saccadic control, in which engagement precedes disengagement, can produce both types of pursuit responses. We speculate that frontal eye fields and superior colliculi contain the neural architecture required for the observed coordination of saccadic and pursuit eye movements.

◆ **Development of saccadic suppression in children**

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Saccadic eye movements selectively suppress contrast sensitivity to luminance-modulated stimuli of low spatial frequency, by a factor of about 6 (Burr et al, 1994 *Nature* **371** 511–513). We measured the effect of saccades on contrast thresholds in school-age children (11–14 years old). Under conditions of fixation, the children's thresholds for briefly flashed low-frequency grating patches were the same as those of adults, both for luminance and chromatic stimuli. However, when displayed immediately after a saccade, the suppression of luminance-modulated stimuli was more than 3 times as large as that observed in young adults, while equiluminant sensitivity remained normal. A possible explanation for these results is that the magnocellular pathways are not fully developed by adolescence, so saccadic suppression of that pathway is more effective.

◆ **Dissociable temporal and spatial perceptions following saccadic eye movements**

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The term saccadic chronostasis refers to the subjective temporal lengthening of a visual stimulus perceived following a saccadic eye movement. The perceived onset for such a stimulus appears to be antedated to a moment just prior to saccade initiation (Yarrow et al, 2001 *Nature* **414** 302–305). If (i) such an illusion still arises when making a saccade to a moving stimulus, and (ii) the brain constructs a unitary perceptual experience combining spatial and temporal stimulus qualities, we might predict that the initial position of a post-saccadic moving stimulus would be mislocalised backwards along its inferred trajectory. To test this prediction, subjects either smoothly pursued moving stimuli initially presented at fixation (control condition) or saccaded to them prior to pursuit (saccade condition). They made both spatial (initial position) and temporal (duration) judgments in separate interleaved trials. Chronostasis was robust under these stimulus conditions, with post-saccadic targets perceived to have prolonged durations compared with constantly pursued targets. By contrast, mislocalisation judgments were similar in both conditions, with stimulus onset perceived ahead of its veridical position (cf the flash-lag effect). Hence perception of stimulus time is altered without a logically concomitant change in perceived stimulus position during saccadic chronostasis.

ATTENTION AND FEATURES

◆ **Interaction of response criteria across attributes of single objects**

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We have shown that the absolute response criteria (assessed as the z -scores of false alarms in standard yes/no experiments) involved in the detection and discrimination of a given attribute (contrast) of one of two Gabor patches presented either simultaneously at different locations or sequentially (within the same experimental session) remain quasi-equal independently of the relative contrasts (and thus d values) of the two objects. This deviates from the optimal behaviour stipulated by signal detection theory where criteria are set in accordance with sensitivity. Here, we show that interaction of criteria also occurs across distinct attributes of the same stimulus. Subjects detected a contrast or an orientation change of a single Gabor patch. As expected, subjects showed optimal decision behaviour in sessions where only one attribute was tested or where two jointly tested attributes yielded equal d values. When the two attributes

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yielded different d values, criteria for the high/low d values dropped/increased, respectively. Hence, changes within unrelated dimensions of a single visual object may be represented at a unifying meta-attribute level, presumably as a result of the relaxation of attention to the relative change across attributes. The results also suggest that psychophysical decisions are limited by a common source of noise, presumably at the decision level.

◆ **Featural, but not spatial, attention modulates unconscious processing of visual stimuli**

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Does voluntary attention modulate unconsciously processed signals? We investigated this issue with the tilt aftereffect (TAE). During the experiments, we kept the adapting stimulus invisible using continuous flash suppression (Tsuchiya et al, 2004 *Journal of Vision* 4(3) abstract 84) in which a constant stimulus presented to one eye can be continuously suppressed by rapidly changing stimuli presented to the other eye. In experiment 1, the effect of spatial attention was investigated. Observers covertly attended to a spatial marker visible to the dominant eye. The magnitude of the TAE was constant irrespective of whether there was attentional overlap with the invisible adaptor or not. This implies that spatial attention does not produce general enhancement of neural activity at the attended location. Instead, the attentional effect is selective for the signals reaching conscious perception. In experiment 2, we investigated feature-based attention. Observers attended to a visible stimulus at a location away from the adapting stimulus. The TAE magnitude was modulated depending on the orientation of the attended stimulus. Here, voluntary attention did modulate unconscious visual processing. In sum, our findings show that in order to modulate the neural signals of invisible stimuli, stimulus awareness is necessary for spatial attention, whereas it is not for feature-based attention.

◆ **Visual feature binding inside and outside the focus of attention**

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Forming coherent object representations—despite of the fact that visual features are processed separately—is one of the most remarkable abilities of our visual system. Our goal was to dissociate binding mechanisms that are in effect inside the focus of attention from those present outside of its focus. To determine whether two features are bound, we tested whether attention to one feature (colour) would also influence processing of another task-irrelevant feature (motion) of the same stimulus (cross-feature attention—CFA). We investigated CFA effects both in the focus of attention and outside of its focus (global attention). We measured CFA effects on a subthreshold motion prime and thus excluded the possibility that the motion signal was attended directly. We found that global CFA modulation outside the focus of attention spreads to spatio-temporally co-localised features, whereas inside the focus of attention CFA modulation spreads between all features belonging to the same surface or object. These results suggest that there is a binding mechanism at the local stages of visual processing across the visual field that is independent of attention, while another binding mechanism acts in the focus of attention and links all features of the same surface.

◆ **Attentional modulation of brief orientation adaptation to unresolvable patterns**

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Selective visual attention modulates neuronal activation in various cortical areas. This type of neuronal modulation happens even in the early stages of visual processing where specific attributes of visual stimuli are processed. We investigated the effect of visual attention on brief orientation adaptation while subjects were unaware of the orientation of the adapting stimulus. Brief adaptation to an oriented grating impairs identification of nearby orientations by broadening orientation selectivity and changing the preferred orientation of individual V1 neurons. In the first experiment, subjects performed a delayed match-to-sample task in the peripheral visual field. They were asked to report whether two briefly flashed Gabors differ in orientation or not. The second Gabor patch (test stimulus) was preceded by a 400 ms adapting stimulus (unresolvable Gabor patch). In the second experiment, subjects performed the same task concurrent with a secondary task (even/odd judgment) at the fixation point during the adaptation period. Results demonstrated the brief adaptation to unresolvable orientation in the first experiment but no adaptation in the second experiment. We suggest that the unresolvable orientation

information selectively activates the primary visual cortex and this activation (as revealed by brief orientation-adaptation paradigm) is modulated by attention.

◆ **The attentional blink unmasked**

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When two visual stimuli are presented within 100–400 ms of each other, second target sensitivity is markedly reduced. The occurrence of this attentional blink (AB) depends critically on whether the second stimulus is backwardly masked (Geisbrecht and DiLollo, 1998 *Journal of Experimental Psychology: Human Perception and Performance* **24** 1454–1466). We used a simplified AB paradigm in which two contrast-modulated Gabor patch stimuli were presented at different display locations at various temporal separations. The interaction between masking and decisional complexity was investigated in four separate experiments, in which observers made detection or orientation discrimination judgments about backwardly masked or unmasked stimuli. For detection, an AB occurred only when stimuli were masked. By contrast, an AB was found for orientation discrimination for both masked and unmasked stimuli. A fifth experiment showed that the AB for unmasked orientation discrimination was eliminated by increasing the spatial frequency of the Gabors. These differential mask-dependences are explained by a model of visual attention (Smith and Wolfgang, 2004 *Journal of Experimental Psychology: Human Perception and Performance* **30** 119–136) which assumes that: (a) attention affects the rate of information accumulation, (b) masks limit the visual persistence of stimuli, (c) high spatial frequencies persist longer than low spatial frequencies, and (d) orientation discrimination requires longer decisional integration time than does detection.

SYMPOSIUM 1

HOW STUDIES OF VISUAL DEVELOPMENT CAN CONSTRAIN MODELS OF ADULT VISION

◆ **Infant research on figure–ground and global coherence reveals gaps in knowledge of adult vision**

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We discuss two examples of adult models of vision that are informed by infant research: organisational processes in shape and motion perception. (i) Figure–ground assignment. In habituation/recovery experiments we tested whether infants pick up shape information preferentially from regions which are biased as figure rather than ground, by contour convexity, continuity at T-junctions, luminance contrast, and area. Figure–ground assignment has been widely discussed in perceptual theory, models of scene analysis, and the neuropsychology of object processing. However, designing infant experiments revealed the paucity of adult data on the role of these cues and their influence on shape discrimination. (ii) Global processing in form and motion systems. We have used coherence thresholds in patterns of moving dots or oriented line segments as measures of infant global processing in ventral and dorsal processing streams. Tests require both integration of form or motion information within a coherent region, and segmentation of that region from other regions. The relationship between these processes in adult vision remains an open question. In addition, studies on development for motion relative to form coherence in neurodevelopmental disorders (Williams syndrome, autism, perinatal brain damage) can help to define processes necessary for normal adult perception.

◆ **Development of configural sensitivity in human infants and adults**

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Collinearity is a prominent feature of natural images and is a powerful cue for grouping when it exists and for segmentation when it does not. I have been studying both grouping and segmentation aspects of the collinearity problem using visual evoked potentials in human infants and in adults with a history of abnormal visual experience. I have studied long-range integration of collinear cues in both texture and contour integration experiments. Segmentation has been studied in a short-range task that is related to Vernier acuity. While basic competence in the detection of collinearity can be demonstrated early in visual development, full maturation occurs over an extended period of time and is strongly determined by a history of normal binocular experience during development.

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- ◆ **Feature-learning by infants and adults reveals common constraints on visual feature hierarchies**
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One of the most fundamental tasks facing the visual system is how to parse complex scenes into a relatively small set of features. A small hierarchical set of features is an efficient way to represent a large number of scenes, but to acquire it humans need to process and reject an exponentially large number of potential feature combinations (higher-order features) through learning. We summarise recent empirical findings from our laboratory that document the ability of adults and infants to acquire a set of higher-order features in an unsupervised observational learning paradigm. In infants, a set of elements (simple shapes) are presented in particular spatial configurations, with some element pairs defined by high conditional probabilities and other pairs forming spurious coincidences (noise pairs). After meeting a criterion of habituation, infants show evidence of discriminating coherent pairs from noise pairs. Adults presented with more complex multi-element scenes (a) acquire higher-order element configurations, (b) fail to retain as useful features those that are embedded in these higher-order configurations, and (c) use incoherent configurations as 'break points' between chunks that define coherent higher-order features. These results suggest that the same constraints on statistical learning are operating in infants and adults as they learn new higher-order visual features.

- ◆ **Auditory – visual interactions in infants and adults**
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I asked how effectively auditory (A) and visual (V) inputs are combined in infants, by recording infants orienting responses (eye movements) to A only, V only, and A–V targets in video, and compared RTs (age range: 1 to 10 months). Infants older than 4 months responded faster to the A–V and to the V, relative to A stimuli. Yet there was no evidence for A–V RT to be shorter than that predicted from probability summation (race model), thus no evidence for nonlinear interaction. This is consistent with neurophysiological findings from multisensory sites in the superior colliculus of infant monkeys showing that multisensory enhancement of responsiveness is not present at birth but emerges later. Unlike infants, adults A–V RTs violated the race model, indicating nonlinear and effective combination of A and V inputs. To assess the role of attention in development of A–V integration, I employed a visual motion-ambiguous display, in which normal adults perceive bouncing of two objects only when a sound is given at the right timing. The habituation–dishabituation results for infants suggest that attention develops and becomes effective in utilising auditory input to resolve visual motion ambiguity only at and after 5 months of age.

SYMPOSIUM 2

SPACE, TIME, AND THE VISUAL CONTROL OF ACTION

- ◆ **Coordinate transformations for sensory-guided movements**
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Sensory-guided behaviours require a coordinate transformation between sensory and motor representations. In the posterior parietal cortex, a part of the brain involved in this transformation process, auditory and visual signals converge on subregions involved in the planning of saccades and reaches. Interestingly, many of the neurons represent the locations of the targets in a visual (retinotopic) frame of reference. This common reference frame may reflect the predominance of vision in primates and may facilitate hand–eye coordination. The activity in the spatial maps for reaching and saccades is updated with each eye movement when subjects are planning reaches. However, under natural-viewing conditions where subjects generally make many eye movements and only a few reaches, the reach planning activity in a population of cells occurs just before the reach. As a result, normally these reach-specific neurons do not require adjustments in their activity to compensate for eye movements. The relationship of the activity that occurs just prior to reaching in natural conditions to delay activity that is seen under more constrained experimental conditions is the subject of current experiments.

- ◆ **Multiple modes of control for grasping**
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On the strength of neuropsychological, neurophysiological, and psychophysical evidence, Goodale and Milner (1992 *Trends in Neurosciences* 15 20–25) suggested that separate visual pathways are engaged for conscious object perception and for the control of object-directed actions such as

grasping. Recent evidence from neuropsychological and psychophysical studies suggests that the distinction between conscious object perception and action control is not so straightforward. For example, when memory for a previously seen target is required, the control of action appears to depend on the same visual processing that drives the conscious percept of the object. I review evidence from our laboratory and others suggesting that visuomotor control engages quite different mechanisms when the action is carried out in real time, as compared to when the action is carried out in the absence of direct visual input from the target object. This evidence suggests a broader distinction between two modes of control for grasping: one mode that is independent of visual cognition and a second mode that is not. This view has implication for the interpretation of neurophysiological studies that utilise delayed-action tasks to understand the neurobiological substrates of sensorimotor transformation.

- ◆ **Mediating action versus here-and-now visuomotor processing: Evidence from optic ataxia**
Y Rossetti, L Pisella, A Vighetto¶ (Espace et Action, Institut National de la Santé et de la Recherche Médicale, UMR – INSERM, Unité 534, Université Claude Bernard, 16 avenue Lépine, Case 13, F 69676 Bron, France; ¶ Hôpital Neurologique, 59 boulevard Pinel, F 69003 Lyon, France; e-mail: rossetti@lyon.inserm.fr)

It has been proposed that optic ataxia and visual agnosia are doubly dissociated. This dissociation has provided the main argument for anatomical distinction between dorsal and ventral visual streams to the functional distinction between perception and action. However, insufficient evidence has been collected for such double dissociation. Several criteria are reviewed: (i) Exploration of the visuomotor behaviour in central versus peripheral vision has not been matched for the two types of patients. (ii) The temporal constraints of visual processes impaired in these two conditions appear to play a crucial role in the apparent dissociation. (iii) The necessary reductionism of conditions used to study action has led to an excessive consideration of optic ataxia as a global deficit for action. Altogether, optic ataxia appears to result from a specific impairment of immediate visuomotor control rather than visually guided action as a whole. The only double dissociation between optic ataxia and visual agnosia appears in the time dimension rather than the perception–action dimension. Optic ataxia patients improve when the object is re-presented rather than when it is simply present. These results are discussed in the light of recent research on optic ataxia and on motor control, and directions for future research are proposed. Specifically, optic ataxia could be better associated with the environment-dependence-syndrome observed in frontal patients.

- ◆ **Steering a middle course: The dorsal stream processes non-target as well as target objects**
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When we reach out to pick up an object, we have to process not only the shape, size, and location of the target object, but also the visual properties of other objects that could potentially constitute obstacles to the action. Although there has been extensive neurophysiological, neuropsychological, and neuroimaging research on the visual processing of target properties during reaching, there has been little or none concerning the processing of non-target objects. I present evidence from studies of patients with neglect, extinction, optic ataxia, and visual form agnosia to argue that the human dorsal stream mediates both kinds of visuomotor processing, and that this processing can proceed efficiently in the absence of visual awareness.

ORAL PRESENTATIONS

SEARCH AND TRACKING

- ◆ **Visual object tracking across hemifields in a split-brain patient**
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Several lines of evidence have confirmed that visual information transfer between the two hemispheres is severely impaired following transection of posterior part of the corpus callosum. Here, we investigated whether attentive visual object tracking across vertical meridian of the visual field is possible for a posterior callosotomised patient (MD). We asked MD to track one bouncing ball among four identical distractors while fixating at the centre of the screen. Target crossed the vertical midline in half of the trials. Her performance in crossed conditions was significantly above chance level but it was lower than in uncrossed conditions. To further explore the capability of transfer of spatial information, we asked her to make decisions about horizontal alignment of two balls presented simultaneously in one of three conditions: both in the right or

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left hemifield, or each in one hemifield. We have previously shown that she is not able to perform a shape-matching task for stimuli presented to different hemifields. But in this alignment task MD was able to compare the location of two bilaterally presented stimuli significantly above chance level. Our results suggest that interhemispheric transfer of position information required for spatial attention is preserved in the absence of posterior corpus callosum.

◆ **Saccadic learning and template tuning**

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Improvement in human perceptual judgments such as orientation, hyperacuity, and position discrimination is mediated by template/weighting tuning. Here, we investigated the effects of practice on 1st saccade accuracy during search. We used the classification image technique to test whether saccadic learning is mediated by improvements in the optimality of the underlying templates. We recorded eye movements of three observers searching for a bright Gaussian target among four dimmer distractors presented equidistant along the circumference of a circle. Trials were divided into 4 blocks of 1000 trials to quantify the accuracy of the 1st saccade (considered to be correct if it landed closest to the target location). Two observers showed performance (percentage correct) improvements ranging from 16% to 20% with accompanying significant increases in the optimality of the estimated templates (measured by the correlation between the estimated templates and the ideal-observer template). The remaining observer showed little improvement in performance and no increase in template optimality. We conclude that saccadic learning is mediated by increases in the template's optimality.

◆ **Investigating salience mechanisms by using the effects of surrounding frame on the tilted – vertical asymmetry in visual search**

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We measured the stimulus duration required to detect target lines that differed in orientation from distractor lines. Tilted targets amongst vertical distractors required shorter durations than vice-versa. Surrounding the stimulus with a square frame tilted by the same amount as the tilted lines reduced or reversed this asymmetry; a vertical frame had no effect. Treisman and Gormican (1988 *Psychological Review* **95** 15–48) found similar results using reaction times. Li (2002 *Trends in Cognitive Sciences* **6** 9–16) proposed that V1 mechanisms determine salience in visual search. According to this proposal, the advantage for tilted targets could arise from weaker iso-orientation suppression of obliquely tuned V1 cells, since fewer cells encode oblique orientations. The frame effect can be explained by proposing that the sides of the frame inhibit responses to lines parallel to the frame. This predicts no effect of a frame constructed from elements with orientation perpendicular to the side of the frame. This prediction was supported by some subjects, but not others. When alternate frame elements were black and white (on a grey background), so that a large V1 receptive field aligned with the side of the frame would show no response, the frame effect disappeared for some subjects.

◆ **Further investigations on the loss of positional information when tracking multiple dots**

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Human observers can simultaneously track up to five randomly moving dots (Pylyshyn and Storm, 1988 *Spatial Vision* **3** 179–197). However, the ability to detect a deviation in a straight-line target trajectory is compromised when distractor (undeviating) trajectories are presented (Tripathy and Barrett, 2003 *Journal of Vision* **3** 340a). We further investigated this loss of information. In previous experiments (Narasimhan et al, 2004 *Journal of Vision* **4** in press, abstract C8), the stimuli were several linear, non-parallel, left-to-right trajectories, each moving at the same speed. At the midline of the monitor indicated by vertical markers (reached simultaneously by all trajectories), the target trajectory deviated clockwise/anticlockwise while the distractors disappeared. The observers' deviation thresholds rose steeply with increase in the number of distractors. Here, all trajectories continued beyond the midline, and the target changed colour at the midline. Unlike the previous experiments, the transients directed attention towards the target. Even for simple linear/bilinear trajectories with the latter half of the target trajectory clearly identified, we found that observers had little information regarding the first half of the target trajectory: thresholds increased linearly from $\sim 3^\circ$ to $\sim 35^\circ$ when the number of distractors increased from 0 to 3, further implicating a failure either of attention or of working memory.

◆ **Feature processing asymmetry in a colour and orientation conjunction-search task**

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Distinctive visual cortical areas process specific visual features of objects. Does this imply that individual features are also processed independently? To investigate this, visual-search performance for individual features was compared with performance for these same features in a conjunction-search task. Subjects searched for a target among 12 distractors while their eyes were tracked. Accuracy and latency of the initial saccade in a trial were measured. In a feature-search task, colour contrast and orientation difference for 70% correct discrimination performance was determined for each individual subject. Next, with stimuli set to these individually determined threshold levels, search performance was measured for each feature separately as well as during a conjunction task. Colour-discrimination performance was slightly better in conjunction search than in feature search. In contrast, performance on orientation discrimination dropped dramatically in conjunction search compared to feature search. Importantly, in conjunction search, saccadic latency in correct colour and correct orientation trials was approximately equal, ruling out a speed-accuracy trade-off explanation for this finding. We conclude that, when information needs to be combined to perform a task, processing of one feature can be dependent on the processing of another one, resulting in asymmetric performance.

FACE PERCEPTION

◆ **Influences of object knowledge and geometric properties on the hollow-face illusion**

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We performed a series of experiments to investigate the role of object knowledge, geometric properties, and patterns of shading on the perception of the hollow-face illusion. Effects of inversion on objects other than faces are interpreted as showing that the effect of object knowledge is not specific to faces and is not 'all-or-nothing'. Experiments with a virtual hollow face to give control over geometric properties and taking the texture contrast needed to see the face as concave as a measure of strength of the illusion showed that absolute depth does not appear to be critical but that there is a preference for local as well as global convexity. Last, an experiment with varying the orientation of the face in 90° increments with light from the right showed that both absolute orientation and whether light is from above or below relative to the face are important. Thus, in response to Heard and Chugg (2003 *Perception* 32 Supplement, 50), we argue that both object knowledge and a local and global preference for convexity affect the perception of inside-out objects. These illusions provide evidence of a role for object knowledge in the interpretation of depth cues, and for the existence of internal three-dimensional representations of objects.

◆ **ERP effects of Thatcher faces under delimited presentation times**

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Thatcher faces, which are faces in which the eyes and mouth regions are turned upside-down, are recognised as being severely distorted when presented upright but hardly distinguishable when inverted. Common theories explain this effect by the loss of configural information for inverted faces. We investigated neural correlates of this effect using event-related potentials (ERPs). Sixteen right-handed participants performed yes/no identity decisions for Thatcher or original (familiar) faces, presented for 34 ms or 200 ms in 0°, 90°, or 180° orientation. For the occipito-temporal N170 we found (i) strong effects of orientation, and (ii) differential amplitudes for Thatcher and original faces, not only at 0° orientation, but also for inverted faces. For later ERP components, these effects were additionally modulated by presentation time. Moreover, there were behavioural hints of differential importance of configural and featural processing for short and long presentations times. Microgenetic accounts for explaining these findings are discussed.

Monday

◆ **Polarity-dependent category shifts in adaptation to facial expressions**

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When subjects make forced-choice classifications of facial expression on images from a morph between two expressions, one can measure a balance point, where subjects are equally likely to identify either expression. Typically, adaptation to one of the endpoints of the morph sequence causes the balance point to move towards the adapting stimulus. Contrast negation of faces is reported to affect the extraction of surface-based information (used for identification) more than edge-based information (used for recognition of facial expression). We find that the magnitude of adaptation is substantially greater when normal (rather than contrast-reversed) adaptors are used. This dependence on contrast inversion may be taken to imply that the expression aftereffect is dependent upon surface-based, rather than edge-based, information. Our second experiment was a replication of the first, except that different actors were used for adaptation and test stimuli. Our results show that the polarity-dependent effect generalises across faces. Finally, we tested the assumption that the adaptation-dependent shift of balance point indicates an actual shift of category boundary. Discrimination thresholds are commonly held to be lower around category boundaries. We show an adaptation-dependent effect on expression discrimination, conformant with a shift of category boundary.

◆ **Repetition blindness for famous faces**

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Repetition blindness refers to a difficulty in detecting and reporting occurrences of a repeated item shown in a sequence of words or pictures of objects presented at a rapid rate (8–10 items s^{-1}). With pictures of objects, repetition blindness is unaffected by differences in size, orientation, and view. Words, letters, and pictures of objects are stimuli that represent categories. In contrast, photographed faces not only represent a unique category—faces—but also represent unique individual exemplars. We investigated effects of repetition when the stimuli were pictures of faces of famous individuals. Sequences of two or three photographs of faces, some with a repetition, were shown (each sequence preceded and followed by pattern masks). The second occurrence of a repeated face was identical, differed in orientation, or was a different photograph of the same person. Repetition blindness occurred for same repeats, different-view repeats, and different photographs of the same person. In the final experiment, the stimulus sequence included both a famous face and the printed name of that person on repeat trials and a different name on control trials. We consider the implications of these results for theories of the mechanisms involved.

◆ **The orientation of attention to famous faces perceived without awareness depends on participant's attitude towards the target person**

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We carried out three experiments to investigate the orientation of attention to famous faces presented under conditions that precluded awareness. Masked 17 ms faces were presented in simultaneous pairs of one famous and one unfamiliar face, matched on physical characteristics, one each in the left and the right visual field (LVF and RVF). These were followed by a dot-probe presented in either LVF or RVF to which participants made a speeded two-alternative forced-choice response. Participants subsequently evaluated the famous persons on an affective scale. Results suggested that attention was oriented towards the faces of famous persons evaluated as good, and oriented away from the faces of persons evaluated as 'strongly evil'. The within-item analysis, in which a famous face appeared to attract the attention of participants who regarded the person as 'good' but not the attention of participants who regarded the person as 'strongly evil', argues against any confounds arising from differences among stimuli and supports the role of participant affective attitude. In the awareness-check task, performance was at chance in discriminating famous from unfamiliar faces presented under the same conditions, confirming the absence of awareness. We conclude that facial identity can be detected without awareness, and that orientation of attention depends on affective attitude towards the target person.

TUESDAY

ORAL PRESENTATIONS

TEMPORAL VISION AND WORDS

◆ **Visible oscillations: Illusory-motion-induced jitter and spatial acuity**

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When neighbouring high-luminance-contrast and low-luminance-contrast borders move together, the lower contrast border can appear to jitter rapidly, ~ 22 Hz (Arnold and Johnston, 2003 *Nature* **425** 181–184; see <http://electra.psychol.ucl.ac.uk/derek/MISC.htm> for details and demonstrations). This should impair the precision of spatial judgments. Two pairs of horizontal green bars (CIE $x = 0.28$, $y = 0.59$, $1.4 \text{ deg} \times 0.3 \text{ deg}$) were centred 1.8 deg and 3.4 deg left and right of fixation. Each pair moved vertically in opposing directions (4.5 deg s^{-1}). On each trial, there could be a vertical displacement between the bars on one side of fixation. Observers reported which pair contained the displacement. We compared conditions where all bars moved over subjectively equiluminant static red columns (CIE $x = 0.60$, $y = 0.34$, $1.8 \text{ deg} \times 8.4 \text{ deg}$), and no jitter was seen, with conditions where one bar of each pair was centred across a moving red rectangle. The height of the rectangle was varied to manipulate the proximity of high-luminance-contrast and low-luminance-contrast borders. When the two types of border were nearby, illusory jitter was visible and detection thresholds for spatial misalignment increased. This demonstrates that illusory-motion-induced jitter has a quantifiable influence on a measure of spatial acuity.

◆ **Temporal properties of brightness induction**

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The brightness of a target depends on its surround, which exerts influence through lateral interactions mediated by interneurons. A time lag is introduced between the registration of the surround and its effect on target brightness. De Valois et al (1986 *Vision Research* **26** 887–897) used a matching technique and found that induced brightness modulations existed only at temporal frequencies below 2.5 Hz. Paradiso and Nakayama (1991 *Vision Research* **31** 1221–1236) and Rossi and Paradiso (1996 *Vision Research* **36** 1391–1398) suggested that brightness percepts are determined by a fill-in process whose signals propagate at $110\text{--}150 \text{ deg s}^{-1}$ ($6.7\text{--}9.2 \text{ ms deg}^{-1}$). We sinusoidally counterphased the inducing grating of a grating induction display (McCourt, 1982 *Vision Research* **22** 119–134) to create a counterphasing-induced grating within the test field. Adding a second (genuine luminance) counterphasing grating in temporal and spatial quadrature phase to the induced grating transforms the brightness modulation into a traveling wave (motion). Varying the temporal phase of the added luminance grating permits a precise estimate of the temporal phase lag of induction. Results indicate that induction lag is remarkably short, on the order of a few milliseconds, and does not vary with inducing field height in a manner that suggests a fill-in process.

◆ **Scotopic (rod) adaptation**

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The ability of the visual system to operate over a 10^{10} range of intensities from starlight to bright sunlight despite the limited range of neurons (c.100) is a remarkable feat of biology. Here, we focus on adaptation over the lower scotopic (rod) range of vision. We measured rod temporal sensitivities, monoptically, and phase delays, dichoptically, as a function of adaptation level over the range -3.8 to 0.2 log scotopic trolands. This novel combination of data provides a more complete characterisation of the effects of light adaptation than is possible with sensitivity measures alone. We find that light adaptation is associated with unexpectedly large improvements in rod temporal modulation sensitivity and advances in phase as the rod system adjusts itself (presumably mainly post-receptorally) from being optimised for the detection of single photons to the detection of multiple photons. The sensitivity and phase data can together be accounted for by a simple model that is made up of a cascade of c.2 leaky integrators with time constants that shorten with adaptation coupled with some (modest) frequency-independent sensitivity scaling. Thus, only two adaptation-dependent parameters are required to characterise the entirety of scotopic adaptation below mesopic (rod–cone) levels.

Tuesday

◆ **Stimulus quality has no impact on the benefits of word context**

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Massaro and Cohen (1994 *Journal of Experimental Psychology: Human Perception and Performance* 20 1107–1128) reported decreased word benefit with longer stimulus durations in a word-superiority task. I found that stimulus duration had no impact on the benefit of word context in a visual crowding task (Fine, 2003 *Psychonomics Abstract* 252). Massaro and Cohen also concluded that reduced stimulus quality would increase the benefit of word context. While brief stimulus durations may reduce stimulus quality, here I explicitly test this hypothesis by varying stimulus contrast. Eight observers identified the middle letters of 3-letter words and non-words. Target letters were presented at 5° left and right of fixation for 125 ms with 15%, 30%, and 60% contrast relative to a light background. The difference between words and non-words was 37%, 40%, and 33% for the 15%, 30%, and 60% contrast conditions, respectively. These differences were not statistically significant ($p = 0.251$), while the effect of contrast on the words and non-words was ($p < 0.001$). These findings suggest that the benefit of word context not only does not increase with decreased stimulus quality, but that, if present, it does not vary. Differences with Massaro and Cohen may be task-dependent.

◆ **Flanker effects in word-recognition and attention research**

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One important goal in vision research is the understanding of object recognition. To study contributing processes, targets are often presented with flankers. In letter-recognition and word-recognition research, flankers severely impair the identification of flanked targets, which is referred to as the crowding effect. In studies examining visual attention, distractors can facilitate or inhibit target-detection performance, depending on the relation between the target and flankers. To examine these partly contradictory findings, an experimental approach was developed which allows the measurement of the portion of correct responses as well as response latencies in detection, identification, and localisation tasks with the use of same stimuli and a 2AFC procedure in each task. Detection of a flanked target was the easiest task, followed by identification, and localisation was most difficult. Whereas the proportion of correct responses was largely affected by the target position, latencies were not. In three experiments, variations of spacing, of stimulus-onset-asynchrony between the string and a mask, and of the kinds of instruction resulted in various differences between tasks and measures. Preliminary theoretical suggestions are presented for commonalities and differences between processes underlying detection, identification, and localisation performances.

PERCEPTION AND ACTION: EYE MOVEMENTS

◆ **Temporal course of pre-saccadic allocation of attention**

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Stimuli presented during the preparation of a saccade are more accurately perceived when their location coincides with the saccadic target. To explain this phenomenon, some authors claim that spatial attention cannot be withdrawn from the saccadic target until the execution of the saccade. To investigate this issue, we measured orientational acuity for Gabor patches presented at different delays after the go-signal for the saccade. Observers fixated the centre of a circular array of 8 disks. The fixation point was then replaced with an arrow indicating the direction of the required saccade. Disappearance of the arrow constituted the go-signal. During the preparation of the saccade, all disks were replaced with Gabor patches (7 vertical, 1 tilted) for 50 ms. The location of the tilted one coincided or did not coincide with the saccadic target and was constant across a session—observers were informed of this location. After saccades, observers reported the orientation of the tilt. Perceptual performance was best when saccade target and perceptual target had the same location; it was worse right after the go-signal and improved thereafter. We suggest that attentional resources are divided between perception and saccadic programming, the latter having priority in the early phase of saccadic preparation.

◆ **Attentional selection prior to the execution of sequential goal-directed eye and hand movements**

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We first studied attentional allocation before sequential hand movements, using a dual-task paradigm which combined movement preparation with a perceptual discrimination task. The stimuli

consisted of a circular array of 12 letters. Participants were required to perform a sequence of two or three pointing movements to targets, in a clockwise direction along the array. The results demonstrate that before onset of the movement sequence, attention was focused at all movement-relevant target positions, while discrimination performance was close to chance level at the action-irrelevant locations. Interestingly, performance at the intermediate locations between the movement targets was also at chance, providing evidence for a division of attention among noncontiguous locations. A second experimental series was devoted to attentional allocation before a sequence of saccades to two targets, in a similar experimental approach. In contrast to the findings for manual movements, we found no indication of attentional deployment to the second movement target before the onset of the first saccade. We suggest that manual movement sequences are prepared as a whole, establishing a motor program. Saccades, however, are always controlled on-line, requiring attention to be focused at the target location of the next saccade. [Supported by the Deutsche Forschungsgemeinschaft, FOR480.]

◆ **Grasping the diagonal illusion: A differential effect on perception and action**

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Findings that visual illusions affect perception much more than action provide strong evidence for the dual-system hypothesis (Goodale and Milner, 1992 *Trends in Neurosciences* 15 20–25). In disagreement with this model, however, several researchers have found similar illusion effects on perception and action that still remain largely unaccounted for. In this study, we measured the effect of the diagonal illusion (DI), an illusion never tested before in this line of research, on perception and action. Maximum grip apertures (MGAs) from grasping responses under closed-loop (CL) and open-loop (OL) conditions were used as a measure of visuomotor performance, whereas perception was assessed by MGAs from manual estimations (ME). As expected, the DI had a smaller effect on action than on perception; specifically the effect significantly increased from CL to OL and from OL to ME. These results suggest that the diagonal illusion exerts a differential effect on perception and action that is consistent with the dual-system hypothesis. An additional benefit of using the DI is that, unlike previously used illusions, it can be induced by purely three-dimensional, graspable, objects. It therefore provides a unique opportunity to investigate the effect of this class of illusions on perception and action.

◆ **Early compensation for smooth-pursuit eye movement in motion detection**

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To detect object motion, the visual system has to differentiate between self-produced retinal image slip and retinal slip resulting from physical object motion. Indeed, when an observer moves (his body, head, or eyes), the retinal projection of the distal world moves on the retina, thus activating retinocentric motion detectors. To optimise the detection of motion, the system has to compute real or ‘allocentric’ motion from the information provided by the retina and the extra-retinal signals. From studies of compensation (the phenomenon by which retinal and extra-retinal signals are combined), it is not yet clear when and where this compensation occurs (Thier et al, 2001 *NeuroImage* 14 S33–S39; Tikhonov et al, in press *NeuroImage*; Bach and Hoffmann, 2000 *Vision Research* 40 2379–2385), nor what happens before it takes place. We used a modified visual-search paradigm to characterise the reference frame of motion detection. We found that motion detection is already allocentric for stimulus durations as short as 150 ms. For shorter durations, motion detection is retinocentric. These results indicate that compensation occurs very quickly (150 ms) after image onset and that another mechanism, retinocentric, is available prior to that but in a sub-optimal fashion.

◆ **Induced dependence of colour perception on eye-movements**

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Sensorimotor theories of perception argue that action plays a constitutive role in all perception, even in cases such as colour vision, where action is not usually considered to be required. According to these approaches, colour could be defined by the specific transformations induced in cone excitation by eye movements. Replicating an old, controversial experiment of Kohler, we used left-field blue/right-field yellow spectacles to introduce an artificial regularity between eye movements and colour changes. Focusing on short-term effects and dynamic aspects of the exposure and test stages, we obtained measurable adaptation in colour judgment in 40 min. This perceptual learning resulted in the dependence of colour judgment on the direction of eye movements, in a way that compensated for the sensorimotor regularity introduced by the

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spectacles. A second computer-controlled experiment confirmed these results for luminance judgment after 20 min of exposure. Our experiments established clearly the necessity of eye movement for perceptual learning and argue for a role of action in colour vision.

PERCEPTUAL LEARNING AND MEMORY

◆ **Category learning as an example of perceptual learning**

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Category learning is a task in which observers unconsciously learn visual patterns and their implicit knowledge can be demonstrated in subsequent classification tasks. This is in contrast with the usual perceptual learning tasks in which observers are instructed to learn and are often given feedback. However, category learning shows similar characteristics to perceptual learning, including location specificity. Category learning for dot patterns in one retinotopic location does not transfer to other locations. This is surprising because it does not seem likely that we could only recognise dogs or chairs in one visual location. This could be because dogs and dot patterns are very different visual stimuli. Or it could be because we have prior experience with dogs in many parts of our visual fields. We have found that a more complicated novel stimulus (2-D line drawing of a 3-D object) showed little or no learning transfer. In addition, increasing the number of training locations to two did not increase the amount of transfer. These data suggest that the differences between recognising dogs and dot patterns are more subtle than needing a 3-D stimulus or additional training locations. Possibilities are discussed.

◆ **Perceptual training with Kanizsa stimuli reveals homologous representations for illusory and real contours in V1**

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The assumption that perceptual learning, the modification of perception and behaviour following sensory experience, involves changes in the stimulus-processing sensory areas themselves is based mainly on psychophysical or electrophysiological evidence. Our purpose was to investigate the neuronal correlate of perceptual learning using functional magnetic resonance imaging (fMRI). Participants were trained in a curvature discrimination task with illusory contours (Ringach and Shapley, 1996 *Vision Research* **36** 3037–3050). We assumed performance improvements to depend on the formation of a reliable representation of the completed contour which we thought to involve the recruitment of neural assemblies responding to the stimulus. We predicted an increase of the BOLD response at locations in visual cortex that responded to real contours at visual field positions identical to those of the illusory contours in a localiser scan. According to their psychophysical performance pattern, participants were subdivided into learners and non-learners ($n = 10$ each). Learners showed the predicted increase in BOLD response from pre-training to post-training blocks in V1, whereas for non-learners the signal courses did not differ. The current findings provide evidence for the potential of plastic changes in the circuitry of early visual cortex as a result of sensory experience.

◆ **Do masks terminate the icon?**

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Iconic memory is operationally defined by part-report experiments: if an after-coming cue prompts selective report from a briefly presented target array, recall performance is proportionately better than that achieved in whole-report [Sperling, 1960 *Psychological Monographs: General and Applied* **74**(11) whole no 498, 29]. If a mask is presented after the target, the mask is thought to be superposed on the target in the iconic representation, or to displace it from the representation (eg Gegenfurtner and Sperling, 1993 *Journal of Experimental Psychology: Human Perception and Performance* **19** 845–866). But could a cue presented after an effective mask still allow selection within the target array? A target array of letters was followed by a random pattern mask. We compared two different target–mask ISIs: 0 and 100 ms. Cues could be presented at delays of 120, 220, 320, 420, 520, or 620 ms. At ISI = 0 ms, performance was at chance, for part-report and whole-report. At ISI = 100 ms, with the shortest cue delay, observers demonstrated a part-report advantage of around 25%–30%. As cue delay increased the part-report advantage decreased. These results are inconsistent with an iconic memory that is automatically displaced or overwritten by new information. Our data provide evidence either for a store that rejects or attenuates task-irrelevant material, or for a store that preserves separately the representations of the target and its after-coming mask.

- ◆ **Neural correlates of priming in vision: Evidence from neuroimaging and neuropsychology**
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Many lines of evidence show that our visual system is not simply a passive recipient of visual information. For example, we typically orient faster than otherwise to stimuli that have recently been behaviourally important. Using functional neuroimaging and neuropsychology we have investigated the neural correlates of such priming in a pop-out visual-search task. Priming effects, seen as suppression of BOLD activity as target colour or position are repeated, are particularly striking in regions connected with attentional mechanisms, such as in the intraparietal sulcus (see also Yoshida et al, 2003 *Perception* **32** Supplement, 93) as well as the frontal eye fields, suggesting that the priming may involve enhanced attentional processing of the primed colour or position. Effects specific to colour repetition were seen in ventral, colour-specific areas. Effects specific to position repetition were found in inferior parietal cortex and inferior frontal cortex, which is consistent with our findings from neuropsychology on patients with damage centred on inferior parietal cortex with defective attentional mechanisms, who indeed show abnormalities in position priming but not in colour priming in this paradigm.

- ◆ **Does attention control directly enter into visual working memory?**
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Schmidt et al (2002 *Perception & Psychophysics* **64** 754–763) were the first to show that attention can automatically influence the transfer of perceptual representations of colours into visual working memory. For this, they used attention-directing cues presented before or after a memory array consisting of six coloured squares. Given that colour perception and shape perception require different attentional processing, we predicted that relations between working memory and attention will not be the same for colours and shape. Furthermore, to better simulate ecological visual conditions, cues directed attention during the presentation of the memory array. To do so, we used a pop-out: one shape differed from the others with respect to the colour. We found that performance was more accurate when a cued shape was probed than when an uncued shape was probed. However, unlike Schmidt et al (2002), we found this performance improvement more important when cues were presented before or simultaneously with the array presentation than when cues were presented after it. In conclusion, attentional mechanisms play an important role in the transfer of information about shape into visual working memory and also in its perceptual encoding. These attentional effects differ with dimensions of the visual stimulus.

PERCEPTION AND ACTION: PLANNING

- ◆ **Movements can be adjusted in response to changes that affect future actions**
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In daily life, most of our actions do not involve a single movement, but sequences of related movements. Most studies analysing the flexibility of motor control have used movements to a single target, so little is known about our ability to adapt one movement of a sequence to changes in the targets of the subsequent movements. The results of a previous study suggested that this is possible, but the effects were very modest. In this experiment, we tried to get larger effects by examining how a movement changes if we add a subsequent movement or cancel the following movement. Subjects moved a stylus across a digitising tablet. On half the trials there was only one target, but sometimes a second target appeared as soon as the subject started to move. In the other half, there were two targets but sometimes the second target disappeared. Subjects moved faster when there were two targets. They also were able to adapt to a change during the first movement: the deceleration phase was 50 ms shorter whenever subjects had to make a second movement. Thus, subjects are able to adjust their movements online in response to a change that affects their future actions.

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Tuesday

◆ **Movement planning and decision making under risk**

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In Trommershäuser et al (2003 *Journal of the Optical Society of America A* **20** 1419–1433) we examined human movement planning in briefly presented scenes. Subjects earned monetary rewards and penalties by rapidly touching colour-coded objects distributed at random locations in the scene. These movement-planning tasks are formally equivalent to decision making under risk and, in contrast to the grossly sub-optimal performance of human subjects in decision-making experiments, our subjects' performances were indistinguishable from optimal. We present an experimental study where we explicitly compare performance in movement-planning tasks to the predictions of a standard model of human sub-optimality in decision making—cumulative prospect theory (CPT) (Tversky and Kahneman, 1992 *Journal of Risk and Uncertainty* **5** 297–323). This model incorporates three patterns of failure in human decision making under risk: exaggeration of small probabilities, loss aversion, and distortions of value. Six naïve subjects were instructed to 'make money' in movement-planning tasks similar to those above. We varied penalty conditions and spatial configurations and compared subjects' performances to CPT. Subjects' performances were inconsistent with the predictions of CPT. Human movement planning under risk seems to be immune to the errors in judgment that have been reported for human decision making in equivalent pencil-and-paper decision-making tasks.

◆ **Precision for ballistic pointing depends on initial visual signal**

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Goal-directed hand movements like grasping and pointing are more accurate when visual information is available. We examined whether precision for pointing is limited by the quality of the visual signal. Subjects were asked to point, as rapidly as possible, to a high-contrast dot presented on a touch-screen; the hand was always visible. Pointing errors (SD) were measured as a function of target eccentricity. For any block of trials, the dot could appear at random at one of eight positions on a fixed eccentric radius; a small amount of additional position jitter was added on each trial. We measured pointing errors when the target dot remained visible until the finger touched the screen (~500 ms), and when the dot was presented briefly (110 ms). For both target durations, pointing errors increased with eccentricity, although the increase was smaller for long durations. This is surprising because it suggests that the quality of the visual signal available before the reach is made remains influential in determining the precision of the endpoint, even with an opportunity to foveate both the target and the hand during the long target duration.

◆ **The role of texture in judging time to contact**

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When an object is going to hit you between the eyes, the time to contact is a simple function of the rate of optical expansion. When it is going to pass you, matters are more complicated. For instance, your view of the object changes as it moves, so its image will not only expand, but also deform. We examined whether this information helps subjects to estimate the moment that the object will pass. The objects were binocularly simulated spheres, for which the projected outline remains circular, but the texture deforms and translates within the outline during the approach. We presented either solid or textured spheres that were either rotating in space (nulling the texture motion within the outline) or not. The trajectory was displayed between 0.5 s and 0.7 s. Subjects had to decide whether the object passed them before or after a reference time (1 s) signaled by a beep. When there was no texture, subjects judged that the ball passed later than in the other two conditions. Thus the texture seems to be used to judge the object's time to contact, but we did not find evidence that subjects consider the motion of the texture within the contour.

SYMPOSIUM 3

FUNCTIONAL BRAIN IMAGING OF FORM AND MOTION PERCEPTION

◆ **Using angular declination and ground-surface representation for intermediate-distance space vision**

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The ground-surface representation can be a reference frame for space vision in the intermediate distance (2–20 m). On the basis of the ground-surface representation, absolute distance is

derived from the angular declination of a target. When the visual system reliably codes the ground surface and angular declination, distance judgment is accurate. Our studies support this proposal. We showed that: (i) the angular declination is referenced to the eye level that depends on both the visual (eg optic flow and perspective cues) and body senses; (ii) the angular declination is reliably coded, even in the reduced-cue condition that causes errors in judging target position; (iii) to accurately represent the ground surface, the visual system first uses the reliable near depth cues to form a near ground surface representation, which it then uses as a template to integrate the more distant surface based on texture information; (iv) when the requirements for the surface integration process is not met (eg owing to reduced cues or texture discontinuation), the visual system resorts to representing the ground surface with increased dependence on its intrinsic bias. This can lead to distance judgment errors, as the intrinsic bias is not always accurate while the angular declination is.

◆ **Brain systems processing global form and motion**

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Sensitivity to coherent organisation (common direction of dot motion; concentric or parallel alignment in line segment arrays) is a signature of intermediate global processing in pathways analysing form and motion information. Our earlier fMRI work (Braddick et al, 2000 *Current Biology* 10 731–734) showed that sensitivity to coherent versus incoherent organisation (a) was a property of extra-striate rather than striate cortex; (b) showed non-overlapping areas responding to form and motion coherence, but not a simple ventral/dorsal segregation. We have investigated in more detail the areas responding to global form coherence, and their relation to psychophysical sensitivity. We have tested whether these areas show linear or nonlinear relations between BOLD signal and coherence: middle occipital and ventral occipital foci were linear, while intraparietal sulcus and medial ventral occipital foci showed inverted U responses, suggesting a less direct role in form sensitivity. We also report dissociations and overlap between areas responding to parallel and concentric organisation. In conjunction with psychophysical results, these allow a start in dissecting different processes sensitive to mid-scale and large-scale pattern structure. We also discuss these systems in relation to developmental findings and neurodevelopmental disorders. [Supported by MRC Programme Grant G790850.]

◆ **fMRI responses predict speed and contrast discrimination thresholds**

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We studied the relationship between fMRI responses and visual discrimination thresholds using a simple model of neuronal population responses. fMRI contrast–response functions and psychophysical discrimination thresholds were acquired from subjects performing either a speed or contrast discrimination task on moving sinusoidal gratings. fMRI contrast–response functions increased monotonically in area V1, but were flat in area MT+. Perceptually, increases in baseline contrast lead to an increase in contrast-discrimination thresholds, while speed-discrimination thresholds increased only slightly with contrast. Surprisingly, fMRI contrast–response functions did not depend on the task. However, a simple population-based model shows that speed-discrimination thresholds are most consistent with fMRI responses in MT+ and contrast-discrimination thresholds are most consistent with V1 responses. Our study demonstrates the critical significance of modeling the underlying population code in understanding the relationship between fMRI responses and visual perception.

◆ **Characterising the sub-regions of the human V5/MT complex**

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The primate V5/MT complex comprises several sub-regions, but little is known of their human homologues. We have examined V5/MT with fMRI in terms of specificity to optic-flow stimuli, a key characteristic of primate MST. Stimuli were large fields of moving dots, forming global flow patterns or random motion. Rotating wedges of moving dots were also used to provide

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retinotopic maps and to study receptive-field (RF) size (Smith et al, 2001 *Cerebral Cortex* **11** 1182–1190). Two distinct sub-regions were found within the human V5/MT complex. One appears to be activated by all moving-dot patterns, including random motion. It shows strong signs of retinotopic organisation, is only weakly activated by stimuli confined to the ipsilateral hemifield, and has relatively small RFs. It corresponds to human MT of Huk et al (2002 *Journal of Neuroscience* **22** 7195–7205). The second sub-region is located anterior to MT. It shows substantial ipsilateral activation and only weak signs of retinotopic organisation. It corresponds to MST of Huk et al. In this area, activation varies markedly with optic-flow structure. Estimated mean RF size is greater than in MT. The results suggest that human MST is specialised for global flow properties, while human MT is not.

◆ **Brain activity along the apparent motion path—recurrent feedback of area hMT/V5 to V1?**

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Two visual stimuli displayed alternately at certain spatiotemporal intervals may give rise to apparent motion (AM). Higher extrastriate visual areas (MT and associated regions) play an important role in the construction of this perceptual state (Muckli et al, 2002 *Journal of Neuroscience* **22** RC219, 1–5). Here, we used functional magnetic resonance imaging (fMRI) at 1.5 and 3 T to analyse the activation in early visual areas during the perception of AM. We mapped retinotopic visual areas and the cortical representation of three locations (upper, middle, lower). AM was induced by stimuli presented alternately at the upper and the lower location. We find AM-related activity in primary visual cortex (V1). We can map this V1 activity to the path of the visual illusion (middle location). And we can show that this AM-related activity in V1 persists when subjects are engaged in an attention-demanding centre task. In addition to our fMRI experiments, we performed an EEG experiment. We have identified an AM-related early change of the classical VEP in the latency range of 92–105 ms and a later change (~150 ms). A plausible interpretation of our fMRI and EEG results is that cortical feedback from hMT+/V5 induces a selective increase of activity in V1 along the AM trace.

◆ **Neural correlates of visual exploration**

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Visual exploration is an active process involving sensory and motor control components. Functional MRI was used to study the neural correlates of visual exploration. By comparing the BOLD responses evoked during steady fixation to that found for conditions requiring the subjects to saccade to visual targets, the role of visual, oculomotor, and associational cortical areas in different tasks was assessed. In these tasks, subjects followed a visual cue to execute or inhibit a saccade (go/no go), or they followed an internal rule to move their eyes or their attention to specific locations in space. These visually guided tasks are also compared with memory tasks or self-guided tasks, in which the subject saccades to remembered locations in the dark. Comparison of the resulting patterns of activation indicates that areas beyond eloquent oculomotor cortex underlie our ability to direct attention, and our eyes, to locations of interest within the visual field.

◆ **Spatial and temporal distribution of cortical representations of faces and objects**

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Functional brain imaging has revealed a complex, macroscopic organisation in the functional architecture of the ventral object-vision pathway. Numerous studies have found regions of ventral temporal cortex that consistently demonstrate category-related response preferences, most notably a region that responds maximally during face perception—the fusiform face area (FFA). Faces and numerous other object categories, however, also evoke distinct patterns of response across wider expanses of ventral temporal cortex, including distinct patterns of response in cortical regions that respond submaximally to the category being viewed, suggesting that the representation of faces extends beyond the regions defined by category preference. Thus, representations of faces are distributed locally within ventral temporal cortex. A second, locally distributed representation of objects exists in lateral temporal cortex, in the posterior superior temporal sulcus. Whereas the representation in ventral temporal cortex appears to contain information about the appearance of object form, the representation in lateral temporal cortex appears to contain information about how faces move and about aspects of faces that can change with movement, such as eye gaze direction and expression. Neural responses to faces are also distributed across time. The early and late parts of responses to faces and objects show different effects of memory and attention and may reflect a differentiation between early feedforward processing

and later processing with stronger effects of inter-regional interactions. Thus, the neural representations of faces and objects appear to be distributed in time as well as in space.

◆ **Perceptual decision-making in human prefrontal cortex**

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On the basis of findings in monkeys, it has been proposed that perceptual decisions are made by integrating the outputs from selectively tuned pools of sensory neurons. To test whether a similar mechanism is at work in the human brain and where this computation might be performed, we used functional MRI while subjects decided whether a degraded image was a face or a house. Activity within left dorsolateral prefrontal cortex was greater for suprathreshold than for perithreshold stimuli and covaried with the difference signal between face and house selective regions in ventral temporal cortex. Thus, even for high-level object categories, the comparison of the outputs of different pools of selectively tuned neurons could be a general mechanism by which the brain computes perceptual decisions.

SYMPOSIUM 4

NATURAL COLOUR CONSTANCY IN RETINA AND CORTEX

◆ **Why do strawberries look red? Natural colour constancy in retina and cortex**

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Colour constancy refers to the ability to extract information about surface colours independently of illumination conditions. A ripe strawberry, for example, appears the same red when viewed under a blue sky or a reddish sunset. Since Land's pioneering work, discussion has centred on the issue whether colour constancy is achieved primarily in the retina or visual cortex. Recently, the debate has shifted to a consideration of the constraints imposed by various psychophysical tasks and instructions. Humans can judge illuminant colour, reflected-light colour, surface colour, and the relationship between surface colours within a scene. Such observations suggest that colour constancy may not be a unitary phenomenon, and that its different aspects may be mediated at different levels in the visual system. Several questions therefore arise: are the tasks of surface estimation and illuminant estimation complementary, insofar as good performance in one implies poor performance in the other? How does retinal adaptation alter performance? Is colour vision tuned to the statistical composition of natural surfaces and illuminants? What role does colour-opponent processing in retina and cortex play in colour constancy? These and related questions are explored here in order to better understand what we mean when we ask: "Why do strawberries look red?"

◆ **Colour constancy of real 3-D objects**

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Colour constancy is typically studied in the laboratory with the use of simulated two-dimensional uniform surfaces under spatially uniform illumination, in asymmetric matching paradigms in which observers simultaneously view two scenes with two different illuminations. But, in the natural world, colours of objects under different light sources are rarely compared in this way. Instead, colour constancy will typically rely on colour memory: colours of objects must be compared to remembered colours to be judged the same or different, under changes in illumination and context that typically take place over minutes, hours, or days. To understand how colour constancy contributes to the perception of real objects in the natural world, and how colour memory contributes to colour constancy, we have developed a setup in which observers are able to adjust the apparent colour of real 3-D objects under controlled illumination. We find differences in colour constancy for textured, shaded 3-D objects versus flat, homogeneous coloured patches—colour constancy for objects is better because colour acceptance thresholds are lower—as well as differences in colour memory for objects under changing versus unchanging illumination. We conclude that colour constancy in the natural world cannot be explained by purely retinal mechanisms.

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◆ **Colour appearance in complex scenes**

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Natural scenes have many chromaticities in view simultaneously. Colour perception of such scenes, composed of a patchwork of many colours, cannot be understood with theories that explain colour shifts from uniform backgrounds. Several processes of cortical origin affect colour perception in variegated chromatic scenes. (i) Chromatic induction from a contiguous uniform surround is modulated by the magnitude of chromatic contrast in outlying regions. The outlying chromatic contrast is equally effective when presented to either the same eye as the inducing surround or the opposite eye. (ii) A background pattern composed of more than one chromaticity can shift colour perception more strongly than a uniform field at any chromaticity within the pattern. The receptive-field organisation that accounts for these colour shifts has been found only in visual cortex. (iii) Stereoscopic depth perception improves colour constancy of 3-D scenes, compared to binocular viewing of the same scene with no disparity. (iv) Colour memory of a surface after 10 s follows the physical stimulus of the light reaching the eye but after 10 min is much less affected by the illuminant during learning (colour-constant representation).

◆ **The contribution of memory colours to colour constancy**

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We investigated whether memory colours—the typical colours of objects—do contribute to colour constancy. We presented subjects with digitised photographs of naturally occurring fruit and vegetable objects. The subjects had to adjust the photographs (by changing the mean colour in a two-dimensional colour-opponent space) until the isolated objects appeared neutral gray. The background illumination was neutral gray or shifted towards red, green, yellow, or blue. Subjects also had to make adjustments to uniformly coloured discs, uniformly coloured shapes corresponding to the objects, or to a version of photographs where individual pixels were randomly swapped. The objects were typically perceived in their memory colour when the average pixel colour was gray. For the objects to appear gray, subjects adjusted the average colour by about 5%–10% in the colour direction opposite to the memory colour. For example, the banana was adjusted to a bluish average colour until it appeared gray. No such effect was found for the uniformly coloured discs or shapes or for the photographs with the randomly swapped pixels. These results show a small but reliable high-level memory effect on colour constancy.

◆ **Roles for local adaptation and levels of reference in colour constancy**

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By determining the locations of boundaries between colour categories, we measured changes in colour appearance as a function of the simulated illumination on a variegated background. Under prolonged adaptation to each illuminant, observers demonstrated a high degree of colour constancy. Using backgrounds that were chromatically biased, we tested whether this stability depends on the illuminant's cone-coordinates estimated from scene statistics. The chromatic bias of the background had little effect on the classification of test materials. We then (unknown to the observer) simulated conflicting illuminants on the test and on the background. Under these conditions, information about the background illuminant is provided by the spatial context, while information about the test illuminant is available only by collating local information over successive trials. Observers continued to demonstrate colour constancy. To examine the relative roles of automatic adaptation and perceptual strategies, we reduced the duration of exposure to the test, compared to exposure to the background (under the conflicting illuminant). The results suggest that mechanisms that preserve information across successive presentations are critical in supporting colour constancy. In particular, we identify temporally extended but spatially local adaptation, and perceptual adjustments to levels of reference, as key determinants of the stability of colour appearance.

◆ **Colour-constancy is coded in the retina**

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The stage in the visual system where colour constancy is induced is an issue of intense debate. Edwin Land's retinex model (Land, 1986 *Vision Research* 26 7–21) postulates that both the retina and the cortex are involved in the mechanism for colour constancy. Recently, it was proposed that the horizontal-cell to cone feedback system is responsible for an essential coding step of

colour constancy (Kamermans et al, 1998 *Vision Neuroscience* **15** 787–797), implying that retinal ganglion cells already transmit colour-constant information. The key features of Kamermans's model are that horizontal cell feedback is spectrally and spatially very broad, and that the synaptic gain of the cones strongly depends on the strength of the feedback from horizontal cells. This makes the synaptic gain of the cones strongly dependent on the spectral composition of the global illumination. We present direct evidence that these changes of the synaptic gain are fundamental for the generation of colour constancy and colour induction. These experiments are the first direct evidence that the retina performs crucial calculations for colour constancy.

◆ **Colour-constancy mechanisms in primary visual cortex**

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Colour constancy is thought to be achieved by taking into account the chromatic context in which a stimulus is seen. To investigate the role of primary visual cortex (V1) in contextual chromatic interactions that may support colour constancy, responses of single units in V1 of awake macaques to colour stimuli presented in different chromatic contexts were recorded. Changing the chromaticity of the background influenced the responses to receptive field stimuli in a way that was similar to the perceptual colour shifts induced by chromatic backgrounds as measured psychophysically in humans under comparable stimulus conditions. Likewise, contextual colour patches, presented several degrees of visual angle away from the receptive field, had an effect on the neural responses that was similar to their perceptual effect. However, varying the separation of these remote patches from the receptive field revealed that the spatial range of the interactions was more limited in V1 neurons than in perception. The results show that early stages of the primate visual system may contribute to colour constancy, but also indicate that the computations underlying colour constancy are not completed at the level of primary visual cortex.

◆ **Colour constancy and colour pathways in human and macaque**

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Human functional neuroimaging experiments have identified a colour area on the ventral surface of occipital cortex. However, the precise function, location, and extent of this area are disputed as is its possible homology with macaque V4. The discovery of this area has also diverted attention from measurements in other parts of the colour pathways. We present two results from our humans and macaque neuroimaging work. (i) Measurements in V1 show that changes in the background cone absorption rate influence the response gain to a constant-amplitude probe stimulus. The response gain appears to be controlled separately within each of the cone classes. These gain changes are significant for colour constancy and appear to be localised in the retina. (ii) Macaque cortex shows strong responses to isoluminant colour both dorsally and ventrally in V2 and V4. In humans, the largest responses to the same stimuli are confined to the ventral surface anterior to V3v. These data indicate that colour signals are processed in a pathway beginning at the retina and extending well into extrastriate cortex. Colour constancy is refined at several stages along this pathway. Finally, there appear to be differences between the humans and macaque colour pathways.

ORAL PRESENTATIONS

VISUOMOTOR CONTROL

◆ **Reaching to visual cues: 3-D cue-integration strategies for motor control**

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Visually guided hand movements pose unique problems for understanding 3-D cue integration. We investigated how the brain integrates cues for planning and online control of movements. Subjects placed a cylinder onto a textured, circular target surface that varied randomly in slant (orientation in depth) between trials while they were viewing a binocular image of the surface in a 3-D virtual environment. By either presenting stimuli with conflicts between binocular and monocular slant cues at the beginning of a trial or perturbing the cues at movement onset, we were able to measure the relative contributions of the cues to movement planning and online control. Further, by correlating the slant trajectories of the cylinder over time with the cue perturbations, we derived a time-varying measure of the influence of the cues during the movement.

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Monocular cues slightly dominated binocular cues for planning movements, but binocular cues strongly dominated online control. Dynamic analysis revealed that the information from monocular cues accrued more slowly than the information from binocular cues, suggesting that the difference between cue-integration strategies for planning and control reflect differences in the time course of visual processing of the two cues.

◆ **Online adjustment to visually indicated changes in object weight**

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People can adjust their reaching-to-grasp movements online to sudden changes in spatial properties of a target, such as its position or size. We investigated whether they can also do this when a non-spatial property—weight—suddenly changes. Guiding your movement by using visual cues about an object's weight is less direct than using visual cues about its position. The former depends heavily on experience and is expected to be processed by the (slow) ventral stream instead of the (fast) dorsal stream. We asked participants to reach out and lift an object. Sometimes a weight was visibly added to, or removed from, the object after the participants had started their movement. The delay between the grasp and the lift, and the lifting speed, depended only on the final weight of the object, irrespective of whether the object had changed weight. Thus, participants can adjust online to a visually indicated change in weight. Most participants used more time to move to a changed object than an unchanged object. However, a lack of correlation between this increase in time and the amount of adjustment suggests that this time was not used for reprogramming the movement, but was an involuntary reaction to the change.

◆ **Decoupling eye and hand movement direction in visually guided reaching**

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Hand movements across the workspace vary in speed and accuracy. Both right-handed and left-handed movements (in right-handed participants) achieve higher peak velocities in their own (ipsilateral) side of space. Some components of these hemispatial asymmetries may be related to within versus between hemispheric processing, and others are related to biomechanical differences in hand inertia. A third possibility remains unexplored: eye movements accompanying the hand movements to ipsilateral targets are in a congruent direction with the reaching hand. Although asymmetries in saccadic eye movements tend to be idiosyncratic, these may interact with hand movements in visually guided reaching. To explore these issues, participants were required to reach to targets when fixation position was varied across the workspace, which allowed for decoupling of eye-movement direction and hand-movement direction. Remarkably, right-handed arm movements were facilitated when the accompanying eye movement was rightward, and left-handed arm movements were facilitated when eye-movement direction was leftward. Results are discussed with respect to asymmetries in eye–hand coordination.

◆ **Sub-optimality in human movement planning with delayed and unpredictable onset of needed information**

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In motor tasks with explicit rewards and penalties, humans choose movement strategies that maximise expected gain (Trommershäuser et al, 2003 *Journal of the Optical Society of America A* 20 1419–1433). We examined how strategies vary in response to unpredictable delays of needed information about the reward structure. Subjects rapidly touched a target region while trying to avoid hitting an overlapping penalty region placed randomly to the left or right of the target. The subject received rewards and incurred penalties for hitting the corresponding regions within 700 ms. Late responses were heavily penalised. The penalty region was displayed 0, 200, or 400 ms after the reward region and the subject could not know where it would be until then. Movement trajectories were measured with an OptoTrak 3020 Motion Tracker. Five naïve subjects participated. Reaction times were found to remain constant across conditions. Movement times differed significantly for the different delays, being on average 20 ms longer for the 400 ms delay. The analysis of velocity profiles indicated that prolonged movement times were due to subjects slowing down in the second half of the movement. Mean movement endpoints were closer to the penalty region than predicted for an optimal strategy and performance dropped below optimal in both delay conditions.

◆ **Visuomotor task in age-related macular degeneration patients**

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Relations between perception and action can be modified by training. Age-related macular degeneration (AMD) patients, (central scotoma, $1.7 < VA > 0.5$ logMAR), complain of clumsiness in daily-life tasks and poor reading efficiency. In order to restore their abilities in these tasks, we used perceptual learning processes. The patients spontaneously develop preferred retinal loci (PRLs) in an attempt to catch visual information straight ahead. The shift between PRLs leads to the loss of spatial references. We investigated the consequence of this loss on a pointing task. We measured the amount and distance of mis-pointing during a random presentation of targets on a computer touch-screen in a group of more than twenty patients, comparing the results with those of a group of healthy age-matched subjects aged 60–90 years old. The results showed an increase of dispersion in patients and no spontaneous improvement over time. We also investigated the role of visuomotor training (tracing, circling, crossing) on stabilisation of one TRL (trained retinal locus) and improvement of reading performance. The results show a significant improvement of reading efficiency and accuracy in visuomotor tasks. In line with studies on cortical plasticity and the role of feedback processes, these results support sensori-motor rehabilitation of patients with macular lesion.

MOTION AND FORM: DEVELOPMENTAL AND CLINICAL DATA

◆ **Receptive-field properties of MT neurons in infant macaques**

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Neurons in macaque MT/V5 are almost all selective for the direction of motion. Many are also pattern-direction selective (PDS) and signal the true motion of complex objects. Motion sensitivity is poor in infant monkeys, and we wondered whether this reflects the postnatal development of response properties in MT neurons. Almost all MT cells were direction-selective even in the youngest infants (1 week old), but we found three striking maturational changes in MT responses. (i) Neuronal firing rates were low in 1-week-old infants and increased by a factor of 10 during maturation. (ii) Neuronal dynamics were very sluggish in infants, and became nearly adult-like by the age of 16 weeks. (iii) PDS neurons were very rare in infants, and even by the age of 16 weeks were only half as common as in adults. Our results suggest that substantial postnatal visual experience is not needed to establish the basic direction selectivity of MT neurons. Responsiveness and temporal precision become largely adult-like by the age of 16 weeks. The maturation of pattern-direction selectivity takes considerably longer, and we conjecture that it is the development of this neural computation within MT that is related to the slow course of behavioural development.

◆ **Slow maturation of form and motion perception in primates**

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Recent data from our laboratory suggest that the important limitations on visual performance in infants lie downstream from V1, in the extrastriate cortex. To target development of extrastriate visual areas we used two tasks that reflect processing in either the form or motion pathways. We compared the development of form and motion perception in individual monkey subjects aged 6 weeks to 4 years. Motion discrimination was tested by detection of coherent motion, either translation or rotation, in random-dot kinematograms. Form discrimination was tested by detection of coherent organisation, either concentric or linear, in Glass patterns. In each case, the monkey's task was to determine which of two targets had coherent motion or structure. Contrast sensitivity was measured for comparison. The results show that motion discrimination is demonstrable at earlier ages than form discrimination. Both functions develop over an extended time course up to about 3 years of age. We suggest that form and motion perception develop late in comparison to basic spatial vision. Our results have implications for understanding the differential maturation of dorsal and ventral stream extrastriate areas.

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◆ **Perceptual deficits in autism and Asperger syndrome: Form and motion processing**
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People with autistic spectrum disorder can exhibit visu-spatial and visuomotor deficits. It has previously been shown that people with autism have an impairment in motion processing that may be associated with their visuomotor deficits, but no spatial-integration deficit has been found to underlie reported differences in object recognition and 'central coherence'. Here, we report experiments in which we have measured form and motion thresholds for detecting a Glass stimulus of varying coherence in a field of random dots. A coherent visual patch was depicted by dots separated by a rotational transformation in space (form coherence) or space-time (motion coherence). To measure parallel visual integration rather than serial search, stimuli were presented for only 250 ms. We compared form-coherence and motion-coherence detection thresholds for a group of children with autism, a group of children with Asperger syndrome, and a matched control group. We report for the first time that children with autism show a form-coherence deficit, one which may underlie higher-level deficits in face processing and central coherence. Results also show that children with Asperger syndrome perform at the same level as controls.

◆ **Distinct developmental trajectories in three systems for spatial encoding between the ages of 3 and 6 years**

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A variety of processes for spatial encoding have been described in adults, but developmental studies have not always distinguished these successfully. In this study, seventy-three children (aged 3 to 6 years) searched for hidden objects, from the same or from a different viewpoint, in a factorial design that distinguished path integration, scene recognition, and indirect landmark cues, and in which the walking demand was matched across conditions. Main effects of path integration and scene recognition were found at each age, and differences between conditions followed the pattern reported on a comparable adult task (Wang and Simons, 1999 *Cognition* 70 191–210): retrieval was facilitated by a familiar view, but impaired when the familiar view conflicted with a path-integration cue. There were distinct developmental trajectories for three systems: high competence in scene recognition was attained before the age of 3 years, whereas path integration and indirect landmark use improved, at different rates, over the age range. A surprise question at the end did not elicit verbal descriptions of the hiding places until the age of 5 years. Preliminary data for adults suggest the interesting possibility that some components of spatial memory are close to maturity before the age of 6 years, while further improvements in performance depend on verbal strategies.

◆ **Spatial distortions and temporal instability of amblyopic vision**

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We investigated quantitatively the spatial distortions and temporal instability in amblyopic vision. In a first experiment, amblyopic subjects were asked to describe and draw the percept of their amblyopic eye, with a special focus on temporal distortions. In a second experiment, they were asked to reconstruct concentric circles point-by-point, by using either the dominant or the amblyopic eye. In a third experiment, the reliability of the subjective amblyopic percept was investigated with a matching task. We found that three out of four strabismic amblyopes and two out of three strabismic-anisometric subjects, but only one out of four anisometric amblyopes sensed temporal instability, in addition to spatial distortions. Temporal distortions were seen mainly for higher spatial frequencies. The type of temporal instability could be twofold: either the whole pattern was perceived as jittering, or some parts were perceived as moving. There was a positive correlation between spatial and temporal distortions. The matching task yielded less distortions than the drawing and the reconstruction tasks. These results suggest that strabismus, in addition to amblyopia, is needed to elicit significant spatial and temporal distortions. Further experiments are needed to clarify the differences between the results of qualitative and quantitative methods.

SYMPOSIUM

BELA JULESZ MEMORIAL

◆ **Is there learning in early vision (Julesz #16)?**

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In *Dialogues on Perception* (1995, Cambridge, MA: MIT Press) Bela Julesz discusses 38 strategic questions about visual perception, an elaboration of a list he presented in 1990 (abstract in *Perception* **19** 346). Questions are introduced in random order, with #16 being: “Is there learning in early vision?” and “Where is its locus?”. Though Julesz, in the *Dialogues*, considers this question close to a metaphysical problem, the experimental results available today allow for better insights. In particular, powerful learning effects were observed with texture discrimination, providing evidence for low level of plasticity in adults. The difficulty in identifying the loci in the visual system that are capable of plastic changes seems to be a result of the rich connectivity within the visual system, and between different brain modules, and the consequent distributed perceptual processing. Our recent results, obtained with detection and discrimination of contrast, show a relative immunity to plasticity when using localised targets (Gabor signals). Plasticity is invoked when spatial context is introduced (Adini et al, 2002 *Nature* **415** 790–793). This result points to the interaction between local and global processes as a trigger for plasticity, and is explained by a network model, resembling the cooperative Julesz model of stereopsis, with associative learning rules.

◆ **Beyond fourth-order texture discrimination: generation of extreme-order and statistically balanced textures**

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Julesz (1962 *IRE Transactions on Information Theory* **8** 84–92) drew attention to the general problem in texture discrimination to account for the inference of texture generation rules in texture samples. A theory of induction of the ensemble generation rule from individual samples of statistically defined textures is developed to account for the concept of discriminability from random textures. New texture paradigms are introduced to avoid contamination by luminance extrema, to control local and long-range texture properties, and to provide patterns without global statistical structure. Local luminance contamination is avoided by novel orientation plaids, in which higher-order rules govern the orientation of local elements rather than their colouring. These textures allow evaluation of texture discrimination up to thirty-second order by cortical pattern elements. Long-range processing is studied by random strip rotation and interlacing of independent textures. Each substantially degrades the visibility of the fourth-order textures, revealing that the fourth-order information is conveyed largely by local rather than long-range perturbations from random statistics. Finally, textures statistically equated at all orders can be defined, but may nevertheless readily be discriminated in human vision. The discrimination on the basis of local perturbations implies that human vision assesses textures through a local sampling window, and is largely insensitive to longer-range statistical properties.

◆ **Illusion and random-dot stereograms**

R L Gregory (Department of Psychology, University of Bristol, 8 Woodland Road, Bristol BS8 4JX, UK; e-mail: richard.gregory@bristol.ac.uk)

Bela changed the way all of us thought about perception; especially, though by no means entirely, on stereo vision. His wonderful random-dots technique illuminated not only stereo, but also several not obviously related issues, including localising the source of the Müller-Lyer illusion (central not retinal), and revealing the remarkable speed of visual processing (by changing the dot pattern some twenty times a second, and finding the phenomena unchanged). A beautiful depth-phenomenon seen with random-dot stereograms is reversed ‘pseudo-parallax’, changing as the observer moves, though there is no significant change of the images of the eyes.

◆ **Random-dot stereograms, dipoles, and motion standstill**

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If, when perceiving a fused image in a stereoscope, the left-eye and right-eye images are pulled apart to force the eyes to diverge, at a certain point fusion breaks and the eyes return to

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their neutral position. Julesz called this phenomenon hysteresis and proposed a dipole analogy to describe it, but never formulated a dipole-hysteresis equation. The inherent asymmetry of the hysteresis phenomenon is better described by a physical energy-well model, or a cooperation–competition neural network. When dynamic random-dot stereograms (DRDS) define a raised-bar shape, and that bar is oscillated rapidly back and forth, the left-eye and right-eye components move together (rather than in opposition as above). Julesz and Paine discovered that at certain oscillation rates the sensation of motion disappeared but the stereo-defined bar was still visible—‘motion standstill’. These subjective judgments have now been corroborated by objective methods and with simple unidirectional linear motion. The DRDS-defined motion is shown to be perceived exclusively by the third-order motion system. But motion standstill is shown to be a remarkable property of pattern vision in conjunction with the failure of all motion systems.

WEDNESDAY

ORAL PRESENTATIONS

MOTION 1

◆ **Spatial resolution for motion segregation**

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We investigated spatial resolution for perceiving form defined by motion with two different techniques: grating acuity—the capacity to discriminate a grating defined by alternating stripes of motion from bidirectional transparent motion; and alignment acuity—the capacity to localise the position of motion-defined edges with respect to markers. For both tasks, the stimuli were random noise patterns, low-pass filtered in the spatial dimension parallel to the motion. Both grating and alignment resolution varied systematically with spatial-frequency cutoff and speed. Best performance for grating resolution was about 8 cycles deg^{-1} (for unfiltered patterns moving at 1–4 deg s^{-1}), corresponding to a stripe resolution of 4 min of arc. Grating resolution corresponds well to estimates of smallest receptive-field size of motion units under these conditions, suggesting that opposing signals from units with small receptive fields (probably located in V1) are contrasted efficiently to define edges. Alignment resolution was about 2 min of arc at best, under similar conditions. Whereas alignment judgment based on luminance-defined edges is typically 5–10 times better than resolution, alignment based on motion-defined edges is only 2 times better, suggesting motion contours are less efficiently encoded than luminance contours. Various models for resolution and alignment are considered.

◆ **Local noise (not efficiency) limits direction integration in the periphery**

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We used an equivalent-noise paradigm to examine direction integration across the visual field. Stimuli were 500 ms movies presented monocularly either at the fovea or at 4°, 8°, or 16° in the nasal hemifield of the dominant eye. Movies showed a patch (radius 2 deg) of 32 low-pass elements (SD = 4 min of arc) moving at 4 deg s^{-1} (infinite lifetime) with directions drawn from a wrapped-Gaussian distribution. We estimated direction-discrimination thresholds by having subjects judge if overall direction was clockwise or anticlockwise of vertical-upwards, for a range of offsets of the stimulus direction. By measuring such thresholds at various directional standard deviations, we could estimate how much performance was limited by the ability of observers to resolve the direction of any one element (local/additive noise) and how much by their efficiency at pooling directions (global/multiplicative noise). Results indicate that direction discrimination deteriorates with eccentricity but only at low directional SDs. This is consistent with raised local directional-noise in the periphery but no change in pooling efficiency. We also show that motion coherence (MC) thresholds (measured with an 'up-versus-down' task) rise with increasing target eccentricity and conclude that MC thresholds are influenced by both local and global limits on direction integration.

◆ **Do noise carriers impair the detection of motion direction in first-order and second-order patterns?**

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Thresholds for identifying the direction of second-order motion (contrast-modulated dynamic noise) are consistently higher than those for spatial orientation, unlike the case of first-order gratings for which the thresholds are typically the same. Two explanations of this phenomenon have been proposed: either first-order and second-order patterns are encoded by separate mechanisms with different properties, or dynamic noise selectively impairs sensitivity to second-order motion direction but not orientation. The former predicts the two thresholds should remain distinct for second-order patterns, irrespective of the temporal structure (static versus dynamic) of the noise carrier. The latter predicts direction thresholds should be higher than orientation thresholds, for both second-order and first-order patterns, when dynamic (but not static) noise is present. To resolve this issue we measured direction and orientation thresholds for first-order (luminance) and second-order (contrast or polarity) modulations (1 cycle deg^{-1} , 1 Hz) of static or dynamic noise. Results were decisive: the two thresholds were invariably the same for first-order stimuli but markedly different (direction thresholds ~50% higher) for second-order stimuli, regardless of the temporal properties (and overall contrast) of the noise. This suggests that first-order and

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second-order motions are processed separately and mechanisms encoding second-order stimuli cannot determine direction at the absolute threshold for spatial form.

◆ **The perceived global direction of visual zigzag motion**

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A moving random-dot pattern was presented for 3 s. The direction of motion was modulated in time between motion vectors \mathbf{v}_1 and \mathbf{v}_2 with an angle of 140° between them. Physical global direction was defined as the line constituted by the positions of a single dot at the ends of each modulation period. The perceived global direction was experimentally determined by a matching procedure. For equal speeds and durations of \mathbf{v}_1 and \mathbf{v}_2 the perceived direction always coincided with the physical one. However, when \mathbf{v}_1 lasted for 1/3 (and \mathbf{v}_2 for 2/3) of the modulation period, the perceived direction deviated from the physical one; it was shifted towards the direction of the motion with shorter duration. The deviation increased up to 10° with decreasing modulation frequency (10 to 4 Hz) and with increasing global speed ($2-6 \text{ deg s}^{-1}$). When \mathbf{v}_1 and \mathbf{v}_2 lasted equally long, but \mathbf{v}_2 was twice as large as \mathbf{v}_1 , the perceived global direction was shifted towards the direction of the slower motion. The involvement of processes of integrating and filtering of information provided by labeled detectors, selectively tuned to motion directions, is discussed.

◆ **Computational neurobiology of visual illusions: The flash-lag and Fröhlich effects emerge from simple neural networks**

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In the flash-lag effect (FLE) a moving object is perceived ahead of a stationary stimulus flashed in spatial alignment. This illusion has received conflicting interpretations in the intense debate that followed its rediscovery by Romi Nijhawan. Several explanations have been proposed in order to account for the FLE and its dependence on a variety of psychophysical attributes. Our aim was to obtain the primary traits of the original FLE from the simplest rules governing neuronal integration. Instead of translating any existing conceptual model of the FLE into a 'mathematical representation, we started from well-known features employed in theoretical models of real neurons and neuronal networks. Here, we show that a simple feedforward neural network, implementing either the leaky integrate-and-fire or the FitzHugh–Nagumo mathematical models, is able to reproduce the standard FLE and several related manifestations, such as its modulation by stimulus luminance, trajectory, cueing, and spatial predictability. The model also reproduces the essence of the well-known Fröhlich effect (the misperception of the starting position of a newly moving object). Our results show that a minimal set of elements, based on realistic neuronal mechanisms, yields a unified account of these visual illusions and possibly other perceptual phenomena.

PERCEPTUAL ORGANISATION

◆ **Hiding a red item in a sea of green: Failure to pop-out from simultaneous onsets**

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We present a new psychophysical paradigm designed to distinguish the information in abrupt stimulus onset from that in the display following onset. It enables us to test hypotheses concerning the role of temporal relations in the grouping of internal neural events, because the timing of transient neural responses to stimulus onset is closely related to the external events. Two arrays, each of about 70 short line elements filling randomly selected positions within 10×10 grids, were first displayed. Then around 10 new elements of the same kind were added to each array. The task was to detect one of these new elements, which differed from all the others in appearance and/or onset time. Under these conditions, observers have difficulty even in detecting one red item among several green ones, if all appear simultaneously. However, onsets that differ in time by around 40 ms can be reliably detected. We present evidence that it is cortical timing, rather than the timing of events in the outside world, that is crucial in determining whether pop-out occurs. In contrast to some previous studies, our results suggest that temporal cues can have a stronger effect than spatial cues in determining perceptual organisation.

◆ **Beyond grouping by proximity in regular dot patterns**

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A collection of discrete objects is often perceptually organised into groups. Kubovy and colleagues proposed a 'pure distance model' (PDM) that predicts grouping by proximity for all possible dot lattices (Kubovy et al, 1998 *Cognitive Psychology* **35** 71–98). We present a new kind of regular pattern: dot-sampled structured grids (DSGs), that can be perceptually organised into parallel lines or curves. We show that the perceptual organisation of DSGs violates the PDM. We also show that, although grouping by proximity constrains the number of predominant organisations in DSGs, it does not predict our results. Moreover, our results are inconsistent with predictions based on findings from contour-detection experiments that use random-dot patterns. We present data from experiments in which we manipulated the density, relative proximity, and curvature of possible contours in DSGs. We found significant effects of each in addition to effects of stimulus duration. We discuss our findings in relation to (i) Gestalt theory, (ii) contour detection, (iii) geometry-based stimulus coding, and (iv) the perception of 3-D surfaces. We conclude that DSGs yield results that are unexpected and relevant to both spatial and temporal aspects of perceptual organisation.

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◆ **Bayesian prior influences stereo depth discrimination**

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Our aim was to quantify the degree to which object recognition versus no-recognition influences stereo discrimination. A static point-human (13 points) was presented stereoscopically and upside-down such that no subject recognised it. Two red dots depicted one forearm (hand–elbow), while two green dots depicted the other forearm. The remaining dots were blue. Subjects discriminated if the 3-D distance between the red dots was greater than that between the green dots. The projected 2-D distances were always equal. The method of constant stimuli was used, without feedback, with six levels of difference in the 3-D distances. After measurement of the psychometric function, a movie of the upright human walker was presented for recognition. The psychometric function was measured again with the upright human. In the first control experiment, the above procedure was repeated without the movie. In the second control, the elbows were replaced with hip points, while the 3-D distances were kept unchanged. Fifty-one subjects participated. In the experimental condition, discrimination worsened after recognition. In the first control experiment, discrimination slightly improved. In the second control experiment, discrimination improved. We conclude that the prior that two forearms are equal in length impedes discrimination. When such prior is ineffective, recognition facilitates discrimination.

◆ **Subjective direction of ambiguous transparent motion is biased by veridical motion of a translucent but not opaque context**

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We investigated how interpretation of an ambiguous display depends on its context. Two rotating random-dot cylinders were presented bilaterally on a black background. Varying the contrast between opposite-moving dots on the context cylinder (C) modulated its transparency, biasing its perceived rotation in favour of the direction of brighter dots. For such biased stimuli, veridical reversals of dot motion (every 3–6 s) reliably determined perceived direction of rotation. The ambiguous test cylinder (T) was always transparent with no veridical motion changes. Subjects simultaneously reported concurrent perceived rotation direction of C and T using two response keys for each hand. Results reveal new stimulus-dependent constraints on context integration. (i) Phase-locking significantly increased for cylinders with collinear axes, ie appearing to form a single tube. (ii) Phase-locking between reported rotation directions of C and T was maximum with perfectly transparent ambiguous Cs, declining with increasing C opacity. This corroborates Grossmann and Dobbins (2003 *Vision Research* **43** 359–369), but new control conditions discount possible confounds of dot density and luminance differences between opaque and transparent cylinders. (iii) Veridical C motion-reversals reliably triggered subjective T reversals, but only when both opponent motion vectors were visible in C at intermediate transparencies.

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◆ **Unraveling the behavioural evidence for temporal binding**

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If two images are displayed in rapid cyclical order, we perceive them as a single, fused image. However, recent studies have revealed that visual ordering and grouping can be influenced by minor temporal offsets of this sort, and it has been suggested that this effect reveals the presence of a neural ‘temporal binding mechanism’. This mechanism would serve to keep multiple mental representations of one object distinct from those of other objects. An alternative explanation is that involuntary eye movements are responsible for converting the temporal offset of the two images into a minor spatial offset in the compound, test image. To test this hypothesis, I replicated one of the recent studies over several viewing distances, and discovered a significant increase in performance as viewing distance increased ($p < 0.01$). Further studies with an eye tracker confirmed the link between eye-movement amplitude and sensitivity to the temporal offset. Hence, the work reveals a role for involuntary, fixational eye movements in the perception of temporally asynchronous stimuli. As a result, our sensitivity to very brief temporal asynchrony is open to re-interpretation in terms of a purely spatial mechanism, thereby undermining support for the temporal-binding hypothesis.

MOTION 2

◆ **Critical band masking in optic flow**

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We used a masking paradigm to determine the information contained in optic flow that is used by observers to determine their direction of motion. We made linear digital movies of the visual field at driving speeds up to 70 miles h^{-1} . The movies were presented in forward or reverse sequence in space-time filtered dynamic noise. Observers identified whether the motion was forwards or backwards with feedback. The rms contrast of the noise was fixed, the rms contrast of the movie was under the control of a staircase. The dynamic noise was digitally filtered with notch space-time filters that attenuated all components within a single octave of spatial frequency (SF), temporal frequency (TF), or speed. Contrast thresholds were band-pass tuned for SF, centred on 4 cycles deg^{-1} (broad TF spectrum). There was little or no tuning for TF (broad SF spectrum). Speed-filtered noise produced band-pass tuning functions whose peak shifted with driving speed. Thus observers use different spatiotemporal frequency combinations at different task speeds at approximately the same eccentricity, instead of a unique optimal motion component.

◆ **Motion signals in Glass pattern sequences**

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A sequence of independent Glass patterns of the same type appears to move coherently (Ross et al, 2000 *Current Biology* **10** 679–682). Furthermore some neurons in the superior temporal sulcus (MT/MST) respond to Glass-pattern sequences as they do to apparently similar coherent global motion (Krekelberg et al, 2003 *Nature* **424** 674–677). The aim of this study was to determine if coherently directed motion signals can be found in a sequence of independent Glass patterns even though none have been explicitly introduced. Subjects observed short sequences of rotational Glass patterns, then, later, the same sequences again shown in reverse order, reporting the direction of motion (clockwise or anticlockwise) seen on each presentation. Some sequences were completely independent; others contained rotational motion signals. Control patterns were composed of randomly oriented dipoles of the same point separation as the systematically oriented Glass pattern dipoles. The tendency to report a reversed direction of motion for a reversed sequence was found to be no different for Glass pattern sequences than for control sequences and thresholds for detecting the direction of real motion signals were little different. It follows that Glass patterns organise motion by indicating a path of motion. They do not introduce directed motion signals when shown in sequence.

◆ **fMRI reveals that MT processes motion using a high-level code, not motion energy**

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Three types of input drive motion processing: (i) luminance displacement (motion energy) drives first-order, (ii) form displacement drives second-order, and (iii) attentional tracking drives third-order processing. Just because MT neurons respond to luminance displacements does not necessitate that MT processes motion primarily in terms of motion energy: luminance displacements might also be coded as moving objects. fMRI was used to determine whether MT responds to motion energy or object motion. Three stimuli were used in blocks: (1) a moving illusory

'Kanizsa' rectangle, (2) a control stimulus where the same pacmen changed out of phase, eliminating the rectangle percept, and (3) a 'real' moving rectangle defined by luminance contrast. Areas that respond more to motion energy should have a higher BOLD signal for (3) than either (1) or (2), whereas areas that respond to object motion should respond more to (2) (four objects moving) than for (1) or (3) (one object moving). V1 BOLD response was found to be greatest for (3) and MT BOLD response was found to be greatest for (2). It follows that areas that process motion in terms of motion energy (V1) can be distinguished from areas that process object motion (V3A, MT) and areas that process object shape (V4v, posterior fusiform).

- ◆ **Motion visualisation, synthesis, and perception using 4-D multiple-view spatiotemporal volumes**
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Image sequences or video can be viewed as spatiotemporal volumes $\langle x, y, t \rangle$, with motion reflected in the structure of the volume. In previous work, we described a system we have designed for 3-D visualisation and interactive exploration of spatiotemporal information (Nikolov et al, 2002 *Perception* 31 Supplement, 122), and how special effects, such as fluid motion, time sections, swapping motion direction, and others, can be generated by spatiotemporal volume processing [Gardner and Nikolov, 2004 *Proceedings of CVMP 2004* (London: IEE Press) pp 145–154]. In an increasing number of applications, multiple sensors simultaneously acquire images of an object or scene, which can be considered as taken from different 'viewpoints', v . In this way, 4-D spatiotemporal-viewpoint $\langle x, y, t, v \rangle$ data sets can be constructed. We used our 16 video cameras rig to capture video sequences of different dynamic scenes and by view-synthesis software to generate intermediate 'virtual' views to populate the 'viewpoint' dimension. Visualisation of such 4-D volumes through computation of cuts and slices, and playing these 3-D solid volumes with different shapes as new video sequences, allows the perception of object motion in time and from multiple viewpoints, and the creation of new complex motion effects. Swapping the time and viewpoint dimensions leads to other novel visual effects.

- ◆ **Separating the edge-based detection of object motion from the objectless detection of motion energy**

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Motion-energy models are founded on the idea that low-level motion perception entails the detection of spatiotemporal changes in raw luminance (ie oriented energy) irrespective of other stimulus features, including the boundaries that segregate an object from its background and/or delineate the parts of the object. In this respect, the distinction between motion based on the detection of an object and motion based on the detection of motion energy corresponds to Wertheimer's distinction between beta motion and objectless phi motion. Support for this correspondence comes from a striped stimulus that produces Mach bands. Over time, luminance increases spread rightward over the length of the stimulus, but in a way that produces stimulus information specifying successive leftward motions of the edges of the stripes. This leftward motion is perceived when conditions make it possible to localise the edges. Otherwise, objectless phi motion is perceived in the motion-energy specified, rightward direction. These results, which cannot be accounted for by attentive feature tracking, suggest that there are independent mechanisms for the detection of object motion and the detection of objectless motion energy, a functional separation that may be valuable for discriminating the motion of objects from the optic flow produced by the perceiver's self-motion.

OBJECT RECOGNITION AND SHAPE

- ◆ **Disruptive colouration and background pattern matching in insect crypsis**

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Analyses of crypsis generally focus on how well an individual represents a random sample of the background, yet camouflage is also achieved by breaking up the outlines of an animal: 'disruptive colouration'. Although disruptive colouration works in combination with background matching, it is logically distinct. The theoretical predictions were tested with respect to avian vision in field experiments involving artificial 'moths' composed of printed card ('wings') with mealworms (edible 'body'). In experiment 1, 'moths' were uniformly coloured black or brown, or had background-matching patterns consisting of brown and black, placed either in the centre of the moth, randomly, or at the edges (disruptive). Moths were placed along transects on oak

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trees and 'survival' (detection rate) in the face of bird predation was monitored over 24 h. In experiment 2, we tested the prediction that strongly contrasting pattern elements provide greater disruptive effects. Each moth comprised two colours, occurring equally frequently on oak bark, and exhibited either disruptive markings, random markings, or was uniformly coloured as the average of the colour pairs. On the basis of survival analysis of the data, we assessed whether both background matching and disruptive patterning conferred significant, independent survival benefits.

◆ **Retinal image determines perceived shape despite intervening saccade**

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When components of a shape are presented asynchronously during smooth pursuit, the retinal image determines the perceived shape, as if the flashes belonged to the pursued object and therefore moved with the eyes. When saccades shift our gaze between structures of interest, there is no reason to expect anything to have moved with the eyes. We therefore examined how people judge the separation between targets flashed before and after a saccade. Subjects tracked a jumping dot with their eyes. Targets were flashed at predetermined retinal positions, with a 67–242 ms interval between them. After each trial, subjects indicated where they had seen the targets. We compared trials in which subjects made a complete saccade between the presentations of the two targets, with ones in which the eyes did not move between the presentations, and with ones in which only one target was presented. For short inter-target intervals, subjects' judgments mainly depended on the retinal separation, even when there were conspicuous visual references nearby. Presaccadic mislocalisation or perisaccadic compression of space could not account for the results. Thus, the retinal separation determines the perceived separation between targets presented with a short interval between them, irrespective of any intervening eye movements.

◆ **Object recognition. Parts, wholes, and the conjunction index**

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How do we identify an object? Joining two old ideas—part and conjunction—provides an answer. Some objects can be recognised by detecting a single feature, but to recognise most objects we must detect a combination of several features—a 'conjunction'. The long-standing question whether an object is recognised as a whole or by parts distinguishes a single global conjunction over the whole object from a combination of several local conjunctions computed over distinct regions of the object. In evaluating conjunctions, human vision always includes features over a minimum area—the 'conjunction field'—that depends solely on eccentricity. Viewing peripherally (object two diameters away from fixation) prevents recognition by parts while sparing holistic recognition. In a preliminary survey, all objects recognised holistically are simple shapes like a vase or letter. Most objects, including faces and words, are recognised by parts. Viewing peripherally, normal observers meet all the clinical criteria for visual agnosia.

◆ **Perception of corners of different angles in human subjects**

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Vasarely's nested-square illusion shows that corners can be perceptually more salient than edges. On the basis of this illusion we developed a novel visual illusion, the alternating brightness star (Martinez-Conde and Macknik, 2001, Abstract Viewer/Itinerary Planner, Program No.12.4, Washington, DC, Society for Neuroscience, online), showing that sharper corners are more salient than shallow corners (corner angle salience modulation, CASM) and that the same corner can be perceived as either bright or dark depending on whether its angle is concave or convex (corner angle brightness reversal, CABR). Here we quantified both CASM and CABR psychophysically. Subjects performed a two-alternative forced-choice task to decide the brighter of two stimuli: a standard and a comparator. The comparator was a gradient of corners (11 angles: $\pm 30^\circ$, $\pm 60^\circ$, $\pm 90^\circ$, $\pm 120^\circ$, $\pm 150^\circ$, 180°). The standard was made of pseudorandomly scrambled segments of luminance. Standard and comparator had the same average luminance as the grey background, and all conditions were presented in randomised order. As predicted, we found that sharp corners generated stronger percepts than shallow corners (CASM). Corner gradients appeared bright or dark depending on whether the corner was concave or convex (CABR). These results align closely

with similar results from testing computational models of early receptive fields with the same stimuli.

◆ **Developmental differences in judgments on the beauty of design and natural objects, and abstract art work**

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Whereas some people claim that beauty lies in the eyes of the beholder, it may be argued that the aesthetic experience is a quality of the perceptual system of humans. Here, the hard-wired aesthetic response, indicated by the agreement of subjects using spontaneous judgments on the beauty of a series of objects, is examined. In the first experiment, there was a substantial agreement of schoolchildren aged 12 to 13 years about the beauty of design objects (8 chairs), but the rank order differed totally from the rank order of adults. In judging the beauty of (5) human female bodies, younger children aged 5 to 10 years consistently preferred the prototype, whereas children 12 to 13 years old replicated the judgments of adults preferring the composite of the 4 most attractive bodies (cf Kersten, 2004 *Perception* **33** Supplement, this issue). Whereas children aged up to 10 years consistently preferred the more complex (earlier) Mondrians, adults preferred the less complex (later) works. In this series of experiments there was a substantial agreement between children in judging the beauty of a series of objects. The reasons for the different rank orders derived from children of different age groups are discussed.

MOTION AFTEREFFECTS

◆ **Divisive and subtractive inhibition in the motion aftereffect**

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According to the standard model of the motion aftereffect, adaptation weakens the output of V1 motion detectors tuned to the adapting direction, thereby stimulating an opponent stage downstream, possibly in V5/MT. Despite the success of this model in predicting the response of neurons to counterphasing gratings (Kohn and Movshon, 2003 *Neuron* **39** 681–691), some problems remain: in particular, why is there a motion aftereffect to stationary stimuli? We suggest that adaptation produces a directionally selective loss of sensitivity, but also directly unbalances the opponent mechanism. We fit full threshold-versus-contrast functions for gratings drifting in the adapting and null directions with four-parameter transducer functions. The transducers had different semi-saturations, but were otherwise identical. Next, we found that, when added to a grating drifting in the null direction, a grating drifting in the adapting direction needed greater contrast to produce stationary flicker than would be expected from merely comparing the inferred transducer functions. A similar discrepancy emerged when we measured the probability of reporting motion in the adapting and null directions as a function of actual motion direction and contrast. We suggest that this (small) unbalancing is due to a subtractive signal at the opponent stage.

◆ **Spatial invariance of motion aftereffect across eye movements**

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Motion aftereffect, which is a perceptual manifestation of the neural activity of motion-selective neurons after exposure to a prolonged motion signal, can be translated across space. This translation invariance is called 'remote motion aftereffect' (R-MAE). Using a re-fixation paradigm, we investigated the spatiotopy of R-MAE when the retinal representation of the visual stimuli was displaced owing to eye movements. First, we asked subjects to foveate a rotating radial pattern for several seconds. After disappearance of the rotating stimulus, subjects had to saccade to another location on the screen. After re-fixation, we presented a counterphasing radial pattern either in the spatial equivalent location of the adapting stimulus in the periphery of the retina or in the opposite spatial location with the same eccentricity from the fovea. We compared the durations of dynamic MAEs in these two conditions. Our results showed that R-MAE is stronger for new retinal location that corresponds to the spatial location of the adapting stimulus. This result indicates that the neural substrate of R-MAE distinguishes between retinal image translations caused by eye movements and real external image displacements.

Wednesday

- ◆ **Electrophysiological evidence for independent speed channels in human motion processing**
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A variety of psychophysical studies suggest that motion perception in humans is mediated by at least two speed-tuned channels. To study the neurophysiological underpinnings of these channels in the human visual cortex, we recorded visual evoked potentials (VEPs) to motion onset. An adaptation paradigm allowed us to (a) isolate and extract direction-specific cortical responses and (b) assess cross-adaptation in the speed domain. VEPs resulting from the onset of leftward or rightward motion at either low (3.5 deg s^{-1}) or high (32 deg s^{-1}) speeds were recorded from three occipital recording sites in eleven subjects. For each of these test stimuli, responses were collected after adaptation to one of five different conditions: a static adaptation pattern (baseline), adaptation to low-speed motion either in the same or in the opposite direction as the test, or adaptation to high-speed motion in the same or in the opposite direction as the test. We report considerable direction-specific adaptation for same adaptation and test speeds, while we found no direction-specific adaptation across speeds. We supplement these electrophysiological data with corresponding psychophysical results. This lack of direction-specific cross-adaptation in the speed domain demonstrated with physiological and psychophysical techniques, supports models of at least two speed channels in the human motion system.

- ◆ **Aftereffects and the schizotypal personality**
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Schizophrenics have been subjected often to psychophysical testing. Studies of visual aftereffects have produced equivocal results, perhaps because the participants are under heavy medication or because they are ill-equipped for psychophysics. The construct of the 'schizophrenic spectrum' which includes schizotypal individuals who are 'functionally intact, non-psychotic, unmedicated and unhospitalised', presents a stable population in which to conduct these studies. We have conducted experiments with thirty participants, who completed Raine's schizotypal personality questionnaire (SPQ). Participants fixated a rotating spiral for 60s and subsequently reported MAE duration. Five measures were recorded for each participant. Mean MAE duration was significantly longer in the high schizotypy group (33.4 s) than in the low schizotypy group (20.0 s) when participants were divided by median-split into two groups based on their SPQ scores. In order to determine the magnitude of the McCollough effect (ME), participants adapted for 4 min to alternating horizontal green-and-black gratings and vertical magenta-and-black gratings. Participants then reported the magnitude of any colour seen on black and white test patterns presented at a range of orientations. High schizotypy scores were significantly correlated ($r = 0.40$, $p < 0.05$) with high ME magnitude. The significance of these results is discussed.

- ◆ **Motion aftereffect storage is not based on slower recovery in the dark, but on faster gain-equalisation during testing**
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Suppose a motion aftereffect (MAE) for certain adaptation and test stimuli lasts T . Then, if we close our eyes after adaptation during a waiting time equal to MAE duration T , we unexpectedly still have a MAE, of duration T_R . This phenomenon is (somewhat presumptuously) called 'storage'. It is often quantified by the storage factor $\sigma = T_R/T$. A more complete quantification is a Spiegel function, that is, residual duration T_R as a function of waiting-time duration T_w . We measured Spiegel functions for the sMAE (a low-speed MAE seen with a static test pattern) and dMAE (a higher-speed MAE seen for dynamic test stimuli). We could easily mimic Spiegel functions and reproduce appropriate σ values with a MAE network-model containing divisive gain-controls, that always recover and adapt in the same way, with the same time constant. Crucial is that the test stimulus weakly adapts all motion channels of the system. This equalises the gains of adapted and unadapted channels before the adapted channel by itself reaches its resting state. Evidence for this aspect of the model is summarised. 'Storage' therefore appears to be a misnomer. The mathematical structure and physiological plausibility of the model are discussed and its storage properties are quantified.

BINOCULAR VISION: PSYCHOPHYSICS◆ **Perceptual consequences of binocular matching by correlation: Effects of disparity waveform and waveform orientation**

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A binocular correlation model predicts several aspects of human spatial stereoresolution (Banks et al, 2004 *Journal of Neuroscience* **24** 2077–2089). Performance of the model is limited by two properties: the smallest available correlation window, and the assumption that disparity is constant across small image patches consistent with the physiology (Nienborg et al, 2004 *Journal of Neuroscience* **24** 2065–2076). The model predicts that the form of disparity modulation should affect stereopsis. We presented square-wave and sawtooth-wave corrugations in random-dot stereograms and measured coherence thresholds (signal dots/total dots) for vertical and horizontal corrugations. We observed two effects: (i) coherence thresholds were lower for square than sawtooth waves, and (ii) thresholds were lower for horizontal than vertical orientations. The first effect is predicted by the correlation model, because square waves have regions of constant disparity. The second effect is consistent with the slant anisotropy of binocular vision (Bradshaw and Rogers, 1999 *Vision Research* **39** 3049–3056); it implies that the correlation windows used by the visual system are not isotropic (Tyler and Kontsevich, 2001 *Vision Research* **41** 2235–2243).

◆ **Centre – surround inhibition strengthens binocular rivalry suppression**

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Presenting surround motion in the same direction as one of two moving targets engaged in binocular rivalry leads to increased dominance of the opposite direction of motion. Here, we show that surround motion also increases binocular rivalry suppression. Binocular rivalry was induced by a horizontally moving grating and a stationary concentric target. To measure the strength of suppression, a brief speed pulse was added to the moving grating. Subjects discriminated whether the speed increased or decreased. Speed-change amplitude was varied to find thresholds during dominance and suppression. The dominance-to-suppression ratio quantifies suppression strength. Various conditions compared binocular and monocular surrounds, and same and opposed directions. Suppression strength was greater: (i) for same-direction rather than opposite-direction surrounds, (ii) for binocular rather than monocular surrounds, (iii) for monocular surrounds in the probed eye rather than in the non-probed eye. Overall, surround conditions tended to increase suppression strength relative to the no-surround baseline. We hypothesise that motion surrounds exert inhibitory effects on the central grating analogous to same-direction centre–surround inhibition seen in MT. The strength of suppression in surround conditions compared to no-surround baselines indicates that surround inhibition combines with rivalry inhibition to strengthen suppression of the unseen rival target.

◆ **The Venetian blind effect and Fechner's paradox: Partitioning luminance and contrast disparity information with square-wave gratings into perceived bar rotation and perceived luminance and contrast**

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When a square-wave grating with either luminance or contrast disparity is viewed, one perceives a rotation of the individual bars (the Venetian blind effect—Cibis and Haber, 1951 *Journal of the Optical Society of America* **41** 676–683; Filley and Stine, 1998 *Perception* **27** Supplement, 99; Stine and Filley, 1998 *Perception* **27** Supplement, 106) and an average brightness for the entire fused grating with a brightness for each individual bar (ie perceived contrast of the fused grating). So the luminance and contrast disparity control both the perception of the rotation of the individual bars of the grating and the overall perceived luminance and contrast of the fused images. We have measured the apparent luminance and contrast of fused square-wave gratings over the luminance and contrast disparity ranges that create the Venetian blind effect. Rather than simply responding to the disparities with both perceived bar rotation and apparent luminance and contrast, the visual system responds to the ratio of the luminance and contrast from each eye for bar rotation and to the luminance and contrast of the higher luminance or contrast image of the pair for the perceived luminance and contrast of the fused image (Fechner's paradox).

Wednesday

◆ **Human brain activities in 3-D volumetric object perception**

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3-D volumetric object perception is an important issue in the study of human visual perception. Several years ago, a new visual effect named the ‘mime effect’ was reported (Zhang et al, 1998 *Japanese Journal of Applied Physics* **37** L329–L332), in which an illusory 3-D volumetric object is perceived with binocular viewing due to some stereoscopically displayed inducing objects. On the other hand, it is well known that 3-D perception can also be attained in monocular vision as well as binocular one. Therefore, we studied the volumetric object perception under both above conditions—one was induced by the mime effect with binocular disparity cues, and the other was induced by monocular shading cues instead of binocular ones. We measured human brain activities for these two kinds of perception using fMRI. We found that a wide range of brain areas was involved in both conditions, including prefrontal, parietal, and occipital cortex. But, interestingly, more right frontal cortical areas were activated for monocular perception with shading cues, and more left frontal areas for binocular perception in the mime effect. This implies that the right frontal cortex is more active for processing brightness, and the left is for correlating binocular spatial information.

◆ **Monocular depth perception: More than meets the eye**

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Depth percepts from monocular stimuli are often attributed to mid-level processing that infers occlusion geometry. This account may not be universally applicable; for instance Kaye’s (1978 *Vision Research* **18** 1013–1022) results with monocular bars are consistent with at least three explanations: (i) local sign, (ii) occlusion, and (iii) depth matching via coarse stereoscopic mechanisms. In a series of studies we evaluated each account. Initially we measured perceived depth for monocular and stereoscopic stimuli at a range of offsets. We found that on average 73% (monocular) and 90% (stereo) of responses were correct. We then compared performance for conditions where the unstimulated eye viewed a blank screen at mean luminance or was patched. Performance dropped to chance levels in the patch condition, thus challenging the eye-specific local-detector account. On the assumption of midline fixation, the geometry of monocular occlusion predicts the results of our first experiment; it also predicts that the same results should be obtained for eccentric fixation. However, we found that the depth percept is eliminated with eccentric fixation of 6°. We conclude that our data are inconsistent with explanations based on local sign, or occlusion. Instead, the depth percept reflects the operation of a low-level mechanism which matches dissimilar images at large disparities.

SPATIAL VISION

◆ **Unseen suppressed patterns alter visual awareness in real time**

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A visual pattern can influence subsequent vision via adaptation even when the pattern does not reach awareness. Here we show that a suppressed pattern can alter the contents of visual awareness in real time. When rivalrous gratings are presented intermittently, the percept stabilises: successive dominant images are the same. On the initial presentation, a red grating was brought on 500 ms after a green grating in the other eye to force a red percept. On each subsequent trial observers signalled whether the red grating appeared tilted left or right of vertical. The suppressed grating alternated pseudo-randomly between +40° and –40° on different trials, ensuring that any effect was not due to adaptation. The orientation of a suppressed grating simultaneously repelled the perceived orientation of the dominant grating away from the suppressed grating, without the observer ever seeing the suppressed grating. This finding demonstrates that the dominant and suppressed images during rivalry are not processed independently and that awareness during rivalry is not necessarily interchangeable with awareness during ‘normal’ non-rivalrous vision. The degree to which a suppressed pattern affects the dominant percept needs to be taken into account in utilising rivalry as a tool to investigate the neural concomitants of visual awareness.

◆ **Spatiotemporal dynamics of coaxial and parallel contrast facilitation suggest distinct mechanisms**

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Human observers are more sensitive to a foveal Gabor target when it is presented in the context of collinear and coaxially displaced Gabor flankers than when presented alone (Polat and Sagi, 1993 *Vision Research* **33** 993–999). We examined the dynamics of this surround facilitation by measuring modulation of the target contrast detection threshold at multiple exposure durations and target–flanker separations. The minimum exposure required to induce facilitation (facilitative delay) was found to monotonically increase with target–flanker separation (3–8 carrier wavelengths). After transforming visual to human striate coordinates, the rate of increase in facilitative delay across cortical space was estimated to correspond to $0.13\text{--}0.20\text{ m s}^{-1}$, with the faster values associated with lower spatial scales and greater visual angles. These inferred propagation velocities are interesting, as they closely correspond with optically imaged depolarising activity observed to propagate across striate cortices of several species (eg Bringuier et al, 1999 *Science* **283** 695–699). We also compared the spatiotemporal dynamics of both iso-oriented and ortho-oriented surround modulation and infer that facilitative velocity is much faster in the context of parallel, compared with coaxial flankers. A physiologically derived model based on differential conduction velocity is proposed to account for these configuration-specific modulatory dynamics.

◆ **What is compulsory in crowded orientation signals?**

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Discriminating small stimuli in known locations is impaired when they are surrounded by nearby irrelevant stimuli (crowding). Thresholds follow a linear trend suggesting compulsory linear averaging during crowding (Parkes et al, 2001 *Nature Neuroscience* **4** 739–744). To test the linear-averaging hypothesis, we devised a magnitude-estimation technique to explore response distributions. Subjects were required to indicate the direction and the perceived magnitude of the tilt of a small tilted target (2.5° eccentricity), under different conditions: displayed alone; surrounded by 8 vertical elements (crowded); surrounded by 8 elements tilted with the target (yoked); or randomly replacing one of the 8 vertical elements (micro-search). Thresholds for both the target alone and the yoked condition were about 1° , while in the crowding and the micro-search conditions they were around 10° for our four observers, showing clear evidence of crowding. For the target-alone condition, the distribution of magnitude estimation was unimodal, centred around the actual tilt of the target. However, for all conditions of crowding, the distribution is clearly bimodal, with two distinct peaks corresponding to errors and correct answers. Monte-Carlo simulations show that the bimodal distribution cannot result from linear summation, but is well predicted by a nonlinear model such as ‘compulsory uncertainty’ in crowded conditions.

◆ **Binocular summation, interocular suppression, and contrast gain control: psychophysical model and data**

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Typical contemporary models of luminance contrast masking include a contrast gain control stage in which target contrast is divisively suppressed by a more global pool of image contrast signals. Empirical support for this cross-channel masking over earlier within-channel formulations rests on the analysis of the shape of contrast-masking functions (Foley, 1994 *Journal of the Optical Society of America A* **11** 1710–1719). We first show that the slope of the psychometric function is similarly diagnostic. We then extend an earlier within-channel formulation of dichoptic masking (Legge, 1984 *Vision Research* **24** 385–394) to include a binocular gain control that yields interocular suppression of monocular signals prior to binocular summation. The model provides excellent predictions for (i) psychometric functions and (ii) monocular, binocular, and dichoptic masking functions for parallel and orthogonal superimposed masks, measured by us and by others. The model accommodates our finding that dichoptic orthogonal masking occurs for both superimposed and annular masks at low target spatial frequencies ($0.46\text{ cycle deg}^{-1}$ for 200 ms). The model can be ‘lesioned’ to abolish binocular summation but preserve dichoptic masking, as has been reported in amblyopia (Levi et al, 1979 *Science* **206** 852–854). The model can also describe monocular/binocular contrast matching functions (Legge and Rubin, 1981 *Perception & Psychophysics* **30** 49–61) rather better than an alternative version in which binocular summation precedes contrast gain control.

Wednesday

◆ **Orientation-specific contrast adaptation: Testing the predictions of de-correlation, de-noising, and gain-control models**

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Two experiments designed to test the predictions made by gain-control, de-correlation, and signal de-noising models for the orientation-specific effect of spatial contrast adaptation are proposed. Subjects adapted to either (i) a sinusoidal grating; or (ii) an orthogonal plaid pattern. A yes/no forced-choice paradigm was used to measure contrast thresholds as a function of the contrast of adaptor and the relative orientation between adaptor and adapted signals. For the plaid adaptor, threshold contrast elevations were maximum when the orientation of the test grating and plaid components matched, but minimum when the test grating bisected the orientations of the plaid. As a function of increasing adaptor contrast, threshold elevations were found to saturate at low adapting contrasts. It is concluded that the early saturation and orientation specificities of the threshold contrast effect for plaid adaptors are inconsistent with predictions made by gain-control and de-correlation models. The results are consistent with signal de-noising models of adaptation where the parameters of an environmental model are adjusted according to the temporal and spatial components present in the adapting visual signal.

BINOCULAR VISION: CORTEX AND DISPLAYS

◆ **Dichoptic visual masking and the processing of visibility in human cortex**

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Our object was to verify whether any areas in the human occipital lobe fail to correlate to the visibility of simple targets during dichoptic masking. We broke down the visual hierarchy into visual area regions-of-interest by conducting retinotopy measurements using standard retinotopic mapping techniques. Next, we measured the BOLD responses to a dichoptic version of the standing-wave-of-invisibility illusion. We then compared the amount of target suppression in the dichoptic versus monoptic conditions for each occipital visual area (V1, V2, and V4), averaged across hemispheres. In order to guarantee that observers maintained fixation, they viewed all stimuli while conducting a simple task at the fixation point not directly related to issues of visibility (press button when fixation point blinks). Fifteen subjects were run in a standard fMRI block-design GE 1.5 T, one-shot EPI, FA 90°, epochs 20 s, TR = 2.5 s, 25 axial slices. We found that activity in extra-striate areas correlated with both dichoptic and monoptic visual masking, whereas activity in the striate cortex did not. These findings suggest that the circuits responsible for maintaining the awareness of simple targets may be localised to areas downstream of V1, but within the occipital lobe.

◆ **Improved stereoscopic performance with consistent vergence and accommodative cues in a novel 3-D display**

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When a disparity-defined stimulus is presented on a conventional display, the vergence-specified distance is generally inconsistent with the focal distance. This vergence-accommodation mismatch can cause discomfort and fatigue as well as distortions in 3-D percepts. We have developed a novel device to display images at three focal distances in order to minimise vergence-accommodation mismatches. Each eye's view is the sum of images presented at three focal planes. To simulate object positions between the planes, image intensities are weighted by inverse distance from the planes. We assessed experimentally the utility of the device relative to conventional displays. Observers viewed random-dot stereograms of sinusoidal corrugations. First, observers fixated a cues-consistent target. Next, the stereogram appeared at a new distance which sometimes was cues-consistent (vergence and accommodation matched) and sometimes was cues-inconsistent (vergence and accommodation different). We found that observers were able to determine corrugation orientation in less time and at higher spatial frequency in cues-consistent than in cues-inconsistent conditions. Thus, making the vergence and accommodation stimuli compatible yields an increase in both speed and spatial precision. We conclude that, compared to conventional displays, significant improvements in stereoscopic performance can be achieved by using our three-plane display device.

◆ **Colour-dependent binocular interactions in macaque visual cortex**

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Many binocularly driven neurons in macaque V1 and V2 are sensitive to the relative spatial phase of gratings presented to the two eyes. This confers a selectivity for binocular disparity. For this tuning to be stable to variations in chromaticity, the spatial distributions of signals from the different classes of cones in the two retinal mosaics would need to be the same—a constraint hard to satisfy, since the different cone classes are randomly arranged in the mosaic. We investigated the stability of interocular phase tuning in 73 V1 and V2 neurons of anaesthetised macaque. Both eyes were driven by identical moving gratings, defined by achromatic or L–M modulation, presented in a series of relative phases. Most neurons that were phase-tuned for one grating were phase-tuned for both. Among neurons that responded well to both achromatic and chromatic gratings, the preferred interocular phase could vary widely with colour direction. This interdependence of binocular and chromatic tuning suggests that the spatial distributions of cone inputs differ in the two receptive fields—perhaps reflecting indiscriminate drawing on signals from all available cones—and makes it unlikely that the neurons could support chromatic stereopsis.

◆ **Lateral cortical specialisation for cyclopean motion-in-depth**

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We studied the fMRI activation to cyclopean motion-in-depth entirely based on disparity modulation (CMID). We eliminated the interocular velocity difference cue that accompanies classical stereoscopic motion-in-depth by using dynamic random-dot autostereograms (DRDSs) based on continuous monocular dynamic noise containing no coherent motion information. Block fMRI design was used. Both the test and the null were based on full-field DRDSs, refreshed every 60 ms. In experiment 1, apparent CMID (the stereomotion test) was contrasted with a zero-disparity plane (static null). In experiment 2, to balance for disparity, the same CMID test was contrasted with null period incorporating the CMID disparities as static planes. Retinotopic areas and hMT+ were mapped in separate scans. fMRI responses were obtained on a GE Signa 3T scanner with spiral acquisition in 23 coronal slices, 3 mm thick, at 3 s TR. Test and null stimuli alternated for 9 s each in 36 blocks per scan. The CMID activation in both experiments was substantially shifted anterior to the hMT+, with minimal activation inside hMT+. No significant difference was found between activation with disparity-balanced or non-balanced nulls, implying that these CMID areas are not concerned with disparity per se.

◆ **Effects of monocular cues on user-adjustable depth in 3-D TV**

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In 3-D TV, visual comfort tends to decrease with increasing binocular disparity (eg because of an increase in accommodation-vergence conflict, or more perceptible cross-talk). Therefore, investigating the minimal amount of disparity that is necessary to benefit from stereoscopic depth in 3-D TV is an important issue. We performed an experiment on the effects that monocular cues have on user-adjustable depth. Thirty-six computer-generated scenes were used with five systematically varied properties: texturing, shading, occlusion, in-scene depth, and number of objects. The images were created in real time by means of two (virtual) cameras in a 3-D scene. Participants were asked to interactively increase the stereoscopic depth setting of the initially 2-D image by increasing the camera-base distance in order to achieve a noticeable (minimal) stereoscopic depth sensation. In line with other research, results showed that a camera-base distance that is smaller than the normal human interpupillary distance suffices for a noticeable stereoscopic depth percept. Significant effects of monocular cues were found for texturing and shading, which decreased the required amount of stereoscopic depth set by the participants. In addition to implications for depth-cue integration, our findings support the development of flexible data formats for depth rendering in 3-D TV.

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THURSDAY

ORAL PRESENTATIONS

COLOUR: RETINA AND ENVIRONMENT

◆ **Purkinje shift and retinal noise**

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A visual pigment molecule in a retinal photoreceptor cell can be activated not only by absorption of a photon but also spontaneously by thermal energy. Thermal activations cause the cell to give electrical responses that are indistinguishable from those to real photons and thus constitute an intrinsic noise that sets an ultimate limit to the sensitivity of vision. Barlow (1957 *Nature* **179** 255–256) suggested that the Purkinje shift of spectral sensitivity for night vision (scotopic, blue-sensitive) compared with day vision (photopic, red-sensitive), which goes in the wrong direction in relation to the illumination spectra, might reflect the noise advantage conferred by pigments that require high energy (blue photons) for activation and are therefore less frequently activated by heat. However, this idea has long been regarded as superseded, as activation energies for photic and thermal activation have seemed to differ by a factor of 2. We present a new model for thermal activation suggesting that the difference is an analytical artifact and that photic and thermal activation energies may be quite similar, as assumed by Horace Barlow. The model accurately predicts the steepness of the average relation between spectral absorbance and thermal noise empirically found for both rod and cone visual pigments.

◆ **Variation of red – green dichromats' colour constancy in natural scenes**

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The aim of this study was to test red–green dichromats' ability to discriminate between illuminant and surface-reflectance changes in natural scenes. Stimuli were simulations of natural scenes presented on a colour monitor with 10-bit resolution per gun. The natural scenes were obtained with a fast hyperspectral imaging system. Six different scenes (including rocks, foliage, and buildings) were tested. In each trial, two images were presented in sequence, each for 1 s, with no interval. The images differed in the phase of daylight on the scene: first with correlated colour temperature 25 000 K, then 6700 K. The spectral reflectance of a region in the second image was changed randomly, consistent with a local change in daylight. The observer's task was to decide whether a particular surface in the successive images was the same (pure illuminant change) or different (illuminant change with a surface-reflectance change). The performance of four deuteranopes and five protanopes varied considerably across the scenes tested, with mean colour constancy indices (± 1 SEM) of 0.48 (± 0.13) and 0.19 (± 0.10), respectively (1.0 representing ideal performance). Deuteranopes seemed less disadvantaged than protanopes, performing close to normal with some scenes.

[Supported by the Wellcome Trust.]

◆ **Mesopic spectral sensitivity derived from reaction times**

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The wavelength-dependence of reaction times in the high mesopic range is reportedly described by $V(\lambda)$ both foveally and off-axis. Our aim was to characterise mesopic spectral sensitivity by measuring reaction times to broad-band stimuli. Stimuli with a range of spectral distributions were generated on an RGB monitor. The background was a neutral grey, and took one of four luminances: 0.01, 0.1, 1, and 10 cd m^{-2} . Each stimulus was a 2 deg Landolt ring, flashed for 500 ms, 10 deg from fixation. Spectral sensitivity functions of the form $V_{\text{mes}}(\lambda) = aV(\lambda) + (1 - a)V'(\lambda)$ were fitted to the results at each background luminance. The value of a decreased linearly with the logarithm of luminance from 1 at 10 cd m^{-2} to 0.06 at 0.01 cd m^{-2} . Although spectral sensitivity was best described by $V(\lambda)$ at 10 cd m^{-2} , $V(\lambda)$ overestimated reaction time. This was found to be due to effects of colour, which were not accounted for in the function $V_{\text{mes}}(\lambda)$. Similar effects were seen at the intermediate light levels, but not at 0.01 cd m^{-2} . In conclusion, mesopic spectral sensitivity based on a linear combination of $V(\lambda)$ and $V'(\lambda)$ accounted for much of the variation in reaction times, but reaction time also depended on the activity of the chromatic mechanisms.

◆ **Colour preference: Sex and culture**

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Previously (Hurlbert et al, 2003 *Perception* 32 Supplement, 129), we reported results of a preliminary study into sex differences in colour preference. Here we examine biological and cultural factors over a larger population. Observers (56 females; 51 males; age range 18–24 years) performed a paired comparison task for colour stimuli varied in hue, saturation, and luminance. As before, we find robust sex differences in hue preference: the average female strongly prefers pinks and lilacs, while the average male has less marked preferences; both ‘dislike’ yellow–greens. These differences are more marked for the UK-born sub-sample (36 females; 27 males) than for the China-born one (18 females; 19 males). UK males prefer darker and less saturated colours, while UK females prefer brighter and more saturated colours. In the China-born sub-sample, both sexes prefer brighter colours, and the males prefer more saturated colours. Principal component analysis of the hue preference curves reveals that for all observers, the S-cone value of hue accounts for the greatest variance, while the second principal component closely matches the LM-cone-opponent value of hue. The value of the second principal component correlates with menstrual cycle phase in females. We postulate that these differences may have an origin in sex-specific specialisations for behavioural tasks, such as frugivory.

◆ **Natural illumination, shadows, and primate colour vision**

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Previous research has established that the red–green opponent system in primate colour vision is optimised for encoding the spatio-chromatic properties of scenes containing red or yellow fruit/leaves on a background of green leaves. The efficient detection of such items is based on the fact that the red–green system removes shadows. This shadow-removing process operates even when the shadow has a blue or green tint from scattered light. In addition, information from the red–green system has been shown to be stable against changes in natural illumination. The invariance of the red–green system to shadows and changes in natural illumination, and its orthogonality to the yellow–blue system, imply that the yellow–blue system should be particularly efficient at encoding the difference between light directly reflected from the ground, and light which has undergone Rayleigh scattering. We present data obtained in Kibale Forest, Uganda, and in UK locations, which support the idea that the red–green system removes shadows, and the yellow–blue system responds particularly to the difference between scattered and direct light. The data are based both on a computational analysis and on psychophysical measures of scene segmentation over distances of several kilometres, in which Rayleigh scattering has a strong effect on cone responses.

CORTICAL CODING AND ORGANISATION 1

◆ **Unsupervised learning of coordinate transformations using temporal coherence**

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The visual system converts location information from retinal to several other more relevant coordinate systems. This mechanism has been modelled previously by neural networks trained with supervised and reinforcement learning. Here, we use a simple and biologically plausible trace-Hebbian unsupervised learning mechanism based on the principle of temporal coherence (Földiák, 1991 *Neural Computation* 3 194–200). This algorithm had been used previously to learn invariance to positional shifts. Here we show that this simple unsupervised mechanism, presented with a static environment scanned by smooth and saccadic eye movements can also learn eye-position invariance and coordinate transformations. As an example, a representation defined in retinal coordinates is transformed into one in head-centred coordinates. The neural tuning found in area 7a shows tuning modulated both by retinal position and eye position, which is consistent with the dual tuning properties of the input representation of our model. The network uses the constraint of temporal continuity without explicit teaching or reinforcement to learn the appropriate pooling connections to achieve a tuning effected only by head-centred coordinates, independently of retinal and eye positions. The network is demonstrated on 1-D and 2-D input image sequences. The mechanism is sufficiently general to apply to other coordinate transformations as well.

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◆ **Border ownership and attentional modulation in neurons of the visual cortex**

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Neural signals in V2 represent not only local visual information, such as the contrast and orientation of edges, but also the side of the object to which an edge belongs ('border ownership'—Zhou et al, 2000 *Journal of Neuroscience* **20** 6594–6611). We interpret this as evidence for preattentive visual organisation and hypothesise that V2 serves as an interface for top–down attentional selection. Specifically, we propose the existence of neural circuits that group image features that likely belong to the same object, and assume that top–down attention mechanisms can access these grouping circuits. We studied the representation of two overlapping figures in a selective-attention shape-discrimination task in which border ownership and side of attention could be manipulated independently. The hypothesis predicts that (i) single neurons should show both border ownership and attentional modulation, and (ii) the side of attention enhancement should be the same as the side of border ownership (because attention uses the same circuit that produces the border-ownership effect). We found effects of both attention and border ownership in 46 of 95 cells (48%). Attentional modulation and border-ownership modulation were positively correlated ($r = 0.48$, $p < 0.001$). These findings support the hypothesis.

◆ **Origin of suppressive signals in the receptive-field surround of V1 neurons in macaque**

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Stimulating the region surrounding the classical receptive field (CRF) of a neuron in primary visual cortex (V1) suppresses responses to stimuli in the CRF. To probe the source of this suppressive signal we measured the temporal and spatial-frequency tuning of surround suppression, and its susceptibility to contrast adaptation, in V1 of anaesthetised macaque. With neurons driven by optimal stimuli confined to the CRF, responses were strongly suppressed by surrounding gratings moving at a broad range of temporal frequencies (from 0.6 Hz to 30 Hz), extending from well below to well above the range within which most cortical neurons respond. Responses were also strongly suppressed by surrounding gratings at a broad range of spatial frequencies (including spatially uniform fields), extending well below the range of spatial frequencies to which most cortical neurons respond. These observations suggest that the suppressive signal originates at a stage in the visual pathway before the development of sharp spatiotemporal tuning. Prolonged stimulation of the surround by a high-contrast moving grating substantially reduced the capacity of the surround to suppress responses. The effect of adaptation was greater than would be expected from changes in sensitivity of LGN neurons. Our findings implicate input layers of V1 in producing surround suppression.

◆ **Principal component analysis of good-continuation cues**

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Prior studies of the ecological statistics of good-continuation cues for contour grouping have ignored the sequencing of edges along contours or have restricted attention to cues between neighbouring edges. Here we examine the statistics of good continuation between pairs of edges as a function of their separation along a curve. Edges in a sample of natural images are first detected and localised to sub-pixel accuracy. Edges bounding prominent objects are then hand-traced in sequence, and the two angles induced by linear interpolation between edge pairs are extracted. We report a number of new results: (i) A principal component analysis reveals that parallelism and co-circularity form a roughly decorrelated basis for good continuation over all edge separations. (ii) The inferential power of the good-continuation cues is maximal for neighbouring edges, falling steadily to roughly half peak for separations of 64 edges. (iii) While for neighbouring edges the parallelism cue is stronger than the co-circularity cue, this reverses for edges separated by 4 edges or more, suggesting that estimation noise limits the utility of the co-circularity cue at small separations. (iv) Statistical distributions for good continuation are found to be more kurtotic for man-made objects than for natural objects.

◆ Unmasking the two streams

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We tested the suggestion that there are two separate visual streams in the human cerebral cortex: a ventral stream providing conscious perceptual information for cognitive operations including planning actions, and an evolutionarily older dorsal stream for rapid simple motor acts, not necessarily conscious. We depth-reversed cognitive visual space, with the hollow-face illusion, which is a large and stable cognitive (knowledge-based) effect. Participants 'flicked' targets on the hollow mask seen in reversed depth (recorded with 'Optotrack'). We found that for fast flicks—initiating the ancient ventral system—the fingers directed at the real locations; for slow pointing or tracing, they followed the illusory apparently convex face. So the same visual stimulus can result in opposite effects for conscious perception and rapid action; as expected for the 'two streams' concept, but otherwise surprising.

COLOUR: PSYCHOPHYSICS

◆ Chromatic adaptation to moving stimuli

A Werner (Department of Experimental Ophthalmology, University of Tübingen Eye Hospital, Röntgenweg 11, D 72074 Tübingen, Germany; e-mail: annette.werner@uni-tuebingen.de)

Colour vision is generally investigated with static stimuli. However, under 'real viewing' conditions, colour is, of course, often seen in combination with motion—where movement is relative to the observer. In this experiment, I investigated the implementation of chromatic adaptation during motion. The monochromatic test patterns were produced on a colour monitor and consisted of a 2 deg × 2 deg test patch ($I_{\text{test}} = 19.3 \text{ cd m}^{-2}$), in front of a checkerboard background (20 deg × 20 deg; $I_1 = 28.3 \text{ cd m}^{-2}$; $I_2 = 10.3 \text{ cd m}^{-2}$). Chromatic adaptation was measured for the transition from D65 adaptation ($u' = 0.197$, $v' = 0.468$) to a green adaptation light ($u' = 0.166$, $v' = 0.472$; $t_{\text{adapt}} = 5 \text{ s}$). The effect of chromatic adaptation was measured by a hue-cancellation technique for the achromatic appearance of the test patch. Four conditions were tested: (i) test patch and background static; (ii) test patch moving, background static; (iii) background moving, test patch static; (iv) test patch and background moving. Velocity of motion in all experiments was constant at 0.04 ms^{-1} . It was found that (i) motion of the stimuli per se did not impair chromatic adaptation, and (ii) relative motion, but not motion of the stimuli per se, facilitated adaptation significantly ($p < 0.01$). The results indicate specific interactions—co-processing of colour and motion signals in the cortex.

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◆ Colour discrimination for spatially separated targets

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When comparing the spatial frequency or the contrast of two Gabor patches, subjects' accuracy does not depend on separation up to 10 deg. This result challenges models of spatial comparison that postulate hard-wired comparators extracting local differences in stimulus attributes (Danilova and Mollon, 2003 *Perception* 32 395–414). We report here that colour discrimination does vary with separation. The stimulus patches were sectors of an annulus centred on the fixation point. Their centres were located on an imaginary circle of 5 deg radius and their separation varied from 2 to 10 deg in separate blocks. The chromaticities of the reference and test patches were specified in an analogue of MacLeod–Boynton space, using 10° fundamentals. In this space, the grey background corresponded to equal-energy white. The test patches were fixed in their $L/(L+M)$ coordinate and thresholds were measured in the $S/(L+M)$ direction. The curves relating discrimination thresholds to spatial separation were U-shaped, having a minimum at 3–4 deg and reaching a plateau at 5–6 deg. The results suggest that at small separations the visual system can use dedicated mechanisms extracting local colour differences. But these operate over a limited range, and with increasing distances the comparison may be performed more centrally.

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◆ Induction of novel colour categories in a non-categorical colour space

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The properties of colour categorisation within a cardinal colour space were examined to assess both the degree of analysis possible at this level of representation, and the relationship between

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cone excitation and categorical perception in colour. To this end, the study quantified the category boundary effect (CBE) for pre-existing and novel categories within a non-categorical (cardinal) colour space. The stimuli were 8 deg coloured discs described by vectors distributed throughout the equiluminant plane. The stimulus duration was 500 ms and the contrast 20 times detection threshold. The study required the following five stages. (i) Four observers freely categorised the equiluminant plane of cardinal space. This allowed the identification of subjective category and boundary regions. (ii) Discrimination was measured within and across subjective categories. No CBEs were apparent for any observer. (iii) A subjective category was selected and a novel boundary induced through training. (iv) Discrimination was retested as in stage (ii). Once again, no CBEs were found. (v) After no less than four weeks observers repeated stage (i). Repeated free categorisation revealed the presence of the induced novel categories which suggests categorical colour perception in the absence of any CBEs.

◆ **Lightness compression causes hue changes in Gelb chromatic staircases**

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Gelb illumination causes lightness compression (Cataliotti and Gilchrist, 1995 *Perception & Psychophysics* **57** 125–135). On the other hand, (i) hue perception is modified by luminance (Bezold–Brücke effect), and (ii) the use of basic colour terms is constrained by surfaces lightness (Boyton and Olson, 1987 *Colour Research and Application* **12** 94–105). We tested if lightness compression can affect hue perception and hue naming. In experiment 1, we replicated the Gelb staircase effect using a CRT calibrated monitor. Four experimental conditions were ran: (i) dark surround, (ii) non-adjacent white frame, (iii) Mondrian (luminance range = 30 : 1), and (iv) non-adjacent Mondrian. As expected, lightness compression was maximum for (i), but lightness constancy increased gradually from (ii), through (iv), to (iii). In experiments 2 and 3, chromatic staircases were presented. Lightness compression along with hue changes were obtained, supporting the idea that it is not luminance per se, but lightness, which is important for hue perception. The pattern of results seems to follow chromatic selectivity (Krauskopf et al, 1986 *Vision Research* **26** 23–32): the matched reflectances for chromatic stimuli were systematically higher than what should be expected from the results obtained for achromatic stimuli.

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◆ **Colours produced under high-spatial-frequency tritanopia (HSFT) are unique hues**

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Fine details of a scene may change their neutral colour when the scene is viewed from a distance. This colour illusion (HSFT) is believed to result from the paucity of the S-cone mosaic on the retina (Logvinenko, 2001 *Perception* **30** 223–232). We found that the illusory colours were very close to the unique yellow, blue, or green hues. The method of adjustment was used to determine the unique hues for the same two observers for whom illusory colours were previously measured for neutral, horizontal test strips presented on coloured backgrounds (Hutchinson and Logvinenko, 2003 *Perception* **32** Supplement, 147). On a Sony colour monitor controlled by a PC equipped with a video card (VSG 2/5), a bar (same as the matching bar in the previous experiment) was presented on an equiluminant (25.0 cd m^{-2}) neutral background. A keyboard allowed observers to change the hue of the bar. The observer was asked to adjust the hue of the bar so that it appeared either unique green, unique blue, or unique yellow. Each unique hue was measured for seven levels of saturation, each measurement being repeated five times. A remarkable similarity was found between the unique hue and illusory loci.

CORTICAL CODING AND ORGANISATION 2

◆ **Achromatic surface constancy in primary visual cortex: A neural model implementing long-range inhibition**

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How does the brain discount changes in overall illumination intensity to encode achromatic (grey-scale) surface colours? Recent neurophysiological evidence suggests that subsets of neurons in cat primary visual cortex use long-range inhibition to discount global illumination changes

whilst maintaining sensitivity to local reflectance changes (MacEvoy and Paradiso, 2001 *Proceedings of the National Academy of Sciences of the USA* **98** 8827–8831). A neural model, with three successive processing stages, is developed to simulate: (a) instantaneous photoreceptor signal compression with an adaptation process, (b) local centre–surround encoding of spatiotemporal luminance changes (retina and LGN), and (c) global discounting of the illuminant, by means of long-range inhibition, analogous to neurons in cat visual cortex. The model provides a good quantitative fit to population data of MacEvoy and Paradiso, exhibiting a saturating activation function with increases in local luminance and relative invariance to global luminance changes. Unlike some alternative models of achromatic surface processing, centre–surround units transmit substantial luminance information to the cortical units. This luminance information could then be used by the cortex to generate illuminant-invariant responses in a subset of neurons, as in the present model, while allowing other neurons to perform tasks that depend on information about the illuminant, such as extracting shape-from-shading.

◆ **IC in IT. Illusory contour processing in macaque inferior temporal cortex**

Z Chadaide, T Tompa ¶, E A Garab ¶, L Lenti ¶, E Franko ¶, G Csifcsak ¶, G Sary ¶, G Kovács §, G Benedek ¶ (Department of Neurology, University of Szeged, Semmelweis u. 6, H 6720 Szeged, Hungary; ¶ Department of Physiology, University of Szeged, Dom ter 10, H 6720 Szeged, Hungary; § Department of Cognitive Sciences, Budapest University of Technology and Economics, Stoczek u. 4, H 1111 Budapest, Hungary; e-mail: chadazed@hotmail.com)

Perception of non-existent boundaries, as in the case of Kanizsa shapes is not yet fully understood. Imaging studies have suggested widespread activation of extrastriate cortices as a response to such stimuli in humans. In monkeys the role of V1 and V2 in perceiving illusory contours (IC) is well established at the single-cell level, but the contribution of ventral visual areas in IC processing has never been investigated in this manner. We designed an experiment where we could explore the role of macaque inferior temporal cortex (IT) in IC processing. We trained a monkey to discriminate 20 geometrical shapes into two arbitrary categories, presented as line-drawings (LD), luminance defined (LUM), and Kanizsa-type illusory shapes (IC). We recorded single neurons from the IT cortex. We found 52 IT cells which responded to IC-defined shapes selectively. Moreover, comparison between the different conditions on a population level revealed that the tuning curves of IC were similar to LUM, but different from LD. Our result shows that IT cells process information about IC, and representation of IC is similar to luminance-defined but different from those defined by line drawings. This indicates a dissociation of edge and contour-based shape processing at this level of the visual system.

◆ **Luminance correlations define contrast discrimination in natural images**

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Luminance patterns encode shape and surface structure of objects in our environment. Humans can detect gradations of 0.5%–1% of background luminance. Here, I ask whether this level of sensitivity to luminance gradations (contrast) is determined by the amount of ecologically meaningful information available in natural scenes. In the first experiment, subjects discriminated natural images I from their ‘posterised’ versions $I(n)$, in which the number of luminance gradations was reduced to n . In the second experiment, residual images $I_{\text{res}}(n) = I - I(n)$ were discriminated from white-noise images, which lack any luminance correlations and thus information content. Although the aim of one experiment was to test contrast discrimination and that of the other was to test sensitivity to information content in the form of luminance correlations, performance in the two experiments matched remarkably well. Furthermore, as a function of n , the signal detected in both experiments was well fitted by the mutual information between nearby image pixels in the residual image $I_{\text{res}}(n)$. This suggests that human sensitivity to luminance contrast is optimised to extract all ecologically useful information encoded by the luminance patterns of natural scenes.

◆ **fMRI of brightness perception**

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The perceived luminance, or brightness, of a surface depends on the luminance of the surface itself and the spatial distribution of luminance values in its surround. We made fMRI measurements in human V1 and V2 while subjects viewed disks that underwent perceptually similar

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brightness changes caused either by changes in disk luminance or by changes in the surround luminance. We measured the 3T fMRI BOLD signal at different locations in V1 and V2 (identified by retinotopic mapping). We compared activation caused by 1 Hz luminance modulations of either the disk (14 deg diameter) or surrounding annulus (7–17 deg radii). In both conditions, powerful responses were found at the V1 and V2 locations representing the boundary between the disk and annulus. Activity fell with distance from this edge representation. V2 responses were more pronounced than those in V1. Within the region representing the disk, modulating surround luminance resulted in lower activation than modulating the luminance of the disk itself. In this region in V2, but not in V1, we observed a small increase in activation during both centre and surround modulation. This suggests that (some of) the computations of that underlie the perception of brightness in humans occur in V2.

◆ **Eccentricity encoding in human parietal cortex**

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Retinotopically represented increases in activity (Barash, 1991 *Journal of Neurophysiology* **66** 1095–1108) are exhibited by the (primate) lateral intra-parietal cortex in response to visual stimuli and prior to spatially guided saccades (Colby, 1996 *Journal of Neurophysiology* **76** 2841–2852). In a recent fMRI study, with the remembered saccade task, a homologous region in humans was described (Serenó, 2001 *Science* **294** 1350–1354) which exhibited a systematic representation of polar angle. Here, we examine whether eccentricity, as well as polar angle, encoding is observable in the parietal cortex. Functional data were acquired at 3 T while performing a remembered saccade task that phase-encoded polar angle. Each scan, of 7 stimulus cycles (duration 8 min) with fixed eccentricities of 5°, 10°, and 15°, was repeated 4 times. Phase-encoded functional maps were visualised on flattened representations of cortical grey matter, segmented from anatomical scans (VISTASOFT, Stanford, CA, USA). Cortical surface distances were calculated by using regions of contiguous activity ($p < 0.01$). All subjects exhibited a lateral-to-medial shift of parietal activity with increasing eccentricity. Centre-of-mass Talairach coordinates were (25, 65, 49), (30, 65, 43), and (32, 67, 41), for eccentricities of 5°, 10°, and 15°. Cortical distance travelled was 16.3 mm and 9.4 mm for increments 5°–10°, 10°–15°. Thus, encoding of polar angle and eccentricity is observed in human parietal cortex, supporting previous primate studies.

SYMPOSIUM 5

TAKING A SECOND SHOT: PROCESSING OBJECT SHAPE, FEATURES, AND IDENTITY ACROSS MULTIPLE EYE FIXATIONS

◆ **Taking a second shot: Processing object shape, features, and identity across multiple eye fixations**

P De Graef (Laboratory of Experimental Psychology, University of Leuven, Tiensestraat 102, B 3000 Leuven, Belgium; e-mail: Peter.DeGraef@psy.kuleuven.ac.be)

Visual object recognition is a fast and powerful process. As indicated by both psychophysical work and neurophysiological data, objects can be recognised with minimal exposure durations, in crowded displays, and at great eccentricities. Yet there can still be some argument how powerful this process really is. I illustrate this in two ways. First, some of the most compelling evidence for fast object recognition in complex scenes (Biederman et al, 1982 *Cognitive Psychology* **14** 143–177) is shown to demonstrate search rather than recognition. Second, impressive ERP-based measures of the speed of object identification (eg Schendan and Kutas, 2003 *Journal of Cognitive Neuroscience* **15** 111–135) are shown to be too slow, given the speed of object-directed eye movements driven by high-level scene semantics. In addition to questions surrounding the raw power of visual object recognition, one should also ask the more fundamental question whether everyday perception ever uses this power. Specifically, when viewers are allowed to explore visual scenes, they seem to use a multi-sample approach to object recognition, integrating peripheral pre-saccadic object views with foveal post-saccadic object information. The purpose of this symposium is to address these questions and suggest some possible answers.

◆ **Whats in the first shot? Parallel and preattentive processes in visual scene perception**

R VanRullen (CNRS–Centre de Recherche Cerveau et Cognition, 133 Route de Narbonne, F 31062 Toulouse Cedex, France; e-mail: rufin@klab.caltech.edu)

Moving our eyes around to explore the world comes so naturally and effortlessly that we don't usually appreciate how much can be perceived at a single glance. This can be tested, however, by psychophysical methods (visual search, dual task, backward masking) as well as electrophysiological markers of processing speed. Typically, high-level information about a scene (eg does it contain an animal, a vehicle?) or a familiar object or face can be accessed in less than 150 ms.

This can be done even when attention is occupied elsewhere. Surprisingly, some simpler objects cannot be processed under these conditions if they do not correspond to meaningful categories (eg is this disk red on the left or right side?). This ability to preattentively access high-level, semantic information about objects must be contrasted with a (somewhat contradictory) inability to do this in parallel for many objects at once. Altogether, the available data suggest that the first glance at a complex scene, rapidly lighting up selective neuronal populations throughout the ventral pathway, provides high-level information about few (but not all) relevant objects in the scene, that can already trigger selective behaviour and, of course, guide subsequent eye movements.

◆ **Pre-attentive and attentive object representations across saccades for saccade targets and bystanders**

F Germeys, K Verfaillie (Laboratory of Experimental Psychology, University of Leuven, Tiensestraat 102, B 3000 Leuven, Belgium; e-mail: filip.germeys@psy.kuleuven.ac.be)

Under natural viewing conditions, object perception is trans-saccadic by default. Specifically, by means of a saccadic eye movement peripheral objects are brought into foveal vision for further scrutiny. To provide continuity across saccades, pre-saccadic information needs to be stored (trans-saccadic memory) and integrated with new post-saccadic information, possibly in the form of episodic object files. Research on the nature of these stored representations suggested that trans-saccadic memory may be limited to pre-saccadically attended objects. However, recent data obtained in trans-saccadic-preview-benefit studies and trans-saccadic-change-detection studies with post-saccadic blanking manipulations provide evidence for both an attentive and a pre-attentive component in trans-saccadic memory. The similarities and differences between the properties of this trans-saccadic pre-attentive representation and within-fixation pre-attentive representations are discussed. In addition, a general model of trans-saccadic object perception which incorporates both an attentive and a pre-attentive level of representation is presented.

◆ **Learning and generalising pattern categories across the visual field—hard and soft constraints on transsaccadic object perception**

M Juttner (Neuroscience Research Institute, School of Life & Health Sciences—Psychology, Aston University, Aston Triangle, Birmingham B4 7ET, UK; e-mail: m.juttner@aston.ac.uk)

Previous research in pattern-classification learning suggests that internal representations of objects acquired in foveal and extrafoveal vision are intrinsically different in terms of their perceptual dimensionality. A supervised-learning paradigm employing sets of compound Gabor signals was used to compare category learning and spatial generalisation in foveal and extrafoveal view. The two tasks revealed a distinctly different dependence on viewing condition: unfamiliar pattern categories could be fully learned only within an extremely narrow visual field that seems essentially limited to the fovea. In contrast, categorical object knowledge acquired at one retinal location could be partially transferred (generalised) to other retinal sites, and from one hemifield to the other. Moreover, there was a distinct asymmetry in performance with respect to the visual hemifield in which the signals were originally learned. From these experiments, learning and generalisation emerge as two functional key dimensions to characterise the role of foveal and extrafoveal vision in object perception. These findings impose constraints on the type of cooperative mechanism that may be active during saccadic eye movements.

◆ **Object file representation of form and meaning**

R D Gordon (Department of Psychology, North Dakota State University, Fargo, ND 58105, USA; e-mail: Robert.D.Gordon@ndsu.nodak.edu)

Successful interaction with one's environment requires the maintenance of stable object representations in the face of dynamic visual input. Object files, temporary representations of object tokens, have been proposed to serve this purpose. As described by Kahneman et al (1992 *Cognitive Psychology* 24 175–219), object files represent the currently available properties of an object; theoretically, this might include perceptual properties such as colour, shape, or orientation, as well as semantic object properties or object identity. Object file representations are updated as new information becomes available, and provide continuity when the perceptual input changes (eg because of object motion or saccadic eye movement). Recent evidence suggests that, in many cases, object files do not represent perceptual features of an object; instead, they appear to represent relatively abstract, post-categorical information (such as the object's identity). Such representations are robust to superficial changes in object appearance, and may be ideally suited to supporting object memory across saccades.

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SYMPOSIUM 6**HOW TO UNDERSTAND VISUAL CORTEX**◆ **Anaesthesia and the art of model-driven neurophysiology**

M Carandini (Smith-Kettlewell Eye Research Institute, 2318 Fillmore Street, San Francisco, CA 94115, USA; e-mail: matteo@ski.org)

Fifty years of research on the early visual system (LGN and V1) have revealed key determinants of visual responses, such as receptive fields, non-classical surrounds, gain control, and adaptation. Most of these advances were obtained under anaesthesia. Anaesthesia allows the measurement of responses of single neurons for many hours, without distraction from eye movements and cognitive influences. The resulting data have yielded powerful quantitative models, bringing the practice of systems neuroscience closer to that of sciences like physics. A drawback of anaesthesia is that it blocks the very processes that direct, influence, and benefit from LGN and V1 mechanisms. For example, it prevents frequent minute eye movements, which might be essential for natural stimulation. Moreover, gain control may serve to allocate visual attention, and this function can only be studied in an awake brain. Nonetheless, anaesthetised preparations still have much to contribute. First, the mapping of existing models unto the biophysics is not clear. Insight into biophysics may come from studies *in vitro*, but must be validated *in vivo*. Second, it is not known whether existing models can predict responses to complex/natural visual scenes. Investigating this matter requires the extensive measurements from single neurons that are only possible under anaesthesia.

◆ **Bridging the gap between neural activity and visual perception by using electrophysiology in trained monkeys**

G DeAngelis (Washington University School of Medicine, Saint Louis, MO 63110, USA; e-mail: gregd@cabernet.wustl.edu)

The combination of psychophysics and invasive electrophysiology in alert, trained primates has emerged as a potent approach for studying visual cortical function. Each of these techniques is powerful alone, but together they confer a number of distinct advantages. First, this approach allows direct comparison of psychophysical sensitivity and neuronal sensitivity. Second, it allows one to correlate neuronal activity with the animal's percept, rather than just the sensory stimulus. Third, by directly manipulating neuronal activity (by microstimulation or reversible inactivation), we can establish causal links between neuronal activity and perception. Limitations of the alert monkey preparation include the difficulty involved in studying multiple brain areas simultaneously, extensive behavioural training time, limited neuronal recording stability, and the potentially confounding effects of eye movements. Using this approach, however, one can investigate not only how visual information is coded by neurons, but also how visual signals are 'read out' of neuronal ensembles to form perceptual decisions. I provide evidence that these techniques can elucidate the strategy by which an animal reads out cortical maps to perform visual discrimination tasks. These read-out strategies are likely to be highly dynamic and modifiable on the basis of the specific demands of the task.

◆ **What fMRI can tell us about how visual cortex works**

D Heeger (Department of Psychology and Center for Neural Science, New York University, 6 Washington Place, New York, NY 10003, USA; e-mail: david.heeger@nyu.edu)

fMRI offers an empirical approach, complementary to electrophysiology and psychophysics, to studying the function of the visual cortex. Although fMRI has limited spatial and temporal resolution compared with single-unit electrophysiology, and provides an indirect measure of neural activity, it has a number of virtues which I illustrate using recent results from my laboratory on perceptual transitions during binocular rivalry. Traveling waves of activity were measured simultaneously in multiple visual areas, while observers experienced corresponding perceptual waves in which the dominance of one pattern gradually rendered the other pattern invisible. These waves of activity propagated over subregions of cortex that corresponded retinotopically to the perceptual waves, and the spatiotemporal dynamics of cortical waves co-varied with the propagation speeds of perceptual waves. When attention was diverted from the perceptual waves, there were differing results across visual areas; cortical waves were preserved in V1 but not in extra-striate areas. These findings illustrate how fMRI can be used to reveal the spatiotemporal dynamics of cortical activity with a spatial resolution of ~ 1 mm and a temporal resolution of ~ 100 ms, the interplay between multiple visual areas, the relationships between cortical activity and perception, and the dependence on cognitive factors such as attention.

◆ **The joy of psychophysics**

J Harris (School of Biology [Psychology], University of Newcastle upon Tyne, Newcastle upon Tyne NE2 4HH, UK; e-mail: J.Harris@ncl.ac.uk)

Psychophysics has been used to probe the human visual system for over 150 years. I argue here that it remains an essential tool for obtaining a full understanding of human visual function. The problem we study is that of understanding what processes are involved in vision, and how they take place in the visual areas of the brain. The talk starts by illustrating how considering the responses of a normal whole visual system can yield surprising and fascinating results. One of the key strengths of psychophysical methods is that they lead to specific predictions about the sorts of physiological mechanisms one might expect to find in the brain. Examples illustrating this are mostly taken from binocular vision. Care must be taken when using psychophysics to make inferences about specific cortical function and organisation. I illustrate techniques that have provided some success in this area, but urge caution in how far we take those inferences to directly link psychophysical and physiological performance. The talk ends by touching on some of the links between psychophysics and other methods for understanding brain function, and pondering what we might lose if we no longer pursued vision science using these most traditional of methods.

ORAL PRESENTATIONS

LIGHTING AND SHADING

◆ **Explanation of a lightness hangover in the Mondrian world**

A Gilchrist, V Annan (Department of Psychology, Rutgers University, 101 Warren Street, Newark, NJ 07102, USA; e-mail: alan@psychology.rutgers.edu)

When an observer looks into a small room, the interior of which is completely covered with patches ranging from dark-gray to black, the lightest patches (actually dark-gray) appear white. If several real white patches are now introduced, they initially appear self-luminous. These gradually become merely white, while all the other patches become darker, but this change is remarkably slow, taking more than 2 min. We report a series of experiments exploring this lightness hangover and testing several explanations, including adaptation and anchoring. If the lights are briefly switched off while the white patches are introduced, no hangover occurs; the anchor is immediately recalibrated. The length of the hangover correlates strongly with the number of patches in the room. We conclude that the hangover is caused by conflicting cues to the illumination. The increase in highest luminance produced by adding the white patches signals that the illumination has changed and the anchor should be updated. But the presence of so many patches that remain constant in luminance suggests that the illumination has not changed. Thus the greater the number of constant patches, the slower the application of the new anchor.

◆ **Stopping the Hermann grid illusion by simple sine distortion**

J Geier, L Sera, L Bernath (Department of Psychology, Eötvös Loránd University, Izabella u. 46, H 1046 Budapest, Hungary; e-mail: janos@geier.hu)

Almost the only explanation of the Hermann grid illusion is the Baumgartner model: the effect is generated by the response of cells having concentric ON–OFF or OFF–ON receptive fields (ie a Mexican-hat weighting function). This model predicts that the illusion is independent from the relative directions of the right-angled intersections. Some authors (Wolfe, 1984 *Perception* 13 33–40; for a review see Ninio and Stevens, 2000 *Perception* 29 1209–1217) show that the magnitude—not the existence—of the illusion depends on certain geometrical properties. We made some simple distortions to the Hermann grid that make the illusion disappear totally while the Hermann-grid character remains. The most effective of these was to replace the straight lines with sine curves leaving the intersections right-angled. The illusion is found to disappear at a surprisingly small sine amplitude (amplitude/period $< 1/10$). We supported these results with psychophysical measurements ($n = 29$). Simple geometrical consideration shows that the distortions produced here do not change the weighted sum of the receptive field. We conclude that the Baumgartner model is not an adequate explanation of the Hermann grid illusion, because its prediction is contrary to the observations. The same distortions applied to the scintillating grid made the scintillations disappear.

◆ **The interaction of luminance and texture amplitude in surface depth perception**

G S Barbieri-Hesse, A J Schofield, M A Georgeson¶ (School of Psychology, University of Birmingham, Birmingham B15 2TT, UK; ¶Neurosciences Research Institute, Aston University, Birmingham B4 7ET, UK; e-mail: G.BarbieriHesse@bham.ac.uk)

Previous studies have suggested separate channels for detection of first-order luminance modulations (LM) and second-order modulations of the local amplitude (AM) of a texture. Mixtures of LM

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and AM with different phase relationships appear very different: in-phase compounds (LM + AM) look like 3-D corrugated surfaces, while out-of-phase compounds (LM – AM) appear flat and/or transparent. This difference may arise because the in-phase compounds are consistent with multiplicative shading, while the out-of-phase compounds are not. We investigated the role of these modulation components in surface depth perception. We used a textured background with thin bars formed by local changes in luminance and/or texture amplitude. These stimuli appear as embossed surfaces with wide and narrow regions. Keeping the AM modulation depth fixed at a suprathreshold level, we determined the amount of luminance contrast required for observers to correctly indicate the width (narrow or wide) of 'raised' regions in the display. Performance (compared to the LM-only case) was facilitated by the presence of AM, but, unexpectedly, performance for LM – AM was as good as for LM + AM. Thus, these results suggest that there is an interaction between first-order and second-order mechanisms during depth perception based on shading cues, but the phase dependence is not yet understood.

◆ **Discounting luminance contrast produced by an illumination edge**

A Logvinenko (Department of Vision Sciences, Glasgow Caledonian University, Cowcaddens Road, Glasgow G4 0BA, Scotland, UK; e-mail: a.logvinenko@gcal.ac.uk)

It is well-known that shadows are underestimated in everyday life. This phenomenon was measured quantitatively. Twenty observers were presented with a piece of black paper illuminated by two lights so that there was an illumination edge across it. Luminance of the shadowed and lit halves was 4 cd m^{-2} and 41.5 cd m^{-2} , respectively. Observers were also presented with a series of 14 reflectance edges (mounted on the shadowed part) made up of two adjacent squares: black (made from the same paper as that used to create the illumination edge) and grey ones. Reflectance ratio, and therefore luminance contrast (grey over black), varied in approximately equal steps from 1.47 to 9.43. The observers were asked to point out which of the reflectance edges had the same luminance contrast as the illumination edge. Observers' choices fell into the luminance ratio range 2.50–5.61 with the mean of 4.24. Therefore, on average, observers judged the luminance ratio produced by the reflectance edge as apparently equal to a 2.5 times higher luminance ratio produced by the illumination edge. Thus, luminance contrast produced by an illumination edge was discounted by a factor of 2.5 (cf Logvinenko and Ross, 2003 *Perception* 32 Supplement, 40–41).

◆ **1924–2004: 80 years of Benary's perceptual belongingness—from lightness perception to the synchronisation hypothesis**

T Agostini, D Nikolic¶, A Galmonte (Department of Psychology, University of Trieste, via S Anastasio 12, I 34134 Trieste, Italy; ¶ Department of Neurophysiology, Max Planck Institute for Brain Research, Deutschordenstrasse 46, D 60528 Frankfurt, Germany; e-mail: agostini@units.it)

The concept of perceptual belongingness was introduced by Benary (1924 *Psychologische Forschung* 5 131–142), observing that lightness perception is not a mere result of local interactions among visual features but depends on their perceptual organisation. For the past 80 years this concept has guided a number of scientists in the investigation of the principles of visual processing [Musatti, 1953 *Archivio di Psicologia, Neurologia e Psichiatria* 5 544–577; Kanizsa, 1979 *Organization in Vision: Essays on Gestalt Perception* (New York: Praeger/Greenwood Publishing Group); Agostini and Proffitt, 1993 *Perception* 22 263–272; Gilchrist et al, 1999 *Psychological Review* 10 795–834]. Nevertheless, for a long time, this concept has been considered blasphemous as regards the processes underlying contrast, while a similar concept emerged within the feature-binding theory (Treisman and Gelade, 1980 *Cognitive Psychology* 16 97–134) and had a great success. The reverse-contrast cube by Agostini and Galmonte (2002 *Psychological Science* 13 88–92) provided evidence that attentional binding mechanisms are responsible for belongingness and, then, for contrast induction. Therefore, this 80-year old concept provides a much needed framework for the investigation of the causal relationships between the synchronisation of neuronal activity as the prime candidate for the physiological counterpart of belongingness/binding (Singer, 1999 *Neuron* 24 49–65) and the neuronal discharge rates evoked by lightness contrast. [Supported by MIUR Grant 2002094812-0]

BIOLOGICAL MOTION

- ◆ **Cortical MEG response to biological motion is specifically affected by periventricular lesions**
M Pavlova, F Marconato¶, A N Sokolov§, C Braun#, I Krägeloh-Mann (Developmental Cognitive Neuroscience Unit, Children's Hospital, University of Tübingen, Hoppe-Seyley-Strasse 1, D 72076 Tübingen, Germany; ¶ Dipartimento di Psicologia Generale, Università degli Studi di Padova, via Venezia 8, I 35131 Padua, Italy; § Institute of Psychology, Braunschweig University of Technology, Spielmannstrasse 19, D 38106 Braunschweig, Germany; # MEG-Center, Institute of Medical Psychology and Behavioural Neurobiology, Gartenstrasse 29, D 72074 Tübingen, Germany; e-mail: marina.pavlova@uni-tuebingen.de)

We asked whether and, if so, how cortical activity in response to biological motion is modulated by congenital damage to periventricular regions. To this end, we assessed changes in the MEG response to point-light configurations recorded in adolescents with periventricular lesions. Participants performed one-back repetition task with a set of stimuli consisting of a point-light walker and a scrambled configuration. Patients produced a greater number of misses in response to the walker, whereas no difference was found between the patients and healthy controls in response to the scrambled configuration. The psychophysical data nicely dovetail with the dynamics of MEG activity. Root-mean-square analysis shows that early (140–170 ms) brain activation over the right parietal cortex in response to biological motion was weaker in patients, but did not differ between the patients and controls in response to the scrambled figure. This is the first evidence for stimulus-specific modulation of cortical activity by periventricular lesions. We further compare the time-course and dynamic topography of MEG response to biological motion with the findings in healthy adults (Pavlova et al, 2004 *Cerebral Cortex* **14** 181–188). We conclude that the perceptual system is vulnerable to early periventricular brain damage. The impairments in patients persist despite extensive visual experience, whereas psychophysical and fMRI data indicate that intact biological-motion processing can occur after long-term visual deprivation (Fine et al, 2003 *Nature Neuroscience* **9** 915–916).

- ◆ **Biological motion promotes rivalry**
T Watson, J Pearson, C W G Clifford (Colour Form and Motion Laboratory, School of Psychology, University of Sydney, Sydney, NSW 2006, Australia; e-mail: tamaraw@psych.usyd.edu.au)

Binocular rivalry is believed to be mediated at multiple levels of the visual processing hierarchy. We investigated whether the grouping of global form on the basis of biological motion can promote rivalry in stimuli that might otherwise appear perceptually superimposed. A red and a green point-light walker were simultaneously presented, one to each eye. The walkers were arranged so that they occupied the same region of the visual field but were displaced vertically to ensure that the trajectories of individual dots did not overlap. Subjects monitored the predominant colour of the perceived dots. Rivalry, as measured by predominance of one or other colour, occurred for 50%–60% of stimulus duration. In a condition designed to control for rivalry on the basis of stimulus colour or local dot motion, the dots comprising each walker were evenly distributed between the eyes but coloured so that dots presented to one eye were red and dots presented to the other eye were green. Under this condition walkers were typically not seen. This reduced rivalry to less than 10% of stimulus duration. These results demonstrate that conflicting perceptual interpretations based on biological motion are robust enough to initiate rivalry. This illustrates the significance of top–down knowledge in the interpretation of degraded visual input.

- ◆ **Perceptual grouping while observing multiple ambiguous point-light figures**
J Vanrie, K Verfaillie (Laboratory of Experimental Psychology, University of Leuven, Tiensestraat 102, B 3000 Leuven, Belgium; e-mail: Jan.Vanrie@psy.kuleuven.ac.be)

Observers presented with multiple copies of an ambiguous stimulus tend to give the same interpretation to all stimuli. This 'perceptual grouping' is said to be the result of globally operating top–down feedback (Grossmann and Dobbins, 2003 *Vision Research* **43** 359–369). Previously we demonstrated that certain point-light figures (PLFs) can be considered ambiguous figures with respect to their global depth orientation (Vanrie et al, 2004 *Perception* **33** 547–560). To examine the possible role of top–down processes in the perception of this type of more complex stimuli, we investigated whether observing multiple ambiguous PLFs leads to the same kind of perceptual-grouping phenomena and how these phenomena are affected by changes in various stimulus features. Participants were presented with two PLFs and had to indicate the global depth orientation of the figures. The degree of similarity of the figures was manipulated in several ways. The data show that perceptual grouping indeed occurs and that, although strongest for identical PLFs, the coupling persists across differences in phase (actions synchronised or

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not), viewpoint (frontal or three-quarter views) and, in some cases, even the action itself (same or different). Hence, these results indicate a differentiated role for top-down processes in the perception of multiple ambiguous point-light stimuli.

- ◆ **Biological motion patterns are preferentially approached by naïve newborn chicks (*Gallus gallus*)**
F Marconato, L Regolin, G Vallortigara¶ (Department of General Psychology, University of Padua, via Venezia 8, I 35131 Padua, Italy; ¶ Department of Psychology and B.R.A.I.N. Centre for Neuroscience, University of Trieste, via S Anastasio 12, I 34123 Trieste, Italy; e-mail: fabio.marconato@unipd.it)

Johansson's hypothesis (1973 *Perception & Psychophysics* **14** 201–211), that sensitivity to biological motion might have an innate, rather than acquired, base is hard to test in humans. Previous results showed that chicks pre-exposed to different point-light patterns can then discriminate between displays depicting a walking hen and a rigid motion (Regolin et al, 2000 *Animal Cognition* **3** 53–60). We investigated spontaneous preferences of newly hatched chicks for biological versus non-biological motion displays. Few-hour-old, dark-hatched chicks underwent a 6-min simultaneous free-choice test between two different computer-presented point-light motion displays. Such patterns could represent either a walking hen, a scrambled version of the walking hen, a rotating solid, or a random-dot motion. Results showed that the walking hen was not preferentially approached when compared to its scrambled version ($t = 0.394$, ns), although both these patterns were preferred when confronted by solid rotation ($p < 0.001$) and by random-dot motion ($p < 0.01$). Naïve chicks seem therefore to exhibit a spontaneous preference for biological displays, such preference appearing to rely on local rather than global motion cues.

- ◆ **Infants' discrimination of facial motion**
J Spencer, J O'Brien, A Johnston¶, H Hill§ (Brunel University, Cleveland Road, Uxbridge UB8 3PH, UK; ¶ University College London, Gower Street, London WC1E 6BT, UK; § ATR Human Information Science Laboratories, 2-2-2 Hikaridai Seika-cho, Soraku-gun, Kyoto 619-0288, Japan; e-mail: janine.spencer@brunel.ac.uk)

Faces play an important part in the development of human social interaction (Kleinke, 1986 *Psychological Bulletin* **100** 78–100; Baron-Cohen, 1994 *Cahiers de Psychologie Cognitive* **13** 513–552). Here, we report two experiments in which we used animated averaged faces to examine infants' ability to perceive the motion of faces. The faces were computer-generated with the use of the motion information recorded from human volunteers while they spoke. We tested infants aged 4–8 months to assess their ability to discriminate facial motion sequences (experiment 1) and identify the faces of individuals (experiment 2) on the basis of combined rigid and non-rigid motion. Infants were habituated to one sequence with the motion of one actor speaking one phrase; following habituation, infants were presented with the same sequence together with motion from a different actor (experiment 1), or a new sequence from the same actor coupled with a new motion sequence from a new actor (experiment 2). Infants demonstrated a significant preference for the novel actor in both experiments. These findings suggest that infants aged between 4 and 9 months can not only discriminate complex and subtle biological-motion cues but also detect invariants in such displays.

MONDAY

POSTERS 1

COLOUR

◆ **The role of S-cones in global motion processing: Evidence for an ON- and an OFF-S-cone mechanism**

S Wuerger, A Ruppertsberg, J Martinović, M Bertamini (Centre for Cognitive Neuroscience, School of Psychology, Eleanor Rathbone Building, Bedford Street South, Liverpool L69 7AZ, UK; ¶ Department of Optometry, Richmond Building, University of Bradford, Bradford BD7 1DP, UK; e-mail: s.m.wuerger@liverpool.ac.uk)

We have previously reported that human observers can extract global motion from random-dot kinematograms (RDKs) for S-cone-isolating modulations only if the individual blobs are large (about 1 deg) and the displacement of each blob is more than about 1 deg (Ruppertsberg et al, 2003 *Vision Neuroscience* **20** 421–428). Here, we test whether global motion is extracted by a single bipolar S-cone pathway or by two unipolar mechanisms. We generated RDKs consisting of a single colour (S-cone increments or decrements) or of mixed colours, ie S-cone decrements and S-cone increments mixed, and measured colour contrast thresholds for both conditions. From the single-colour thresholds we predicted the thresholds for the mixed-colour condition assuming two different models: a single-mechanism model and a two-mechanisms model. For all four observers, the two-mechanisms model predicts the mixed-colour thresholds better than the single-mechanism model, which is consistent with previous findings by McLellan and Eskew (2000 *Vision Research* **40** 2449–2465).

[Supported by the Wellcome Trust.]

◆ **Resolution acuity for S-cone increment and decrement gratings in peripheral vision**

M Vidinova-Zlatkova, R S Anderson, A Vassilev ¶ (Vision Science Research Group, School of Biomedical Sciences, University of Ulster, Cromore Road, Coleraine BT52 1SA, Northern Ireland, UK; ¶ Institute of Physiology, Bulgarian Academy of Sciences, BG 1113 Sofia, Bulgaria; e-mail: mb.vidinova@ulster.ac.uk)

Recent data suggest that separate S-cone ON and OFF pathways subserve the blue–yellow post-receptor mechanism. We measured resolution (and hence responding ganglion-cell density) at 13° and 20° eccentricity using gratings designed to selectively stimulate the S-cone ON and OFF pathways. Gratings were modulated from background white to either the 90° or 270° direction in DKL space, producing +80% or –80% S-cone contrast, respectively, and 0% L-cone and M-cone contrast. Two additional directions were tested to examine the effects of macular pigment absence and lens yellowing. The gratings used slow temporally rising hue (cosinusoidal step) to aid selective S-cone increment or decrement stimulation. Resolution acuity was measured at different luminance ratios of the grating bars to the white background to find the individual isoluminant point. The data displayed an isoluminance plateau when acuity was minimum, performance rising on either side. Isoluminant acuity was consistently higher for S-cone increment gratings than S-cone decrement gratings which also looked more blurred. Chromatic aliasing was observed for both types of gratings. The same result was obtained along the additional colour axes tested. These data suggest different responding ganglion cell densities for the resolution of S-cone increment and decrement stimuli.

[Supported by the Wellcome Trust.]

◆ **Spatial summation of S-cone-selective isoluminant stimuli**

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Vassilev et al (2003 *Vision Research* **43** 2875–2884) have reported an asymmetric summation effect for S-cone increments and decrements in human vision. Ricco's area of complete spatial summation was found to be larger for decrements than for increments at the retinal periphery. Since the two-colour threshold method of Stiles was applied for S-cone isolation, the asymmetry might arise from channel polarisation towards yellow at an opponent stage caused by the bright-yellow component of the background used to isolate the S-cones. In the present experiments, the background was white ($x = 0.310$, $y = 0.316$). Isoluminant S-cone-selective stimuli of variable size were presented along the White-S90 and White-S270 axes in the DKL colour space. Detection threshold was measured as cone contrast. This allowed for both construction of threshold/area curves and comparison with previous data. Ricco's area was larger in the White-S270 axis than in the White-S90 axis at the periphery (20 deg along the temporal horizontal

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retinal meridian). Moreover, the threshold cone contrasts were similar to those of our previous experiments employing bright-yellow adapting stimuli. The data contradict the channel polarisation hypothesis of asymmetry in summation of S-cone increments and decrements. [Supported by Wellcome Trust and Cambridge Research Systems.]

◆ **S-cone increment and decrement thresholds: Effects of stimulus duration**

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We have previously found that Ricco's area of S-cone increments across the tested visual field follows closely the density and dendritic-field size of the small bistratified cells, known to be S-ON retinal ganglion cells, while Ricco's area for S-cone decrements does not correlate with known retinal morphology (Vassilev et al, 2003 *Vision Research* **43** 2875–2884). The data would suggest the existence of a separate S-cone OFF pathway if our stimuli, 100 ms pulses, were preferentially stimulating ON or OFF neurons depending on stimulus polarity. In order to test this possibility, we measured detection threshold for blue-on-yellow test stimuli of different duration. The assumption was that the response to the leading stimulus edge would dominate at short but not at long durations. Small-size increments and decrements of blue light were presented on a bright yellow (400 cd m^{-2}) + blue (1.4 cd m^{-2}) background at 20° from fovea. Detection threshold of decrements was higher than of increments at short durations and the difference diminished up to the duration of 200–500 ms. We assume that a duration of 100 ms for S-cone-selective stimuli is short enough for preferential stimulation of ON or OFF neurons depending on stimulus polarity.

[Supported by the Wellcome Trust.]

◆ **Estimating chromatic contrast thresholds from the transient visual evoked potential**

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Chromatic contrast thresholds may be estimated by regression to zero visual evoked potential (VEP) amplitude (eg Campbell and Maffei, 1970 *Journal of Physiology* **207** 635–652). However, the characteristics of the human colour vision system present difficulties with this method. Chromatic signals are mainly processed by neurons tuned to low temporal frequencies. Low-temporal-frequency stimuli elicit transient VEPs. Threshold assessment based on transient VEP amplitude is difficult for reasons of variable VEP morphology, poor correlation of VEP amplitude with stimulus level (Jenkins et al, 1985 *Ophthalmic and Physiological Optics* **5** 441–449), and possibly non-correlated Fourier power spectra. We investigated the viability of an alternative method of chromatic-contrast-threshold assessment based on the reproducibility of transient VEP morphology (McCulloch and Skarf, 1991 *Investigative Ophthalmology & Visual Science* **32** 2372–2381). We compared VEP and psychophysical threshold in a within-subjects design. Success rate for threshold estimation based on VEP reproducibility was 100%, and 67% for estimation based on amplitude measurement. Mean VEP thresholds were 4.9% and 4.2%, respectively, and were not significantly different from psychophysical thresholds. Our results suggest that chromatic contrast thresholds estimated from VEP reproducibility are a viable alternative to those based on VEP amplitude measurement.

◆ **Colour appearance: The influence of surround variance**

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Brown and MacLeod (1997 *Current Biology* **7** 844–849) reported that test patches embedded in a uniform neutral surround appear more saturated than the same patches presented in a variegated surround with the same average colour. We investigated how this gamut-compression effect is influenced by the purity of the test patch and the distribution of variance within the surround. In the first experiment, patches of different purities were presented in a uniform surround and matched by patches presented in a variegated surround. It was found that the gamut-expansion effect is not constant for a given surround, but decreases with increasing purity of the test patch. A further important observation, at odds with a simple explanation in terms of adaptation, was that subjects were often unable to establish a satisfactory match when the target patch was of low purity, ie when the target-surround contrast was low. In additional experiments, we varied the distribution of variance in the surround. Our results show that the influence of the surround variance is a predominantly local, and not a global, phenomenon: The gamut-compressing effect of the variance decreased rapidly with increasing retinal distance of the colour modulation from the test patch.

◆ **Contrast colour and contrast colour from flicker**

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Classical phenomena of contrast colours are obtained by placing a light achromatic circle surrounded by a coloured annular region (say, red): the circle no longer appears achromatic, but is tinged with the opponent hue. Here, we present a new phenomenon: when the red annulus is temporally modulated with an annulus also achromatic as the inner circle, observers perceive a greenish annulus surrounding a circle which now appears reddish. We call this phenomenon contrast colour from flicker (CCFF). We determined the temporal characteristics of the CCFF, associated with inversion of the perceived colour of the circle, along different colours of the annulus and different spatial contexts. We found that both phenomena persist when changing the annulus colour to blue, green, or yellow, and are strongly affected by background context. However, they differ in the temporal dynamics: both phenomena occur over the whole scale from several milliseconds up to two minutes, but CCFF depends on an instantaneous adaptation mechanism for colour appearance. This suggests that these phenomena may depend on different adaptation mechanisms.

◆ **Simultaneous colour contrast in uniform and variegated surrounds: Common and specific effects**
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We present evidence from asymmetric colour-matching experiments which strongly suggests that uniform surrounds evoke induction effects of a very peculiar nature, not representative of colour-induction effects in general. We compared the induction effects resulting from using a pair of uniform surrounds with those resulting from using a corresponding pair of variegated surrounds. The data curves obtained with variegated surrounds could be well described by simple von Kries scaling. The uniform surrounds, however, yielded a curious and unexpected result, namely a sharp step in the data curve indicating that a range of clearly distinguishable comparison patches were matched by identical test patches. Outside the region of this step, the data curves obtained with both kinds of surrounds were practically the same. These data can be accounted for by assuming that the induction effect observed in uniform surrounds is the result of two distinct mechanisms: a simple gain control mechanism, which is also triggered by variegated surrounds, and a contrast-coding mechanism specific to the uniform surrounds.

◆ **Influence of subject's viewing behaviour on grey settings**

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In numerous studies on colour constancy or colour induction, subjects have to adjust a test spot such that it looks achromatic. Subject's viewing behaviour during these settings is often not controlled or reported. Here, I show that whether and to what degree the subject visually explores the stimulus by looking around in the surround and whether the subject focuses on the test spot can have a substantial impact on the results of grey settings in variegated surrounds. In a series of experiments, different viewing instructions and techniques manipulating the degree of visual exploration of the surround were compared with respect to the degree of constancy as measured by the shift of grey settings in coloured surrounds. The main result is that in variegated (but not in homogeneous) surrounds, ample exploration can increase colour constancy compared to focusing the test spot by as much as 20% (here 100% colour constancy means that the subject chooses as grey the average chromaticity of the surround). Thus, if this factor is not experimentally controlled, it can inflate variance, lead to questionable conclusions, and reduce comparability between different studies.

◆ **Effects of contrast, saccade length, and stimulus size on the visibility of colour breakup in field-sequential colour displays**

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Colour breakup refers to the perception of red, green, and blue patches adjacent to a luminance edge when one is viewing a high-contrast image on a field-sequential colour display, in which the red, green, and blue colour components are presented as a high-frequency temporal sequence. Saccadic eye movements have been shown to be one of the primary causes of the phenomenon, since during a saccade the colour components become spatially displaced on the retina. We investigated the effects of stimulus-background contrast, saccade length, and stimulus size on the visibility of colour breakup. The method of adjustment was used to determine the contrast threshold for the perception of colour breakup during saccades. In the experiment, a static white

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square was presented at the centre of the display. The subjects made controlled horizontal saccades across the stimulus. Contrast was varied by changing the luminance of the background while the luminance of the stimulus was held constant. The results indicated that (a) the phenomenon was visible only at relatively high contrasts (~ 0.7 or higher), (b) the absolute sensitivity for detecting colour breakup increased with saccade length, and (c) detection sensitivity was highest for mid-sized stimuli in relation to saccade length.

◆ **A study of parameters that affect the outcome of the Rayleigh match**

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The aim of this study was to account for the large inter-subject variability in the parameters of the yellow match and to explain the poor correlation between these parameters and estimates of chromatic sensitivity based on colour discrimination thresholds. Nagel matches and colour detection thresholds were measured in some 125 normal trichromats and 120 colour-deficient observers. The CAD (colour assessment and diagnosis) test was used to measure red–green and blue–yellow chromatic sensitivity in each subject. The task involved direction discrimination of colour-defined moving stimuli buried in dynamic luminance contrast noise. A model was developed to examine how cone photoreceptor density changes, pre-receptor absorption differences, shifts in peak photoreceptor spectral responsivity, post-receptor amplification of cone signals, and the spectral width and composition of the red–green mixture and the yellow reference field affect the outcome of the Rayleigh match. The Nagel matches reveal large inter-subject variability in the distribution of red–green mixtures, even within normal trichromats. The correlation between the parameters of the yellow match and chromatic discrimination thresholds was poor. The observed inter-subject differences in the parameters of the yellow match can be predicted successfully by adjustment of one or more of the model parameters.

◆ **Differential scaling factors account for chromatic sensitivity in peripheral vision**

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The spatial processing of most visual tasks is homogenous across the visual field apart from a change in scale. We investigated the eccentricity-dependent variation in scale for the cardinal chromatic [L/M, S/(L + M)] and achromatic [L + M] mechanisms in an attempt to account for the many reported observations of the loss of selective chromatic sensitivity in peripheral vision. We measured contrast sensitivity for all three mechanisms across a range of eccentricities, using isoluminant chromatic or achromatic Gabor patches. All stimuli were simply magnified versions of each other—a method of spatial scaling (Watson, 1987 *Journal of the Optical Society of America A* **4** 1579–1582). We obtained estimates of the magnification required to equate sensitivity in central and peripheral vision, quantified by the parameter E2—the eccentricity at which stimulus size must double to maintain foveal performance. Sensitivity across all eccentricities could be accounted for simply by a change of scale. In other words, there is no qualitative difference in chromatic sensitivity across the visual field. However, very different scaling factors were required for the two chromatic mechanisms [L/M < 2° versus S/(L + M) > 5°]. It is this factor which explains the differential loss of sensitivity to L/M stimuli relative to S/(L + M) previously reported (Mullen and Kingdom, 2002 *Visual Neuroscience* **19** 109–118).

◆ **Temporal nulling of induction from spatial patterns modulated in time**

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Asymmetric colour matches (Monnier and Shevell, 2003 *Nature Neuroscience* **6** 801–802; 2004 *Vision Research* **44** 849–856) demonstrate that receptive-field (RF) organisation accounts for chromatic assimilation from nearby inducing light and for chromatic contrast from more distant inducing light. Here, we used temporally varied chromatic inducing light to infer RF organisation by an independent method that does not require colour matching. A test ring was flanked on each side by four concentric rings, alternating between chromaticities that appeared purple or lime. Either the two purple or the two lime rings were temporally modulated in chromaticity. The observer's task was to adjust the temporal amplitude and phase of the test-ring chromaticity, modulated from purple to lime, so the test appeared to be steady (no perceived temporal variation). The nulling phase of the test was found to be out of phase with the temporal modulation of contiguous rings, and in phase with modulation of noncontiguous rings. These nulling measurements are consistent with the RF organisation inferred previously from colour appearance measurements: an out of phase (in phase) null is the signature of chromatic assimilation (contrast). Further, varying the temporal frequency of inducing light affected assimilation and contrast about equally.

◆ **Simple reaction times to the onset of motion of chromatic and luminance stimuli**

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Simple reaction times (RTs) were measured for the detection of motion onset of 1 cycle deg^{-1} sinusoidal luminance gratings and equiluminant chromatic gratings that were modulated in chromaticity along the L/M and S/(L + M) cardinal axes. The variation with contrast of motion-onset RTs is well described by a modified Pieron equation: $RT = RT_0 + k(1/C)$, where RT_0 is the asymptotic RT, and C is the rms cone contrast. The constant k provides a measure of the contrast dependence of the RT on the different chromatic and luminance motion stimuli and can be measured over a range of velocities. RTs to the onset of S/(L + M) chromatic motion exhibit a much greater contrast dependence than those to either L/M chromatic or luminance-defined motion, particularly at low velocities. The results raise the possibility that these differences in contrast dependence reflect the fact that L/M and S/(L + M) motion signals have different physiological substrates; the former being mediated by the parvocellular system and the latter by the koniocellular system. This is consistent with the view that the sensory component of RTs is dictated by the properties of pre-cortical processing pathways.

◆ **The chromatic selectivity of motion adaptation on perceived motion and spatial localisation**

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Adaptation to motion generates aftereffects in the perception of motion (MAEs) as well as in the spatial localisation of visual stimuli (LAEs). To assess chromatic selectivity of these aftereffects we employed a motion-nulling paradigm to measure the magnitude of MAEs induced by isoluminant chromatic adapting gratings (velocity = 2 deg s^{-1}), on test gratings modulated along different chromatic axes in colour space. The MAEs generated were strongest when the adapt and test stimuli were modulated along the same chromatic axis, and weakest when the adapt and test axes were orthogonal in colour space. LAEs were examined with a two-element Vernier alignment task to measure the displacements induced by a pair of isoluminant Gabor test patches drifting at 1.75 deg s^{-1} in opposite directions on stationary test stimuli. The magnitude of the LAEs was unaffected by the chromatic composition of the adapt and test stimuli. Our results reveal a dichotomy between the effects of motion adaptation on perceived motion and perceived position, with the former, but not the latter, exhibiting chromatic selectivity. This reflects the generation of MAEs by low-level inputs, sensitive to rudimentary stimulus attributes, compared to high-level adaptation for the LAEs where there is pooling across different stimulus attributes.

◆ **Colour modulates perceived depth in combined shading-plus-texture patterns**

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The 'colour-shading effect' (*Nature Neuroscience* 2003 **6** 641) describes how perceived 3-D shape-from-shading in luminance patterns is enhanced by non-aligned, and suppressed by aligned chromatic patterns. Is the effect limited to situations where shading is the only depth cue, or does it operate with multiple depth cues? Stimuli consisted of $0.75 \text{ cycle deg}^{-1}$ sinusoidal gratings of orientation, luminance, and colour, combined into 'tri-gratings'. The orientation grating consisted of Gabor micropatterns whose orientations were modulated sinusoidally about horizontal, but whose envelope orientation was left-oblique. The shading (luminance) grating was multiplicatively combined with the orientation grating, while the colour grating was additively combined. Subjects adjusted the amplitude of a stereo-grating to match the perceived depth of the tri-grating. It was first established that when the shading and texture gratings were of the same orientation, they combined synergistically to determine perceived depth. When the colour grating was added to the texture-plus-shading combination, perceived depth was enhanced when the colour grating was out-of-phase, and suppressed when the colour grating was in-phase with the shading grating. In conclusion, colour contrast can modulate the perceived depth of stimuli containing not just shading but multiple depth cues.

◆ **Colour filling-in in afterimages**

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Our object was to find out (i) whether filling-in occurs in a negative afterimage from prolonged fixation of a coloured stimulus; and (ii) whether it is identical to that observed in the actual

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stimulus (Hamburger et al, 2003 *Perception* **32** Supplement, 155). Stimuli consisted of a 7.0 deg uniform disk surrounded by two rings of 3.5 deg width each. Red–green–blue and blue–green–red (Munsell value 8) hierarchies were used for testing, while stimuli with complementary colours served as controls. Subjects fixated binocularly in the centre for 30 s. In the afterimage, the sequence in which a given region imparted its colour onto an adjacent region differed from that in the actual stimulus. While the colour of the outer ring filled-in the entire stimulus, afterimage filling-in occurred only from the inner ring onto the disk. Similarly, if a 0.9 deg black annulus was used to separate the rings from the disk, uniform blackness spread inward, whereas no whiteness spreading was seen in the afterimage. We conclude that filling-in of colour occurs in the afterimage, although it differs from that in the actual stimulus in direction, spatial sequence, extent, and relative frequency. Results suggest that stimulus-driven filling-in and afterimage-driven filling-in obey different rules.

◆ **The influence of chromatic adaptation on colour afterimage**

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Chromatic afterimages yielded by inducing stimuli blinking on a CRT display controlled by a computer were measured to investigate the effects of background which provide subjects' colour adaptation. The crossing point of lines which connect inducing stimuli and induced aftereffects on the chromaticity plane was very close to the white point of the CRT display which shows observers' chromatic adaptation. This result of measurement suggests a strong effect of background of the stimuli, and that the selectivity of these aftereffects for adaptation is inconsistent with the hypothesis that chromatic afterimages are provided only by bleaching of photopigments on the retina. These effects of adaptation suggest instead that higher mechanisms of our visual system participate in the chromatic afterimage.

◆ **Induction of McCollough effect causes changes in capacity for constant perception of colour**

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These experiments were designed to reveal the mechanisms underlying the McCollough effect (ME). We argue that the emergence of ME is associated with activity of colour-constancy mechanisms. We have examined capacity for constant perception of pigment colours before and after acquisition of ME. ME induction procedure was carried out according to the standard paradigm. For determining capacity for constant perception of pigment colours the following procedure was implemented: initially two colour samples, green and red, were presented under white illumination. In the course of experiment, chromaticity of illumination was changed gradually by introduction of coloured filters, with the intensity of overall illumination kept unaltered. For each stimulus, we determined the percentage of colour light in overall illumination at which the samples became achromatic for a subject. Our experiments showed that ME acquisition causes statistically significant shifts (increase or decrease) in colour-constancy perception capacity. In control experiments we examined subjects repeatedly, at certain time intervals, without ME induction, and found that there were no significant changes in the capacity for constant perception of colour. Results indicate that ME induction initiates processes of recalibration of colour-constancy mechanisms.

◆ **Pattern-contingent colour aftereffects are formed at a subconscious level**

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We assumed (Intskirveli et al, 2000 *Bulletin of the Georgian Academy of Science* **162** 140–143) McCollough-type aftereffects arise from compensatory and correcting mechanisms (colour constancy, in particular). New empirical support for this hypothesis has been found in our experiments on eighteen healthy human subjects. They were presented with tachistoscopic stimuli in the standard paradigm for acquisition of the McCollough effect (McCollough, 1965 *Science* **149** 1115–1116): horizontal black–red and vertical black–green gratings. The one novelty was that the exposure time was chosen individually for each subject, and equalled the maximum time during which it was possible to recognise the grating orientation without recognising the colour. In our experiments, this critical time was 1.5–2 ms. After each presentation, the display was filled with a multi-coloured masking image. After 15 min adaptation the subject was shown the test image: a combined grating, consisting of horizontal and vertical black-and-white stripes. Seventeen subjects acquired a clear-cut McCollough effect. Horizontal stripes were perceived as greenish, and vertical ones as pinkish. The major quantitative indices (power of the effect and retention

duration) did not differ from those observed in the standard paradigm. Seeing a coloured aftereffect in conditions where the subject does not see the colour of adapting gratings implies that the main compensatory shifts must be generated at a subconscious level.

◆ **Chromatic mixture of colour afterimage**

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Prolonged viewing of a highly saturated colour produces its complementary colour in the neutral test field (successive contrast), and the effect of the complementary colour is also perceived over space (simultaneous contrast). To understand better colour contrast, we examined colour appearance of a central grey test field on a two-coloured surround at equiluminance under a few conditions. In experiment 1, the central test field on a bichromatic adapting surround split by an imaginary centre line appeared mixed coloured in the successive afterimage with each complementary colour of the two adapting colours; for instance a yellowish colour induced by green/red successive contrast colours of a red/green adapting surround. The successive test field did not appear half-red half-green on each side influenced by different chromatic surroundings. Other experiments were conducted under different conditions: (i) surroundings composed of red/green equiluminant horizontal gratings, (ii) two-coloured surroundings at different luminance ratios, and (iii) varied test-field sizes. We obtained the same afterimage as in experiment 1, regardless of various properties of the surround and test areas. These results show chromatic mixture of colour contrast induced in the afterimage.

◆ **A measurement of subjective colour of Benham type on a luminous screen**

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Measurement and modeling of subjective colour have been extensively studied and attention has been drawn to the difficulty of precise measurement of colours. We can observe chromatic colours originated from a rotating Benham disk on a luminous screen which appear to be too pale to be correctly matched by current methods. We introduced a cancellation method appropriate for a pattern produced by a digital signal. Four fundamental colours, R, Y, G, and B, were used to reduce the colours on their addition to the black prolonging arcs. Five naïve subjects adjusted them to cancel out the chromaticity in their percept. The obtained data are the amounts of R, Y, G, and B components. All subjects got an achromatic pattern by using two colours without any difficulty. The colours perceived by each subject were shown to be the complementary colours. The calculated values were nearly identical to those obtained by direct colour matching in a subsequent measurement. We can measure subjective colours easily and precisely in this way. Adopting more saturated colours as cancellation colours, and defining reference white under some rules, we would find the data more useful for analysing the mechanisms of these types of colour perception.

◆ **Comparison of the affective impressions in chromatic and achromatic images**

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Achromatic images are frequently produced in the field of photography as a fine art, although chromatic images are common in everyday life. Since the invention of colour photography, there has been a myth that black-and-white images are more artistic than colour images [Newhall, 1982 *The History of Photography: From 1839 to the Present* (New York: Vintage)]. We investigated the possible difference between chromatic and achromatic images in affective impression. The stimuli were 90 colour photographs made by various techniques and 90 corresponding converted gray-scale images. The participants rated their feelings on positive–negative, dynamic–static, and light–heavy dimensions, which were found from affective words when using factor analysis. Achromatic images gave negative impressions, whereas chromatic images invoked positive feelings. Participants received a stronger static impression for achromatic images than chromatic images. For the light–heavy dimension, achromatic images made a heavy impression, while chromatic images produced a light one. These results showed that the impressions of images could be changed depending on whether image is chromatic or not. This implies that artistic impression on photographic images could be related to negative, static, and heavy feelings.

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- ◆ **Realistic rendering of a gradient in illumination does not increase chromatic induction**
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When two identical surfaces are seen within differently coloured backgrounds, they often appear to have slightly different colours. One interpretation of this phenomenon is that the visual system attributes part of the difference in background colour to a difference in illumination. If so, we might find a large difference in perceived colour if we make it evident that the difference in local background chromaticity is caused by a difference in illumination. To achieve this, we simulated various regularly patterned backgrounds of coloured surfaces, illuminated by two light sources. The whole background was illuminated by one distant light source (eg standard illuminant C), while one corner of the background was also illuminated by a bright lamp (eg standard illuminant A). Subjects adjusted a test circle, which was far from the simulated lamp, to appear to have the same hue and brightness as a reference circle right under the lamp. Irrespective of the pattern of the background, subjects set the test spot to a much lower luminance than the reference, but to a very similar chromaticity. Thus adding evidence that the differences in local background chromaticity are caused by differences in illumination does not have much influence on the perceived colour.

- ◆ **Anisotropic breakdown of additivity of colour dissimilarity in abnormal trichromats**
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Metric colour spaces posit that dissimilarities are integrable, or additive. A given number of just-noticeable-differences between two hues should add up to the same degree of dissimilarity, whichever region of colour space they transect, or in which direction. However, anomalous trichromats may show compression of colour space at the shortest scale, in the form of elevated discrimination thresholds (decreased distances) along particular directions, yet still judge large colour dissimilarities normally. Dissimilarities among 15 stimuli in one study (Paramei and Cavonius, 1999 *Perception & Psychophysics* **61** 1662–1674), and 36 stimuli in a second study (Paramei et al, 2001 *Color Research Application* **26** S230–S234), were rated by normal and anomalous trichromats, as well as dichromats. These data were re-examined for scale-dependent distortions of each observer's colour space. The ratings were scrutinised directly, and also analysed with individual-difference multidimensional scaling to transform them into colour spaces, with large and small scales handled separately. Moderately anomalous observers showed colour-space compression when they rated small dissimilarities but not in their large-dissimilarity ratings. This decoupling between scales suggests some form of compensatory gain-control mechanism. A metric colour space can represent dissimilarities between these observers only approximately.

- ◆ **Detecting tetrachromacy in human subjects**
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Human tetrachromacy is a rare condition in which the retina contains four different types of wavelength-selective photoreceptors (cones). There exist reports of both L-cone tetrachromacy, and M-cone tetrachromacy (two subtypes of the long-wave-sensitive or the middle-wave-sensitive cones in the same retina). We developed two psychophysical procedures, one for identifying L-cone tetrachromacy, and another to test for M-cone tetrachromacy. First we presented to subjects 720 nm and 760 nm monochromatic lights in the two halves of a vertically split circular field viewed through the aperture of a Pulfrich spectrophotometer. Subjects were asked to adjust the intensity of the 720 nm light to achieve a perfect match; we expected that L-cone tetrachromats would always sense a residual hue difference between the two lights. In testing for M-cone tetrachromacy, we looked for a peak of discriminability (corresponding to the sensitivity crossover of two slightly different M-cone subtypes) in the middle portion of the spectrum while the subjects' L-cones and M-cones were desensitised by a mixture of 380 nm and 720 nm lights. Eighty colour-normal subjects were examined; one L-cone tetrachromat and one M-cone tetrachromat were identified. Further examination of these subjects is in progress.

◆ **Chromatic filters and colour vision deficiency**

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Chromatic filters are known to improve anomalous colour vision [eg Ábrahám, 2001 *Periodica Polytechnica (Budapest)* **45** 3–10]. We compared the relative efficiency of four commercial filters: Skylet Fun (F1), Thrama (F2), Lila (F3), and F560 (F4). Spectral transmission curves were: (F1) smoothly increasing from short to long wavelengths; (F2) as in (F1) but with additional moderate maximum (430 nm) and minimum (490 nm); (F3) similar to (F2), but with higher maximum (460 nm) and lower minimum (530–580 nm); (F4) a sharp step at 560 nm from zero to full transmission. The Nagel anomaloscope, the conventional and a computerised Farnsworth–Munsell 100-hue test served to select twenty-five, out of forty-four, young adults—according to unison indication across tests: twenty colour deficient, five normal—for further examination. Filters were monocularly (non-dominant eye) and binocularly tested for their efficiency with Ishihara and Velhagen colour plates, a modified Holmgren wool test, and natural-scene colours. The results were complex, resisting simple attribution to diagnosed deficiency (prot-/deuteranomaly, prot-/deuteranopia). Overall, F2 (monocular) improved colour vision significantly, followed by F4 (monocular) and F2 (binocular); whereas F4 (binocular) and F3 (monocular) changed it for the worse. Improvement of colour discrimination was also found in normal observers.

◆ **Chromatic diversity of natural scenes**

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The number of discriminable colours is often assumed to be of the order of several million but the extent of detectable chromatic diversity present in individual natural scenes is an open question. Here, the aim was to estimate the number of discriminable colours seen in natural scenes. Hyperspectral data were obtained from a set of natural scenes over the range 400–720 nm at 10 nm intervals (Nascimento et al, 2002 *Journal of the Optical Society of America A* **19** 1484–1490) and the representation of each scene in CIELAB space computed for all pixels of the image. The number of discriminable colours was estimated by counting the number of unit volumes in the three-dimensional volume defined by the scene when represented in CIELAB space. We found that the number of discriminable colours estimated in a scene could vary by an order of magnitude from scene to scene, but rarely exceeded 10^5 , indicating a limited chromatic diversity.

◆ **Variation of surface-colour judgments in natural scenes**

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Observers can readily discriminate between illuminant changes and surface-colour changes in Mondrian-like patterns, but it is not known how representative this performance is of vision in natural scenes. To investigate this, an experiment was performed with simulations of natural scenes presented on a computer-controlled colour monitor with 10-bit resolution per gun. The natural scenes were reproduced from data obtained with a high-resolution hyperspectral imaging system. Twenty scenes (including rocks, foliage, and buildings) were tested. In each trial, two images were presented in sequence, each for 1 s, with no interval. The images differed in the phase of daylight on the scene, first with correlated colour temperature 25 000 K, then 6 700 K. The spectral reflectance of a region in the second image was changed randomly, consistent with a local change in daylight. The images, viewed at 100 cm, subtended $\sim 17 \text{ deg} \times 14 \text{ deg}$. The observer's task was to decide whether the particular region in the successive images was the same or different. Performance for eleven observers with normal colour vision was quantified with a standard constancy index. Index values ranged from 0.44 to 0.99 (1.0 representing ideal performance), indicating that colour constancy may be strongly dependent on scene content.

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◆ **The relationship between categorical perception and memory bias towards the prototype**
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Shift towards prototype (STP) and categorical perception (CP) may be the same phenomenon (Pilling et al, 2003 *Memory & Cognition* **31** 539–551). In STP, memory errors are biased towards the category prototype; in CP, within-category discrimination is harder than cross-category discrimination. In a delayed same–different task, the shift of the target memory towards the prototype increases target–test separations for cross-category pairs but reduces them for within-category pairs, giving apparent CP. Here, we explore the relationship between STP and CP by measuring memory errors and JNDs across the green–blue colour region varying in Munsell hue only. Errors and JNDs were measured in Munsell units. Target colours were chosen from a yellow–purple continuum on the monitor, either with the target present, or following a 5 s delay. JNDs were measured at seven locations with a 2AFC chromatic edge-detection task involving ZEST. STP manifested itself by errors of different signs either side of the prototypes for both delays, and CP by local discrimination maxima at the prototypes and a minimum at the boundary. CP and STP were correlated for simultaneous matching, but not for delayed matching, suggesting a degree of independence between CP and STP.

◆ **Categorical perception of colour is flexible and language dependent**
 E Özgen, I R L Davies, G Widdowson (Department of Psychology, University of Surrey, Guildford GU2 7XH, UK; e-mail: e.ozgen@surrey.ac.uk)

It is not yet clear whether categorical perception (CP) of colour (superior cross-category discrimination versus within-category) is learned or inherited. One way in which CP might be learned is through language; this implies that languages with different colour terms may lead to corresponding different patterns of CP. Evidence supporting this possibility exists (Özgen and Davies, 2002 *Journal of Experimental Psychology: General* **131** 477–493). However, measures used in the study of colour CP have traditionally relied on memory (eg 5 s retention interval), or subjective judgments (eg of similarity). It is possible that ‘perception’ has little to do with it. Thus, a direct test of low-level perceptual sensitivity is needed. Here, we use a 2-temporal-AFC edge-detection task to estimate hue-difference detection thresholds with ZEST. In experiment 1, we showed that category learning across a novel hue boundary leads to dramatic drops in thresholds only along the induced boundary but not in the within/novel-category regions. In experiment 2, we compared English speakers with speakers of African languages which encode blue and green with a single term (no blue–green boundary). Africans had higher detection thresholds across the blue–green boundary than English speakers, while in neighbouring regions no such difference was found.

◆ **Evidence for multiple processing stages involved in colour judgments under changing illumination**
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Studies of colour constancy indicate that subjects partially discount illumination changes by means of a low-level mechanism, involving chromatic adaptation, and that a more complete adjustment is performed on the basis of higher-level estimates of global illumination change. We investigated this hypothesis by presenting subjects with two successive arrays of colour patches, instructing them to judge whether (a) the colour of the central patch stayed the same or (b) it underwent a change consistent with a global illumination change. The colour of the central patch in the two displays either stayed the same, changed in illuminant-consistent way, or changed to a point intermediate (in CIE space) between the no-change and illuminant-consistent points. In condition (b), subjects correctly identified the illuminant-consistent changes without misidentifying the no-change and intermediate-change transformations. However, in condition (a), subjects performed near chance when judging whether the colour stayed the same and misidentified (as not changing) instances in which the colour changed only partially. Moreover, judgments in condition (a) were faster than those in condition (b). We interpret these results as being consistent with a fast (low-level) discounting mechanism and a slower (high-level) mechanism estimating global illuminant changes.

◆ **Locating Spanish basic colours in CIE L*U*V* space: Lightness segregation, chroma differences, and correspondence with English equivalent**

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Five experiments were performed to answer the following questions: Which are the Spanish basic colour categories? Where are they located in colour space? Are they different in number or localisation from the English ones? Experiment 1 (elicited lists), experiment 2 (synonymy estimation), and experiment 3 (free monolexemic naming) (a) confirmed the existence of eleven basic categories (the eleven classics), (b) showed two synonymous terms (morado and violeta) to name a category equivalent to the English purple, and (c) showed two categories—beige and garnet—close to be basic. Experiments 3 and 4 (monolexemic naming) and experiment 5 (free signaling of prototypes and good exemplars) provided very specific colorimetric delimitation of the Spanish eleven classics (plus beige and garnet). In order to compare our results with the British equivalents, all were translated to CIE L*U*V* space, allowing us to reach the following conclusions: (1) Spanish and British basic categories are essentially equivalent in number and colorimetric delimitation. (2) Our research extended and complemented previous work in: (2A) delimitation of achromatic categories; (2B) their links with chromatic categories (red and orange have no link with achromatics); (2C) most basic categories are used only in a restricted lightness range.

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CORTICAL CODING AND ORGANISATION

◆ **Three types of gamma-oscillatory processes in the lateral geniculate nucleus of the cat visual system**

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Gamma-oscillation characteristics in the responses of neurons of cat lateral geniculate nucleus to presentation of semitone and binary test images in their receptive fields were studied. Spectral characteristics (in the range of 20–100 Hz) of neuronal responses to adequate stimuli were analysed. 5930 peristimulus histograms of responses plotted on the basis of 177900 neuronal impulse responses were examined. The following results were obtained: (a) Neurons that give rise to oscillations with significantly different frequencies in response to common stimuli were revealed in the set of cells. According to this feature, three types of neurons were described with oscillation mean values of 26.95 ± 4.35 , 52.02 ± 9.05 , and 85.79 ± 7.19 Hz (SD). (b) Mean values of gamma-oscillation dominant frequencies in responses of neurons of all three types remained constant (within the limits of scatter) with alteration of spatiotemporal parameters of stimuli. (c) Although the frequency ranges of the neuronal responses reported here are clearly separated from each other, there might exist a functional dependence between these ranges, with a simple numerical relationship of 1 : 2 : 3 being suggested. This relationship might indicate a potential functional coupling of neurons with oscillatory responses at an early stage of visual processing.

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◆ **Selectivity and ergodicity in striate complex cells**

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Probability distributions of the responses of macaque striate complex cells to a large set of images were measured. Selectivity was defined in terms of the shapes of these distributions, specifically as distribution kurtosis or entropy. To examine how receptive-field properties determine selectivity, two models of complex cells were created with slightly different receptive-field profiles. The selectivities of the models bracketed the data from above and below. It was found that a key determinant of selectivity is the spatial-frequency tuning of the cells. Units tuned to high spatial frequency have high selectivity, while units sensitive to low spatial frequencies have low selectivity, regardless of the location of the tuning-curve peak. The $1/f$ spatial-frequency spectra of the stimuli appear to be an important factor producing this behaviour. Although complex cells have high selectivity or sparseness relative to a Gaussian reference distribution, they do not maximise sparseness, as we can create model complex cells with slightly different receptive-field profiles that have much higher sparseness. We raise the possibility that high sparseness is the result of distortions in the shape of response distributions caused by nonlinear, information-losing transforms, unrelated to information theoretic issues of efficient coding and redundancy reduction.

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◆ **Selectivity of hemispheric effects in the crossed – uncrossed difference paradigm**

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When a visual target is presented to one hemifield, responses to the target made with the ipsilateral hand (uncrossed responses) are faster than responses made with the contralateral hand (crossed responses), because crossed responses require transfer of information between the hemispheres. This difference in response times is termed the crossed – uncrossed difference (CUD) and provides an estimate of interhemispheric transfer time. We investigated the CUD by applying rTMS over the left or right occipital cortex during a target-detection task. Eleven subjects were required to make speeded key-press responses when detecting a stimulus presented at 5° eccentricity to the left or right of the fixation. Relative to sham rTMS, the CUD was increased by inhibiting the crossed latencies only when rTMS was applied to the hemisphere processing visual information. However, there was no change in CUD as a consequence of rTMS delivered over the hemisphere that was not processing visual input at the time of stimulation. This result differs from that of Marzi et al (1988 *Behavioural Brain Research* **30** 183–192) who found an increased CUD irrespective of whether or not the visual area stimulated was receiving retinal input. Our results suggest that our effects were caused by stimulation of V1, whereas Marzi et al were targeting extrastriate cortex.

◆ **Non-classical receptive-field inhibition and its relation to orientation-contrast pop-out and line and contour salience: A computational approach**

N Petkov, M A Westenberg (Institute of Mathematics and Computing Science, University of Groningen, Postbus 800, 9700 AV Groningen, The Netherlands; e-mail: petkov@cs.rug.nl; website: <http://www.cs.rug.nl/~petkov>)

Non-classical receptive-field (non-CRF) inhibition has been suggested as the possible origin of various perceptual effects, such as overestimation of an acute angle between two lines (Blakemore et al, 1970 *Nature* **228** 37–39) and orientation-contrast pop-out (Knierim and van Essen, 1992 *Journal of Neurophysiology* **67** 961–980; Nothdurft et al, 1999 *Visual Neuroscience* **16** 15–34). Computational models of two types of cell that incorporate non-CRF inhibition, which are based on Gabor energy filters extended by surround suppression of two kinds, isotropic and anisotropic, were introduced in Petkov and Westenberg (2003 *Biological Cybernetics* **88** 236–246). These computational models are applied to the images used to demonstrate the referred perceptual effects. The results of these computer simulations confirm the rightness of the hypothesis of a possible functional role of non-CRF inhibition in the referred and further effects, such as reduced salience of lines and contours embedded in gratings [Galli and Zama, 1931 *Zeitschrift für Psychologie* **31** 308–348; Kanizsa, 1979 *Organization in Vision, Essays on Gestalt Perception* (New York: Praeger)], and reduced salience of contours surrounded by textures. The algorithms and images are available on the internet (<http://www.cs.rug.nl/~petkov>) for use by other researchers. A demonstration is given on site.

◆ **Gabor filtering augmented with surround inhibition for improved contour detection by texture suppression**

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Gabor functions are adequate models of simple-cell receptive fields (Daugman, 1985 *Journal of the Optical Society of America A* **2** 1160–1169; Jones and Palmer, 1987 *Journal of Neurophysiology* **58** 1233–1258). Gabor-energy filters have been used to model complex cells (Morrone and Burr, 1988 *Proceedings of the Royal Society of London, Series B* **235** 221–245). Such filters augmented with non-classical receptive field inhibition (Nothdurft et al, 1999 *Visual Neuroscience* **16** 15–34) were demonstrated to mimic various perceptual effects (Petkov and Westenberg, 2003 *Biological Cybernetics* **88** 236–246). Furthermore, they substantially outperform previously known contour-detection algorithms (Grigorescu et al, 2003 *IEEE Transactions on Image Processing* **12** 729–739). Nowadays Gabor filters are widely used in various scientific fields: visual perception, computational neuroscience, image processing, and computer vision. We implemented a Gabor filter augmented with surround inhibition and made it available on internet (<http://www.cs.rug.nl/~petkov>) for use by other researchers. Users can choose from the image material available on the site or upload their own images. The following parameters can be selected: preferred wavelength; preferred orientation; phase offset; aspect ratio; bandwidth; number of orientations; half-wave rectification threshold; superposition of results for different phase offsets; type, strength and area of surround inhibition; post-processing. The site includes a number of examples of visual perception effects.

◆ **Framework for testing biological-utility hypotheses**

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Various aspects of the visual system have been claimed to have certain biological role. The usual argument is that a given neural mechanism would help an animal to perform better a certain task. Such speculations are typically not supported by quantitative measurements and statistical studies. I propose a framework for verification of biological-utility hypotheses that includes defining a measure that quantifies the performance of a given subsystem in a certain task and collecting statistics about this measure on a reasonable number of images. A hypothesis is confirmed or rejected by using the distribution of the performance improvement/degradation values obtained by taking the considered mechanism into account in a computational model of the concerned subsystem. This framework for utility verification follows an approach previously deployed for the comparison of biologically motivated contour-detection algorithms in a computer science context (Grigorescu et al, 2003 *IEEE Transactions on Image Processing* **12** 729–739). The framework is applied to non-classical receptive-field inhibition for which the detection of object contours (Petkov and Westenberg, 2003 *Biological Cybernetics* **88** 236–246) and texture boundaries (Nothdurft et al, 1999 *Visual Neuroscience* **16** 15–34) has been suggested as probable biological utility.

◆ **Spatiotemporal dynamic theory of the phenomena of figural aftereffects**

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A new dynamic theory of the figural aftereffects is proposed. (i) The phenomena are not merely the effect of simple lines, but encompass the whole surroundings. Therefore the explanation of Koeler et al (1944 *Proceedings of the American Philosophical Society* **88** 299–357) is inadequate, because the conclusive factor in it was just the distance between the inspection figure (IF) and the test figure (TF). (ii) The spatial and temporal effects act as a complex process as in stroboscopic movement. The study of the contour effect by Werner (1935 *American Journal of Psychology* **47** 40–64) was taken into account and the increment threshold at the inner and outer parts of the figures was measured. The region assumed to be the figure appears smaller than ground region of the same size owing to the segregation process. In the aftereffect, when IF is removed, the IF region may be in a state of reversed figure–ground relation, and the continuously presented TF that is subject to this aftereffect alters its appearance. In the case of large IF and a small TF circle, TF is presented in the middle of a uniform ground and appears smaller. But in the case of small IF and large TF, TF is presented in a heterogenous field, in which the centre is of the ground type and then the border, of figure type, appears larger.

◆ **Spatial-frequency-dependent visual-evoked-potential gender differences in children**

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It is well established that visual evoked potential (VEP) latency and amplitude differ across gender. Gender difference varies with age, but, in general, VEPs recorded from males are of longer latency and lower amplitude than those recorded from females. While there is no broad agreement why these differences exist, they have been attributed to a range of factors, including head size, hormone levels, and core body temperature. In the present study, transient VEPs were recorded from children and adults in response to achromatic vertical sine-wave gratings at a range of spatial frequencies (1, 3, 5 and 7 cycles deg^{-1}), pattern-reversed at a frequency of 2 Hz. Our results show that head size and latency are poorly correlated ($R^2 < 0.2$), indicating that head size is not a significant factor in VEP gender differences. In adults, we found no gender difference in VEP latency or amplitude ($p > 0.1$). In children, we found that gender differences in latency are spatial-frequency-dependent, with differences apparent at 3 and 5 cycles deg^{-1} ($p < 0.001$) but not at 1 or 7 cycles deg^{-1} ($p > 0.2$). These findings may indicate a gender difference in the development of spatial channels.

◆ **Feasibility of joint time – frequency analysis in the segregation of early and late component of visual evoked potentials**

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Noradrenergic system plays an important role in the formation of bioelectrical activity of the primary visual cortex because of its unique innervation pattern and synaptic organisation, and the electrophysiological effect of noradrenaline. The metabolism of noradrenaline is under genetic control, resulting in very stable interpersonal biochemical and bioelectrical differences. A significant

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negative correlation was found between CI–CII, CII–CIII amplitude of the visual evoked potential (VEP) and the platelet MAO activity [Magos, 1998, in *Recent Advances in Human Neurophysiology* Eds I Hashimoto, R Kakigi (Amsterdam: Elsevier) pp 455–465] giving further support to the interaction of these two levels. Although the origin and the timing of early and late VEP components are different, a temporal overlapping can be assumed between them. Overlapping can bring significant inaccuracy into the amplitude measurements. To study this hypothesis, VEP curves from forty subjects were submitted to feasibility of joint time–frequency analysis. VEP proved to be a multicomponent curve. The frequency content of the early and the late components fell into different frequency ranges. To separate them, 7-order inverse Chebyshev bandpass filter was used, the low and high cut-off frequencies were set at 3.5–16 and 0.1–3.5 Hz. Filtering significantly modified the amplitude of CI–CII and CII–CIII amplitudes. In the range below 6 μ V the filtering increased while in the range over 6 μ V filtering diminished the VEP amplitude.

- ◆ **Spatiotemporal dynamics of information flow in a model of the visual thalamocortical system**
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The thalamus is a complex structure consisting of a number of functional nuclei, of which first-order nuclei receive input from the periphery and are connected to the neocortex [Sherman and Guillery, 2001 *Exploring the Thalamus* (San Diego, CA: Academic Press)]. The thalamocortical network has attracted a great deal of research, and the most studied of the nuclei is the visual lateral geniculate nucleus (LGN). The LGN receives input from the retina, which is faithfully relayed to V1. Layer 6 then feeds back information (Thomson and Bannister, 2003 *Cerebral Cortex* **13** 5–14) to the same thalamic area. Simultaneously, the LGN innervates the thalamic reticular nucleus, which also receives projections from the cortex and innervates the LGN (Pinault and Deschenes, 1998 *European Journal of Neuroscience* **10** 3462–3469). The connectivity is well-understood, but the purpose of this monosynaptic circuit remains unknown. In order to understand the information flow through this network, we present a population-level model, which includes the major cell types. Results are reported, which show the comparison between experimental patterns of spatiotemporal activity in response to the presentation of transient visual stimuli, and theoretical results from simulations of the model.

- ◆ **A dynamic model for the visual perception of motion using parallel, lateral, and inferential interactions**
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Measurement of the motion field from a video flow is an ill-posed problem. We address here a neuromimetic model to restore the true motion field using a dynamic model based on the comparison of mathematical, neuroscientific, and psychophysical observations. This model is based on a multilayered model of the MT cortical area. Its input is the detection of moving multiscale contrasts from V1 which uses an overcomplete representation. A first layer of MT consists of interactions of these local detectors to provide a raw input as given by classical filtering models. A learning scheme based on Bayesian inference, which takes the form of a Hebbian rule, tunes the weight between neurons so as to provide a probabilistic representation of the optic flow. Finally, this ‘feedforward’ representation is dynamically compared with previous but uncertain detections by a similar inferential rule. This model is compared with nonlinear models, such as partial differential equations, and we applied it to a model of inference in biological vision by replicating a range of psychophysical experiments which precisely measure the dynamic effect of the aperture problem.

- ◆ **Improved rate scalable video coding using wavelets**
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Video scalability denotes a specific type of video compression in which sequences of varying quality are embedded within a larger bitstream. For streaming-video applications on the internet, one of the problems is that users have different bandwidth limitations. Generally, this is solved with the user being able to choose between three different types of resolution, or some other bandcontrolling settings, like quality. We wanted to achieve something that is truly service transparent; that means that, no matter what connection speed or terminal type the user has, he/she will get the best possible video transfer. Our video coding can compress video in two modes: single-frame and multiple-frame. In the single-frame mode only one frame is compressed at a time, and in the multiple-frame mode a wavelet transform is applied to a sequence of frames to remove

temporal redundancy. An improved algorithm that stores the most important coefficients in an embedded way is used. We have achieved promising results in both single-frame and multiple-frame mode which are very similar to those produced by JPEG and MPEG. We also investigated the influence of the 2-D and 3-D wavelet filter type on the compressed bitstream.

- ◆ **Modelling global to local cortical interaction for scene analysis and perspective retrieval**
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During global processing, local elements are grouped into a perceptual whole, whereas during local processing elements are viewed as separate objects. Global and local processing has been widely studied with compound letters (Navon, 1977 *Cognitive Psychology* 9 353–383). For more complex stimuli, computer-vision research has shown that coarse blobs are recognised before fine edges (Schyns and Oliva, 1994 *Psychological Science* 5 195–200). Some studies suggest that top-down projections serve to modulate the responsiveness of cells at previous stages of the processing hierarchy (Hupé et al, 1998 *Nature* 394 784–787). Assuming these results, we tested how long-range and short-range interactions between local and global processes influence image perception. With psychophysics experiments we tested the relative importance in small and large images of the categorisation task (using a priming paradigm). We investigated a model of V1 based on a Gabor filter, with a modulating loop based upon interaction. The experiments showed a priming effect of global cues on local ones. The proposed model can be used for high-level tasks (eg classification) as well as low-level ones (eg perspective extraction).

- ◆ **Retinotopic map properties and spatial filtering**
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A model of spatial-frequency filtering processes at the level of 4C layer of the striate cortex is proposed. The model does not interfere with the filtering performed by the cortical receptive fields per se. It is based on the literature data providing evidence on conformal mapping of the visual field representation at the primary visual cortex and uniformity of short-range horizontal connections of cortical neurons. Illusory figures were used as input to test the model. The output patterns as response to the figures were computed. Psychophysical experiments employing the same illusions were performed as well. A rather good correspondence between the model predictions and the experimental measurements of distortions of perceived shape and size was observed. In practice, the neurophysiological model provides a simplified and relatively fast algorithm of calculations of filtering parameters.

OBJECT RECOGNITION

- ◆ **fMR adaptation reveals modular representations of inanimate objects and places in human visual cortex**

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The way information about objects is represented in visual cortex remains controversial. One model of human object recognition poses that information is processed in modules, highly specialised for different categories of objects; an opposing model appeals to a more distributed representation. To address this debate, we used fMR adaptation (the reduction in fMRI activity that follows the repeated presentation of identical images). First, we localised regions in visual cortex that showed selective responses to different categories of complex objects (faces, inanimate objects, or places). These regions of interest were then used as a mask for the subsequent analyses of fMR adaptation. We report that activity in object-selective regions in the lateral occipital lobe was reduced after repeated presentation of the same inanimate object. In contrast, place-selective regions in the parahippocampal gyrus showed a reduced response to repeated presentations of the same image of a place. Adaptation to places in parahippocampal gyrus was largely invariant to changes in image size or viewpoint. The absence of fMR adaptation in face-selective regions challenges the idea that a more distributed representation underlies object and place perception.

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◆ **Brain mechanism of view-generalisation processes in 3-D object recognition: An optical topography study**

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The ability to generalise from stored views of an object to novel views plays an important role in achieving viewpoint-independent object recognition. To clarify the brain mechanism of view generalisation, we measured participants' brain activity during a view-generalisation task using optical topography. In the experiment, participants were presented serially with two views of novel paper-clip objects, and judged whether they were the same objects or not. When the same object was shown, the angular difference between views was 0°, 15°, or 45° around the vertical axis. From 3–12 s after the second view presentation, depending on the conditions, concentration of oxy-hemoglobin (C-oxy) in the occipito-temporal region changed significantly. In the 45° condition, the increase of C-oxy was significantly smaller than in other conditions. This reflects the activation of object representation by a process like template matching. In the parietal region, we found an increase of C-oxy under all conditions. This result is consistent with previous studies indicating that the parietal region is involved in recognising non-canonical views. Our findings suggest the presence of a view-generalisation process which is activated independently of the angular difference between views through the dorsal pathway.

◆ **Human brain regions involved in 3-D object learning and top–down processing**

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A fundamental issue in object recognition is how visual representations of three-dimensional (3-D) objects are learned and used for analysing input information. In this study, we conducted an fMRI experiment to identify the human brain regions involved in visual learning of novel 3-D objects, and in top–down processing based on previously acquired 3-D representations. The experiment consisted of learning and test phases. The learning phase involved repetition of three blocks which required discrimination, encoding, and recognition of paperclip-like 3-D objects with disparity and shading information. In the test phase, top–down and bottom–up structure judgment tasks were alternated. The former task required access to acquired object representations to judge the 3-D structure of the given images, whereas the latter task required only the input information. Statistical analysis of data revealed that visual learning of 3-D objects increased the activation of an area within the fusiform gyrus. However, during the top–down processing, the intraparietal sulcus, the premotor area, and the lateral occipital area were significantly activated, in addition to the fusiform area. The results suggest that dynamic interactions among different cortical regions play a crucial role in top–down processing based on 3-D object knowledge.

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◆ **Intracranial ERPs recorded in the infero-temporal cortex dissociate between orientation-dependent and orientation-invariant identification of visual objects**

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Visual recognition performance depends on the orientation of placed objects with a base and a canonical orientation, but is independent of the orientation of unplaced objects that have no base and are frequently seen in different orientations (Vannucci and Viggiano, 2000 *Perception* 29 287–302). Thus, visual object identification can be both orientation-dependent and orientation-invariant depending on tasks and stimuli. However, the exact neuropsychological and neural correlates of these recognition processes are still unclear. To address these questions, we recorded intracranial event-related potentials (ERPs) from subdural electrodes placed upon the infero-temporal cortex in eight epilepsy patients undergoing invasive pre-surgical evaluation while they identified placed and unplaced visual objects presented in different orientations. We found that intracranial ERPs mirrored the behavioural effects of orientation. Placed, but not unplaced, objects elicited neural responses that were sensitive to orientation and more negative, going over between 100 and 250 ms to misoriented visual stimuli. Moreover, all stimuli elicited an early positive component peaking around 200 ms that was reduced and delayed only for misoriented placed objects. These results indicate that the behavioural dissociation between orientation-dependent

and orientation-invariant visual object identification is based on early stimulus processing mediated by the infero-temporal regions.

◆ **Types of geometrical transformations and the perceptual similarity of figures**

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The recognition of objects mostly depends on the detection of the features that remain invariant over geometrical transformations. This study concerns the question about the type of transformation we perceive as the most similar to the initial object (model). The stimuli were asymmetrical planes and the linear patterns were varied by the level of complexity. There were model figures (M) and their transformations (T), according to the canons of (i) Euclidian, (ii) projective, and (iii) topological transformations. The sets of stimuli consisted of the model figure and two types of its transformations (T_x and T_y). The subjects were asked to indicate which of the stimuli from the set are dissimilar from the other two. The order of the transformations by their perceptual similarity to the models was (i) Euclidian (rotation), (ii) projective (horizontal and vertical), and (iii) topological (expansion and compression). The results have shown that the perceptual similarity generally depends on the number of invariant features: the greater the number of invariant features, the greater the perceptual similarity. However, the perceptual similarity depends also on the type of transformation: rotated figures (more invariant) are perceived as less similar to the model than the horizontal projection (less invariant).

◆ **Structured but view-dependent representations for visual 3-D object classification**

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We used a procedure of supervised category learning for teaching observers to classify unfamiliar 3-D objects from computer graphic 2-D views. Having reached criterion, the subjects were tested for generalisation with views from novel viewpoints. The duration of this procedure was about 2.5 h. A control group of observers showed a certain degree of mean generalisation but performance was view-dependent. Generalisation improved for a second group that acquired prior knowledge from passively watching virtual object models rotating in depth on a computer screen. Generalisation improved even more strongly for a third group that acquired prior knowledge by actively exploring with their hands physical 3-D object models. During haptic activities subjects were blindfolded. Both types of prior object knowledge were gathered for 5 min before category learning. The improvement of generalisation by seeing additional sequences of 2-D views is consistent with ‘view-based’ recognition theories that represent 3-D objects as collections of views. Yet such theories cannot explain the reinforcement of visual object classification through haptic prior knowledge. Therefore we conjecture that relational 3-D object attributes from executive memory [Fuster, 2003 *Cortex and Mind* (Oxford: Oxford University Press)] are linked cross-modally to view-based representations. The resulting representations would be structured but they mediated view-dependent classification.

◆ **Viewer-external frames of reference in 3-D object recognition**

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Most models of object recognition assume that object recognition is based on the matching of the 2-D view of the object with representations of the object stored in memory. They propose that a time-consuming normalisation process compensates for any difference in viewpoint between the 2-D percept and the stored representation. Our experiment shows that this normalisation is less time-consuming when it has to compensate for disorientations around the vertical than around the horizontal axis of rotation. By decoupling the different possible reference frames, we demonstrate that this anisotropy of the recognition performance is not defined with respect to the retinal, but with respect to the gravitational or the visuo-contextual frame of reference. Our results suggest that the visual system may call upon both the gravitational vertical and the visual context to serve as the frame of reference with respect to which objects are gauged in 3-D object recognition.

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◆ **Perceptual representation of within-category similarity of everyday objects**

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Theories of object recognition and categorisation agree upon the importance of similarity between stimuli. We used 257 line drawings of everyday objects, consisting of 7–12 exemplars within 24 basic-level categories (Op de Beeck and Wagemans, 2001 *Perception* 30 1337–1361). We manipulated similarity using a morphing procedure that created intermediate stimuli between the four extremes in a two-dimensional space derived from similarity ratings on the original line drawings, as well as contour and silhouette versions. Contour stimuli within this semiparameterised stimulus space were then used in a sequential matching task, in which subjects had to judge whether both objects belong to the same category. Basic-level categorisation performance, reaction times and error rate, deteriorated with increasing amount of morphing transformation between two successively presented category members. This systematic effect was found for biological and artifact categories, and it was quite robust for different types and amounts of image changes. Using similarity ratings on the selected set of stimuli and their morphs, we confirmed that the morphing procedure did indeed alter the degree of similarity parametrically. Stimuli that have a high percentage of overlap were rated as more similar than stimuli that were further away in the morphing procedure.

◆ **The influence of the mask on the direction of subliminal priming effect**

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Choice reaction times to visual stimuli may be influenced by preceding subliminal stimuli (primes). Some authors reported a straight priming effect, ie responses were faster when primes and targets called for the same response than when they called for different responses. Other authors found the converse. As a prime and target we used right-pointed or left-pointed arrows, but for masking we used 4 types of mask (2 arrow masks, 2 non-arrow masks). Our results suggest that the sign of the priming effect depends on mask structure. Reversed priming was obtained only for masks containing the searched-for feature even though informational content of the masks was neutral. With masks of irrelevant structure, straight priming effects were found. Thus, masks are not passive stimuli whose roles are limited to rendering the prime invisible. Rather, processing of the mask may interact with prime and target processing.

◆ **Object preference in peripheral vision**

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The functions of peripheral vision for object perception remain largely unknown. Recent studies with fMRI (eg Levy et al, 2001 *Nature Neuroscience* 4 533–539) suggest that natural viewing of objects influences cerebral organisation. Faces that we usually explore in central vision activate visual areas corresponding to the central visual field, whilst buildings that we usually see in peripheral vision activate visual areas corresponding to the peripheral visual field. Following this assumption, we assessed, in a behavioural experiment, whether natural viewing is driving perceptual abilities on objects in peripheral vision and if this influence depends on task requirements. Faces and buildings were displayed at eccentricities varying from 6° to 60°, in two different tasks: detection and categorisation (known versus unknown). Performance was better for buildings than for faces in the categorisation task in peripheral vision, supporting therefore Levy's assumption. However, performance was better for faces than for buildings in the detection task in peripheral vision, suggesting an influence of stimulus physical characteristics and structural properties of peripheral visual system. These results suggest that, either by physical stimulus characteristics or natural viewing, depending on the task demand, an object preference in peripheral vision is induced.

◆ **The principle of good continuation in space and time can guide visual search in the absence of spatial priming or contextual cueing**

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Previous research has shown that repetition of the same target features or target spatial position over time can improve search. It has also been shown that a consistent relationship between

a given target and the features or spatial arrangement of the accompanying distractors can similarly improve search. Thus it appears that the spatial and non-spatial characteristics of the target and/or the distractors are somehow retained by the visual system and used to guide visual processes such as object recognition and search. Here, we introduced a paradigm for manipulating the sequential structure of target position across trials independently of target features and contextual information. Results show that visual search is improved or impaired, respectively, when the target appears at an implicitly expected or unexpected position, according to the principle of good continuation of the target's successive positions across trials. These results are not merely due to bottom-up spatial priming, since facilitation also occurs for positions far from those recently occupied by the target, nor to contextual cueing, since the relative positions of the target and distractors are kept constant. These results demonstrate that the principle of good continuation in space and time can guide visual selective attention and ease search processes and object recognition.

◆ **Functional properties of a cortical region selective for images of the human body**

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Functional magnetic resonance imaging (fMRI) has been used to localise a number of category-specific neural areas including faces (Kanwisher et al, 1997 *Journal of Neuroscience* 17 4302–4311). More recently, Downing et al (2001 *Science* 293 2470–2473) localised a cortical region in the lateral occipitotemporal cortex, termed the 'extrastriate body area' (EBA), that responded selectively to images of the human body. Here, in line with the results of Downing et al, we have successfully localised a region selective to images of the human body in the lateral occipitotemporal cortices. Next, using the fMR-adaptation (fMR-A) technique developed by Grill-Spector et al (1999 *Neuron* 24 187–203), we were able to study specific neuronal populations and their functional properties in the EBA. This technique was used to investigate the levels of neuronal adaptation induced by varying the frequency of repeated (EBA-sensitive) images. Specific properties of human body images were then manipulated (viewpoint, size, position, familiarity, and illumination), and fMR-A was used to establish whether neuronal populations in the EBA were sensitive to these changes. Thus, we have been able to gain some insight into the possible functional role of the EBA.

◆ **Prerequisites of perceptual awareness**

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The human visual system has a degree of modularity with some regions specialised for object recognition (regardless of location) and others specialised for processing spatial information (regardless of object identity). It has been argued that perceptual awareness only occurs when both object identity and object location are bound together. This model predicts situations of subliminal stimulus presentation where subjects can detect either identity or location of an object, but cannot report both features simultaneously. To test this hypothesis, participants were presented with visual stimuli on a computer screen. Three task instructions were given; detect identity, detect location, or detect both identity and location of the stimulus. Stimulus duration was reduced in advance on the third task until accuracy was at chance level. Subsequently, accuracy in all three tasks was measured while stimulus duration remained constant. The results confirmed the hypothesis: even though participants were at chance performance when required to bind identity and spatial location, they performed significantly above chance when required to solely detect identity or spatial location. This suggests that information regarding identity and location of an object can still be preserved, even when those two sources of information are not bound together to give rise to awareness.

◆ **The role of action affordances in visual object recognition**

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Brain areas involved in action representation (pre-motor cortex, posterior parietal cortex) are activated when subjects name pictures of artifactual objects, like tools (eg Chao and Martin, 2000 *NeuroImage* 12 478–484). Moreover, psychophysical evidence indicates that manipulable objects automatically potentiate possible actions (eg Tucker and Ellis, 1998 *Journal of Experimental Psychology: Human Perception and Performance* 24 830–846). We investigated whether knowledge about action affordances is actually involved in object recognition. We examined with a priming paradigm whether objects with congruent affordances are named more accurately than objects with incongruent affordances. Two gray-scale pictures of artifactual manipulable objects were

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sequentially presented (tools, kitchen utensils, musical instruments). Subjects were required to name the objects. Stimuli were briefly presented and masked. The presentation time of the second object was adjusted individually in an adjustment phase so that accuracy approached 80%. In the congruent condition, both objects afford the same action (eg 'twisting', 'pouring'), while the affordances differ in the incongruent condition. Stimulus pairs in both conditions were matched for baseline accuracy, word frequency, word length, as well as visual and semantic similarity. Naming accuracy was significantly higher in the congruent condition. These findings substantiate our hypothesis that action affordances play an important role in the identification of artifactual manipulable objects.

◆ **Fragmental figure perception**

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Natural scenes involve the perception of objects that overlap one another, implying that such objects represent incomplete images for the observer. We have attempted to investigate the dependence of recognition for line drawings of everyday objects upon the parameters of their regular fragmentation as an extension of our earlier investigations (Chihman, 2003 *Perception* 32 Supplement, 122). Stimuli were contour figures with identical gaps between fragments of equal length. Forty-five observers were asked to observe and recognise each figure as it appeared. The size of objects varied from 30 min of arc to 20 deg. The length of fragments and gaps were changed during the experimental sessions. Recognition was found to depend on fragment length, gap length, and object size. The percentage of correct responses decreased with increasing fragment length. It decreased as object size was reduced below 60 min of arc. Modeling showed that object confusion matrices can be explained by the low-spatial-frequency context of images. Available local features can influence correct recognition. The data were also compared with participants' estimated subjective complexity judgments of the same stimuli. A correlation between complexity and recognition percentage for each object was obtained.

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◆ **Object substitution masking of realistic objects**

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When 4 dots surround an unattended target and their offset is delayed relative to the target's offset, the non-overlapping trailing dots act as a mask. This phenomenon is known as object substitution masking (OSM) (Enns and Di Lollo, 1997 *Psychological Science* 8 135–139), but so far had not been demonstrated for realistic objects. We used 26 ms exposures of circular arrays of 8 object line drawings, displayed at 4° eccentricity. During presentation, one object (target) was surrounded by 4 dots. After 26 ms, all objects disappeared, while the dots remained on for durations ranging from 0 ms (common offset) to 300 ms. Participants' task was to determine whether the target was oriented to the left or the right. In addition to trailing mask duration, we varied set size and target–distractor distance. Performance revealed an OSM effect: as trailing mask duration increased, discrimination of object orientation decreased. In addition, performance suffered when displays contained more distractors. This effect occurred even in the common offset condition, indicating that set size did not increase target–distractor confusion after display offset. Instead, it affected target discrimination before display offset, as suggested by a more adverse effect of closer distractors.

◆ **Influence of a priori knowledge on the efficiency of the human visual system in the case of observation of dynamic images**

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We investigated experimentally how a priori knowledge affects the efficiency of the human visual system in the case of observation of dynamic achromatic and pure chromatic images. We used images of moving objects in the presence of noise of different intensities and performed the research by our method of comparative measurements. Under high intensities of noise at short durations of object presentation (up to 80 ms), uncertainty of the instant of appearance of the moving object leads to a substantial drop in efficiency (by up to 100 times). When the intensity of noise is low, then at long durations of object presentation the efficiency drops only slightly. We also found that the efficiency as a function of duration of the moving object presentation has a minimum at 120 ms. The location of the minimum is independent of the uncertainty of

initial location of the object in the image, of the instant of the object appearance, and also of the noise intensity.

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◆ **'Same' versus 'different': A disparity in the task**

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Human observers do not use all information available in an image for object recognition (Braje et al, 1995 *Vision Research* **35** 2955–2966), but seem to adopt a flexible approach (Giraudet et al, 2000 *Perception* **29** Supplement, 82) mostly depending on the task. This assumption was tested with a discrimination task with natural images. A set of three objects, seen from three different points of view, was considered. The background supported no semantic relevant information for object identification. Test images were a combination of objects images, spatially filtered or not, and a contrast level of white noise. The observer's task was a same-versus-different forced choice with spatial alternative. The percentage of object image against noise was adjusted by means of an adaptive algorithm. Discrimination thresholds provided efficiency measure, whereas reaction time allowed for processing cost estimation. As previously reported, higher performance was obtained with images tuned on medium spatial frequencies, and no viewpoint invariance was observed. For all eight subjects, in contrast with Lawson and Bühlhoff's (2003 *Perception* Supplement, 116) results, a comparative analysis between same and different pairs of objects points towards a lower cost for the latter. This can be discussed in terms of different levels of processing.

PERCEPTUAL ORGANISATION

◆ **The effect of illusory contours, luminance, spatial uncertainty, and aging on visual detection**

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The effect of aging, spatial cues, mean luminance, and illusory contours on target detection was investigated. The target appeared (i) joining dots; (ii) superimposed on an illusory contour (Kanizsa square); (iii) joining rectangles; (iv) joining inverted pacmen; or (v) alone without spatial cues (control). The rectangles generated a weak illusory contour, but no illusory contour was generated by the inverted pacmen. The Kanizsa square, rectangle, and inverted pacmen conditions had the same luminance and the same figure-ground contrast. A 4AFC procedure was used with a classical staircase. There were twelve participants, six younger (mean = 40.8 years) and six older (mean = 64.3 years). The younger group detected the target significantly better than the older (no group × condition interaction). Detection in the Kanizsa square condition was significantly worse than in the dot condition and significantly better than in the control condition. No difference was found between conditions with the same luminance (Kanizsa square, rectangles, and inverted pacmen). These results, congruent with previous research (Salvano-Pardieu et al, 2001 *Perception* **30** Supplement, 37; Wink et al, 2002 *Perception* **31** Supplement, 73), failed to find evidence for subthreshold summation with illusory contours, and demonstrate the importance of spatial cues and luminance in target detection.

◆ **Effects of (mis-)alignment of illusory contours and physical contours**

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Various displays are studied in which the (mis-)alignment of physical and illusory contours has been manipulated. The perceptual outcome appears to be strongly affected by this manipulation. For example, when an illusory square, induced by a quadruplet of 'pacmen', is misaligned with an underlying grid, the resulting pattern appears to be rather confusing. Observers report different interpretations and occasionally experience a displacement of the part of the grid that falls inside the illusory square. The perceptual effect of the misalignment between illusory and physical contours becomes apparent if one compares this pattern with one in which thin physical contours have been added at the locations where illusory contours would otherwise emerge. Here, observers report a much more stable interpretation. Most specifically, there is a strong impression that the physical contours constitute the boundary of a 'piece of glass' through which the grid is being watched. The latter impression vanishes when the pacman inducers are removed and only the physical contours are left. It is concluded that, depending on the actual spatial

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locations, the underlying illusory and physical contour mechanisms may compete or cooperate with each other, and may thus induce unique percepts.

◆ **Goodness of regularity in dot patterns: Global symmetry, local symmetry, and their interactions**

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Goodness is a classic Gestalt notion, defined as salience or perceptual strength of a given pattern. All operational models of goodness have assigned a central role to mirror symmetry but not much attention has been paid to the distinction between global and local mirror symmetry, and their possible interactions. We designed eight different types of dot patterns (all consisting of 80 dots), combining different numbers (0, 1, and 2) and orientations (parallel or orthogonal to each other) of local and global axes of symmetry (affecting 50% or 100% of the dots, respectively) at different orientations (vertical and horizontal). Each of a large number of trials (eg 640) consisted of a short presentation (eg 200 ms) of a new dot pattern, which subjects had to classify as regular or random. We hypothesised that the overall goodness of patterns is not a simple sum of the amount of regularity present in them but depends on cooperation and competition between symmetries. The results confirmed our hypothesis, showing that performance in this regularity-detection task did not increase in a linear way when some symmetries were added to other symmetries.

◆ **Dot-sampled structured grids: From geometry to perceptual organisation**

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If regular patterns are to be used effectively in the study of perceptual organisation, we must first understand their geometric properties. Kubovy (1994 *Psychonomic Bulletin & Review* 1 182–190) proposed to use dot lattices to explore grouping by proximity. He described the geometry of six lattice types and developed a method of measuring the perceptual strength of grouping by proximity. We extended the work of Kubovy to dot-sampled structured grids (DSGs) defined by arbitrary differentiable functions along two axes. Unlike dot lattices, DSGs are not defined by purely local geometric properties. We present a formal geometric analysis of these patterns and a method to quantify both global and regional grid properties. Although DSGs are not limited to any particular differentiable functions, we provide exact characterisations of specific families of DSGs. We believe the DSGs we have chosen will be useful for the study of perceptual organisation and the Gestalt principles of grouping by proximity, parallelism, and good continuation. Because structured grids are commonly used to model 3-D surfaces, we will therefore be in a position to reconcile quantitative models of 2-D and 3-D perceptual organisation.

◆ **Induced size depends on figure – ground organisation**

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Size induction was studied with the use of the Delboeuf configuration (two concentric circles). The instructed order of judgment was to start with (i) the inner circle or (ii) the outer circle. This favoured alternative segmentation of the configuration into either (i) a central disk (figure) on a circular plate or (ii) a ring ('doughnut' figure) with a hole (ground). The ratio of inner-circle to outer-circle diameters varied between 0.27 and 0.88 and the diameter difference was between 5.5 and 33.0 mm. Apparent size of the circles was determined by category rating (1–9). Induced size depended on the diameter ratio and the diameter difference. Apart from the contingency on stimulus parameters, figure–ground organisation had a significant effect on the inner circle (the outer circle was hardly affected): when the inner test circle emerged as figure it was estimated more veridically—and apparently more resistant to the inducing context—than when it appeared as ground (mean overestimation 13.5% versus 18.3%; $p < 0.01$). The observed effect presumably reflects attentional enhancement of visual processing of the 'figure' (Müller et al, 2003 *Nature* 424 309–312) that biases competition at the expense of 'ground' processing (Kastner and Ungerleider, 2001 *Neuropsychologia* 39 1263–1276).

◆ **Interactive processes in figure–ground segmentation: Effects of occlusion, shape concavity, and contrast polarity**

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In a series of visual-search experiments we investigated how figure–ground segmentation is affected by occlusion cues, surface information, and contrast polarity. Observers searched multi-element displays for a convex shape among concave distractors, or the reverse. Targets and distractors were presented either with or without flanking surfaces which acted as a local ground. When there was no local context, search was more efficient for concave than for convex targets. This held also when there was a local contextual ground with opposite contrast polarity to the search stimuli. However, overall search efficiency was reduced when the elements were embedded in a local ground. The presence of an occlusion cue between the central surface and the local ground in the items only moderately improved performance over that when there was no occlusion. Removing contrast between figure and ground (by using line-drawn elements) removed the benefit in detecting shape concavity, indicating a critical role for surface contrast information in figure assignment. Finally, varying contrast polarity between local surfaces and the background also reduced the benefit for shape concavity. The results suggest that figure–ground coding is particularly influenced by contrast and contrast polarity differences between surfaces.

◆ **The role of the Gestalt principle of similarity in the watercolour illusion**

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The watercolour illusion consists of two main effects: a long-range assimilative colour spreading (colouration effect), and properties imparting a strong figure status (figural effect) to a region delimited by a dark (eg purple) contour flanked by a lighter chromatic contour (eg orange). In four experiments, the strength of the watercolour illusion to determine figure–ground organisation was directly compared (combined or pitted against) with the Gestalt principle of similarity both of colour and line width. The results demonstrated that (i) the watercolour illusion and, particularly, its figural effect won over the classical Gestalt factors of similarity; (ii) the watercolour illusion cannot be due to the colouration effect as suggested by the similarity principle; (iii) colouration and figural effects may be independent in the watercolour illusion; and (iv) the watercolour illusion can be considered as a principle of figure–ground segregation on its own (watercolour principle). Two parallel and independent processes as proposed within the FACADE model (Grossberg, 1994 *Perception & Psychophysics* **55** 48–120; 1997 *Psychological Review* **104** 618–658) are suggested to account for the two effects of colouration and figural enhancement in the watercolour illusion.

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◆ **Unified mechanisms in the disambiguation and grouping of visual information in motion, stereo, and monocular depth perception**

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Visual cortical processing is segregated into pathways, each consisting of several cortical areas. We identified key mechanisms of local competitive interaction, feedforward integration, and modulatory feedback from higher stages as common principles of cortical processing of static and moving form. It is proposed that these mechanisms form the core of cortical integration and segregation of ambiguous information to implement a principle of evidence accumulation and feedback hypothesis testing and correction. We demonstrated (Bayerl and Neumann, 2003 *Perception* **32** Supplement, 19–20) that a model of recurrent V1–MT interaction disambiguates motion estimates along extended boundaries by filling-in. Here, we show that identical mechanisms along the ventral V1–V2–V4 pathway are utilised for the interpretation of (i) stereoscopic disparity and (ii) relative depth segregation of a partially overlapping form. Disparities are detected by local correlation-sensitive mechanisms similar to motion-sensitive detectors. In the case of monocular depth assignment, the mechanisms utilised for motion disambiguation facilitate the interpretation of relative depth triggered by occlusion junctions. The results show that initial ambiguities are resolved by propagation of sparse cues via feedback modulation. Our simulations substantiate the proposed model with key mechanisms of integration and disambiguation in cortical form and motion processing, and predict the time course of cell activities indicating figure ownership.

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◆ **Perceptual grouping of serially presented motion-picture shots**

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We investigated what factor affects the perceptual grouping of serial presentation of motion-picture shots. We used motion-picture shots of an actor going away from the camera and coming back to it. We removed the first and the last frames of the original shots on a stepwise basis to obtain three motion-picture shots of different durations (20, 18, and 17 s). All three shots were presented once to ten subjects, who were asked whether they perceived that the actor's walking motion would continue or discontinue even after the end of each shot. Three shots of different durations were each presented repeatedly, after which the subjects were asked to rate the continuity between the shots. The results demonstrate that completeness of motion was rated high when the shot of 20 s duration was presented once only, but that discontinuity of shots was perceived when they were presented repeatedly. When the shot of 17 s duration was presented once only, completeness of motion was rated low, but when it was presented repeatedly, shots were perceived as if continuous, like a single event. Our interpretation is that good continuation of shots is one of dynamic Gestalt factors contributing to unification of motion pictures.

◆ **Perceptual grouping factors compete for salience**

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Both psychophysical and neurophysiological findings suggest that segmentation of a texture boundary based on orientation contrast is facilitated by contextual influences of elements collinear with, or parallel to, the boundary. Stimuli consisted of 8×8 test-matrices of Gabor elements all with the same orientation except those in one external row or column. After a short presentation interval, test matrices were masked by a matrix with no orientation cues. We measured the temporal threshold, defined as the test-matrix duration for discriminating (75% correct) the orientation of texture boundary. Experiment 1 showed that orientation discrimination of the row or column flanked by uniform texture was faster in configurations with 0° or 90° than with 45° or 135° orientation differences, although orientation contrast was fixed, confirming that segmentation is faster when local elements are collinear with the texture border. Unexpectedly (experiment 2), in the 0° or 90° configuration, there is a two-fold increase in thresholds when uniform texture in the matrix has the same orientation as the border. These results suggest that implicit processing of uniform texture on the basis of long-range lateral interactions occurs and interferes with the explicit process of texture boundary.

◆ **Endogenous control of attention can guide perceptual grouping**

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Most visual and attentional theories presuppose that grouping is a pre-attentive, bottom-up, and early process. But we empirically showed that endogenous control of visual attention, induced by prior knowledge about perceptual abstract organisation, could guide perceptual grouping. Visual stimuli were 3×3 matrices of simple elements organised by proximity and similarity principles. Participants had to indicate if target matrix, shown for 170 ms, and test matrix were identical or different. Given that only one element changed between target and test, performance on this difficult task was linked to participants ability to quickly extract the organisation of target matrix. To furnish knowledge about perceptual organisation, a source matrix was presented before target onset. Source and target perceptual organisations were more frequently analogous than different. We found that performance on target-test comparison was significantly more accurate when source and target were analogous. Several control experiments show that such a performance does not result from strategic factors but is a direct consequence of attentional preparation. Consequently, we can conclude that grouping of elements in complex structured stimuli is constrained by previous abstract and structural knowledge: grouping process is dependent on top-down influences.

◆ **The force of symmetry revisited: Symmetry-to-noise ratios regulate (a)symmetry effects**

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Freyd and Tversky's (1984 *American Journal of Psychology* 97 109–126) data suggested that human observers tend to overestimate relatively high levels of symmetry (symmetry effect), and tend to underestimate relatively low levels of symmetry (asymmetry effect). The holographic

approach to visual regularity (van der Helm and Leeuwenberg, 1996 *Psychological Review* **103** 429–456), however, predicts that, at any level of symmetry, both symmetry and asymmetry effects may occur as a consequence of correct estimates of symmetry-to-noise ratios. This prediction was tested in two experiments, with tasks and stimuli similar to those in Freyd and Tversky's study. First, subjects had to judge whether a noisy symmetry is more similar to a slightly more symmetrical variant or to a slightly less symmetrical variant. Second, for every pair of stimuli in such a triadic comparison, subjects had to judge which stimulus is the more symmetrical one. The results from both experiments are in fine agreement with the holographic predictions, and show that (a)symmetry effects indeed depend on symmetry-to-noise ratios.

- ◆ **Riesz transforms for the isotropic envelope estimation of Müller-Lyer illusion images**
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The Müller-Lyer illusion has previously been explained as a result of visual low-pass spatial filtering, although, in fact, the illusion persists in band-pass and high-pass filtered images without visible low spatial frequencies. A new theoretical framework suggests that our perceptual experience of the global spatial structure of an image corresponds to the AM component (or its magnitude, also called envelope) of its AM–FM decomposition. Riesz transforms (a natural multi-dimensional isotropic generalisation of the 1-D Hilbert transform) were used to estimate the envelope of different versions of the Müller-Lyer figure. It is shown that the illusion is physically in the local amplitude of the vector-valued monogenic signals of these figures, including those without low spatial frequencies. This result is compatible with the idea that information about geometrical illusions is present in the visual stimuli, although it contradicts the popular belief that the relevant spatial information for these illusions is carried by the lower spatial frequencies of their Fourier spectra.

- ◆ **Localisation and identification of illusory surface with binocular stereopsis**
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We examined which is earlier: the configuration processing of a 3-D illusory surface, or segmentation processing. For this purpose we compared the reaction time required to identify the configuration and judge the location of an illusory surface. Test patterns were presented by an SGI system. Two test pattern conditions were presented. In the localisation condition, the participant judged where an illusory surface was. In the identification condition, the participant identified the configuration of an illusory surface. The targets were presented either until the participant responded or for 1500 ms, and were immediately followed by a mask in the shape of a circle covering all of the target locations. We found that the reaction time required to judge the location of an illusory surface was significantly faster than that required to identify the configuration when the illusory surface appeared stereoscopically nearer. Control experiments ruled out explanations in terms of grouping of aligned edges and symmetry of inducers as location cues. Our results provide evidence for localisation of an illusory surface, as segmentation is faster than identification of formation. From these results, we conclude that segmentation processing is not influenced by the overall form of illusory surface, and suggest that 3-D illusory surfaces are represented independently of configuration processing.

- ◆ **Perception of hidden figures: A microgenetic analysis**
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We compared the phenomenological and processual aspects of the perception of hidden figures. The question was whether the more probable percepts of hidden figures, compared to the less probable percepts, were generated in the earlier stages of the perceptual process. In a pilot study, the subjects were asked to say what they see in a complex linear pattern. The three most frequent and the three least frequent perceptual descriptions were selected. In a further experiment the microgenesis of the perception of hidden figures was investigated. The primed matching paradigm and the same–different task were used. In each experiment, the two types of test figures were contrasted: the more frequent and the less frequent ones. There were two prime types: identical (equal to test figures) and complex (a pattern with hidden test figures). The prime duration was varied (50 ms and 400 ms). The main result indicates that, in the case of complex priming, the more frequent test figures were processed significantly faster than the less frequent ones in both prime duration conditions. These results suggest that the faster the processing of a figure, the more probable is the perceptual generation of this figure.

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◆ **A new cue to distance in a case of amodal completion**

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We studied a well-defined set of line drawings that we call 'completion by folding'. Such completion occurs when four quadrilaterals are arranged in such a way that two of them (called visible tails) look like a sheet of paper folded around an interposed rectangle. This is a type of amodal completion with unification which is produced even when current models do not foresee such a perceptual solution. We advance the hypothesis that such amodal completion depends on a 3-D interpretation. That is, the interposed rectangle may be seen as a parallelepiped. This hypothesis can account for those figures where the amodal unification occurs without the classical amodal completion constraints. In two experiments, we investigated the possibility that the geometrical horizontal distance between the two visible tails could be a new cue to relative distance. In experiment 1 we used the size-constancy effect to test the plausibility of the 3-D hypothesis. In experiment 2 we investigated the effect of the distances between the two tails on the degree of perceived depth. Experiment 1 confirmed the presence of the perceived depth, while results from experiment 2 confirmed a direct dependence of perceived depth on the physical distances of the two tails.

◆ **New motion-induced blindness observed in Pulfrich situation**

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Bonneh et al reported that, when a global moving pattern was superimposed on high-contrast stationary stimuli, the latter perceptually disappeared and reappeared alternately for periods of several seconds. They called this phenomenon motion-induced blindness (MIB). In this research, a simulated rotating transparent cylinder composed of 100 white dots was superimposed on 100 stationary green dots. When observers watched these stimuli wearing a red filter on their right eye, all the stationary green dots perceptually disappeared and reappeared. The new MIB was observed only when the cylinder rotated and observers wore a red filter. As the luminance contrast of either the green dots or white dots against the background was reduced, or as the number of either green dots or white dots decreased, the duration of MIB decreased. Also, the depth of the cylinder relative to the stationary dots affected the duration of MIB. These results imply that the new MIB is different from the original MIB, and that the new MIB cannot be explained by binocular rivalry. Furthermore, the results imply that the surface interpretation process is involved in the new MIB.

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◆ **Switching dynamics of multi-stable visual perception: A time-varying stochastic model**

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The time-varying nature of visual perception was modelled with the use of face/vase-like stimuli. The model first detected junctions with combinations of filter convolutions. This determined, locally, the occurrence of occlusions and assigned relative depth values. The integration of the collective relative depth values macroscopically determined the depth relationships of two halves of the image, one being the figure (ie the owner of the edge) and the other being the background. To introduce stochastic properties, random numbers with semi-normal distribution were applied to the junction signals. Top-down feedback connections skewed the probability density function of the random numbers in favour of the revealed depth order. In addition, adaptation and its recovery processes were implemented in the protocol. The combination of response enhancement by feedback slow adaptive decay of the response and its recovery, with the help of stochastic variation of the signals, generated the time-varying bi-modal system which switches the output in time, as in human perception. In addition, the model successfully mimicked the prolongation of the alternations when the stimulus was presented intermittently as reported in binocular rivalry and other bistable figures (Leopold et al, 2002 *Nature Neuroscience* 5 605-609).

◆ **One + one = two?—The effects of nonspatial object clustering on numerosity estimation**

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How is numerosity estimation affected by additional structural information in visual displays? Two experiments were performed to investigate if the linking of dots by line segments, thereby

forming clusters of polygons (nonspatial clustering), leads to systematic estimation errors: either an underestimation effect similar to that observed in classical experiments on clustering by spatial proximity, or an overestimation effect caused by the additional line segments which increased the overall number of objects. Our findings demonstrated the existence of a significant underestimation effect for nonspatial clustering. In addition, the relative magnitude of the underestimation increased along with the number of objects and with cluster size. Apparently, the number of clusters cannot be ignored when estimating the number of dots: The perceived number of dots is computed as a type of weighted mean of dots and objects. Finally, we observed that the presence of an equivalent number of line segments as in the previous condition, but unaligned with the dots, reduced the underestimation effect to a constant relative magnitude. Independently of cluster size, a constant proportion of dots is enclosed by the polygons. The polygons apparently 'mask' the enclosed dots, causing the constant underestimation.

◆ **Scrutinising is more than attending**

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Scrutinising a detail in an object usually follows conscious intention. Do the mechanisms involved in scrutinising differ from mechanisms involved in focusing attention? I explored the processing of discontinuities in lines, which are important segmentation signals and give the means to divide objects into parts. Stimuli were made up with collinear or parallel line segments. Subjects decided whether the stimuli included a discontinuity right or left, and gave their response by pressing a right or left response key. When parallel lines were displayed immediately after collinear lines, or the reverse, RTs were higher when the discontinuity was on the same side in the two successive stimuli than when it was on opposite sides. I show here that the different types of modulation mechanisms (ie the 'collinear-parallel' or the 'parallel-collinear' order) are not sensitive to the same attentional manipulations. Only the modulations corresponding to an activation of the processing of a gap between collinear elements appeared to require a conscious intention. The results suggest that voluntarily scrutinising, but not simply attending an object, allows the activation of the processing of discontinuities in lines, which would otherwise be deleterious for the identification of the objects.

◆ **Perceived kinetics in launching and triggering events**

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In launching and triggering effects [Michotte, 1946 *La Perception de la Causalité* (Louvain: Publications Universitaires)] object A moves towards object B and, when the two objects make contact, B starts to move. Phenomenally, the movement of A appears to cause the movement of B: either mechanically, in launching, or psychologically, in triggering. Perceived kinetics of these events have been explored in four experiments. We measured P50, the point of subjective equality between experimental stimulus and standard stimulus, of the perceived velocity of B. We found that P50 in control condition, obtained on adding a pause before the motion of B ($P50 = -0.005 \text{ deg s}^{-1}$), is different from P50 of experimental conditions: in launching (i) the P50 is $+0.56 \text{ deg s}^{-1}$; in triggering (ii) the P50 is $+0.42 \text{ deg s}^{-1}$. Moreover, in launching paradigm, P50 is also affected by kinetic variations of the objects before and after the collision, related to the impression of 'force' of the impact. In the decreased-force condition (iii) a small effect is found: P50 is $+0.34 \text{ deg s}^{-1}$; in the increased-force condition (iv) the P50 is $+0.96 \text{ deg s}^{-1}$. These results suggest that kinetic properties of causal and triggering displays are based on the global organisation of the events.

◆ **To what extent are local – global visual deficits in Williams syndrome found at a purely perceptual integration level?**

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Although purely perceptual processes cannot account for all Williams syndrome (WS) visual impairments, they might contribute to local – global visual deficits. Using Navon tasks, Fayasse (2003, PhD thesis, University of Liège, Belgium) asked WS individuals to reproduce from memory (or copy) large letters (global form) made of small letters (local forms). When the number of component letters increased, the reproduction/copying accuracy of global figures did not improve as with controls. Fayasse suggests WS individuals have difficulties disengaging from local components of the stimulus. In our perceptually based connectionist simulation using

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a simple recurrent network (SRN—Elman, 1990 *Cognitive Science* **14** 179–211) we posit the necessity of visual scan of component elements in order to recognise the larger global form. This perceptual model also predicts that motion, particularly coherent motion of components, aids global form recognition/reproduction. Global coherent motion seems to aid the perception of global forms in controls and WS individuals (Abreu et al, 2003 poster: “Autism, brain, and development”, Collège de France, Paris). We examine the response of WS individuals to motion situations (from whole-form global motion to local motion of component elements) in kinematogram-Navon tasks. The SRN model also predicts that coherent movement of local forms within the global form will improve perception of the latter.

◆ **Vasarely's vision**

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Victor Vasarely was born in Pécs in 1908. He studied at the Bauhaus Budapest in 1929 and moved to Paris in the following year. He died, a French citizen, in Paris in 1997. Vasarely is considered to be one of the founders of Op Art. From the 1940s he produced black-and-white geometrical designs that rendered vibrant a variety of visual phenomena that are usually overlooked. These included Hermann–Hering grids, border contrast, contrast reversals, depth ambiguities, and manipulations of Gestalt grouping effects. He also produced moiré patterns from the interference between geometrical designs printed on transparent and opaque surfaces. Vasarely explored a range of chromatic contrast phenomena in producing the shimmering appearances of his paintings. He was a prominent exhibitor in The Responsive Eye exhibition held at the Museum of Modern Art, New York, in 1965. Many of his large works, as well as his early ones, can be seen at the Vasarely Múzeum, Budapest. In contrast to his subtle amplifications of minor visual effects, his written descriptions of his works were virtually impenetrable. He should be celebrated as an intuitive visual scientist rather than a theorist of art.

◆ **Purely visual saltation illusion similar to cutaneous, auditory, and cross-modal ‘rabbit’**

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When a train of stimuli presented in one location is followed by stimulation in another location, the intermediate stimuli are perceived as shifted in the direction of the apparent motion. This illusion was originally discovered for cutaneous (Geldard and Sherrick, 1972 *Science* **178** 178–179), and auditory (Bremer et al, 1977 *American Journal of Psychology* **90** 645–654) stimulation. Recently, Kamitani and Shimojo [2001 *Journal of Vision* **1**(3) abstract 478] reported a cross-modal version. Here we report unimodal ‘rabbit’ illusion in vision. Three bars were flashed in succession (24 ms duration, 118 ms ISI). The first and third flashes were 2.4 deg apart, 4–16 deg from fixation. The second flash appeared either (a) at the first location, or (b) inbetween first and last. Five naïve observers were asked to discriminate the two conditions, as well as control two-flash apparent motion. d' was estimated from the receiver operator characteristic curves. Observers were found to discriminate condition (a) versus (b) for 4 deg ($d' = 1.04 + 0.26$ mean + SEM, $p < 0.01$) but not for 16 deg ($d' = 0.16 + 0.09$, $p > 0.05$) separation. Performance was high for (a) versus control condition ($d' = 1.96 + 0.77$ versus $1.25 + 0.39$). The illusion was also found to depend on ISI and distance between first and last bars. Results demonstrate purely visual ‘rabbit’ in periphery.

◆ **On the grid (from the viewpoint of painting)**

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There are many things to say about the notion of a ‘simple grid’. In the case of painting, it concerns the equal distribution of parts, and in this respect is an expansive structure. The grid allows a non-hierarchical image organisation and plays an important role not just in architecture, city-planning, construction, etc, but also as a tool for the distinction in a simple figure–ground scheme which leads to the discussion of relational questions: How minimal can the difference of brightness be to still reassemble some parts? Where is the point which connects the structure of the grid and where does it fall apart? The fascinating fact for the arts is the continuous redefinition of things through the perception process, always linked to a larger field of meaning. A certain feature or a paradox that appears in painting contradicts the notion that grids and other arrangements of exact geometrical forms can lead to ‘vague’ visual experiences. This can be caused through minimal changes within a regular structure. The reduction of visual constructs and their constituent elements helps to demonstrate specific interactions or relations inherent within those constructs.

SHAPE PERCEPTION

◆ VEP responses to different Glass pattern configurations

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Glass patterns are made by dot pairs organised to generate a perception of global structure. Psychophysical experiments show that threshold for detecting translational Glass patterns are higher than for concentric (global circles) or radial patterns (Wilson and Wilkinson, 1997 *Vision Research* **37** 2325–2330; 1998 *Vision Research* **38** 2933–2947). There is other evidence that this lower threshold of discriminability is instead dependent on the shape of the aperture through which the pattern is seen (Dakin and Bex, 2002 *Vision Research* **42** 2013–2020), disappearing when square apertures are used. We recorded VEP signals from the alternation between concentric, translational, and radial Glass patterns and matching fields of randomly organised dot pairs using a square background like that used by Dakin and Bex. We found that the VEP responses to the translational, Glass pattern were nearly identical to a control condition consisting of alternations between successive random patterns, while the concentric and radial Glass configurations showed significant differences from control after about 150 ms from the transition from random to organised and at about 100 ms from the transition from organised to random. Our data show that suprathreshold concentric and radial configurations produce larger responses than translational patterns, despite the use of a rectangular aperture.

◆ Measurements of perceived curvature distortions

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The reported psychophysical experiments were intended to test whether or not both the internal angles of an equilateral triangle, square, or pentagon, inscribed in a circle, and the circle arc sizes affect the strength of the ‘puffy arc’ illusion. Subjects adjusted the curvature of the arcs to reduce the illusion to zero thereby producing a measure of the illusion strength. The latter was directly proportional to the arc size (1/5, 1/4, 1/3 of the circle perimeter), and was inversely proportional to the angle size (60°, 90°, 108°). In the single-figure experiments with the internal angle varying owing to curved sides, and the arc lengths remaining unchanged, the illusion varied as well. Nevertheless, the illusion maximum corresponded to the straight-side figures and not to the curved ones, irrespective of the figure type and, consequently, of the internal angle size. The ‘puffy arc’ illusion shows an effect similar to that of the ‘radius’ illusion: the larger an arc is, the smaller its radius appears. A quantitative and qualitative correspondence between the experimental data and predictions of the neurophysiological filter model (Bulatov et al, 1997 *Biological Cybernetics* **77** 395–406) has been found in the study.

◆ The recognition of incomplete contour and half-tone figures

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The recognition of incomplete figures of everyday objects in fovea and beyond was the aim of our project. For fifteen subjects with high visual acuity, aged 18 to 24 years, we measured the necessary minimum of randomly presented parts of the contour. Fixation point was in the centre of the figure corresponding to the centre of the screen. The figure sizes were varied from 5 min of arc up to 20 deg by using different viewing distances. The contour minimum for recognition corresponds to figure size equal to foveola size. Beyond 20 min of arc, up to the resolution limit of 5 min of arc, recognition decreased linearly. For 0.5 to 5 deg sizes the threshold was relatively invariant to the size. The psychophysics and event-related potentials were investigated within the frequency range from 1 to 45 Hz. The relative perceptual availability of global and local features in sparse patterns was investigated during different stages of learning. Interpolation algorithms were proposed and tested in additional experiments. We measured the threshold of incomplete natural half-tone scene recognition. In these experiments, incompleteness was produced with wavelet transforms. The internal noise limitation of recognition was measured. A match filter model of the perception of incomplete figures is proposed.

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◆ **Contour discrimination with biologically meaningful shapes**

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A fundamental problem in object recognition is the lack of a validated metric for shape. In this study we use summation of radial frequency components to provide quantitative descriptions of the bounding contours of fruit. With this description, individual exemplars and the average of a fruit class (eg apples) can be located within a multi-dimensional space. We first derived the parameters of this space by creating a large database of digitised fruit contours from standardised photographs of apples, pears, and avocados. In three subjects, we evaluated threshold sensitivities to differences in fruit shapes around 3 fruit means (apple, avocado, pear) moving in the direction of each of the other mean fruit shapes. Thresholds expressed in a common Euclidean distance metric were found to be better by a factor of 2 around the mean apple shape than around either the mean pear or the mean avocado. These findings are discussed in terms of the contributions of individual radial-frequency components to the thresholds, and in relation to the results of categorical boundary measurements we have been making using the same multi-dimensional fruit space.

◆ **Temporal limits in visual completion**

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Previous studies suggested that visual completion takes measurable time (Reynolds, 1981 *Perception* **10** 107–115), and that the time to completion rises with amount of occlusion (Guttman et al, 2003 *Journal of Experimental Psychology: Human Perception and Performance* **29** 1211–1227). We examined how temporal span and spatial relationship of inducing figures affect the visual completion. Two kinds of Kanizsa-type illusory-contour figures were used as materials. Both displays consisted of four inducing figures and each inducing figure was approximately three-quarter disk. Four inducing figures were presented one by one with SOAs of 17–85 ms. We used a dot-localisation paradigm to probe the precision with which the visual system ultimately represents the contours (Guttman and Kellman, 2002 *Journal of Vision* **2** 355; Unuma and Hasegawa, 2002 *Perception* **31** Supplement, 73). Inducing figures were presented with a small dot superimposed somewhere on the induced illusory figure. Eight observers judged whether the dot appeared inside or outside of the perceived boundary. The results indicate that SOA and shape of illusory figure affect the imprecision of the dot localisation. These findings support the spatiotemporal reliability view [Shipley and Kellman, 2001 *From Fragments to Objects* (New York: Elsevier)] that associates spatiotemporal completion with a restricted temporal window of integration.

◆ **Modelling bistability in perceived slant when binocular disparity and monocular perspective specify different slants**

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We present a mechanistic model that reproduces the behavioural data from psychophysical experiments on bistable perception in perceived slant when binocular disparity and monocular perspective specify different slants. Our model successfully simulates the transition from a regime in which the perceived slant is the average of the two possible slants (small cue conflict situation) to a regime of bistability in which the percept alternates between the two alternatives (large cue conflict situation). Our model also provides for a simple way of accounting for effects of instruction (attention)-based biasing of the percept and successfully reproduces the shift in the distribution of percept durations in between percept changes. The model consists of a layered network structure that determines the location of the peak activation (through winner-take-all competition) in the spatial activity map of the input layer. The percept changes in the bistable situation are triggered by network noise. The mechanics of our model suggest possible sources of such behavioural characteristics as the apparent periodic refreshing of percepts and the retention over short time periods of an effect of the previous percept even if a short pause (absence of stimulus) intervenes.

◆ **Negative afterimage size is modulated by Titchener circles**

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Contrary to belief that negative afterimage is the sole result of photoreceptor adaptation at retinal level, there is evidence for contribution of postretinal factors to the perception of afterimage. To establish whether afterimage size is affected by context information we measured the perceived afterimage size under conditions of the Ebbinghaus illusion of size contrast. In an adaptation phase, observers fixated on the centre of a red inducer circle (diameter = 1.55 deg) for 50 s. The inducer then disappeared and six light-green (Titchener) circles were displayed around the fixation point. The diameters of these peripheral circles were either small (0.46 deg) or large (3.1 deg) in different trials. Each subject reported his/her perceived afterimage size by adjusting the length of a line to match the diameter of perceived afterimage by means of mouse clicks. The results show that perceived afterimage size is significantly larger when afterimage is surrounded by small Titchener circles. Thus, negative afterimage is susceptible to Ebbinghaus illusion. We suggest that our perception of negative afterimages is modulated by context information. A neural correlate of size contrast illusions such as the Ebbinghaus illusion is believed to develop beyond the retina. Hence, the perception of negative afterimages is modulated by high-level cognitive factors.

◆ **Visual distortions of the 3-D space induced by motion parallax**

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During a frontoparallel translation (Tf), depth changes can be visually perceived along any frontal direction, through motion parallax. Models of this process (Droulez and Cornilleau-Peres, 1990 *Biological Cybernetics* 62 211–224; Xiang and Cheong, 2002 *Proceedings of the British Machine Vision Conference, Cardiff, UK* 1 153–162) show poorer computational performance along Tf, than along its orthogonal in the frontal plane (TfO). We explored the apparent distortions of the 3-D space by measuring the perceived surface curvature along Tf and TfO. The computer-generated stimuli represented dotted ellipsoids or hyperboloids oscillating about a vertical or horizontal axis (± 4.8 deg at 0.5 Hz; Tf orthogonal to the rotation axis) in a large visual field (60 deg). Subjects reported directional surface curvatures on a psychophysical scale. We found that null curvatures are perceived as convex, more strongly so along Tf, than along TfO. Responses are also more variable along Tf. Curvatures of identical sign tend to reinforce each other perceptually (ellipsoids look more curved than hyperboloids). The spin variation scheme (Droulez and Cornilleau-Peres 1990, loco cit.) predicts higher response variability along Tf, and the iso-distortion model (Xiang and Cheong 2002, loco cit.) accounts for the convexity trend along Tf. We conclude that during lateral translations the visual space undergoes complex apparent distortions, which are only partially explained by computational models.

◆ **Do they all go together when they go?**

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Flat ambiguous shape-from-shading figures, of mixed convexities and concavities, all tend to flip together when the shading switches as from lighting above to below or vice versa [Ramachandran, 1988 *Scientific American* 259(2) 76–83]. We used actual convexities and concavities, of various depths, and measured how they look under different lighting conditions. We find that, when the depths are shallow, they all go together when the lighting is changed, but with increasing depths of the shapes the general assumption of convexity prevents them looking concave.

◆ **The contribution of eye movements to anorthoscopic percepts under free-viewing conditions**

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Our purpose was to investigate the contribution of pursuit eye movements to the integration of figures moving behind a slit (anorthoscopic perception). Outline shapes were moved across a simulated slit (without visible borders) on a CRT screen. Eye movements were monitored with a dual-Purkinje image eye-tracker. The slit width was adjusted so that there were spontaneous transitions between periods in which observers saw a horizontally moving shape and periods in

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which they saw only vertically moving contour segments. Subjects reported transitions between these alternative percepts. On half the trials the slit was retinally stabilised to eliminate pursuit-dependent retinal painting. During periods of figure perception, there was often low-amplitude spontaneous pursuit of the horizontal figure motion. Lower-amplitude pursuit was also sometimes observed when no figure was reported. Irrespective of figure perception, pursuit amplitudes were larger with stabilisation. However, the total percentage of time that a shape was seen, and the duration and frequency of episodes of figure perception, were not significantly different during stabilised and non-stabilised viewing. Our findings suggest that, although anorthoscopic figure percepts can elicit spontaneous pursuit under free-viewing conditions, this pursuit and the pattern it produces do not contribute to the formation or maintenance of those percepts.

◆ **Judged versus perceived causality in visual and action-outcome sequences**

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Previous research showed a dissociation between judgments of causality and perceived causality for Michotte's launch events: perceived causality shows no contingency effects. In standard action-outcome sequences, however, contingency effects appear both in causality judgments for event sequences and in responses to individual trials. We investigated what could be responsible for this difference. A first group saw sequences of launch events, with subjects controlling movement of shape A via a robot arm, so that subject's own action launched shape B. A second group of yoked subjects merely saw the resulting collisions, as in standard perceived-causality studies. In a third group, subjects made A launch B, but saw only the beginning and final motion; the collision itself was occluded. In a fourth group, subjects set B in motion by keyboard press, as in standard action-outcome studies. Contiguity effects were larger in groups seeing collisions than groups without this visual experience. In all four groups, contingency effects appeared only for judgments of causality, but not perceived causality. Accordingly, such dissociations are not limited to purely visual (rather than action-based) or natural (rather than arbitrary) events. The results are discussed in relation to current theories of perceived causality and causal judgment.

◆ **The subjective categorisation of paintings**

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Our aim was to explore the criteria relevant for the subjective categorisation of paintings. On the basis of the chronology and the dominant representational tendency, the universe of paintings was divided into four categories, each being a subject of a separate experiment: primitive art, figural realism, stylised realism, and abstract art. A sample of 21 paintings per category was chosen, so as to represent its formal, thematic, and stylistic diversity. Reproductions of the paintings were presented in pairs (each with each; 210 pairs per category). The subjects were asked to judge the dissimilarity of the paired paintings on a seven-point scale. Multi-dimensional scaling with three dimensions provided the most interpretable dimensions: simple–complex, subtle–rough, and spiritual–animal for primitive paintings (stress = 0.189, $r^2 = 0.690$); portrait–landscape, dramatic–calm, and surface–depth planes for figural realism (stress = 0.273, $r^2 = 0.614$); wide-angle–close-up, conservative–erotic, and hyperrealistic–sketched for stylised realism (stress = 0.166, $r^2 = 0.779$); chromatic–achromatic, horizontally/vertically oriented–diagonally oriented, and texture–figure for abstract paintings (stress = 0.192, $r^2 = 0.647$). The results indicate that the subjective categorisation of paintings is based on two groups of factors: formal and thematic. Further research is required to investigate relative dominance of the factors.

◆ **Feeding behaviour facilitates the emergence of preferences for symmetrical peckable items in newly hatched domestic chicks**

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Pecking preferences for symmetrical stimuli were investigated in newborn domestic chicks (*Gallus gallus*) incubated, hatched, and kept in total darkness until testing. On day 1 (24 h after-hatching) pairs of chicks were placed in front of a set of 8 symmetric and 8 asymmetric stimuli, selected from those employed by Giurfa et al (1996 *Nature* **382** 458–461) and Delius and Habers (1978 *Behavioral Biology* **22** 336–342). For 6 consecutive minutes each chick's spontaneous pecking at any single stimulus was recorded. Chicks were then caged in standard rearing conditions

and retested 24 h later (day 2). No pecking preference was present on day 1, whereas a significant preference for symmetric stimuli appeared on day 2 ($p = 0.001$). To disentangle experience from maturational effects, in experiment 2 chicks kept in total darkness till day 2, were shown to prefer asymmetric stimuli ($p = 0.0001$). In experiment 3, chicks were tested 48 h after-hatching, after experiencing standard rearing conditions, either with or without any food available. Only chicks that had been fed showed a significant preference for symmetric patterns ($p = 0.002$). Feeding behaviour, rather than general visual experience, seems crucial for the emergence of a preference for symmetry. We are now testing chicks using different kinds of peckable items at a controlled degree of symmetry.

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BINOCULAR VISION

◆ **The influence of eye movements on retinal correspondence and the theoretical horopter**

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The theoretical point horopter is traditionally defined as all the locations in space projecting onto identical retinal points in the two eyes. For gaze directions within the horizontal plane, it consists of the frontal parts of the Vieth–Müller circle and a vertical line. For gaze directions outside of this plane, ocular torsion described by Listing's law changes the shape of the horopter into a spiral, first described by Helmholtz. To quantify the effect of eye position changes on retinal correspondence, we extend the definition of the horopter to encompass all those points in space that lie closest to the projection rays originating from identical retinal points. This horopter surface exists for every gaze position and all visual angles. By restricting the amount of residual disparity for points on this horopter, we obtain a surface patch for which the deviation from projection onto identical points stays below this disparity limit. The retinal projection area of this patch is a measure of retinal correspondence and can be used to quantify the effect of eye movements. We apply this tool to an analysis of 3-D binocular eye movements and show that by obeying L2 rather than Listing's law the oculomotor system optimises retinal correspondence.

◆ **Stereoscopic correspondence for ambiguous targets is affected by elevation and fixation distance**

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Observers show a small disparity preference when presented with ambiguous binocular stimuli (McKee and Mitchison, 1988 *Vision Research* **28** 1001–1012). This can be understood if it is assumed that small disparities are more probable than large disparities (Prince and Eagle, 2000 *Vision Research* **40** 1143–1155). A consideration of binocular viewing geometry and the structure of the natural environment suggests that the most likely disparity will not necessarily be zero, and will depend on both elevation and the fixation distance. Their effects on binocular correspondence were therefore investigated. From five different distances, observers fixated a central cross, and were presented with a dichoptic square-wave pattern above or below fixation that could be matched with either a crossed or uncrossed disparity. A clear bias was observed for the ambiguous stimuli, with those presented below fixation tending to appear closer than fixation. Observers tend to report stimuli as closer than fixation with a tendency increasing with increasing fixation distance. No effects of fixation distance were observed for stimuli presented above fixation. These results show a clear influence of elevation and fixation distance on binocular correspondence, consistent with the spatial distribution of disparities in natural images.

◆ **Panum area testing in human fovea**

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The binocular fusion limits were examined as functions of four main eccentricities up to 1° with three-dot stimuli organised in right-angle patterns. In the experiments, subjects pushed one end-dot of the test stimulus horizontally to the left or to the right, also vertically up or down in steps of 0.3 min arc until reaching the fusion limits. In sessions, the orientation and size of the paired stimuli varied: 45°, 135°, 225°, 315° those of the angle bisector, and 10, 20, 30, 40 min of arc those of the side length, respectively. The Panum area was found to have an elliptical shape, with horizontal orientation of the longer axis in all four eccentricities. The ratio of the diameters of the areas was roughly constant, 1 : 2, but their absolute values increased monotonically with the stimulus size. The data obtained are in an agreement with previous findings (Hampton and Kertesz, 1983 *Perception* **12** 161–165) and may be interpreted in terms of the organisation of foveal hypercolumn units and of the cortical magnification factor (Yeshurun and Schwartz, 1999 *Biological Cybernetics* **80** 117–129).

◆ **The perception of continuity in partially occluded gratings**

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What visual cues are important for perceiving partially occluded surfaces as continuous? One way of examining this question is to present, under conditions of occlusion, stimuli which can be

systematically distorted in their continuity. We achieved this by presenting sine-wave gratings with spatial frequencies of 1 to 4 cycles deg^{-1} and orientations of 0° (horizontal) to 45° behind vertical occluding bars of binocularly correlated noise. Presentation was either binoptic (same in each eye) or dichoptic (alternate patches of the grating seen in alternate eyes). Continuity was manipulated by offsetting the phase of the grating by a given amount within each aperture of the occluder. Participants judged whether the stimulus was aligned (no phase offset) or misaligned in a 2AFC task. Phase offset thresholds increased with orientation away from horizontal and with increasing spatial frequency. Analysis of thresholds with spatial frequency suggested that this threshold dependence was consistent with participants requiring offsets of a fixed spatial size. There was no improvement in performance between binoptic and dichoptic presentation, suggesting that binocular mechanisms made little effective contribution to performance. These results argue against the involvement of the high-level binocular integration processes suggested by Forte et al (2002 *Vision Research* **42** 1225–1235).

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◆ **Binocular summation effects in the standard deviation of simple mean reaction times for chromatic changes at isoluminance**

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Here, I analyse whether the standard deviation associated with the expected mean value can support the existence of colour-summation effects, when comparing both monocular and binocular simple reaction times for manual responses for two normal human observers. Circular random stepwise stimuli were presented on a colour monitor of a 2-deg field size. The stimuli were chosen along the luminance achromatic axis and two equiluminance axes [a L&M-constant cone axis and a S-constant cone axis (Boynton, 1986 *Color Research and Application* **11** 244–252)]. A 15 cd m^{-2} achromatic reference stimulus was selected to provide suprathreshold luminance and colour at isoluminance variations. In this latter case, reaction times were measured by the standard procedure (Nissen and Pokorny, 1977 *Perception & Psychophysics* **22** 457–462). A binocular-summation index for the standard deviation was defined. The results confirm the existence of binocular summation both for the mean value and for its associate standard deviation (less variability in the binocular case). A clear distinction was found between the luminance and equiluminance signals, suggesting that the latter type could support second-order binocular-processing mechanisms (a higher mean reaction time, a lesser degree of binocular summation in the mean value, and a higher binocular variability).

◆ **Variability and adaptability of the visual system in binocular rivalry**

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Binocular rivalry, where incongruent stimuli from two eyes compete to emerge in the visual percept, has been regarded as an effective experimental platform for studying the neural mechanism of active vision. Although some statistical properties of the spontaneous alternation have been studied (eg the gamma distribution of dominance duration), the exact nature of spontaneous and induced perceptual alternations remains to be clarified. Here, we show the detailed spatio-temporal structure of ocular dominance pattern in rivalry in the presence of competing salient features (eg moving circles) in a wide visual field (20 deg) by means of spatiotemporal resampling method. A series of statistical analyses on spatiotemporal pattern of dominance suggested similarities between the dynamically adaptable dominance change in the presence of salient features and the apparently random change in the case of neutral competition (eg between orthogonal gratings). On the basis of these results, we construct a generic model, where the spontaneous variability of neural activities is structured into the dynamically adaptive network behaviour constrained by the internal dynamical properties of the cortex.

◆ **Inverse cyclopean texture segregation survives contrast randomisation**

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The border between two differently oriented textures could pop out because second-order filters convert the orientation difference into intensity differences. However, second-order filtering is not a logical necessity. Lateral inhibition between similarly oriented local filters would increase the relative intensity of visual signals elicited by the border, causing it to pop out. Inconsistent with this latter alternative is our confirmation that, under normal viewing conditions, segregation is unaffected when a random contrast is assigned to each texture element. Nonetheless, it remains a plausible explanation for performance with brief dichoptic presentations, in which the texture boundaries should be erased by binocular fusion. To test this idea, 5×5 arrays of Gabor

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patterns, containing one orthogonal target, were presented dichoptically for 200 ms, so that the cyclopean image contained 25 identical plaids. (Rivalry, inconsistent with the percept of plaids, is thought to require presentations longer than 200 ms.) Regardless whether each plaid was presented at 40% maximum contrast or at a random contrast uniformly distributed between 40% and 100%, targets could be located with 85%–90% accuracy. No process that confuses orientation-defined borders with contrast-defined borders can explain this result. Second-order filtering must occur before binocular combination is completed.

- ◆ **Acuity and alignment thresholds under monocular, dichoptic, and binocular viewing conditions**
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Binocular performance is superior to monocular performance in various tasks. However, there have been conflicting reports on how each eye performs when both eyes are kept open (eg Simpson, 1992 *Optometry and Vision Science* **69** 405–410). We assessed monocular, dichoptic, and binocular visual performance using a letter-acuity task and an alignment task in twenty-two subjects with normal vision. For both tasks, the duration of presentation was 100 ms. Under dichoptic viewing conditions, the central test stimulus was presented to one eye alone while both eyes were allowed to view a peripheral fusion stimulus. Visual acuity was assessed with a computer-generated letter E target. The task was to identify orientation of the letter E (four-alternative forced-choice). In the alignment task, three vertically oriented Gabor patches were presented. The subject's task was to align the middle patch with respect to the outer two patches. We found that visual acuity is better under dichoptic than monocular conditions, and binocular acuity was significantly better than the best monocular acuity. In contrast, we found that viewing condition has no impact on alignment thresholds ($p > 0.2$). Our results suggest that monocular signals used in an alignment task are not combined binocularly in the same way as those used in an acuity task.

- ◆ **Induced monocular blur and stereo threshold changes**
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We studied correlation between stereo threshold and different qualities of monocular stimuli. The stereo threshold was estimated by inducing artificial conditions of amblyopia, cataract, and uncorrected anisometropia, and comparing data with results for cases of real aforementioned pathologies. Defocusing with lenses was used to evoke induced uncorrected myopic and hyperopic anisometropia and amblyopia. To simulate artificial cataract we used PLZT and PDLC occluders with controllable light scattering. A third method was a demonstration on PC screen of stimuli with different blurring degree and contrast ratio to induce amblyopia and cataract conditions. The stereo sense was evoked by using light filters or liquid-crystal (LC) shutters for stereopair separation. In all conditions one eye saw constant clear stimuli, but the other eye had qualities with different stimuli. The estimated stereo threshold with colour filters was two times greater when stereo sense was caused by fusing different colour stimuli with the use of colour filters than in the case of achromatic stimuli fused with the use of LC shutters. The stereo threshold value of induced cataract with PLZT and PDLC plates increased very quickly, when the difference between the visual acuity of the two eyes reached 0.4 or more, as compared with similar conditions in defocusing and the method of monitor stimuli. On comparing uncorrected anisometropia or amblyopia with cataract we found that the latter influenced stereo threshold stronger when the eyes had similar differences in the visual acuities.

- ◆ **Apparent motion of monocular lines in different depth planes with lateral head movements**
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We examined the apparent concomitant lateral motion of a stationary monocular stimulus embedded in a stereogram that was viewed with lateral head movements. The random-dot stereogram represented two flat rectangular surfaces, one above the other, at two different distances. Two vertical monocular lines, which were placed at the same physical horizontal position in the two disparate areas, were presented to the left eye. The binocular disparity between the two rectangular areas was varied. Eight observers reported the extent of perceived depth between the two lines before moving their heads, and the extent of perceived concomitant motion of each line while moving their heads (20 cm). We found that (i) the extent of perceived depth between the two lines covaried with the binocular disparity, and (ii) the extent of perceived concomitant

motion of the two lines and that of the rectangular areas also covaried with the binocular disparity. These results are consistent with the idea that the visual system can treat a monocular line as a part of its surrounding binocular area (Shimono and Wade, 2002 *Vision Research* **42** 1127–1135) and the apparent motion can be explained by Gogel's (1990 *Perception & Psychophysics* **48** 105–123) phenomenal geometry.

◆ **The influence of binocular temporal offsets on visual sensitivities**

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Recent neurophysiological data suggest that some binocular neurons are sensitive to both spatial (disparity) and temporal (motion) offsets between the two eyes. Human psychophysics was used to determine whether temporal offsets in binocular stimulus presentation increase noise in stimulus encoding, thus reducing sensitivity. Vernier acuity and stereo acuity were compared, on the assumption that temporal offsets would worsen disparity discrimination, whilst leaving Vernier acuity unaffected. The effects of temporal offsets were examined by measuring discrimination thresholds under four target presentation conditions: continuous (stimulus presented continuously to both eyes for 10 frames/100 ms); alternating (asynchronous binocular presentation for 10 frames; 5 frames per eye); blanking (synchronous binocular presentation, but alternation with a blank screen; 5 frames per eye); and half-continuous (stimulus presented to both eyes for 5 frames). Observers judged whether a target line (45 min of arc \times 5 min of arc) was left/right or in-front/behind the fixation cross. Sensitivity (the slope of the psychometric function) was affected by experimental condition, with best performance obtained under continuous presentation. However, no differences were evident between the other three conditions. Further, the pattern of results was the same for Vernier and stereo acuity, suggesting that these results reflect the contrast reduction of temporally interleaved stimuli, rather than effects of temporal offsets per se.

◆ **The perception of stereoscopic motion in the presence of the 3-D aperture problem**

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Local measurements of 3-D translational motion of a planar surface can be ambiguous when they are done on 1-D features such as lines. This is a 3-D version of the aperture problem, leading to 1-D ambiguity as to the 3-D motion direction. Here, we report the perception of stereoscopic 3-D motion in the presence of the 3-D aperture problem. We found that, (i) when a horizontally inclined plane consisting of vertical lines was moving upward or downward behind an aperture, observers perceived the plane as moving almost toward or away from them; (ii) when the plane was composed of oblique lines and underwent the same motion, observers did not perceive the plane as moving in space, but perceived the oblique lines as sliding on the stationary plane. Taking into account that only the former condition gives rise to a pattern of image expansion or contraction, we argue that such a monocular cue to motion in depth can have a decisive effect on the perceived direction of stereoscopic 3-D motion, and even dominate over the stereoscopic motion-in-depth information in the presence of the 3-D aperture problem.

◆ **Does the detection of surface deformations result from global or local processing of disparity gradient?**

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Perception of slanted and inclined surfaces depends on global, rather than local, processing of the relative-shear disparities (Howard and Kaneko, 1994 *Vision Research* **34** 2505–2517). In earlier work, Graham and Rogers (1982 *Perception* **11** 262–277) studied depth contrast between surfaces and suggested that gradient contrast was more powerful than local disparity in binocular stereopsis. As regards depth 'attraction' and 'repulsion' phenomena, depth interactions have been shown between two closely adjacent points, depending on eccentricity (Westheimer and Levi, 1987 *Vision Research* **27** 1361–1368). In order to investigate the difference between local and global processing of disparities in perceived depth (Glennerster et al, 2002 *Current Biology* **12** 825–828), we measured detection thresholds of surface deformation as a function of disparity gradient, depending on the location of this gradient in the visual field. Continuous horizontal disparity variations were simulated by means of stereoscopic stimuli which consisted of randomly distributed open circles and whose binocular disparities increased linearly with eccentricity from a given eccentricity. We showed that thresholds of deformation detection depend on the disparity gradient and eccentricity at the beginning of disparity variation. Results are discussed in terms of depth contrast scaled in reference to averaged disparity and processing of disparities in deformation detection.

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- ◆ **Interocular stability of eye movements during visual-fixation tasks in 2-D and 3-D stereo surfaces**
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Fixation performance was compared in fifteen subjects for conditions of 2-D perspective and 3-D stereoscopic target presentation. Movements of both eyes were recorded simultaneously with unrestrained head (EyeLink system), for fixations of up to 100 s. Task 1 required ten acoustically timed fixations of 10 s on targets at different 2-D locations. Task 2 required binocular fusion of centrally located stereo targets presented in crossed (near) and uncrossed (far) disparity. In both tasks, accurate fixation persisted only for 2–4 s. In task 1, accumulative effects of binocular diverging drifts occurred with fixation changes from near to far; return of fixation to the nearest target was accompanied by a significant drift correction. Fixation accuracy to the nearest target was higher than to the farthest, despite higher acuity demands of the latter, implying a cognitive mechanism of depth perception. In task 2, vergence initially fluctuated until a proper disparity (sufficient image fusion) was achieved. Then, diverging drifts occurred which were larger with crossed than uncrossed disparities. In both cases, the dominant eye [demonstrated to be more stable in fixating at 2-D targets by Ehrenstein and Wagner (2004 *Perception* 33 Supplement, this issue) showed higher fluctuations, being more active in vergence corrections than the fellow eye.

- ◆ **Eye dominance and interocular stability of oculomotor behaviour during fixation on 2-D surface for restrained and unrestrained head postures**

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The relative stability of binocular eye movements was studied in left-eyed and right-eyed subjects during straight-ahead fixation onto a frontoparallel 2-D display. Movements of both eyes were recorded simultaneously (EyeLink system) for fixation periods of 60 s with head postures restrained (chin-and-head rest) or unrestrained. A sighting task (card test) served to select seven left-eyed and seven right-eyed subjects (matched for age and gender). In addition, binocular balance was examined by Shapiro's test of cortical balance and fixation; and visual acuity was controlled by testing line separation. Restrained and unrestrained head conditions yielded similar results, with overall less oculomotor variability for unrestrained heads. Accuracy of fixation was maintained for only 2–5 s, followed by diverging drifts of up to 3 deg. In all subjects, divergence was asymmetric, ie one eye was more accurate and stable than the other. The more stable eye matched the sighting-dominant eye in 9 subjects (out of 14; 2 undecided, 3 counter cases); Shapiro's test of eye dominance yielded an even closer relation to oculomotor stability (11 positive cases). Thus, eye dominance is related to oculomotor stability during prolonged fixation and might be essential in maintaining the direction of the visual straight-ahead.

- ◆ **A global slant mechanism as revealed by stereoscopic slant aftereffects**

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To clarify whether stereoscopic slant aftereffects are dependent on retinal position, we compared the magnitudes of the aftereffects between two conditions. In the overlapped condition, the adaptation and test stimuli were presented in the same retinal location, whereas in the separated condition, stimuli were presented in different retinal locations. After 2 min adaptation to a random-dot stereogram depicting a 30° slanted surface, observers were required to adjust the test stimulus so that it appeared to them as frontoparallel. Two stimulus configurations were tested. In one condition, disc-shaped or ring-shaped stereograms were presented at the central or peripheral visual fields. In the other condition, rectangular stereograms were presented at the upper or lower visual fields. The magnitudes of the aftereffects were measured as the difference of adjusted slant before and after adaptation. Results revealed no significant difference between overlapped and separated conditions. Moreover, neither the stimulus configurations nor the separation between the adaptation and test stimuli in the separated condition (which varied between 0.5 and 20 deg) were important factors affecting the aftereffects. These results suggest that our slant perception is mediated by a global mechanism covering at least 20 deg of the visual field.

◆ **The effect of visual angle on the perception of planes in depth**

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Deformation of visual space has often been described in the literature; however, this deformation seems dependent on the task that is given to observers. That is why we developed a 3-D task in which three balls, hanging from the ceiling, represented a plane in physical space. The task was to change the height of a fourth ball (the test ball) to make it lie in the plane. We varied the offset and the slant of the plane, and the distance of the observer to the test ball, in such a way that the visual angle varied from 47 to 141 deg in the horizontal plane. We were interested whether the necessity of making head movements (in the 141 deg position) would increase the variance and/or the systematic deviations of the settings of the observers. We indeed found structural deviations from veridical settings. The slant and the tilt of the plane clearly influenced the settings of the observers. However, neither the visual angle nor the height of the entire plane did result in any difference between the settings.

◆ **Oblique effect in a third dimension**

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Even though oblique effect has been an issue in the literature for a long time, it is still unclear whether some kind of performance superiority along major axes is also present in conditions in which a perceived direction results from re-scaling of object's retinal proportions. Our experiment was designed to compare sensitivity to different directions in the depth plane. Three wooden sticks were placed in front of observers in a variety of orientations at either near (2 m) or far (10 m) distance. The task was to place the third stick so that it perceptually matched the direction defined by the positions of the first two sticks. In the case of correct response, there were three collinear sticks. The principal finding is the increasing variety of responses as the target orientation gets farther from the distal direction. It is argued that observers based their judgments on perspective information. This informational source is easily available in distal orientations; its effectiveness, however, decreases toward frontal orientations. Our data do not suggest inferior sensitivity in cardinal directions, and such asymmetry has not been found in other experiments with similar 3-D direction-judgment tasks, such as collinearity, exocentric pointing, or apparent frontoparallels.

◆ **Noise in horizontal-disparity and vergence signals predicts systematic distortions in the estimation of shape**

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Systematic distortions in shape from stereopsis have been attributed to incorrect distance scaling (Johnston, 1991 *Vision Research* **31** 1351–1360). It has been shown previously that noise in early visual signals can predict both biases in three-dimensional structure from motion (Hogervorst and Eagle, 1998 *Proceedings of the Royal Society of London, Series B* **265** 1587–1593), and various forms of geometrical illusion (Fermüller and Malm, 2004 *Vision Research* **44** 727–749). Here, we investigated the role of noise in a maximum-likelihood-estimator (MLE) computer model of shape-from-horizontal disparity and vergence. Realistic estimates of noise in vergence and horizontal-disparity signals for human observers were entered into the MLE model. A psychophysical experiment was also performed, in which observers set the position of the central of three points of light, presented at eye height, so that its separation in depth from the other two points was equal to their horizontal separation. Depth was increasingly underestimated with increasing distance. These systematic distortions in the estimation of shape were predicted by the MLE model. The results demonstrate how distortions or biases in the perception of three-dimensional shape may represent a natural byproduct of 'optimal' processing given a noisy visual input.

◆ **The shape of perceived space**

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The aim of this research was to evaluate whether the elliptic shape of a perceived space is just a consequence of the unequal distribution of depth cues in the horizontal and vertical (fronto-parallel) planes. The experiment was conducted in a forest (uniform distribution of depth cues in both planes), on thirty subjects. Subjects estimated three distances from themselves to a circular marker hanging on a tree (4 m, 5 m, 6 m standards) from two positions: by standing (vertical standards) and lying (horizontal standards). The researcher stood in front of a subject, holding another circle, which was hanging on a rope parallel to the ground. The subjects were asked to

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estimate the distances of the standards, and to guide the researcher to put his circle at about the same distance from them. All individual estimates were significantly different from the standards, and the estimates in the horizontal plane were significantly larger than the estimates in the vertical plane. According to these results, and considering the fact that the distribution of the depth cues in the horizontal and vertical planes was equal, we can conclude that the model of perceptual space has a specific elliptic shape.

◆ **Redundancy in natural binocular images**

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A major source of redundancy in natural images is the similarity between the left-eye and the right-eye images for a binocular viewer. This redundancy was investigated by analysing the statistics of pairs of pixels drawn from either monocular or binocular images. Joint probability functions were formed for pairs of pixels as a function of their spatial separation. Monocular pixel pairs showed a high degree of redundancy. Mutual information was high for adjacent pixels, and reduced as the separation between the pair increased. When each pixel was drawn from a different member of a binocular image pair, mutual information was lower for nearby pixels than for monocular images, and fell off more gradually with increasing separation. This may be attributed to the effects of binocular disparity. Further, for binocular pairs mutual information depended on image location, being higher and falling off more sharply with separation, for points near fixation. This may be related to the fact that disparity is likely to be smaller for central than for peripheral image locations. It is concluded that two-pixel statistics are useful for understanding the redundancy in binocular images, and the distributions of disparities they contain.

◆ **Volume perception of illusory object with binocular viewing**

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We reported earlier that a binocularly unpaired region plays an essential role in the perception of volume of a solid object (Idesawa, 1991 *Japanese Journal of Applied Physics* **30** L751–L754). In our earlier studies, we investigated volume perception (i) using half-moon-shaped textured cylindrical objects (Idesawa, 1997 *Perception* **26** Supplement, 40) and (ii) using a computer-generated stereogram of a cylindrical object with texture (Watanabe and Idesawa, 2001 *Japanese Journal of Applied Physics* **40** L958–L960). A rectangular probe was used to investigate the position in depth where subjects felt that it just touched the object. In both experiments, the detected positions were systematically behind objects with unpaired regions, while they were almost correct for objects without unpaired regions. In the present study, we investigated volume perception using illusory cylindrical objects without texture. A rectangular probe was displayed at different depths in random order, and subjects were asked whether the probe was penetrating the object or not. We found that 50% of penetration responses with unpaired regions were systematically reporting greater depth than those without unpaired regions. Thus, the contribution of binocularly unpaired regions for volume perception was demonstrated in the case of illusory objects without texture.

◆ **Spatial discrimination of illusory contours in depth**

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An illusory occluding contour in depth appears when several lines of irregular orientation and length are terminated by a vertical cut in slightly different lateral positions in the two eyes, consistent with partial occlusion by a near surface (valid occlusion). When the images presented to the two eyes are reversed, the direction of lateral disparity is no longer consistent with occlusion. The lines appear aligned at the cut but without an illusory contour (invalid occlusion). We measured stereoscopic and orientation discrimination thresholds, using the method of constant stimuli, for the contour along the aligned terminators for the above conditions with a line along the cuts in both eyes. Orientation discrimination was also tested for conditions with zero disparity at the cuts. Monocular information and disparity magnitudes were equivalent in the valid and invalid conditions, except for the change in sign. Stereo thresholds were lower in the valid occlusion condition than in the invalid. Orientation thresholds were initially lower in the valid than in the invalid and zero stereo conditions, but these differences reduced with practice. Stereo and orientation thresholds were lowest with a line along the contour. Scene layout analysis rather than image processing determines stereo discrimination thresholds for these stimuli.

◆ **Factors of perceptual rigidity in the interaction between illusory surfaces**

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We reported earlier that perceptual distortion phenomena were observed in the interaction between two crossed illusory rectangular surfaces (45° and 135° orientations in different depth) with binocular viewing and the distortions were systematically induced in the illusory rectangle with longer interpolation span and shorter supporting-edge length (Zhang and Idesawa, 2003 *Perception* **32** Supplement, 80). Here, we investigated the distortion phenomena by modifying one of the following factors: interpolation span (IS), supporting-edge length (SL), and width of illusory rectangle (W). The results showed that the illusory rectangle with longer SL or with narrower W was harder to distort, while the illusory rectangle with longer IS or with wider W was easier to distort. We then defined a 'rigidity-factor' which was the ratio of SL to the area of the illusory rectangular surface; and verified that distortions were easier to observe on an illusory rectangular surface with smaller rigidity factor. We conclude that the rigidity factor is suitable for representing distortion phenomena induced by the interaction between illusory surfaces.

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◆ **Effects of attention on slant aftereffects in bistable stereoscopic depth perception**

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A promising way to study conscious perception is to expose the visual system to an ambiguous stimulus that generates bistable perception. This provides the opportunity to study neural underpinnings related to the percepts rather than to the stimulus. We studied slant aftereffects in perceptual bistability. We exposed the visual system to a stimulus in which binocular disparity and monocular perspective can specify conflicting surface slants. This stimulus instigates bistable surface slant perception that depends on the disparity–perspective conflict (van Ee et al, 2002 *Journal of Vision* **2** 597–607). We asked subjects to attempt to hold one of the two alternative percepts. To stabilise the percepts in the adaptation phase, we used periodic stimulus removal (Leopold et al, 2002 *Nature Neuroscience* **5** 605–609). Using a nulling technique, we measured whether the slant aftereffect depended on the voluntarily selected percept. The test stimuli were composed of (i) disparity cues, or (ii) monocular perspective cues. We found that there is a distinct effect of attention on the slant aftereffects. Aftereffects measured with disparity cues only, as opposed to perspective cues only, differ greatly and most of them are of the opposite sign.

◆ **Eye-dominance distributions differ between men and women**

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Distributions of eye dominance were assessed together with handedness in a representative sample of 1939 men and 1394 women (matched for age: means 23.5 versus 22.3 years) by a German adaptation (<http://www.ergonetz.de/lateralitaet>) of Coren's inventory (Coren, 1993 *Bulletin of the Psychonomic Society* **31** 1–3). Eye-dominance distributions differed between men and women ($p < 0.05$), with a stronger left-eye preference for women (19.8% versus 16.2%) and stronger right-eye preference for men (68.3% versus 66.2%), respectively, and little difference in the remaining percentages (ambivalent or mildly lateralised). Right-handedness prevailed slightly in females (92% versus 90.1%). Since Coren (1993) found only a (non-significant) tendency for a stronger right-eye preference in males, we checked for a possible right-hand bias on eyedness by comparing eye-dominance distributions only for right-handers: In fact, a slight increase in right-eye (and decrease in left-eye) preferences resulted; the respective sex differences, however, persisted (right-eyed: 71.7% versus 69.4%; left-eyed: 16.6% versus 12.7%; $p < 0.05$). Our results are compatible with findings that sex hormones modify visuospatial abilities (Hausmann et al, 2000 *Behavioral Neuroscience* **114** 1245–1250) with men relying more on left-hemisphere processing than women when engaged in visuospatial tasks (Parsons et al, 2004 *Neuropsychologia* **42** 555–562).

◆ **Functional relation between dominance phase and suppression phase in binocular rivalry**

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Earlier works reported evidence that dominance and suppression in binocular rivalry might not be the two sides of a coin. An increase in the strength of a rivalry stimulus (eg enhancing contrast) makes the stimulus more predominant by a decrease in the duration of its suppression, while the introduction of a global context outside the rivalry region makes the rivalry stimulus

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in the context more predominant by an increase in the duration of its dominance. To investigate the assumption of independence (absence of interaction) of the two processes modulating the dominance and suppression phases in binocular rivalry, we tested the effects of stimulus strength and context in a factorial way in two experiments. As the context, we used moving grating patterns and collinear static Gabor patches in the first and second experiment, respectively. We found that the independence hypothesis in earlier works on dominance and suppression phases was supported only when the level of stimulus contrast was high, giving rise to inconsistent results, ie a significant reduction of suppression duration as the context level went up when the contrast level was low. This aspect of divergence from the independence hypothesis was more salient when a static context stimulus was used.

◆ **Quantitative perceived depth from sequential monocular decamouflage**

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We present a novel stimulus without conventional disparity cues whose perceived depth varies systematically with the relative positions of its vertical edges in the right and left eyes, which were revealed sequentially (delay 80–240 ms). A stationary black rectangle was presented in depth either camouflaged against (crossed disparity case), or occluded by (uncrossed) a uniform black field to render it invisible. A small white vertical feature oscillated horizontally at zero disparity (relative to stationary dots which covered the upper and lower sections of the black field), in order to reveal a section of the black rectangle. This corresponds to either the sequential monocular decamouflage of the black rectangle by the occlusion of a white vertical bar disappearing behind the black rectangle (crossed), or the disocclusion of the black rectangle, appearing on a white background seen through a vertical aperture (uncrossed). Subjects set the depth of a probe to the perceived depth of the black rectangle. Settings showed a significant monotonic increase as a function of disparity for crossed stimuli ($p < 0.01$). However, for uncrossed stimuli, few subjects perceived a distant object partially visible through an aperture, making erratic settings. We conclude that sequential monocular decamouflage can be an effective stereoscopic cue to depth.

◆ **The influence of eye movements on stereopsis**

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The region of coded stimuli in random-dot stereograms (RDSs) can be shifted only in one part of stereogram (type 1) or in both image parts (type 2). We propose that, if observer actively uses eye movements for stereopsis, then upper cyclopean disparity limits (UCDL) for stimuli type 1 and type 2 will be equal owing to motor fusion ($UCDL1 = UCDL2$). Otherwise $UCDL1$ will be twice $UCDL2$. We tested this assumption on seven observers (five males and two females, aged 24 to 54 years). The measurements were made by a staircase method with unlimited presentation time. The RDSs (12 in \times 15 in) with a coded rectangle with uncrossed disparity (3 in \times 6 in) were viewed through liquid-crystal shutters from a distance of 80 cm. For six observers $UCDL1$ was approximately twice $UCDL2$ (2.06 ± 0.31). For one observer $UCDL1$ and $UCDL2$ were approximately equal (0.98 ± 0.12). We conclude that for most observers eye movements do not influence UCDL. But in some cases the motor component of fusion has to be taken into account.

◆ **Perceptual attributes of crosstalk in 3-D TV**

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Crosstalk, the leakage of light between the left and right eye view, is an important issue in (auto)stereoscopic displays. We studied the effect of different crosstalk levels in combination with varying camera-base distances on perceptually relevant attributes such as overall impairment, perceived image distortions (eg double edges, blur), perceived depth, and visual strain. In an experiment, two natural scenes were used, varying in crosstalk (four levels: 0%, 5%, 10%, and 15%) and depth (three different camera-base distances: 0 cm, 4 cm, and 12 cm). We applied the single-stimulus method for subjective testing according to the ITU 500-10 recommendations. Subjects were asked to assess the attributes on a 5-point numerical scale. Perceived depth and visual strain increased with increasing camera-base distance but were unaffected by the different levels of crosstalk. On the other hand, increasing crosstalk level as well as camera-base distance resulted in increased ratings of image distortions and overall impairment. Comparing the results of the two scenes, the perceived image distortions due to crosstalk strongly depend on the scene content. In summary, increasing crosstalk levels affected the overall impairment and perceived image distortions but had no effect on perceived depth and visual strain.

◆ **Seeing beyond the third dimension**

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It is believed that our visual perception is tuned to deal with relations up to a 3-D space (Shepard, 1994 *Psychonomic Bulletin & Review* **1** 2–28). If this were not true, the main consequence would be that our faculty to deal with abstract relationships is not specific of thinking and is already present in perception. We tried to address this issue by exploiting the kinetic depth effect, a case in which the visual system extracts the 3-D metrics of the space from a simple 2-D presentation. We explored an extension of this phenomenon presenting 4 dots, the vertices of pyramids, rotating in a 4-D space. If the visual system were perfectly tuned to the metrics of the 3-D space, the perception of these stimuli would be of a non-rigid object. Our results show that half of the times the presentation of an object rotating in a dimension higher than the third results in the perception of something rigid. This cannot be explained if it is assumed that our visual machinery has evolved to cope with a 3-D Euclidean environment, so confining vision research to a 3-D space may be based on some unwarranted assumptions.

BIOLOGICAL MOTION

◆ **Effects of phase differences between a point-light walker and scrambled walker mask**

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A 'scrambled walker mask' consists of position-scrambled dots that mimic the motion corresponding to the walker's joints (Cutting et al, 1988 *Perception & Psychophysics* **44** 339–347). This mask was assumed to effectively interrupt the local motion processes, such as local rigidity, in perceiving the point-light walker (Thornton et al, 1998 *Cognitive Neuropsychology* **15** 535–552). We investigated the effects of global phase information between the point-light walker ('walker') and the scrambled walker mask ('mask') on discriminating the walker's direction. In the experiment, the 'walker' was displayed in the centre of the screen superimposed by 52 dots of the 'mask'. The phase of the mask was shifted by 0° (in phase with the walker), 45°, 90°, 135°, and 180° (completely out of phase). Observers were instructed to determine the direction of the walker. As a result, performances of the observers increased considerably with increasing phase differences, and reached a peak at 135°. However, when the phase difference was 180°, their performances fell down to almost the same level as at 0°. These results suggested that global grouping effects of moving dots by phase differences facilitated the processing of local rigidity and local motion analyses.

◆ **Recognising famous gaits**

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We are currently developing a semi-automatic system for the reconstruction of 3-D human movement data from complex natural scenes, such as movie clips. As part of this project we have collected a database of walking patterns from twenty well-known male actors. The goal of this initial study was to assess whether isolated 2-D motion cues (point-light walkers created via manual tagging) could provide sufficient information for the recognition of famous gaits. Previous research has indicated that familiar individuals (eg work colleagues) can be recognised as point-light figures. Does memory for famous individuals also include characteristic movement patterns? Observers were shown point-light animations depicting several step-cycles from different actors, filmed from approximately 3/4 view. As the animations were extracted from commercial footage, exact camera position, gait cycle (eg number of repeated steps), and extraneous behaviours (eg additional hand movements) could not be controlled. Animations were, however, approximately normalised for size, and the global translation cues were removed. Using both a direct 6-alternative face-to-gait matching test and a standard 2-alternative forced-choice task, we found levels of performance that did not differ from chance. Item analysis revealed that neither self-reported familiarity with the actors nor confidence ratings provided accurate predictors of performance.

◆ **Children's perception of emotion from point-light displays**

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Point-light displays, which capture and present the movements of two actors engaged in a dialogue in only 26 points of light, are sufficient for adults to judge the emotion expressed in the non-verbal behaviour of the actors (Clarke et al *Perception* in press). The purpose of the present study is to determine whether children can also perceive the emotion expressed in such displays. Fifty-four children, 5, 7, or 9 years old, completed a binary-choice task where they were asked to

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indicate which of two simultaneously presented point-light figures expressed one of four possible emotions: anger, joy, sadness, or fear. The results showed that the 7-year-olds and 9-year-olds could correctly identify all four emotions, whereas the 5-year-olds could identify joy and fear readily, but had severe difficulty with anger, and failed to identify sadness above the level of chance. Thus, children as young as 5 years are able to identify some emotions in point-light displays and this ability improves rapidly with age to near-adult levels by the age of 7 years.

◆ **Temporal characteristics of neuronal sources for implied motion perception**

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Viewing photographs of objects in motion evokes higher fMRI activation in human MT+ than similar photographs without this implied motion. MT+ is traditionally considered to be involved in motion perception. Therefore, this finding suggests feedback from object-recognition areas to MT+. To investigate this hypothesis, we measured EEG, which provides information on the involvement of different brain areas over time. Pictures of biological agents with and without implied motion, and random-dot patterns (stationary, coherently moving, and flickering) were displayed. The difference potential between responses to pictures with and without implied motion was maximal at 260 to 320 ms after stimulus onset. Source analysis of this difference revealed one bilateral, symmetric dipole pair in the border region of the occipital-temporal-parietal lobe. In contrast, differences between the three types of random-dot patterns occurred from 100 ms onwards, and corresponded to cascades of dipole activation in a larger area, including that activated by implied motion. Latencies of the implied motion activations are consistent with a feedback projection onto MT+ following object recognition in higher-level temporal areas.

◆ **Dynamic model of form-based biological-motion recognition**

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Last year (Lange and Lappe, 2003 *Perception* 32 Supplement, 34) we presented a model for the recognition of biological motion which focused on form information exclusively. The model used static postures extracted from a walking sequence of a human person, and matched incoming static frames of the stimulus to these templates. Despite its simplicity, the model matched data of psychophysical experiments very accurately, revealing the importance of form information. We improved this model in two major aspects. We used a neurally inspired approach by assuming Gaussian response function for the model's templates. This idea led to an improvement when comparing the model's behaviour to humans for short stimulus durations. We extended the model from its simple static to a dynamic form analysis. The templates were modeled as leaky-integrator neurons providing spatiotemporal profiles. These neurally plausible advancements repeated the good results of our simple static model while improving the similarities between model and humans for short presentation times of the stimulus. We compared our model to experiments which need spatiotemporal integration such as using interstimulus intervals. We found more evidence for the idea that perception of biological motion is possible as a process of dynamic form analysis rather than a structure-from-motion phenomenon.

◆ **Hemifield asymmetry for the perception of biological motion**

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Perception of biological motion is the ability to see a moving human or animal even from white dots marking locations on an invisible moving body. Areas in the parietal, temporal, and pre-motor cortex, as well as in the cerebellum respond to biological motion. Some of these areas (for example the STSp) respond most strongly in the right hemisphere, whereas others are not lateralised. Also, many visual cortical areas represent only visual information from the contralateral visual hemifield. The goal of our experiments was to look for hemifield asymmetries in the perception of biological motion. Subjects judged the orientation of a point-light walker centred at 0°, 10°, or 20° from the fixation point. The ones oriented away from the fixation point were perceived much better than the ones oriented inwards. Control experiments showed that this result was not due to a response bias, or to the back of a walking person being recognised easier. The effect was still present for stationary presentations of the stimulus. As the asymmetry has no biological relevance,

we propose that it must result from an asymmetric representation in the cortex, for example that rightward walking is represented in the left premotor cortex and vice versa.

◆ **Perceptual animacy in schematic motion events**

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Non-rigid motion is often seen as a cue to animacy. As Michotte, we used the perception of non-rigid schematic motion in the absence of animate shape cues. We used computer-animated squares engaged in a caterpillar motion [Michotte 1963 *The Perception of Causality* (London: Methuen)], involving non-rigid expansion/contraction plus translation across the screen. We factorially varied the rate of forward motion, the rate at which the square expanded/contracted, and whether expansion and translation were in the same direction or perpendicular to each other. Seventy observers rated the extent to which the resulting motion looked animal-like. Ratings for stimuli expanding/contracting and translating in the same direction depended on the specific configuration: ratings were highest when the rate of expansion equalled the rate of translation, confirming Michotte's view. When the direction of expansion/contraction was perpendicular to the direction of translation, however, ratings were lower and independent of the configuration, with only a small effect of the rate of expansion. Thus, we found a separation between two groups of stimuli with identical amounts of non-rigid deformation. Clearly, not all non-rigid motions appear animate. This does not depend on the amount of non-rigidity, but on the motion configuration. It would seem promising to consider the idea of perceptual templates for animacy further.

◆ **Failure to automate the semantic processing of social cues in autism**

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Typical people interpret the social signals by which they are daily bombarded in a seemingly effortless fashion. This capacity is, however, quite complex, and may be compromised in autism. To investigate the extent to which social stimuli are processed automatically by autistic and typical participants, we used a new distance-judgment task. The task required a contemplative judgment of spatial distances between social cartoon figures. The social stimuli conveyed by the cartoons were social attention and implied biological motion. The social cues themselves did not need to be analysed in order to correctly perform the task. Therefore, a response bias congruent with the social cues was taken to reflect their automatic, semantic, processing. Low-level and high-level illusions affected the responses. Both typical and autistic participants were significantly influenced by a perceptual low-level illusion induced by the mass distribution of the stimuli. In contrast, only the typical, and not the autistic, participants were influenced by the high-level illusion, induced by the implications of the social stimuli. We conclude that the semantic processing of social stimuli in autistic participants is not automated, which causes their performance on the current task to be superior to that of typical people.

CHANGE DETECTION

◆ **The selective benefits of colour in the detection of changes in naturalistic scenes**

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Previous experiments have shown a benefit for colour over black-and-white naturalistic scenes in a recognition-memory paradigm (Wichmann et al, 2002 *Journal of Experimental Psychology: Learning, Memory and Cognition* **28** 509–519). The current study sought to determine whether this benefit for colour extends to the more direct visual task of change detection. Participants viewed displays of rapidly alternating 'original' and 'modified' scenes interspersed with blank fields (Rensink et al, 1997 *Psychological Science* **8** 368–373). The scene changes were either central to the theme of the picture (CI) or incidental (MI). This classification was conducted prior to testing. For each participant half the stimuli were colour and half were black-and-white, and were presented in a random order. We found that fewer scene alternations were required to detect changes for CI than MI and that scene changes were detected faster in colour than in black-and-white. However, there was a significant interaction between scene chromaticity and thematic content. An effect shown in memory tasks now extends to 'change detection', but with a key distinction between the class of change affected. We suggest that the colour-CI benefit emerges from the processing stream proceeding to IT cortex.

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- ◆ **Temporal requirements for configuration, switch, and shape-change detection in novel objects**
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While we are surprisingly poor at detecting changes in our visual environment, some changes appear to be detected more readily than others. Specifically, changes to the configuration of an object's parts are detected more often than changes involving the shape or switching of parts. The aim of this study was to ascertain the minimum amount of time required to adequately process each of these different types of object changes. Using both one-shot and flicker-change-detection paradigms, we manipulated the duration of each stimulus exposure (40–500 ms, mask duration constant at 160 ms). We found that, at 40 ms stimulus duration, change detection accuracy was close to chance in the one-shot task, but was significantly above chance in the flicker task. For both tasks, and at longer stimulus durations, configuration changes were always detected more accurately than shape changes. Stimulus repetition in the flicker task provided little additional benefit to configuration-change detection. While configuration changes tended to be detected more accurately than switch changes in the one-shot task, no difference between the two was found in the flicker task. These findings suggest that at shorter stimulus durations memory consolidation is needed to accurately detect switch changes.

- ◆ **Effect of goals of cognitive activity on change detection in scenes: Visual representations evolve with goals of task**

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Though change-blindness experiments revealed visual representations of scenes included information about the attended object with an abstract scene schema, they did not explore how visual representations could evolve with cognitive activity. With a change blindness experiment joined to a problem-solving task, we examined observer's ability to report changes on visual scenes while they performed a problem-solving task. In this task, observers had to move a car on a city map displayed on screen, and reached specific sub-goal stages, to achieve the final goal. We assumed that changing the same stage at different moments of the task should have different effects on change detection. As expected, observers reported only changes occurring to the current sub-goal stage with no detection of changes occurring to immediately task-irrelevant stages, even though these changes concerned further relevant stages for the overall problem solving. Moreover, change detection depended on the type of change: stage deletions were more accurately detected than stage displacements. These results suggest that (i) visual representations are basically functional and progressively vary together with task requirements, (ii) the visual system extracts the information just sufficient to solve the current goal from the visual scene, and (iii) change blindness does not result from comparison blindness.

- ◆ **The effect of gist change in image recognition**

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Since the gist of a scene is very quickly processed (Potter, 1975 *Science* **187** 965–966) and is preserved in memory (Simons and Levin, 1997 *Trends in Cognitive Sciences* **1** 261–267), it is likely to be used in detecting changes between images. We therefore expected changes altering the gist of an image to be detected faster and more accurately than changes not altering the gist, even when those changes affect a larger area of the image. A change in gist can be generated by, for instance, adding Dracula teeth to the man of a loving couple. Swapping the hair colour of the couple can generate a change that does not alter the gist. We tested this in an experiment in which participants had to indicate as quickly and accurately as possible whether an image was exactly the same as an image seen in a study phase. The effect of gist on change detection was tested on twenty-four participants who viewed 10 images in the study phase. In the test phase they made 60 same/different decisions. The alterations in gist were detected significantly faster and more accurately. This suggests that gist is one of the first things used for image recognition.

- ◆ **Category effects on implicit-change detection**

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Although observers are often very poor at reporting changes to their visual environment, such changes could be processed by the visual system in the absence of awareness and can affect the subsequent behaviour. In two experiments, we found that, after an image change, observers

performed differently in a task unrelated to change detection, depending on the level of awareness for the change. When observers were aware of the change, the changed item (target) was preferred in the unrelated task to the unchanged item (filter). When observers were unaware of the change, the filler was preferred to the target. Furthermore, in absence of awareness, orientation and colour changes had different perceptual consequences, depending on the semantic properties of the changed items. For orientation changes, we found that a scene transformation that is irrelevant for object recognition (orientation changes for unplaced objects) triggers a response inhibition for the changed item. The exact opposite occurs for colour changes. In that case, a scene transformation that is irrelevant for object recognition (consistent colour change for common objects) produces a response activation, whereas a scene transformation that may hinder object recognition (inconsistent colour change for vegetables) produces a response inhibition.

◆ **Which kind of informativeness map can predict the change detection performance?**

F Bracco, G Spinelli, C Chiorri (Department of Anthropological Sciences, Psychology Unit, University of Genoa, vico S Antonio 5/7, I 16126 Genoa, Italy; e-mail: bracco@nous.unige.it) Among the factors that give rise to the 'change blindness' phenomenon, we wanted to investigate the influence of the informativeness of changing elements on change-detection time. In order to generate an informativeness map of natural scenes, we developed five different methods derived from other experiments on change blindness (Rensink et al, 1997 *Psychological Science* **8** 368–373), scene perception (Antes, 1974 *Journal of Experimental Psychology* **103** 62–70) and scene memory (Holšánová, 2001 "Picture viewing and picture description", in *Lund University Cognitive Studies* page 83). Our purpose was to compare such methods and the maps they produced on the basis of their capability to predict the observer's representation of a natural scene. Second, we wanted to determine the extent to which each map could predict the performance in a change-detection task. We hypothesised that, if an observer would include an element in an informativeness map, he would detect the change of that element in a change-detection task. Conversely, if the element was absent from the map, it would go undetected. Our findings show that not all the methods are predictive of the change-detection performance and we discuss the implications for scene representation and memory.

FACE PERCEPTION

◆ **Face recognition is not template-based**

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In the field of face perception and face representation there are rival theories how faces are encoded, stored, and recognised. On the one hand, template-based and holistic approaches assume that faces are encoded and represented in a kind of template or holistic entities retaining all global configural information. On the other side, local approaches postulate the representation of only local information, such as cardinal features (eg eyes, mouth, nose) or local-configural properties, but not of larger configurations. Subjects had to evaluate fully presented familiar faces (FULL) and familiar faces that consisted only of cardinal features and their global spatial relations (PART) as regards their configural veridicality in a memory task. Even slight alterations to the global configuration were detected quickly and accurately in FULL faces, but not in PART faces. Furthermore, this dissociation was also found for the same material in a simultaneous matching task, which indicates that already the encoding of global face configurations was not possible. Therefore, faces seem to be encoded and represented mainly by means of their cardinal features and their micro configurations, but not on the basis of face templates.

◆ **Recognition of one's own face viewed from a variety of viewpoints**

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Some studies indicate that one's own face is recognised more quickly than both strangers' and familiar faces (eg Troje and Kersten, 1999 *Perception* **28** 483–487). Here, the effects of depth rotation on the recognition for one's own face have been investigated. Stimuli consisted of three levels of familiarity (unfamiliar, familiar, and the subject's own face), and five head angles (0°, the frontal view; 45°; 90°, the profile view; 135°; and 180°, view of the back of the head). Subjects identified the familiarity of each head by pressing one of three buttons when the stimulus was presented randomly. Results showed that the response time (RT) for the subject's own face was faster than that for unfamiliar and familiar faces. As for the subject's own face, the frontal view and the profile view were identified more quickly than the view of the back of the head. RT for unfamiliar faces slowed linearly as head angles changed from the frontal view to view of the back of the head, whereas there were no significant differences in RT for

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recognition of five head angles in the case of familiar faces. These results suggest that levels of familiarity may affect recognition for different views rotated in depth.

◆ **Familiar faces are perceived categorically only when upright**

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We investigated whether the categorical perception (CP) of upright familiar face continua (Beale and Keil, 1995 *Cognition* 57 217–239) survives inversion. CP is said to occur when a physical stimulus continuum is perceptually partitioned into discrete regions separated by sharp boundaries. Such a segmentation can be inferred from the presence of a boundary effect, ie from the better discrimination of between-category pairs of stimuli than of equally spaced within-category pairs. An identity morph continuum was generated by blending the faces of two UK celebrities. Upright and inverted morphs were presented to observers who were familiar with the continuum endpoints. Two paradigms were used: an X–AB discrimination task paired with an identification task and an odd-one-out task, in which the observer selects the most dissimilar from a triad of physically equidistant morphs. In the X–AB task, observers showed improved discrimination only for the upright straddling-the-boundary pairs of stimuli. In the odd-one-out task, choice patterns were strongly biased in favour of the stimulus falling across the boundary only when the triads were presented upright. Our results suggest that the processing of facial configural information, here impaired by inversion, is a prerequisite for observing CP.

◆ **The relationship between affective meanings and categorical judgments involved in the recognition of facial expressions of emotion**

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In our previous study (Watanabe et al, 2004, poster presented at the *First International Workshop: Exploring Social Drain* 11–13 March) participants were made to rate 6 series of 21 schematic faces morphed from one prototypical expression to another of 4 emotions (happiness, surprise, sadness, and anger) in terms of the affect grid technique (Russell et al, 1989 *Journal of Personality and Social Psychology* 57 493–502). Those 4 prototypical schematic facial expressions were the same as obtained in Yamada (1993 *Applied Cognitive Psychology* 7 257–270). In the present study, we used the same 118 faces as stimuli. However, we asked participants to make categorical judgments of the 4 emotions as above. The judgment data by each series were submitted to a probit regression analysis in which the distance of each stimulus from prototype expression in the two-dimensional space of affective meanings was calculated (Watanabe et al, 2004, loco cit.) as independent variable and frequencies of judgments on target category as dependent variable. Frequencies of judgments were significantly fitted to probit function of distances from prototype expressions. The results indicate that the distribution of frequencies judged for a category might be a normal distribution curve the centre of which is at the location of the prototypical expression in the two-dimensional space of affective meanings. Thus the categorical judgments of facial expression can be explained by the kind of the prototype matching model.

◆ **What makes faces look similar to each other?**

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Cabeza and Kato (2000 *Psychological Science* 11 429–433) demonstrated that, despite a widely accepted wholistic view of face processing, individual facial parts were encoded and stored well enough to influence face recognition. We investigated if and how such featural processing might influence the perceived similarity of faces. Forty participants were presented with pairs of faces at the rate of one pair per 2 s and asked to rate the perceived similarity of the pairs. Each pair consisted of either two distinctive or two typical faces whose facial parts were replaced with the same facial part that was either distinctive or typical. As expected, rating data showed that, regardless of the manipulated facial parts, pairs of faces were perceived to be more similar to each other when both faces were typical than when they were distinctive. However, when pairs of faces had a particular facial part in common, they were rated to be more similar to each other when the common facial part was distinctive rather than typical. The results suggest that we perceive greater similarity between faces that are similarly distinctive (rather than similarly typical) in one way or other.

◆ **Ignoring facial expressions of emotion**

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Recent research has questioned the common view that facial expressions are always processed. We used the face flanker task (Palermo and Rhodes, 2002 *Cognition* **82** 225–257) to examine whether the encoding of expressive face flankers is obligatory or whether participants are able to selectively attend to the target expression, ignoring the flankers. Participants ($n = 72$) judged whether target faces were angry or happy. The target faces were flanked by to-be-ignored faces that were either compatible (eg happy when the target was happy), incompatible (angry when the target was happy), or neutral (a neutral expression). We found interference (slowed performance on incompatible compared to neutral trials) when the majority of trials in the block were compatible, but not when the majority of trials were incompatible. The results suggest that participants were able to ignore the flankers when there was substantial incentive to do so, and challenge the idea that face processing is fully obligatory. In conclusion, despite the significance of expressive faces, they can be ignored under some circumstances.

◆ **Sensitivity to the temporal structure of facial expressions**

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We used a same–different task to investigate the human ability to discriminate facial expressions. Two groups of observers participated in the experiment, one evaluating upright and the other upside-down stimuli. Stimuli were movies portraying a face that changed from neutral to an emotional prototype (eg a smile) and back to neutral. In such natural events the peak corresponding to the prototypical expression was closer to the end of the interval. This temporal asymmetry allowed us to construct unnatural expressions by reversing the order of movie frames. Each group of observers participated in two sessions including 16 ‘different’ trials, in which a natural sequence was paired with a reversed sequence, and 16 ‘same’ trials. The ‘same’ trials varied according to the session and were a pair of either natural or reversed sequences. We used a 2×2 design with orientation as a between-subjects factor and naturalness as a within-subjects factor. A strong interaction effect was found. Performance with upside-down faces was unaffected by naturalness. Sensitivity to natural and to reversed changes of expression was equally poor when faces were upside-down, whereas it was clearly higher for natural changes of expression when faces were upright.

◆ **First-order and second-order configural influences on facial expressions**

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We investigated the influence of configural manipulations upon the perception of facial expressions. It has been proposed that facial-identity recognition is primarily influenced by second-order configural information. The influence of configural information on facial-expression recognition is less clear. With a technique of ‘eye-displacement’ it is possible to make large first-order changes whilst only minimally affecting second-order information; and make second-order changes whilst leaving first-order configuration intact (White, 2002 *Perception* **31** 675–682). In the present study, we extended previous work to include all six of the basic facial expressions of emotion. Participants were required to match unaltered faces with manipulated ones in a same–different task. Employing a between-subjects design, participants either matched the faces on the basis of the expression on the faces or the facial identity. Response latencies were longer for matching facial identity with two eyes moved compared to stimuli with one eye moved. This, however, was reversed for expressions with longer latencies in the one-eye-moved condition. These results support the view that facial-identity recognition is primarily influenced by second-order configural information. Further, they suggest that facial-expression recognition is influenced more by first-order configuration.

◆ **The influence of dynamic presentation of smile on the perception of facial attributes**

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Smiles have an important role in human communication. They generally create positive impressions in social interaction. How does smile intensity affect the perception of facial attributes such as attractive, lively, altruistic, beautiful, or powerful impressions? Also, does dynamic presentation of smile have different effects from that of static presentation? We investigated perceptual changes of each facial attribute in dynamic and static presentation as a function of

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peak smile intensity controlled by morphing. The models were eight Japanese. The levels of peak smile intensity were selected from 0%, 30%, 60%, 90%, and 120%. The intensity of 0% corresponded to the neutral, while the intensity of 120% corresponded to the smile caricature. The patterns with one of the peak smile intensities were displayed statically, or presented after the static neutral faces sequentially. In the dynamic condition, the patterns were transformed continuously from neutral to the peak smile intensity. The total duration was 1033 ms in all conditions. The results indicate that the smile intensities and the presentation conditions affect the perception of each facial attribute differently. However, the overall rating scores of those attributes increased almost linearly up to 90%, but there was no large difference between 90% and 120% of smile intensity.

- ◆ **The difference between the facial expressions and interpretations based on cultural difference**
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Although the two principal dimensions of emotion are known to be universal, it is uncertain whether expression and interpretation of the emotion depend on identical facial features and what features receive the main consideration by people with different cultural basis. In study 1, the difference between expressions and interpretations were studied on the basis of evaluation of facial expressions [Chung et al, 1998, in *Winter Seminar of Korean Psychological Association* (Korean Psychological Association) pp 121–160]. The observers grasped the intention of posers using unnecessary and additional facial features as well as necessary features. In study 2, facial expressions of Koreans were evaluated by Chinese participants. They misinterpreted the degree of pleasure because they considered unrelated features which led to misinterpretation. These results imply that the process of expression and interpretation may be different, and cultural basis may influence interpretation of facial expressions.

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- ◆ **Aging affects perceptual and eye-movement biases apparent in chimeric face processing**
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Both neuropsychological and neuroimaging studies have indicated that face processing is predominantly based on right-hemisphere function and there have been suggestions that the right hemisphere might age more rapidly than the left (Meudell and Greenhalgh, 1987 *Cortex* **23** 431–445). Using blended chimeric facial stimuli (Burt and Perrett, 1997 *Neuropsychologia* **35** 685–693), where the left and the right sides of the face are different, we have previously shown that observers tend to bias their responses significantly toward the information on the left, supposedly reflecting this right-hemisphere advantage. Testing twenty-one right-handed young subjects we still found this bias with presentation times as short as 100 ms. We also tested elderly subjects on the same stimuli whilst monitoring their eye movements, and found a reduced left perceptual bias in this population. Further, unlike for younger subjects tested in a previous experiment, there was no significant relationship between response bias and saccadic fixation pattern. These data indicate differential face-processing mechanisms in young and elderly subjects and might be taken as support for selective right-hemisphere aging.

- ◆ **Chimeric faces reveal hemispheric contributions to emotion processing**
A Geiger, J M Kaufmann, S R Schweinberger (Department of Psychology, University of Glasgow, 58 Hillhead Street, Glasgow G12 8QQ, Scotland, UK; e-mail: Anja_Geiger@web.de)
- The left hemiface has generally been thought to be more expressive. A recent study using chimeric faces (Indersmitten and Gur, 2003 *Journal of Neuroscience* **23** 3820–3825) suggested that emotions are indeed expressed more intensely in the left hemiface, but are classified more efficiently in the right hemiface. We created chimeric faces based on the FEEST stimuli. In a forced-choice paradigm (intensity task), participants saw two composites created from corresponding left (LL) and right (RR) hemifaces of the same original picture and selected the more expressive one. Across all 6 basic emotions, participants judged RR composites as more expressive. In an expression classification task in which participants performed 4AFC responses for angry, fearful, happy, and sad composites, the advantage for RR composites was modulated by emotion: while an RR advantage was again present for anger and fear, there was no difference between LL and RR composites for happiness, and an LL advantage for sadness. The discrepancy of our results with earlier reports suggests that laterality effects for facial expressions are strongly affected by stimulus and task factors. Simultaneously recorded event-related brain potentials are discussed with respect to the hypothesis that different neural substrates mediate the perception of different basic expressions.

◆ **Mirror images are immune to face-distortion aftereffect: Long-lasting aftereffect of drawing asymmetrically distorted faces**

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When drawing a portrait, artists claim that looking at a mirror image of the work in progress enables them to notice subtle asymmetrical distortions that are otherwise difficult to detect. This leads to two hypotheses. First, the visual system becomes less sensitive to asymmetrical distortions during prolonged observation. Second, the mirror image is immune to this adaptation. Three-quarter photographs of a face, whose right eye was shifted upward or downward were used in experiment 1. The right-eye position (EP) that appeared most normal was measured psychophysically before and after adaptation to original and mirror images with large up/downward EP shifts. Adapting stimuli were presented immediately preceding test stimuli on each trial. Adapting to original images caused the normal EP to be shifted in the same direction. Adapting to mirror images, however, caused no aftereffect, confirming the two hypotheses. To simulate a drawing process realistically, in experiment 2 subjects copied a facial drawing or its mirror image with a downward-shifted eye from the screen onto a sheet of paper in 15 min. Copying the mirror image caused no aftereffect. But, after copying the original, the normal EP was shifted downward. Furthermore, the magnitude of the aftereffect did not diminish after a 30 min break.

◆ **Neural correlates of face learning and long-term repetition priming**

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There is limited knowledge how representations of faces are formed during familiarisation. According to computational models of face recognition (Burton, 1994 *Visual Cognition* **1** 313–348; Burton et al, 1999 *Cognitive Science* **23** 1–31) the learning of new faces involves the same processes as those that mediate long-term repetition priming of familiar faces. In this pilot experiment, we investigated brain correlates of face learning and long-term repetition priming using event-related potentials (ERPs) and reaction times (RTs). Participants performed an old/new task on famous and unfamiliar faces that were either new, or had been presented once or twice during the experimental session. For familiar faces, irrespective of the number of repetitions, priming effects were found in the form of a reduced N400 effect at centro-parietal electrode sites. For unfamiliar faces, a topographically similar effect was found, but only for faces repeated for the second time. With respect to previous findings that this ERP component reflects facilitation at the post-perceptual, identity-specific level of processing (eg Schweinberger, 1996 *Journal of Experimental Psychology: Learning, Memory, and Cognition* **22** 1383–1407; Schweinberger et al, 2002 *Neuropsychologia* **40** 2057–2073), these findings provide preliminary evidence that face learning and repetition priming are associated with similar brain processes and might originate from strengthening links between face recognition units and person identity nodes.

◆ **Can we recognise sex of newborns by their faces?**

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Faces of newborns commonly estimated as asexual were chosen as stimuli. The observers of different ages (16–70 years), gender, and professional experience were asked to discriminate sex of twenty-eight faces of newborns presented as static (photo) and dynamic (video) images. The experiment with photos consisted of two series: one part of participants was asked to classify faces relying upon the first impression, and the second to do it on the basis of selected facial parts, differing in male and female faces. The probability of correct answers in the first series of experiment was 65.8% for women and 61.3% for men. In all our experiments adult female observers were more effective than male ones. We attribute this fact to the difference of their perceptive strategies. The newborn boys were identified better than girls ($p < 0.05$). Neither the age of the observers nor their professional experience (even a period of work with newborns) influenced the results of the sex-discrimination task. In the second series, in which we increased the analytical part of face perception, the performance significantly deteriorated. The results prove that gender perception of the faces of babies is based mainly upon the prototypical comparison, but also includes an analytical component.

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- ◆ **What are you looking at? The effect of lighting and head rotation on perceived gaze direction**
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In daily communication, we perceive the other person's gaze direction automatically on the basis of the luminance inside the eyes, the positions of the pupils relative to the head rotation, but also as a function of the perceiver's own head and eye positions. Human accuracy of gaze-direction detection was examined in psychophysical experiments. In the experiments, the gazer looked at static and dynamic positions in space, and the perceiver was asked to judge the positions the gazer was looking at. Lighting direction and head rotation of both gazer and perceiver were varied. The effect of showing either one or both eyes of the gazer was also compared. The results showed systematic shifts when lighting and head rotation (perceiver/gazer or both) were changed. The distribution, which is normally centred around the perceiver's head coordinates, becomes skewed and its apex located left or right of the head depending on which eye of the gazer is closed. Comparison between dynamic and static situations showed that eye contact and social attention, as dynamic communicative behaviours, differ if judgments are based on static pictures as compared to more natural dynamic stimuli. The results are used to provide a model for presenting valid gaze-direction in computer-graphics environments.

- ◆ **Perception of gaze direction in portraits and schematic faces: The roles of iris eccentricity and face eccentricity**

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Judging the gaze direction of a portrait is a perceptual achievement probably based on combining cues of eye turn (eg iris eccentricity, the position of the iris within the visible sclera) with cues of head turn (eg face eccentricity, defined here as the position of the eyes–nose–mouth configuration relative to the head outline). In three experiments schematic faces were used as stimuli, involving seven levels of iris eccentricity crossed with three levels of face eccentricity. The tasks were to judge whether the face looks to the left or to the right of observers, to judge whether it looks at observers or away from them, or to judge the gaze direction of the faces in degrees, respectively. All results showed clear and consistent effects of both iris and face eccentricity on perceived gaze direction. The equation

$$\text{judged gaze direction} = 1.3(\% \text{ iris eccentricity}) + 0.61(\% \text{ face eccentricity}) + 2.3$$

accounted for 98% of the variance of the data in the third experiment. The Wollaston effect (identical eyes embedded in different portraits appear to gaze in different directions) and the Mona Lisa effect (eyes of portraits appear to 'follow' observers) can be accounted for in terms of iris and face eccentricities.

- ◆ **Interactions between audition and vision for face recognition**

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We can recognise distinctive faces more easily than typical ones. We investigated whether this distinctiveness effect appears for visually typical faces when these faces have been associated with features that are distinctive in another sensory modality. Participants first learned a set of unfamiliar faces. During learning, half of these faces were paired with distinctive auditory stimuli and half with typical stimuli. In experiment 1, the auditory stimuli were voices. We found that recognition performance in a visual recognition test was significantly ($p < 0.005$) better for faces that had been paired with distinctive voices. In experiment 2, we tested whether voice information improved face recognition directly by association or whether distinctiveness effects were due to enhanced attention during learning. In a priming experiment, participants recognised a face significantly faster ($p < 0.05$) when this face was preceded by its congruent voice. Thus the quality of auditory information can affect recognition in another modality like vision. In experiment 3, the stimuli consisted of non-speech sounds. In this experiment, we tested whether voices and faces represent a special case of cross-modal memory enhancement or whether this distinctiveness effect occurs also with more arbitrary associations. Recognition performance in a visual recognition test suggests that a similar effect is present.

◆ **Recognition memory for Caucasian and Korean synthetic faces**

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Synthetic faces were generated by digitising 37 points on individual face photographs. Using both Caucasian and Korean synthetic faces, we designed an experiment to determine whether there was any memory difference between the two face categories defined only by face geometry and not by skin colour, hair texture, etc. In each experiment, observers first studied four Caucasian and four Korean faces presented in random order. Following this, there was a 15 min rest period before the recognition experiment began. On each recognition trial, one previously studied face was paired with three distractor faces in a spatial 4AFC procedure. Importantly, the distractor faces were all chosen to be orthogonal to one another and to lie a fixed geometric distance from the studied face. Overall recognition memory was 51% correct, far above the chance value of 25%. Recognition memory for Caucasian faces (59%) was significantly greater than for Korean faces (44%), even though observers were never told that the faces comprised two ethnic categories. We conclude that recognition memory for synthetic faces exhibits implicit categorisation effects for the geometry of Caucasian and Korean faces.

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◆ **Repetition effects on memory for unfamiliar faces under rapid serial visual presentation conditions**

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People can accurately identify and report several visual stimuli presented at rates of 100 ms item⁻¹ in a rapid serial visual presentation (RSVP) stream. When an item is repeated in the stream at such rates, however, detection and report of repeated items is more difficult than for non-repeated items. This effect, termed 'repetition blindness' (RB), has been found with visual stimuli such as words, letters, numbers, and pictures of objects. For linguistic stimuli, RB is only found for those with pre-existing representations (words) and not for unfamiliar pronounceable non-words for which a repetition advantage is found. We have recently established that RB is found for photographs of faces for which people have pre-existing representations and which are very familiar (famous faces). This familiar-face-recognition system is also involved in processing never-before-seen, unfamiliar faces. We report the results of an investigation into whether pre-existing representations are required to evoke RB, using photographs of faces that were unfamiliar to experimental participants.

◆ **Face matching across 2-D and 3-D representations**

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Research on face recognition has mainly relied on photographic or video stimuli where the 3-D volumetric information of a face for both training and test materials is limited to the depth cues given by the 2-D pictorial representation. In reality, however, observers can be required to match 3-D faces containing rich binocular depth cues against 2-D representations in photographs. The matching process in this case requires deriving correspondence from different types of depth information. To examine this transfer of information across 2-D–3-D representations, participants were asked to perform identification tasks where only one of the training or test images contained stereo information. Recognition performance of this incongruent condition of dimensionality was compared with two congruent conditions where both images for training and test were shown with or without stereo information. It was found that recognition accuracy for congruent conditions was higher than for the incongruent condition in a yes–no recognition task and a sequential matching task. No difference was found between the results of the two congruent conditions. These results suggest that face recognition is little affected by the absence of stereo information, but can be compromised by the mismatch between the type of depth cues present in the face stimuli.

◆ **Neurophysiological correlates of face recognition: A comparison of 'self' and familiar others**

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We investigated ERP correlates of face perception and recognition using a task where fourteen participants monitored a sequence of images for repetitions. The stimuli included images of unfamiliar faces, highly familiar faces (participants' own faces and the faces of friends), and

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non-faces (flowers). The ERPs showed characteristic early positive (P110) and negative (N170) peaks at both occipital and temporal sites, the N170 amplitude being significantly greater for faces than non-faces and more marked over the right (T6) than the left (T5) hemisphere. While these early components of the ERP did not differ between unfamiliar and familiar other faces, ERPs to familiar faces showed a greater negativity at later time periods (beginning ~330 ms). Finally, a comparison of the ERPs to familiar other and to one's own face at central sites showed increased negativity to familiar others between ~330–480 ms, switching to increased positivity at ~500 ms, a pattern previously reported to distinguish the processing of familiar and unfamiliar faces (Eimer, 2000 *Clinical Neurophysiology* **111** 694–705). The differences we find in the 'self' and 'other' conditions are discussed in terms of familiarity effects and in light of recent behavioural and fMRI studies which propose a dissociation in the processing of one's own face and the faces of others.

◆ **The tuning of face-sensitive mechanisms**

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Not only can we easily distinguish faces from other objects, we can also easily discern their gender and ethnicity. We used a configural adaptation paradigm (Webster and MacLin, 1999 *Psychonomic Bulletin and Review* **6** 647–653) to explore the neural organisation of face perception by means of psychophysics and fMRI. In the psychophysical experiment, observers judged the gender or ethnicity of faces morphed between male and female or between Asian and Caucasian (Webster and MacLin, 1999, loco cit.) We measured the shift in the point along the morph that was apparently neutral in gender or ethnicity before and after adaptation to a set of faces. In the fMRI experiment, subjects were first pre-adapted for 3 min to a set of faces. This was followed by an uneven block design in which faces from the adapted set were presented for 24 s and faces from a non-adapted set were presented for 8 s. We found that face-sensitive mechanisms were both singly tuned (eg selective for gender, unselective for ethnicity), and jointly tuned (selective for both gender and ethnicity). We did not find adaptation effects within V1, suggesting that tuning is driven by top-down categories rather than low-level features. We further demonstrate that these selectively tuned neurons are widely distributed within the ventral temporal cortex.

◆ **The involvement of the 'fusiform face area' in processing facial expression**

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According to leading face-recognition models the processing of facial identity is mediated by a system that includes the fusiform-face area (FFA), whereas the processing of facial expression is mediated by a separate system. We designed an fMRI study to test whether or not these two systems are indeed independent. We used a modified selective-attention paradigm that has been rigorously used behaviourally to study the processing of objects and faces. Participants attended either to the identity or to the expression of the same set of faces. If the processing of identity is neuroanatomically dissociable from that of expression, then one might expect the FFA to show higher activation when processing identity as opposed to expression. Contrary to this prediction, the FFA showed higher activation for explicit judgments of expression over identity. Furthermore, the FFA was sensitive to variations in expression even when subjects were attending to identity. Finally, an independent observation showed higher activation in the FFA for passive viewing of faces when expression was varied as compared to when it remained constant. Overall, these findings suggest an interactive and hierarchical network for the processing of expression and identity, in which information about expression is computed from the unique structure of individual faces.

◆ **Can young chicks take into account the observer's perspective?**

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Being observed by the experimenter influences chicks' latency to move in a novel environment (Gallup et al, 1972 *Animal Behaviour* **20** 166–169; Gagliardi et al, 1976 *Bulletin of the Psychonomic Society* **8**(1) 58–60; Vallortigara and Zanforlin, 1988 *Animal Learning Behaviour* **16** 359–362). We investigated if eye position of an artificial face affects chicks' behaviour, with

particular regard to chicks' sensitivity to the visual information actually accessible to the observer from its own perspective. Three-day-old chicks (*Gallus gallus*, $N = 237$) were asked to rejoin their own artificial imprinting object (a small ball placed 57 cm away). An artificial face with movable eyes could be made to stare at the chick or at the ball, in either a ball-visible or ball-not-visible condition (an opaque barrier could prevent the sight of the goal to the artificial observer). Latency to move and time to reach the imprinting ball were recorded. Results showed that, when the artificial eyes stare at the chicks, latencies are longer for females than males ($p = 0.020$); times needed to reach the ball are overall longer when the artificial eyes focus on the chicks ($p = 0.003$). Moreover, the arrival times of male chicks were lower when the ball was hidden by the barrier ($p = 0.039$).

LIGHTING AND SHADING

◆ Does perceptual belongingness affect lightness constancy?

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The relation between perceptual belongingness and lightness perception has previously been studied in the contrast domain (Benary, 1924 *Psychologische Forschung* 5 131–142). It was shown that two equal gray patches may differ in lightness when they belonged to different reflecting surfaces. Here, we extended this investigation to the constancy domain. In a CRT simulation of a bipartite field of illumination, we manipulated the arrangement of 12 patches—6 squares and 6 diamonds. The same-shape patches could (i) be placed all within the same illumination field; or (ii) form a row across the illumination fields. Furthermore, we manipulated proximity of the patches: they could be (i) touching (forming an X-junction); or (ii) not touching (not forming an X-junction). Observers were asked to perform a lightness match between two adjacent patches one in light and the other in shadow. We found better lightness constancy when same-shape patches formed a row across the fields, with no effect of X-junctions. Since lightness constancy is improved by strengthening the belongingness across the illumination fields, we conclude that belongingness factors may help the visual system to aggregate differently illuminated surfaces, and facilitate the scission process.

◆ Lightness constancy and object pose: Effect of articulation

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We have shown that observers take scene geometry into account when they judge surface lightness. Observers exhibit partial constancy, with large individual differences. In our previous experiments, the standard was presented in relative isolation. Here, we test whether adding surfaces that are always coplanar with the standard increases lightness constancy. Stimuli consisted of a circular gray standard displayed on a flat black plate. In the control condition, the standard was presented in isolation on the plate. In two test conditions, the standard was surrounded by four white (condition 1) or light-gray (condition 2) contextual patches. Plates containing standards of 4 different reflectances were displayed at 7 slants. Seven naïve observers matched the standards to samples on a palette. We analysed the data to define a constancy index. The index takes on a value of 1 for perfect lightness constancy and 0 for luminance matching. The constancy index for the control condition was 0.46, similar to that we measured previously. Constancy indices in the two test conditions were higher (0.78 for condition 1; 0.65 for condition 2). There were again large individual differences. The contextual patches interact with how observers incorporate scene geometry into their judgments of surface lightness.

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◆ Articulation effects in lightness perception depend on co-alignment of borders in target and surround

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We previously presented a model in which lightness is computed by integrating signals generated by edges that are parallel to the borders of a target. We showed effects of varying surround articulation for a stimulus containing such parallel borders (Zemach and Rudd, 2003 *Perception* 32 Supplement, 150). Here, three observers adjusted the luminance of a matching disk to achieve a lightness match to either an incremental or decremental test disk presented on an articulated surround. Surround patterns consisted of either wedges of alternating luminance arranged as a radial fan around the disk, or a radial checkerboard in which each wedge was split into two luminance sections separated by a border parallel to the disk edge. The two patterns had the

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same space-average luminance. Changing the number of wedges in either the radial fan or the checkerboard pattern did not affect target lightness, consistent with the model that says that only surround edges parallel to the target edges induce lightness in the disk. But lightness matches for the checkerboard differed from lightness matches for a radial fan having the same wedge number. Lightness increased for increments and decreased for decrements. These experiments provide strong evidence that a directional edge-integration process underlies lightness perception.

◆ **Chromatic and achromatic perception: When surface colours became self-luminous**

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Lightness perception has been mainly studied in the achromatic domain. How does it work when in a visual scene chromatic and achromatic surfaces are presented at the same time? We used an experimental apparatus set up in a tunnel with Gelb illumination and low articulation. Chromatic and achromatic surfaces have been used after a selection made with previous experiments and photometric measurements. We referred to the general assumptions of the anchoring theory (Gilchrist et al, 1999 *Psychological Review* **106** 795–834). Furthermore, the five-squares experiment by Cataliotti and Gilchrist (1995 *Perception & Psychophysics* **57** 125–135) has been replicated and the results used as baseline. If scaling and anchoring are determined only by the relations among the luminances present in a visual scene, independently from the chromatic qualities of the surfaces, then replacing an achromatic stimulus with an isoluminant chromatic one should not modify the lightness perception of the grey surfaces. Here, we manipulated the relative luminance of the experimental setting by using two sources of illumination. Results show that the lightness of the achromatic stimuli is overestimated when the highest luminance is perceived as a self-luminous source.

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◆ **Dependence of brightness and darkness spreading on transparency conditions**

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We investigated the dependence of assimilation effects that underlie differences in perceived brightness of two equiluminant shapes. The stimulus consisted of two juxtaposed shapes: an oblong shape and a rectangle, both of which had their elongated axis oriented vertically. In addition, the oblong shape had three horizontally oriented protrusions (cf the letter E), whose endpoints overlapped with the rectangle along one of its long sides. Variations in the stimulus conditions concerned especially, but not exclusively, luminance and colour of the overlapping areas, as well as of the gaps between the protrusions. The task was to judge whether the oblong shape was brighter than the rectangle or vice versa. Although the aim of the experiment was to investigate differences in perceived brightness of the oblong shape and the rectangle for the condition in which these shapes were equiluminant, we additionally manipulated the luminance levels of both shapes in order to inhibit judgments based on figural information alone. The main conclusion is that, for strong assimilation effects to occur (ie the brightness/darkness of the protrusions spreads over the two shapes), the conditions for luminance transparency must be fulfilled.

◆ **Textural transparency: A particular case of assimilation?**

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The general definition of transparency as the perception of one surface through another includes different phenomena. Our aim here was to determine the role of spatial frequency in the perception of transparency with texture elements. Experiment 1 was devised to determine at which spatial frequency transparency is perceived when a white bar and a black one intersect in a textured area. Experiments 2 and 3 were conducted to find how transparent the textured area appears as a function of the background lightness. Transparency occurred when the texture elements were still discriminable, but their spatial frequency was ranging from 5 to 10 cycles deg^{-1} ; variation in the background lightness did not change the degree of transparency. We explain the transparency threshold found here by Helson's area-luminance hypothesis [1964 *Adaptation Level Theory* (New York: Harper and Row)], according to which the decrease of spatial frequency determines the transition, along a unique continuum, from assimilation to contrast. In fact, at lower spatial frequencies transparency was not perceived, probably because lightness contrast between texture elements makes this area more heterogeneous; on the contrary, transparency was perceived at higher spatial frequencies, probably because this area appears more homogeneous as a consequence of lightness assimilation.

◆ **Consistent errors in human judgments of material and light-source direction**

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The appearance of objects depends on their material, shape, and illumination conditions. Conversely, object appearance provides us with cues about the illumination. To gain insight into these mechanisms, we rendered spheres, using four physics-based bidirectional reflectance distribution functions (BRDFs) representing matte, glossy, pitted, and velvety surfaces at five light-source directions. Participants were asked to judge whether two spheres were made of the same material. Results reveal many errors in material judgments. This is surprising because of vast differences in BRDFs between the four materials. The pattern of errors consistently shows that pitted and velvety spheres are often confused with matte spheres, but not with each other. Glossy spheres are not often confused with another material. In a separate experiment, participants were asked to judge whether two spheres were illuminated from the same direction. There were few, but consistent, errors in direction judgments. Most errors occurred in the judgment of the glossy spheres. This is probably due to the fact that on a glossy sphere the highlight does not coincide with the light-source direction. Because we find such a different pattern of results in these experiments, it is likely that the errors in material judgments were independent of light-source direction.

◆ **Influence of edge sharpness depends on the number of illumination levels**

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Edge sharpness is considered to be a factor in edge classification: sharp edges signal reflectance difference while blurred edges represent illumination differences. Although this is an oversimplified view, experiments show that surfaces enclosed with a blurred edge are more strongly grouped for lightness computation purposes (Gilchrist et al, 1999 *Psychological Review* **106** 795–834). This applies to surfaces belonging only to one illumination framework. Surfaces split by an illumination edge present a more complicated case. Here lightness is computed on the basis of two principles: area of highest illumination and largest area of illumination (Zdravković and Gilchrist, 2001 *Perception* **30** Supplement, 18). Does the edge sharpness segregating the two area types (highest and largest) affect the lightness? A spotlight was cast on one half of a row of five rectangles, spanning in range from black to white. Sharpness of the edge and the position of the spotlight were varied. The results confirmed previous findings for areas in a single illumination level: a blurred edge is a stronger segregation factor than a sharp edge, measured through the decrease in constancy. However, the same rule does not apply to the segregating edge, where lightness remains the compromise between the two principles.

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◆ **Saccadic responses to glow: differential latencies for light-emitting and light-reflecting objects**

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In most visual scenes, light-reflecting objects contain more task-related information than light-emitting (glowing) objects; however, the latter are often spatially more salient. To reconcile these facts, it has been proposed that an inhibition mechanism might exist to avoid attentional shifts towards glowing objects (Leonards et al, 2003 *Perception* **32** Supplement, 154). We used pro-saccade and anti-saccade paradigms to measure subjects' saccade latencies for stimuli that were perceived as glowing compared to non-glowing stimuli of the same mean luminance and size. Pro-saccade latencies were shorter for saccades towards glowing objects, supporting the idea that such stimuli have higher salience. Following Kristjansson et al (2001 *Nature Neuroscience* **4** 1037), we reasoned that active inhibition for reflexive pro-saccades in the anti-saccade paradigm should be less pronounced for glowing stimuli owing to their genuine inhibition; therefore anti-saccade latencies for glowing stimuli should be shorter than those for reflecting stimuli. However, no differences in anti-saccade latencies were found for the two stimulus types. This questions the existence of an inhibition mechanism to avoid attentional shifts towards glowing objects. However, such a mechanism might come into play in the presence of non-glowing objects.

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◆ The glare effect in depth

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Psychophysical experiments suggest that luminosity thresholds are sensitive to figure-ground articulation. By means of stereoscopic presentations, we examined whether the glare effect, an illusion in which a white target (T) surrounded by coplanar luminance gradients (glare-cross, GC) appears self-luminous, is also sensitive to depth relationships. If this were the case, T should show no or less brightness enhancement when it is not coplanar with GC. Stereograms consisting of GCs and Ts were presented on a CRT against a white background. To manipulate binocular disparity, a small central fixation cross (C) and a surrounding wire frame (F) were added. A white square (S) appeared at the inner right bottom corner of F as a standard stimulus for the rating task. By horizontal displacements of C or GC with respect to F, through binocular disparity we could make T appear either as a hole or as coplanar to GC (S appeared always coplanar with T). Using a 0–9 scale, naïve subjects rated the luminosity appearance of T with respect to S (rated 0). No statistical difference between hole and coplanar conditions was found, suggesting that the glare effect is insensitive to figure-ground articulation and that luminosity is determined prior to binocular stereopsis.

SCENE PERCEPTION

◆ Psychophysical discrimination of natural scenes: Thresholds and subjective ratings

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We have studied how observers detect small differences in digitised monochrome photographs of natural scenes (Párraga et al, 2000 *Current Biology* 10 35–38). Using morphing or other processing techniques, we have made sequences of images where a photograph of one scene changes in 40 or more steps into a photograph of a related scene; eg sequences where a smiling face transforms into a frowning one, one fruit transforms into another, or a landscape with shadows transforms into one without. By measuring discrimination thresholds in 2AFC experiments with reference images taken regularly through an image set, we determined the distance between any pair of images within each set in a threshold-discrimination space. Then, observers gave subjective ratings to the difference in appearance of pairs of images taken from within the sets. Pairs from each image set were randomly interleaved with pairs from the other sets, and the pairs differed by up to 16 discrimination threshold steps. Subjective ratings were linearly related to the number of threshold steps by which the images differed. However, the constant of proportionality differed between image sets—some image changes were more subjectively salient than others.

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◆ Perceptual hierarchy of natural-scene categories

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Grouping natural scene into perceptive categories is of interest both in psychology and in computer vision (particularly for content-based image retrieval). We present a method of determining natural image categories that are relevant for discriminating for that purpose, according to human perceptual organisation. It is based on an extension of the computer scaling experiment designed to study how human observers judge image similarity (Rogowitz et al, 1998 *SPIE* 3299 San Jose, CA; Guyader et al, 2002 *NNSP* Martigny, VS, Switzerland). We project the induced perceptive space by curvilinear component analysis (Demartines and Héroult, 1997 *IEEE Neural Network* 8(1) 148–154) onto a plane, where relevant groups emerge. The novelty is to assess the statistical validity of image associations with a bootstrap process that leads to quantifying the image connexion strength. The resulting hierarchical organisation of categories undermines previous results of classification hierarchy (Vailaya et al, 1998 *Pattern Recognition* 31 1921–1936). In particular, we show that images containing people or animals disturb the hierarchy and lead to favoured links between categories. It is congruent with the fact that live

subjects engender perceptive asymmetries, which are also studied. Other results concern the role of colour on perceptual categories, which slightly modifies the hierarchical organisation in comparison with grey-level images.

◆ **Higher-order statistical redundancy in natural images**

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The structural redundancy found in natural images is believed to have influenced development of the human visual system, and a psychophysical study (Kersten, 1987 *Journal of the Optical Society of America A* 4 2395–2340) has shown that observers can use this redundancy in order to restore missing pixel information in natural images. In a theoretical study, Petrov and Zhaoping (2003 *Journal of the Optical Society of America A* 20 56-66) have shown that only second-order statistical structure contributes to first-order pixel redundancy, but they did not examine the contributions of higher-order structure to second-order interpixel redundancy. In a modified pixel-replacement task, we confirm that the human visual system uses only second-order structure to restore missing pixel information. Further, in a contrast-replacement task, we show that the human visual system can use higher-order statistical redundancy to restore missing second-order (contrast) information in natural images. The results can be accounted for by the behaviour of the second spectrum, a fourth-order statistic that quantifies the spatial-frequency dependence of image contrast. These findings allow us to construct a prototype image-discrimination model that uses fourth-order image information.

◆ **BOLD response in V1 to phase-noise degraded photographs of natural scenes**

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We evaluated the effect of adding phase noise to the spectrum of natural scenes on the responses evoked in human striate cortex. In one condition contrast was allowed to decrease, while in another contrast was held steady as phase noise increased. Five levels of noise (30°, 60°, 90°, 135°, and 180°) were added to the phase spectra of 168 photographs of natural scenes. The intact image and each of the five noise conditions were run in a series of 36 s blocks. Images were presented parafoveally on the horizontal midline while subjects performed a demanding shape-discrimination task with a central fixation cross. Voxels in the region of the calcarine sulcus activated by the intact image were analysed. When the contrast was preserved, the BOLD amplitude did not systematically change with increasing phase noise. When the contrast decreased with increasing phase noise, the BOLD amplitude decreased monotonically. Our data suggest that the striate BOLD response is not sensitive to phase noise when that noise is held independent of contrast. This outcome agrees with other psychophysical data obtained with natural scenes [Braun et al, 2003 *Tuebinger Wahrnehmungskonferenz* volume 6, p.138 (abstract)] and fMRI-data obtained with simple stimuli [Achtman et al, 2001 *Investigative Ophthalmology & Visual Science* 42(4) S407].

◆ **Cue combination: When does information get lost?**

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Several papers have reported a sensitivity to simultaneous variation in two cues that is inconsistent with predictions based on the sensitivity to differences in the individual cues. Is this loss of information caused by the way cues are combined, or by other aspects of the task? Here, we examine how the design of the task influences conclusions about the combination of visual cues for slant. We let subjects match a test surface to a simultaneously visible reference surface, both in slant and surface texture, and varied subtle aspects of the task. Subjects independently manipulated the monocular and binocular slant cues. When the texture on the two surfaces was identical, we found no indication of any combination of cues for which variations were particularly difficult to detect. As we anticipated, when the task made it more difficult to compare the slants or textures, information was lost, so that certain variations became particularly difficult to detect. To confirm the sensitivity of our method, we applied it to colour vision showing that variations in luminance are particularly difficult to detect when combining L-cone and M-cone stimulation to match the appearances of two surfaces.

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◆ **How sensitive are we to inconsistent perspective in a picture?**

I Chen, Y Lin (Institute of Applied Arts, National Chiao-Tung University, 1001 Ta-Hsueh Road, 300 Shin-Chu, Taiwan; e-mail: iping@cc.nctu.edu.tw)

Although the principles of linear perspective have been understood by artists since the 15th century, inconsistencies in perspective can be found in paintings produced since then. However, most perspective errors go unnoticed without close scrutiny. We propose a systematic evaluation of our sensitivity to errors in perspective in a picture. The stimuli were pictures of blocks conforming to one of the perspective rules (single-point, two-point, or three-point perspective). The participant had to pick out a target block that did not agree with the others in perspective. The picture of the target block was taken at a different shooting angle from that of the other blocks. The camera settings for shooting the target were manipulated by moving the camera (i) laterally, (ii) forwards/backwards, and (iii) in rotation. We found that the ease of error detection increased with conditions in the above order. The performance in the single-point perspective condition was only slightly better than chance. The correlation between the absolute displacement of the vanishing points and the performance was evident only within condition. The results indicate that the type of error is more important than the magnitude of error in accounting for error detection performance.

◆ **Influence of object position on perceived spatial layout in a virtual display seen at different angles**

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The optic array projected from a picture, a photograph, or a virtual scene is isomorphic with the one projected by the real environment only if spectators look at it with an eye located at the composition point. Despite geometrical distortions induced when the viewpoint does not match the composition point, pictures rarely appear distorted. The influence of the projective displacement of depicted objects presented on a slanted screen was investigated. The lateral position of objects was varied, resulting in differential inward projective displacement as a function of viewing angle and position. Participants were required to look at a virtual scene representing a landscape seen by a moving observer and including one landmark and two objects. Their perceived locations had to be reproduced on an unslanted aerial view. Lateral position of depicted objects at extreme viewing angles was underestimated. Lateral position of centred objects was overestimated, while that of off-centre ones was underestimated. These results are compared with those obtained by a static viewer. The outward projective displacement due to optic flow seems neglected, since results for both static and mobile observers show that positioning responses at extreme viewing angles depend mainly on the inward projective displacement induced by screen slant.

◆ **The perception of visual inclination in a real and simulated urban environment**

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It is well-known that the perceived inclination of slopes is generally overestimated. We claim that overestimation depends on the use of impoverished stimuli and on the distance between the observer and an inclined surface. Using the paddle method, participants in experiment 1 reported the perceived inclination of a set of urban roads from two different viewing distances. The results show that observers do not overestimate the perceived inclination of slopes when they see roads from the shorter viewing distance, whereas they slightly overestimate the perceived inclination of slopes from the farther distance. In experiment 2, observers reported the perceived inclination of a set of stereoscopic slides representing the same urban roads as in experiment 1. The results show that observers do not overestimate the perceived inclination of slopes when the projected stereoscopic image contains horizontal disparity and simulates the shorter viewing distance; while they revealed a slight overestimation from the farther distance. We found always an overestimation when the stereoscopic image did not contain horizontal disparity, independently from the viewing distance. In conclusion, slopes are overestimated when: (a) horizontal disparity is absent, and (b) the viewing distance is increased.

◆ **Cognitive activity makes visual representations of scenes functional**

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Work on change blindness has revealed that, though observers overwhelmingly fail to detect changes in natural scenes when changes occur during some visual disruption, central changes are more

accurately detected than marginal changes. Consequently, researchers postulate that semantic visual representations involve central-interest aspects of the scene with an abstract schema of the meaning of the scene. But this assumption relies on passive scene viewing. We believe that for active observers (observers performing some task on scenes), visual representations actually imply functional rather than semantic aspects of the scenes. In two change-blindness experiments, we combined two factors: change interest with change task-relevance for both active and passive observers. Results indicated that active observers reported significantly relevant changes more accurately than irrelevant changes, with only a significant effect of change interest for irrelevant changes. As expected, passive observers reported significantly more central changes than marginal changes, with no effect of change relevance on change detection. These results suggest that, as soon as observers have to actively process scenes, goals of the current task progressively guide their focusing attention on task-relevant objects, so that a functional representation, including task-relevant objects with scene schema, gist, and layout prevail over the passive semantic representation of the visual scene.

- ◆ **Boundary extension: Effects of vantage point, magnification, object size, and monocular viewing**
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Boundary extension (BE) is the tendency to remember scenes as if they included information beyond the boundaries. We used 3-D models of rooms and brief retention intervals. Near and far viewpoints from a target object were compared. The results of experiment 1 confirmed BE for close viewpoints (2 m), and for far images magnified to the same retinal size (for target) as near images. The results of experiment 2 confirmed BE whether the rooms were cluttered with furniture or empty. In experiment 3, we used far objects with the same retinal size as smaller near objects, and near objects with the same retinal size as larger far objects. BE was only elicited by large retinal sizes. Several factors appear to contribute to BE (viewpoint, magnification, and retinal size). In experiment 4, we compared binocular and monocular viewing. If BE depends on perceived depth, then monocular viewing should increase it. If BE originates from the conflict from boundaries that do not behave as occlusions, then BE will be increased for binocular viewing. BE was found for binocular viewing, but there was no significant BE for monocular viewing. BE belongs to the domain of picture perception, consistent with the fact that there is no BE for scenes other than when using pictures.

- ◆ **Adaptation to blurred and jumbled scenes depends on observer's ametropia**
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It is well-established that myopic observers are less disrupted by a blurred environment than emmetropic observers. However, this finding applied only to text perception. A recent work confirmed that myopes were more tolerant to blur than emmetropes in the frame of target localisation in natural scenes (Giraudet and Azavant *Investigative Ophthalmology & Visual Science* in press). When natural images are blurred, the global structure of the scene, its context, becomes essential for object perception [Giraudet and Roumes, 2002 *Journal of Vision* 2(7) abstract 523]. Here, we aimed to determine whether differences of blur tolerance as a function of ametropia were due to the ability to use scene context information for object localisation. Subject's instructions were to localise a previously known target in a natural environment. Filtered images were displayed with a normal or jumbled structure. Twenty-four subjects participated in the study: thirteen emmetropes and eleven myopes. Results confirmed that myopes were more tolerant to blurred images than emmetropes and showed that this was due to the way they used scene context information. Furthermore, as exposure to blurred and jumbled images was repeated, myopes exhibited a better ability to adapt to these visual constraints.

- ◆ **New image-restoration system using short-space power spectral subtraction**
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We present a new image-restoration system that is applicable to the restoration of an image degraded by blurring and additive noise. It is assumed that noise power spectral densities are known or can be estimated from a uniform area of image where noise only is present. The short-space spectrum of restored image is estimated in a two-step procedure. First, the power-spectrum estimate of additive noise is subtracted from the power spectrum of degraded image, and, second, the logarithm of the power-spectrum estimate of blurring noise is subtracted from the logarithm of the power spectrum obtained in the first step. In a typical image, each part of the image generally differs sufficiently from the other parts so as to reduce the effect of the nonstationarity.

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The restoration technique developed here is implemented on a short-space basis in which an image is divided into many subimages and each subimage is restored separately and then recombined. The resulting system combined with its short-space implementation is computationally simple and appears to compare quite well in performance with other restoration techniques. Some examples are given to illustrate the performance of the new image-restoration system.

◆ **A multi-resolution colour vision model for human chromatic and achromatic local-contrast discrimination**

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We have previously shown how a simple (low-level), physiologically plausible model of achromatic local-contrast discrimination predicts human performance for discriminating between pairs of slightly different morphed pictures (Párraga et al, 2000 *Current Biology* **10** 35–38). The model does a multi-resolution analysis of the two pictures and detects differences in local contrast in each spatial frequency channel. For the present work, we have developed a dichromatic version of the same basic model, which analyses separately the achromatic and chromatic (red–green) representations of pairs of colour images and simply signals which representation produces the largest contrast difference. This limited version of the model is valid only for foveal detection tasks (given the lack of blue cones in the central fovea), and we expect to develop a full-colour version in the near future. To relate model output values to actual human discrimination thresholds, we calibrated the model against a series of psychophysical experiments where human observers' discrimination thresholds were measured for 49 sequences of slightly different morphed images of fruits (Párraga et al, 2003 *Perception* **32** Supplement, 168). The model was tested by correlating subjects' detection performance in an experiment which involved detecting coloured targets with predictions of the model.

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◆ **Perceived dynamics of static images and emotional attribution**

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Anecdotal observations in art, science, and popular culture indicate that dynamic imbalance can be easily revealed in static images (eg Cutting, 2002 *Perception* **31** 1165–1193). Here, we ask whether and, if so, how perceived dynamics of abstract geometric figures is related to emotional attribution. Participants first estimated perceived instability of static geometric figures ('standing-on-the-top' isosceles triangles, oval egg-shaped figures, and single lines) which were rotated from the vertical orientation in 15° steps in the image plane in two upper quadrants. Then they evaluated the intensity of six emotions (joy, surprise, fear, suffering, disgust, and anger) ascribed to the figures. No link occurred between the deviation of the figures from the vertical orientation and perceived instability. Irrespective of figure form, a strong positive correlation was found between negative emotions (fear, suffering) and perceived instability. By contrast, the strength of intense positive emotions (eg joy) did not relate to perceived instability. Instead, the positive emotions were negatively related to the physical deviation of the figures from the vertical orientation. Schematic depiction of positive, neutral, and negative emotional expressions on the figures did not affect their perceived instability. Overall, the findings suggest that perceived dynamics conveyed by static abstract images enables specific emotional attribution.

TEXTURE

◆ **Transfer of aftereffects between second-order cues**

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Second-order cues are those cues whose processing cannot be accomplished by linear filtering because their impact on the Fourier spectrum is obscure (they do not present any obvious peak in Fourier energy at their own modulation frequency and orientation). There is strong evidence to suggest that second-order cues are detected independently of first-order cues (Georgeson and Schofield, 2002 *Spatial Vision* **16** 59–76), but that adaptation transfers between the two cue types, suggesting a later linkage between the two. However, the majority of work on second-order cues has focused on contrast modulations (CM). To further investigate the mechanisms for processing second-order cues, we considered cues defined by modulations in local orientation (OM). We found

partial transfer of adaptation between luminance-modulated (LM) and OM cues in tilt-aftereffect (TAE) experiments. We also found a partial transfer of TAE between OM and CM cues. Preliminary results from an experiment on perceived strength reduction aftereffect show less transfer of adaptation between OM and CM cues. Taken together, these results suggest that the pathways which process LM, OM, and CM cues are linked at, or before, the site of adaptation. However, a transfer of less than 100% of within-cue aftereffect suggests that information is not completely integrated.

◆ **Tilt aftereffect for texture edges is larger than in matched illusory edges, but there is no difference in cross-adaptation**

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The tilt aftereffect (TAE) has been used previously to probe whether contours defined by different attributes are subserved by the same or different underlying mechanisms. In this study we compare two types of contours between texture surfaces, one with an orientation contrast across the surface edge (OC) and one without, commonly referred to as a subjective contour (SC). Both contour types produced curves of TAE versus adapting angle displaying typical positive and negative peaks, at $\sim 15^\circ$ and $\sim 70^\circ$, respectively. The curves are well-fit by DoG functions, with one Gaussian accounting for the contour adaptation effect and the other accounting for the texture-orientation adaptation effect. The OC produced a larger TAE at 15° than the SC. Cross-adaptation conditions showed no difference between the OC-SC and SC-OC adapt-test conditions, but OC was a stronger adapter of both OC and SC test contours. Finally, adapting with a luminance-defined contour and testing with OC or SC showed a trend of increased TAE compared to OC-OC and SC-SC adapt-test conditions. These results are discussed in terms of processing leading to perception of the contours and their possible sites of cortical representation.

◆ **Side conditions for interactions among feature modules**

M Schmidt, G Meinhardt (Department of Psychology, Institut III, Westfälische Wilhelms-Universität Münster, Fliehdnerstrasse 21, D 48149 Münster, Germany; e-mail: maxe@psy.uni-muenster.de)

A texture patch can be distinguished from its surround if it differs in at least one feature dimension. If there is a difference in an additional feature, detectability is usually enhanced. The degree of enhancement reveals whether the features involved interact or are processed by independent feature modules. While traditional theories claim feature independence (eg Treisman and Gelade, 1980 *Cognitive Psychology* 12 97-136), our data indicate that feature modules interact at an early level. The kind of interaction is modulated by (i) local and (ii) global stimulus aspects. (i) High-contrast features are processed independently. With low feature contrast, we find synergistic processing, defined as detection performance of a redundantly defined texture exceeding the performance predicted from the independence assumption, estimated from the detectability of textures defined by only one feature [Green and Swets, 1973 *Signal Detection Theory and Psychophysics* (Los Altos, CA: John Wiley)]. (ii) Zipser et al (1996 *Journal of Neuroscience* 16 7376-7389) showed that the firing rates of V1 cells change when a texture in their receptive fields is part of a figure compared to ground. Analogously, we find synergistic feature integration for texture figures, but not for random patterns. For targets which cannot be grouped into simple global forms feature processing is independent or even inhibitory.

◆ **Feature synergy in detection and discrimination**

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In natural environments, objects usually differ from the surround in many feature dimensions (contrast, colour, size, or direction of motion). Since studying the gain achieved by redundant target definition has led to conflicting results so far (cf Meinhardt and Persike, 2003 *Spatial Vision* 16 459-478), we tried to identify relevant side conditions for the interaction among feature domains. In particular, effects of feature contrast, objecthood, and spatial and feature expectation were investigated in psychophysical feature detection and discrimination tasks. Using contrast, orientation, and spatial-frequency cues we found that feature synergy, defined as performance increase better than expected on assuming independent feature domains, is bound to two conditions. First, features must be grouped to form textured figures or contours in randomly varying feature environments. Second, contours or figures must be barely visible. No benefit from redundant features is observed when the target object is well visible already with any single feature. Further exploration shows that this scheme of side conditions holds in central and peripheral vision and remains unaffected by attentional modulation, as realised in attend-to and attend-away conditions. Our results indicate that higher-level grouping processes mediate the interaction of feature domains at an early level.

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WEDNESDAY

POSTERS 3

ATTENTION

- ◆ **The effect of an ignored or attended abrupt auditory distractor on representational momentum**
A E Hayes, J J Freyd¶ (School of Sport, Health and Exercise Sciences, University of Wales, Bangor LL57 2PX, Wales, UK; ¶ Department of Psychology, University of Oregon, Eugene, OR 97403, USA; e-mail: a.hayes@bangor.ac.uk)

When observers report the final seen position of a moving object, when the retention interval is short they typically mislocate the position toward the direction of continued motion (representational momentum, RM). When attention is divided across visual objects or divided by a concurrent secondary task, the forward shift tends to increase (Hayes and Freyd, 2002 *Visual Cognition* 9 8–27). However, when an irrelevant visual distractor is presented during the retention interval, the shift decreases or is eliminated (Kerzel, 2003 *Cognition* 88 109–131). We examined two questions: (i) Is Kerzel's finding specific to visual distractors, or will an auditory distractor eliminate RM? (ii) If the distractor is attended rather than ignored, will RM increase? Participants completed an RM task under three conditions differentiated by which event occurred during the retention interval: no distractor (silence); irrelevant distractor (tone requiring no response); attended distractor (tone whose volume must be categorised). All three conditions produced significant forward shifts. The irrelevant distractor produced smaller shifts than silence, but the difference did not approach significance; disruption of RM by abrupt distractors may be specific to visual distractors. The attended tone produced significantly larger shifts than the irrelevant tone, as predicted by previous divided-attention studies.

- ◆ **Assessing attention-mediated facilitation with temporal-order judgments**
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Among other effects, attention speeds up the processing of stimuli. This speed-up is inherent in response times, but it can also be measured directly by comparing the perceptual latency of attended and unattended stimuli in temporal-order judgments. The perceptual latency of the attended stimulus is shortened (Stelmach and Herdman 1991 *Journal of Experimental Psychology: Human Perception and Performance* 17 539–550; Spence et al, 2001 *Psychological Science* 12 205–212). This facilitation can be induced by instruction as well as peripheral cues or primes (perceptual latency priming—Scharlau and Neumann, 2003 *Psychological Research* 67 184–197). Perceptual latency priming is smaller than the time available to shift attention towards the prime's location (Scharlau and Neumann, 2003 *Acta Psychologica* 113 185–203). This holds even if the interval is smaller than the time needed for a shift of attention. The reason for this reduction is not yet clear. One possibility is that the reference stimulus—which is necessary to assess the perceptual latency of the attended stimulus via a comparison—interferes with attentional allocation towards the prime. A method to assess this interference based on these experiments is proposed. Main finding is that facilitation is larger with low interference than with high interference. Conclusions for the use of temporal-order judgments are discussed.

- ◆ **Bottom – up visual attention modeling: Quantitative comparison of predicted salience maps with observers eye-tracking data**
P Le Callet, O Le Meur¶, D Barba, D Thoreau¶ (IRCCyN UMR 6597 CNRS, École Polytechnique de l'Université de Nantes, rue Christian Pauc, La Chantrerie, BP 50609, F 44306 Nantes Cedex, France; ¶ R&D, Thomson Multimedia, 1 avenue de Belle Fontaine, F 35511 Cesson-Sévigné Cedex, France; e-mail: patrick.lecallet@polytech.univ-nantes.fr)

We propose a coherent approach to modeling the bottom – up visual attention, which, unlike classical approaches, uses the main properties of the human visual system. A functional model has been derived from psychophysical experiments. It is decomposed into three parts. Visibility—this implies colour separation into Krauskopf pathways, contrast sensitivity functions, perceptual sub-band decomposition, and intra/inter-pathway masking effects; perception—this part provides a structural description of the achromatic component with an achromatic reinforcement by chromatic context and a centre/surround suppressive interaction; and perceptual grouping—this refers to the higher-level structure construction by grouping and binding visual features (iso-oriented and co-aligned linear structures). Finally, a salience map is computed by filtering with a 2-D Gaussian PSF the outputs of the perceptual-grouping part, to reinforce the region with high density of interest points. To assess this model, we measured the correlation coefficient and the Kullback distance between the predicted salience map and the real one deduced from eye-tracking experiments. On a set of 20 natural-colour images presented to forty observers in a task-free

viewing mode (15 s), we obtained values of 0.7 for the correlation coefficient and about 0.5 for the Kullback distance.

◆ **Effect of the bottom – up salience in the rapid serial visual presentation paradigm**

S Shih (School of Psychology, University of Southampton, Southampton SO17 1BJ, UK; e-mail: sis@soton.ac.uk)

The attentional blink (AB) paradigm was used to examine the effect of bottom–up salience (BUS) by varying the task relevance of BUS and the temporal location of a colour singleton distractor (SD) in relation to that of the second (T2) of the two targets in a rapid serial visual presentation (RSVP) stream. The T2 was never a singleton. Despite the variation in the certainty regarding the BUS of the first target (T1), the number of colour singletons in a stream, and the colour congruence between the singleton T1 and the SD, the results were consistent across the three experiments. Independent of the onset asynchrony between T1 and T2, the SD displayed prior to the T2 increased the identification accuracy of T2 without affecting the AB effect per se. The results were consistent with the proposal that the BUS in RSVP affects the kind of attention gating (automatic versus controlled) that transfers the preliminary representations in the perceptual buffer into working memory (Shih, 2000 *Perception & Psychophysics* **62** 1348–1355). The findings are interpreted in terms of the attention-cascade model that incorporates the AB models and the strength model of spatial visual attention (Shih and Sperling, 2002 *Psychological Review* **100** 260–3)

◆ **Attention and bottom-up processing in visual periphery**

R Daini, S Galimberti, G Vallar (Department of Psychology, Università degli Studi di Milano-Bicocca, 1 piazza dell'Ateneo Nuovo, I 20126 Milan, Italy; e-mail: roberta.daini@unimib.it)

We tested the hypothesis that selective spatial attention affects perceptual organisation mechanisms, such as optical-geometric illusions, in a modulator inhibitory fashion. A previous study on right-brain-damaged patients with left neglect showed a disproportionate increase of illusory effects in the neglected side of space. In experiment 1, forty normal subjects marked the centre of a simple line or a Judd figure, varying the position of the stimuli (centre, periphery) and ocular fixation (free vision, central fixation), in order to measure the illusory effect in reduced attention situations. Results showed a significant increase of the illusory effects in the condition of central fixation and peripheral stimulus, while simple line bisection remained unchanged. Nevertheless, position interacts with the perception of illusions. In experiment 2, twenty normal subjects performed line bisection with the same stimuli in two conditions: (a) stimulus aligned with the mid-sagittal plane of the subject's body and fixation point on the left or right side of the stimulus, and (b) central fixation point and left or right stimulus position. The results replicated the increase of illusory effects for peripheral stimuli, suggesting an interaction between the processing of optical illusions and egocentric spatial coordinates.

◆ **'Pop-out' does not prevent 'crowding'**

C Gheri, J A Solomon, F Felisberti, M J Morgan (Department of Optometry and Visual Science, City University, Northampton Square, London EC1 0HB, UK; e-mail: c.gheri@city.ac.uk)

We investigated whether various manipulations designed to increase target salience would have any effect on crowding, the detrimental effect of flanking stimuli on target identification. Our target and flanks were parafoveal Gabor patterns. Observers had to determine whether the target was tilted clockwise or anticlockwise of horizontal (or vertical). In general, tilt threshold increased with the number of (untilted) flanks and decreased with the spatial separation between target and flanks. Tilting the flanks sufficiently (eg by 45°) to produce target pop-out (confirmed by a variety of measures including 2AFC), resulted in even higher thresholds for identification. Colouring the flanks (or the target, but not both) reduced threshold, but this effect was small and inconsistent between observers. Allowing the target and flank carrier-gratings to drift in opposite directions was more effective in reducing threshold, but not to the level obtained without flanks. We conclude that pop-out has at best modest effects on crowding. If crowding were a consequence of poor spatial resolution in post-attentive mechanisms, then our results would imply that salience helps to focus attention's 'spotlight'.

◆ **Conditions of object-based inhibition of return for spatially overlapping objects**

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Inhibition of return (IOR) refers to the delayed response to a location or an object that has recently been cued. Previous studies of object-based IOR in either dynamic or static displays have used spatially separate stimuli that unavoidably involved spatial representation. It thus remains unclear whether the object-based IOR is a special case limited to the condition in which

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objects are separated in space. To rule out confounding with location-based IOR, we used in this study two overlapping triangles constituting a star of David to examine whether and under what conditions object-based IOR can be observed. An object-cuing paradigm was used in which one of the two triangles was brightened as the cued object. The target was a luminance change in one of the three disks connected to the vertices of the cued or the uncued triangle. The participants judged whether the target brightened or became more dim. Results from three experiments showed that object-based IOR occurs when a long enough cue-to-target SOA is used, as well as when another object is inserted between the sequential presentation of the cue and the target. [Supported by the National Science Council of Taiwan, NSC90-2413-H-002-021.]

- ◆ **Spatial cueing and inhibition of return in detection, discrimination, and conjunction tasks**
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Peripheral spatial cueing produces an early facilitatory and a later inhibitory effect on detecting a target at the cued location. We examined the function of the attentional system that is first attracted and then repelled by the cue: is the same system involved in stimulus detection, feature discrimination, and feature binding? Targets consisted of two differently coloured letters, appearing side by side on either the cued or the uncued position. Varied were the stimulus onset asynchrony (SOA) and the task. In the detection task, participants had to react to target onset; in the discrimination task, they had to react if the target contained the letter X; and in the conjunction task, if the X was red. Overall, reaction times were fastest in the detection task and slowest in the conjunction task. The facilitatory cueing effect and the inhibition of return (IOR) occurred in the detection task and the conjunction task, with an identical time course (maximum IOR at 600 ms SOA). In the discrimination task, neither facilitation nor IOR was observed. We conclude that possibly the same attentional system that helps visual orienting is involved in feature binding, whereas feature discrimination does not rely on this system. Moreover, our results support the common notion that IOR enhances attentional search.

- ◆ **Interaction between contingent attentional capture by colour and endogenous orienting induced by a spatial cue**
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Previous studies showed contingent attentional capture by a task-irrelevant colour distractor even outside the focus of attention, regardless of whether attention is maintained on fixation (Folk et al, 2002 *Perception & Psychophysics* **64** 741–753) or the action of shifting attention to a specific location is required (Liao and Yeh, 2003 *Perception* **32** Supplement, 133). In this study, we used a spatial-cuing paradigm to examine the interaction between contingent attentional capture by colour and spatial orienting. A central cue or a peripheral cue was presented first, followed by the target display after different stimulus onset asynchronies (SOAs). Four letters of different colours were shown in the target display, and participants judged whether the red target indicated by the spatial cue was a U or an H. The distracting effect (ie slower RT with a red distractor presented) and the compatibility effect (ie faster RT with identical distractor–target pair) were taken as evidence for contingent attentional capture. Results showed clear contingent attentional capture under short-SOA conditions; however, this effect disappeared under long-SOA conditions. These findings reveal different time courses for the interactions between endogenous orienting with central and peripheral cues and contingent attentional capture by colour. [Supported by the National Science Council of Taiwan, NSC91-2413-H-002-013.]

- ◆ **Perceptual load effects on attentional capture with and without voluntary attention orienting**
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Previous research has shown that voluntary attention on a location overcomes the incongruity of simultaneous exogenous capture of attention on another location by a transient luminance change. This possibility to override attentional capture could be influenced by perceptual load. It is known that perceptual load affects the processing of irrelevant stimuli. In the present research the hypothesis was that voluntary orienting would overcome incongruent attentional capture only with high perceptual load (HPL) and not with low perceptual load (LPL). We used a same–different discrimination task with a valid or neutral spatial precue to orient voluntary attention, and a transient luminance change in an orthogonal location marked on the previous placeholders display to produce exogenous capture. The HPL condition consisted of eight possible stimulus locations previously marked by an eight placeholders display, and the LPL condition consisted of four. Our results did not support the second-order interaction, but there were some

effects of perceptual load. The results show that attentional capture congruent with stimulus location benefits processing both with and without simultaneous orienting of attention, and both with HPL and with LPL. However, for attentional capture incongruent with stimulus location we have found an accuracy cost only with LPL, and with HPL there was a small RT due only to the condition without orienting. We found also that for RT, voluntary orienting overcomes any attentional capture.

◆ **Temporal uncertainty and the attentional blink**

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When two targets are embedded in the stream of rapidly presented distractors, the correct identification of the first target (T_1) results in a deficit for a second target (T_2) appearing within 200–500 ms. This non-monotonic U-shaped attentional blink (AB) function has been shown to emerge when both T_1 and T_2 are followed by the masking stimuli in 100 ms. Omitting the T_{1+1} masking stimulus has removed the AB effect in the experimental designs where the blank trials were presented in a block or mixed with no-blank trials. Current research shows that randomising the positions of the blank (100 ms) in the RSVP stream across trials leads to different results than the predictable relation of T_1 and the following blank. The target stimuli were numbers in the stream of capital letters. T_{1+1} blank trials intermixed with randomly after T_1 positioned blank trials design revealed non-monotonic AB function as opposed to the monotonic function found in blocked T_{1+1} blank trials. The blank appearing in positions T_{1+2} to T_{1+6} eliminated the U-shaped AB effect. Therefore, the blank interval appearing after T_1 in RSVP stream may have different effect to the processing of the targets in addition to decreasing T_1 masking effect found before.

◆ **The interplay of sustained and transient attention: The case of illusory boundaries**

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The subjective boundary effect describes a performance impairment at the boundaries of subjectively defined regions in a localisation task (Carrasco and Chang, 1995 *Perception & Psychophysics* 57 1134–1150). To investigate whether such boundary effects, resulting from sustained attention, can be eliminated or reduced by transient attention, we used a detection task in which observers attend to 2 stripes (eg green) in an alternating red–green grating of 4 stripes. Observers detect the presence or absence of a large target disk in one of the attended stripes, ignoring the 10 false-target disks in the unattended stripes (Gobell et al, 2004 *Vision Research* 44 1273–1296). Transient attention, the reflexive allocation of attention to a location, was manipulated by using a peripheral cue adjacent to the target. Following a 333 ms grating, a brief cue preceded a 12×12 array of white disks (11 large, 133 small) which appeared for 100 ms before being masked. A clear boundary effect was observed: accuracy was impaired when the target appeared adjacent to a boundary of the attended regions. The peripheral cue improved performance, compared to the neutral cue, but it did not alter this boundary effect. The resilience of the boundary effect illustrates that transient attention could not override sustained attention.

◆ **The advantage of nearer space in the case of attentional switching in 3-D space under observers are moving situation**

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Most studies of attention have been executed in 2-D space, so the characteristics of attention in 3-D space remain unclear. In this study, the expectancy for a location of a target was controlled by the spatial cuing paradigm (eg Posner et al, 1980 *Journal of Experimental Psychology: General* 109 160–174). The cue in the form of digits indicating target location was used to examine the effect of cue validity under top–down control of attention in 3-D space. The observer's task was to judge whether a target appears nearer or further than a fixation point. Regardless of observation condition (static or moving), the reaction time decreased or increased depending on cue validity. It is suggested that attention in 3-D space operates with depth information. Furthermore, asymmetric switching of attention (attention switches from far space to near space) was faster than the reverse, and depended on the relationship between cued location and actual target location relative to a fixation point. This result indicates that allocation of attention in nearer space is superior to that of in further space. Two factors producing this advantage can be suggested: shifting speed of attention or disengagement of attention.

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◆ **A two-stage scheme for visual object recognition based on selective attention**

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We present a two-stage scheme for visual object recognition: first, a window of attention is determined in a picture by means of low-resolution colour and shape information; then, high resolution visual features (like edges, corners, or T-junctions) are extracted from this window and used in a trained neural network (hierarchically organised radial-basis-function network) for object recognition. This two-stage process reflects some properties of human or monkey vision (eye movements guided by visual attention, high-resolution processing in the fovea, decreasing resolution towards the periphery) and helps to save computational power and perform sophisticated object recognition in real-time. We are at present applying this scheme in soccer-playing robots (our RoboCup team) and in the MirrorBot project, where a robot has to grasp different kinds of fruit. In these scenarios we can select important features for a top-down guidance of the first (attention) process. We present the selected windows and the recognition performance for various pictures, demonstrating the importance of top-down selection of salience features in practical applications. We compare our findings to measurements of human eye movements in demanding sensorimotor virtual-reality tasks.

◆ **Orienting attention without awareness**

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According to the contingent capture hypothesis (eg Folk et al, 1992 *Journal of Experimental Psychology: Human Perception and Performance* **1** 1030–1040), attention capture only obtains if the attentional control settings include the features of the capture object. The alternative view (eg Theeuwes, 1992 *Perception & Psychophysics* **5** 599–606) is that a salient object captures attention in a bottom-up fashion. We present data that show capture when neither of these requirements was present. Observers identified a single white-letter target among black distractor letters in a rapid serial visual presentation sequence. On some (capture) trials, a distractor letter, the top half of which was offset ('sheared') from the bottom half, appeared before the target. The temporal distance by which this distractor preceded the target, and the degree of shearing were varied. Capture was evaluated by comparing identification performance for sequences containing a sheared letter with the baseline (no errant object sequences). At the debriefing, observers were explicitly asked whether they saw the sheared object. When the offset was salient, the sheared object was generally detected, and capture was apparent. But even when observers were not aware of the errant object, capture was observed.

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◆ **Does attention affect transparent motion perception?**

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Human observers can extract motion direction from sets of random dots moving simultaneously in several directions in the same region of the visual field (motion transparency). Preliminary observations suggest that attentional cues can modulate this ability (Zanker and Taylor, 2003 *Perception* **32** Supplement, 43). To study the extent and constraints of attention affecting transparent motion, human observers were presented with a set of 256 dots moving simultaneously in 2–8 directions within a circular aperture. In half of the trials, an arrow (pre-cue) indicated a specific direction of motion before stimulus onset. Another arrow was displayed after the stimulus, prompting the observers to answer whether that direction was present in the stimulus or not. Dot lifetime (path length of each dot) and the number of frames (stimulus duration) were varied independently. Without a pre-cue, observers could reliably detect a particular motion direction in no more than 3 different directions. Pre-cued directions, however, could be detected by most observers in up to 6 transparent directions, the upper limit growing with dot lifetimes up to 32 steps and stimulus durations up to 24–32 frames (300–400 ms). These results point towards spatial and temporal integration processes modulating the attentional bottleneck observed for perception of motion.

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◆ **Reinstating object-based attention under positional certainty**

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Object-based attention is generally explained either in terms of selecting abstract, location-independent representations, or in terms of selecting a region of the visual field belonging to the object without

selecting other regions. In both accounts, attention is assumed to improve the quality of the sensory representation of the selected item or its region. However, Shomstein and Yantis (2002 *Perception & Psychophysics* **64** 41–51) recently demonstrated that the object-based attention would not appear when the target location was known in advance. They interpreted their results by assuming that object-based attention occurs through the setting of priorities for search. The present series of experiments shows that, even under the conditions of positional certainty, object-based attention can appear if there are spatial cues present outside of the focus of attention, or if the target and distractors are sometimes coloured differently from other elements in the display. These results argue against an explanation of object-based attention based on priority in the order of visual search. If advanced knowledge of the target location allows attention to be focused on the target and thereby preventing object-based attention, then that attentional focus is susceptible to spatial cues or colour grouping.

◆ **Effects of cue informativeness and spatial focus on object-based and space-based selection**
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Goldsmith and Yeari (2003 *Journal of Experimental Psychology: Human Perception and Performance* **29** 897–918) obtained object-based effects only under conditions of spread attention, while we found cue informativeness is necessary for object-based selection (Yeh and Lin, 2004 *Journal of Vision* **4** in press, abstract A38). In this study we further examined which factor, cue informativeness or spatial focus, is critical. The double-rectangle spatial-cueing paradigm was used by manipulating the cue validity (informative/non-informative) and the spread of attention (spread/focusing). When an uninformative peripheral cue was used in a detection task and attention was forced to spread widely, the same-object effect was obtained, along with an inhibitory space-based effect (experiment 1). With an informative peripheral cue and focal attention constrained on fixation, the same-object effect remained, but the space-based effect turned into facilitation (experiment 2). When the target was to be discriminated (square/circle) rather than a simple detection of the square, focusing attention on the fixation prevented the occurrence of the same-object effect, but a facilitatory space-based effect was still obtained (experiment 3). These results suggest that both cue informativeness and spread of attention affect the object-based selection. Dissociation and interdependence of space-based and object-based selection were revealed by differences in task demand (detection vs discrimination) and cue validity.

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◆ **Subliminal priming of motor reactions by an irrelevant singleton**

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In a recent study (Jaskowski et al, 2003 *Journal of Cognitive Neuroscience* **15** 911–920), a well visible pair of squares (main stimulus) was preceded by a sequence of four pairs of squares (primes), whereby each pair masked the preceding pair. Participants had to react to the side of the target (a square with small gaps). One of the four primes contained a smaller copy of the target on the same side (congruent) or the opposite side (incongruent) of the target. A benefit for reaction times for congruent and a detrimental effect for incongruent trials was found. This finding may be explained by the direct parameter-specification hypothesis (Neumann, 1990 *Psychological Research* **52** 207–215): masked primes resembling the target may initiate response preparation to the target. Alternatively, the effect could be assigned to an attention shift evoked by a salient feature (gaps). Here, we showed that an irrelevant singleton did attract attention, but its effect on reaction time was weaker than that of the target-like prime. Moreover, the target-like prime exerted its effect even if it had no salient feature. These results show that irrelevant singletons may contribute to priming effects, but cannot fully account for the effect exerted by target-like primes.

◆ **Do you know what you are tracking?**

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In laboratory studies of multiple-object tracking (MOT), observers see a set of identical objects, track a subset of target items for several seconds, then report which items were targets. Capacity is 3–5 objects. However, real-world observers might monitor several quite different objects and wish to determine the location of one specific object (eg: “Where is my child?”). In two experiments,

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observers tracked four of eight unique cartoon animals moving over a backdrop of cactuses. After a random tracking duration, all animals hid behind the cactuses. Accurate responses required observers to track continuously. In a series of experiments, observers were either asked to click on all cactuses occluding target animals (full report) or to click on the cactus occluding a specific target (eg the zebra-target location). Capacity was derived from accuracy corrected for guessing. In all experiments, target location capacity (1.44 to 2.15 objects) was significantly lower than full-report capacity (2.84 to 3.54 objects). However, observers could individuate more than one item, suggesting that featural or identity information is tracked. Tracking ability in MOT may reflect two systems, one tracking individual object representations, and one discriminating targets from non-targets.

◆ **Saccadic object recognition by a Markov decision process in a cascaded framework**

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Important issues in sequential object recognition are to define a strategy for saccadic access of visual information, and the representation of the features under observation. Selective attention has been described from the viewpoint of decision behaviour in experimental psychology (eg Gorea and Sagi, 2003 *Perception* **32** Supplement, 5) and in computer vision within the framework of Markov decision processes (MDPs) [Paletta and Pinz, 2000 *Robotics and Autonomous Systems* **31** 71–86; Minut and Mahadevan, 2001 *Proceedings of the Fifth International Conference on Autonomous Agents* (Montréal: ACM Press) pp 457–464]. The original contribution of this work is to embed the saccadic decision procedure in a cascaded recognition process where visual evidence is probed exclusively at salient image locations. In a first processing stage, salient points are determined from an entropy-based cost function on object discrimination. Local information in terms of code-book vector responses determines the recognition state in the MDP. A reinforcement learner performs then trial-and-error search on useful actions towards salient locations within a neighbourhood, receiving reward from entropy decreases. After training, the decision maker demonstrates feature grouping by hypothesis verification behaviour. The method is evaluated in experiments on object recognition with the COIL-20 database, proving the method being computationally feasible and providing high recognition rates.

◆ **Response-time indicators of the intensity of attention**

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Common to theories of attention is that its effect causes higher activity at the attended site than at surrounding sites. We present three experiments in which attention is manipulated by using three levels of task difficulty of a discrimination task. Identical probes presented in both cued and uncued locations and across difficulty have been used as markers for response criterion effects in cued locations and of the spread of attentional activity to peripheral uncued locations. Two of the experiments relied on covert attention in which fixation was verified by using an eye-tracker. Combining response time data from these three experiments with mathematical models, we sought to separate attentional effects at the early sensory-driven stages of processing from criterion effects at the later decision stages of processing. We tested the hypothesis that the difference in sensory-driven activity levels at attended and surrounding sites is changed as attentional intensity is varied by task difficulty and argue that preparatory attention to location can be represented by a unimodal activity distribution that narrows and increases in peak amplitude as attention intensified. The pattern of results is unchanged by concurrent attention to shapes, which by itself can be characterised similarly.

◆ **Perceptual decision influences V1 neuronal responses to ambiguous three-dimensional objects**

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We studied spike responses of V1 superficial layer neurons in a perceptual-decision task. A rhesus monkey was trained to hold fixation during presentations of a three-dimensional (structure-from-motion) object and to make perceptual decisions in an alternative-choice paradigm while extracellular responses were obtained by single electrode penetrations. The disparity of constituent dots was varied from trial to trial to render objects perceptually ambiguous or unambiguous. Neurons with modulated disparity responses were selected. We estimated the certainty at which the firing rate of a given V1 neuron would allow an ideal observer to predict the monkey's perceptual choice in the task. Neuronal responses to zero-disparity (ambiguous) objects were sorted according to the perceptual decision, and the choice probability was determined for each neuron (Britten et al, 1996 *Visual Neuroscience* **13** 87–100). Based on the sample of 100 neurons,

the firing rate ROC curves showed significant bias from chance starting at 500 ms after the stimulus onset. The choice probability was different from 0.5 for the significant majority of cells. The long latency of the perceptual bias in the V1 responses suggests a feedback from higher visual cortical areas including MT/MST that further raises the question of the involvement of V1 in perceptual awareness.

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◆ **Subitising: analogue magnitude system or object file system?**

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To account for the phenomena of subitising (fast enumeration of objects up to 4, but relatively slow counting above 4) there are two explanations. The analogue magnitude system (or mental number line) theory proposes that discrimination of small numbers is easy because there are relatively great differences between neighbouring quantities (because the representation works according to Weber's Law). The alternative explanation postulates that subitising is caused by object-based visual attention system. This system has a limitation of following not more than 4 objects. Below 4 objects it is sufficient to count the occupied object files. In the first experiment we tested if subitising can be observed only for objects (as suggested by attentional explanation) or for symbolic notations as well (as proposed by analogue explanation) in comparing numerosities. In the second experiment we looked for individual differences in the subitising range, magnitude system sensitivity, and object file capacity. The question is whether the subitising range correlates better with the magnitude system (postulated by the analogue system theory) or with object tracking task (suggested by the attentional theory). On account of wider dispersion, one group of the subjects was found to be advanced in computer gamers showing higher visual attentional performance. The results suggest that subitising is the consequence of object file system, not of mental number line.

◆ **An attention index for the design of drowsiness detectors in car drivers**

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Driver fatigue is a major cause of car accidents, and the development of devices able to detect driver's drowsiness is a top priority for car industries. However, it is necessary to set a gold standard of drowsiness to build up these devices. Given the relationship existing between fatigue and attention, we propose an attention index (IGAT) within the framework of feature-integration models (Treisman and Gelade, 1980 *Cognitive Psychology* 12 97–136) capable of predicting drowsiness. The IGAT index has been developed after a laboratory model based on three experimental tasks measuring selective, non-selective, and sustained attention. Within a pre–post design, we tested eight subjects in 3 sessions during 24 h of sleep deprivation. To validate the IGAT index, we defined a behavioural criterion based on the occurrence of micro sleeps. This procedure provided two data sets: (a) performance (reaction time and errors) for 8640 trials, and (b) behavioural evaluation of 448 min of videotapes. The results obtained for the three tasks are consistent with the predictions of the models, and the study of the concurrent validity shows the efficacy of the IGAT index. The conclusions refer to the contribution of attention indexes to the design of drowsiness detectors for vehicles.

◆ **Visual attention modulates categorical perception effects in basket-ball**

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We showed that categorical perception occurs in expert basket-ball players. From one source, consisting of schematic basket-ball configuration, two targets configurations were built. The first one was manipulated so as to be physically different but in same category, and the second so as to be in another category. Experts were better than novices in detecting changes only when the source and the target belonged to different categories. Thus, expertise in a specific domain increases observers' sensitivity to semantic changes. Yet, change-blindness studies suggest that change detection requires attention. We asked whether this sensitivity to semantic changes depends on previous attentional setting guided by expert knowledge. To do so, we directed observers' attention to changed areas. We found that novices better detected changes when they attended to the changed areas. Exogenous attention induced by experimental manipulations is involved in successful change detection. On the other hand, expert performances decreased for stimuli belonging to different categories, so that the categorical perception effect disappeared.

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Attentional exogenous orientation disturbed expert perceptual processing guided by knowledge. This may result from a conflict between endogenous attention induced by expertise and exogenous attention. We conclude that experts' perception seems to be constrained by endogenous attentional control induced by knowledge.

CLINICAL VISION

◆ Temporal characterisation of phosphodiesterase inhibition in the retina

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Light-evoked field potentials, as well as [14C]Glu release-responses, were measured in the isolated rat retina. Short-term application of phosphodiesterase (PDE) inhibitors, such as Zaprinast or Sildenafil, the active compound of Viagra, were found to increase the amplitude of the pharmacologically isolated photoreceptor component of the light-evoked field potential (Barabás et al, 2003 *Neurochemistry International* **43** 591–595). In contrast, long-term application of Zaprinast was seen to block the light-evoked Glu release-response (Barabás et al, 2002 *Journal of Neuroscience Research* **67** 149–155; Barabás et al, 2003 *Journal of Neuroscience Research* **73** 731–736). These contrasting results led us to investigate the time-course of the effect of PDE inhibition. The effect of long-term inhibition of PDE by Zaprinast evoked a transient increase of response amplitude, followed by a steady decrease to the control level in darkness and below the control level in light adaptation (Barabás et al, 2004 *Neuroscience Letters* **357** 195–198). These observations explain contradicting results on the effects of PDE inhibitors and suggest a slow increase of the stationary cGMP concentration evoked by long-term inhibition of PDE in the isolated rat retina. [This work was supported by the 1/047 NKFP MediChem project, "Center of Excellence" QLK2-CT-2002-90436 and OTKA F043569 grants.]

◆ Comparing multifocal frequency-doubling illusion, visual evoked potentials, and automated perimetry in normal and optic neuritis patients

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We examined frequency doubling (FD) illusion based perimeter (FDT C-20) and FD multifocal visual evoked potentials (FD mfVEPs) in normal and multiple sclerosis (MS) subjects. Threshold testing was performed on a FDT perimeter, with low-spatial-frequency ($0.25 \text{ cycle deg}^{-1}$) sinusoidal gratings that underwent rapid counterphase flicker in 17 visual field regions. Dichoptic FD mfVEPs were recorded by concurrently stimulating 8 regions per eye, each region containing achromatic sinusoidal gratings at 95% contrast. The spatial frequencies of inner regions were $0.4 \text{ cycle deg}^{-1}$ and of outer regions $0.2 \text{ cycle deg}^{-1}$. Recordings were obtained from nineteen normal subjects, twenty-six optic neuritis (ON) patients, and twenty-four MS patients without ON. The FDT data showed an enhancement of sensitivity for ON patients and a decrease of sensitivity for MS patients. mfVEP amplitudes declined in both patient groups. A classification model, containing FDT C-20 regional amplitudes performed at the specificity of 83.7% and sensitivity of 85.5%. A model containing the scaled FDT C-20 thresholds and FD mfVEP amplitudes performed at 100% sensitivity and specificity in the MS patients. In conclusion, FDT C-20 and FD mfVEPs obtained from normal and ON subjects showed a significant diagnostic value in MS subjects.

◆ Glare recovery time in myopes

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Myopic subjects when compared to emmetropes tend to exhibit lower contrast sensitivity. Furthermore, the change in contrast sensitivity at low luminance levels seems to be more pronounced for negative-contrast stimuli (Stoimenova, 2003 *Perception* **32** Supplement, 178). We assume that such changes in contrast sensitivity may render myopes more susceptible to glare and consequently they have longer glare recovery time. To test this hypothesis we compared glare recovery time in young emmetropes and myopes by measuring the reaction time to correctly identify the orientation of a Landolt C with and without a preceding glaring stimulus. The latter was a rapid sequence of strobe flashes viewed at an angle from the line of sight. The Landolt Cs were presented in a positive contrast on a low-luminance grey background. The experimental procedure was implemented on a personal computer provided with SuperLab and Digital I/O card (STP100W, Biopac). The results showed that myopes have a longer glare recovery time than emmetropes. Although part of the difference can be attributed to optical factors, most of it seems to depend on retinal and post-retinal factors. The data also suggest that myopic subjects may be more sensitive to glare during driving at night.

◆ **Comparing multifocal binocular pattern pulse visual evoked potentials in normal and multiple sclerosis patients**

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We compared monocular and binocular pattern pulse multifocal visual evoked potentials (mfVEPs) in normal subjects and multiple sclerosis (MS) patients. Monocular and binocular mfVEPs were obtained by concurrently stimulating 8 regions of cortically scaled heckerboards to sparse pattern pulse visual stimulus. Multifocal responses were recorded from nineteen normal subjects and fifty MS patients, twenty-six of whom had optic neuritis (ON) and twenty-four who had no visual symptoms (MS). We employed multiple regression to examine the differences between the data from a single eye and binocular viewing. We examined the first response negativities (N1), positivities (P1), their implicit times NT and PT, and fitted delays. Binocular mfVEP waveforms had larger amplitudes than monocular ones, but they were also smaller in MS and ON patients. The responses in any single eye and binocular condition were delayed in the patients' study group, but there was no significant difference between monocular and binocular latencies. We also found that the binocular delays were intermediate between the best and the worst eye. mfVEPs recorded to the pattern pulse stimulus in binocular viewing condition have larger amplitudes, but their latencies do not differ from the latencies in monocular responses.

◆ **Oculomotor capture in a patient with a unilateral right temporo-parietal lesion**

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We report an in-depth analysis of the oculomotor capture patterns of a patient with a right temporo-parietal lesion. He was asked to search for a coloured target among three distractors and signalled its location with a saccade. An additional irrelevant distractor was presented to the left or right, appearing with or without an abrupt onset, being either similar or dissimilar to the target (Ludwig and Gilchrist, 2002 *Journal of Experimental Psychology: Human Perception and Performance* **28** 902–912). Compared to controls, the patient was unable to inhibit saccades to distractors that appeared with an abrupt onset, and to those that shared the target colour. An extinction-like effect was demonstrated: he was not distracted when the target was on the right and the distractor on the left, whereas he was for all other conditions. Like controls, his saccade latencies were shorter towards distractors than targets. The latencies were also spatially modulated, being longer for leftward compared to rightward target-directed saccades. This patient's data are in agreement with the salience model proposed by Gottlieb and Goldberg (1999 *Nature Neuroscience* **10** 906–912) that argues for parietal contributions to both stimulus and goal-driven control.

◆ **Letter search test—normal values for different age groups**

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The purpose of the study was to determine the normal values for the performance of five age groups (20–29, 30–39, 40–49, 50–59, and 60–69 years) in the letter search (LS) test. The LS test is a multiple-fixation visual-search task, in which the subject is required to search for and identify an uppercase letter from among an array of numerals. Threshold search time (or inspection time), which is the stimulus presentation time needed for the accuracy of 79% of correct responses, is determined by using an adaptive staircase algorithm. Unlike traditional reaction-time measures, threshold search time is independent of the speed of decision-making and motor response, and thus represents the speed of perceptual processes only. Because of the complex nature of the visual-search task, LS test probably reflects the performance of many brain areas as well as signal transmission in the visual pathways. The results showed that at all set sizes search performance became slower with age. The search times of the oldest age group were about twice those of the youngest age group. We also demonstrated how the LS performance in some pathological brain conditions greatly exceeds the 97.5th percentile of normal values.

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◆ **Perception of optic-flow motion in Down's syndrome patients**

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It is well established that Down's syndrome patients have a tendency to develop Alzheimer's disease, and that Alzheimer's patients show specific deficits in optic-flow motion perception (Tetewsky and Duffy, 1999 *Neurology* **52** 958–965). To examine whether Down's patients may show similar deficits, we measured sensitivity to optic flow with VEP and psychophysical techniques. Our sample comprised sixteen Down's subjects (aged 15–31 years) with mild mental retardation and without significant Alzheimer's clinical symptoms. With a 2AFC procedure, we measured direction discrimination thresholds for random-dot stimuli moving in radial, rotational, and translational trajectories. We found a significant reduction in sensitivity with respect to a control group of matched mental age, with thresholds for Down's subjects 8 times higher than those of controls. We also recorded visual evoked responses for the same stimuli in a subgroup ($n = 7$) of this sample, and found very few significant responses compared with a control group: 23% against 68%. Overall, our results show a substantial deficit in perception of optic-flow motion in a group of relatively young Down's patients. However, at this preliminary stage, we cannot tell if the observed deficit is due to early Alzheimer's symptoms or is a feature of Down's syndrome.

◆ **Blindsight: Simultaneous recordings of 2AFC signal detection and psychosensory pupil responses reveal greater pupillary sensitivity**

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Blindsight, the capacity of patients with fields of cortical blindness to respond to visual stimuli they do not consciously see, can be assessed by psychophysical and physiological methods. So far, pupillary and behavioural responses have been recorded separately, and the published results demonstrate a close correspondence in the sensitivity of the two methods. We here report the results of eight hemianopic patients who performed a 2AFC detection task while their pupillary responses were recorded simultaneously. The target (grey disc, 5 deg diameter, 19 cd m⁻² on 77 cd m⁻² background, display time 307 ms) was presented in random alternation with blank trials; its probability was in 20% or 80% (600 trials each). The patients fixated a central dot and responded by pressing buttons while fixation and pupil responses were recorded with an infrared eye-tracking system (I-View-System® 3.0; SMI). Results show that only two patients performed significantly above chance level ($p < 0.05$), but, pupillometrically, six showed a significant stimulus-probability-dependent pupil dilation (compare: Qiyuan et al, 1984 *Psychophysiology* **22** 530–534); one patient's pupil did not respond at all. We conclude that psychosensory pupil reactions may provide a more sensitive index of implicit information processing than behavioural responses.

◆ **Spatial and motion integration in children with autism**

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Neuropsychological studies have produced controversial results regarding local–global processing in autistic subjects. Here, we investigate spatial and motion integration in a sample of ten autistic individuals, aged 6–16 years, diagnosed by *Autism Diagnostic Interview—Revised*. All subjects underwent psychological, psychiatric and neuropsychological evaluation, which revealed impairment in superior cognitive abilities, while visuo-perceptual abilities were borderline. Control groups comprised chronological and mental age-matched children. To test spatial integration of contours, we measured detection thresholds for a closed chain of Gabor patches (Kovács et al, 1993 *Proceedings of the National Academy of Sciences of the USA* **90** 7495–7497), as a function of background noise of randomly positioned and oriented Gabors, with a 4AFC procedure. Thresholds were measured for different values of local inter-element distance in the target. Motion perception was tested by measuring direction discrimination thresholds of coherent optic-flow stimuli as a function of noise, in a 2AFC procedure. Both experiments showed no significant differences between the performance of autistic and normal subjects. The results suggest that autistic children do not show impaired processing of global patterns.

◆ **Implicit access to colour names in a case of developmental colour agnosia**

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Patients with colour agnosia perceive colour normally, but have difficulty in forming basic colour-categories. This suggests that colour-agnosic patients suffer from relatively high-level impairments in colour processing. In line with observations from object agnosia and prosopagnosia, we hypothesised that these patients might still be able to process colour information at an implicit level. In the present study, we instructed a colour-agnosic patient to perform tasks requiring access to high-level colour information. In one task, the patient viewed a coloured square followed by either associated (red, tomato) or non-associated (red, grass) words. As in normal control subjects, the patient responded more quickly to the associated words. In a second task, the patient was instructed to read a list of words that were either be colour names (red, green, blue) or neutral words, all printed in colour (red, green or blue). The colour words could either be congruent or incongruent with the physical colour. As in normal controls, the patient became much slower in the equiluminant condition and he showed a congruence effect, being slower in the incongruent condition. Taken together, these results indicate that our patient retains access to high-level colour information.

◆ **Sudden change from random to coherent visual motion as an inducer of cortical oscillations in photosensitive epilepsy**

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Flickering or intermittently light is the most common precipitation stimulus in photosensitive epilepsy (PSE). Very few PSE patients are sensitive to stimuli having low spatial or temporal modulation of luminance contrast or low rate of oscillation. However, even if PSE patients do not have any clinical symptoms or show no EEG photosensitivity when viewing 'non-provocative' stimuli, the visual evoked potentials (VEPs) may show abnormal features. We studied VEPs to a sudden change from random to coherent visual motion and to isoluminant reversal of colour (red-green) in a 14-year-old drug-naïve PSE patient and in six healthy controls. In both stimulus types, the stimulus covered the central visual field and the rate of change was 1 Hz. The patient's responses were larger than those of controls. The most prominent finding was a large-amplitude late (500-900 ms) oscillation in the patient's response to coherent rotation onset. Controls showed no such oscillation. We repeated the recording while the patient was in treatment with sodium valproate and clinically seizure-free, and the late oscillations were almost abolished. Our results suggest that some PSE patients may have impaired cortical gain control in motion processing and that this impairment is reduced by gabaergic inhibition.

◆ **Can blindsight outperform 'sighted-sight'?**

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DB, the first blindsight case to be tested extensively, is able to detect and discriminate visual stimuli in his perimetrically blind field that are considerably less detectable than the optimal stimulus parameters often required to elicit blindsight. We tested DB's ability to carry out 3 psychophysical visual tasks in his visual field defect compared to his sighted field. Using a 2AFC paradigm we investigated DB's ability to detect low-contrast Gabor patches and to discriminate between an outline square and a rectangle. Using a forced-response paradigm, DB made a same/different discrimination between the presentation of two rectangles compared to a square and a rectangle. In his field defect, DB detected the presence of an 8% contrast stimulus, compared to a sighted field threshold of 15%. DB also demonstrated significantly superior performance on both the square versus rectangle and same/different task within the field defect compared to the sighted field. DB has demonstrated superior detection and discrimination ability within his cortically blind field defect compared to his sighted field. Monocular testing suggests differences between each eye cannot account for these results. Results are discussed in relation to control experiments on participants with normal vision and potential implications for rehabilitation regimes.

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- ◆ **Validation of a simulation of visual impairments as applied to visually impaired people**
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 Earlier (2003 *Perception* **32** Supplement, 37) we evaluated a method (derived from Peli, 1996 *Journal of the Optical Society of America A* **13** 1131–1138) to visualise the limits of detecting small and low-contrast details in natural images due to changes in distance in unimpaired subjects. Here, we determined whether the same method can be applied to visualise visual impairments of subjects with various impairments [MD, cataract, glaucoma, (diabetic) retinopathy]. A simulated image was constructed in 3 successive steps in which the image was degraded more and more. We used a 2AFC adaptive staircase method. In the 1st step the amount of detectable blur (sigma) was established [removing high spatial frequencies (SFs)]. In the 2nd and 3rd steps SF components in the highest (remaining) SF bands (one-octave wide) were removed with contrasts below some threshold level. The threshold levels (CB1 and CB2) were determined. Simulation parameters (sigma, CB1, CB2) were measured for three images (face, stairs, forest) and the relationship with acuity and contrast thresholds was established. We found a direct (proportional) relationship between acuity and just-detectable blur, independent of the type of visual impairment. We found no correlation between contrast thresholds (Landolt Cs) and contrast levels (simulation). Similar results were found earlier for unimpaired subjects. The relationship between the simulation parameters and acuity and contrast sensitivity is the same for unimpaired and visually impaired people.

- ◆ **The effect of contrast on affective ratings in normal and anhedonic subjects**
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 Processing impairments of emotional information have previously been demonstrated in non-clinical anhedonic subjects, ie subjects with a loss of the capacity to experience pleasure. However, most previous studies explored cognitive processing, and only a few have explored coding and perceptual processes in anhedonics. The aim of this study was to compare the effect of contrast on emotional perception in normal and anhedonic subjects. Thirteen anhedonic and fifteen control subjects performed a visual emotional test, in which they were instructed to rate pleasantness of 30 hedonic photographs of landscapes (sensory pleasure) and social scenes (social pleasure) at each of five levels of contrast attenuation (0.2, 0.4, 0.6, 0.8, 1). Results showed that hedonic ratings of both controls and anhedonics decreased when contrast decreased, while ratings for neutral images were unchanged. However, emotional judgment of anhedonic subjects was less influenced by contrast attenuation, in spite of a normal contrast sensitivity. We hypothesise that emotional perceptual processes interact with early stages of visual contrast coding in anhedonia. In this context, anhedonia may not be a wholly central deficit.

EYE MOVEMENTS

- ◆ **The motion aftereffect and smooth pursuit eye movements**
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 We investigated whether the percept of motion during the motion aftereffect (MAE) can elicit smooth pursuit eye movements without any retinal motion. We used a nulling paradigm to measure the magnitude of the MAE. A moving adapting sine-wave grating was presented for 30 s and followed by a test grating that was either stationary or moved slowly in the adapting or the opposite direction. We measured eye movements during the adapting and testing phase and compared them with the observer's responses with regard to the movement of the test grating. Typically, physically stationary test gratings were perceived most often to be moving in the opposite direction and also smooth pursuit eye movements were observed in the opposite direction, and therefore coincided with the percept. When the test grating was moving in the adapting direction at a speed of about 0.4 deg s⁻¹, subjects perceived it to be stationary. Under these conditions, the average eye-movement speed was close to 0, despite the retinal motion signal caused by the moving grating. We conclude that after motion adaptation smooth pursuit eye movements are possible even in the presence of a stationary stimulus. However, there was no correlation between perceptual judgments concerning the test movement and the corresponding eye movements.

◆ **Neural origins of vergence eye movements**

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Disparity induced by the two different retinal images is an important cue for three-dimensional perception. Several imaging studies with PET or fMRI aimed to elucidate the neural origins of disparity coding. In most of these studies the visual stimuli could provoke vergence eye movements which were not controlled. In recent PET studies, disparity-inducing stimuli were used to study the neural correlates of vergence eye movements. In this experiment, we used fMRI to measure the BOLD signal of the neural networks employed in vergence eye movements as compared to saccadic eye movements in absence of disparity-inducing stimuli. The stimuli consisted of two fixation spots, one for each eye, which were shifted horizontally by 0.3 deg either in phase or in counterphase to induce saccadic or vergence eye movements, respectively. Preliminary results indicate that saccadic and vergence eye movements employ largely the same neural networks. Comparing both types of eye movements we find slightly larger activation in lateral extrastriate areas during vergence eye movements, an area often reported in experiments of responses to disparity. These findings indicate that some of the BOLD responses found in recent experiments on disparity perception can be accounted for by vergence eye movements.

◆ **Effects of richness of depth information on vergence eye movements**

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Visual motion of expansion and contraction elicits vergence responses, which correspond to direction of motion-in-depth that the visual motion represents (McLin et al, 1988 *Vision Research* **28** 883–888; Busetini et al, 1997 *Nature* **390** 512–515). We have shown, however, that changes in size of retinal motion elicit only convergence eye movements regardless of expansion or contraction (Kozawa et al, 2003 *Perception* **32** Supplement, 114). The possible reason for the difference was that our previous experiment used a small Maltese cross (1.55 deg–3.22 deg) that had poorer information of changing in distance compared with the studies of McLin et al and Busetini et al. In this study, we employed a large stimulus textured with chequer pattern, which changed in size (4.84 deg–19.34 deg). The Maltese cross was also used for comparison. We found that expansion of the chequer pattern elicited convergence responses, while contraction elicited no significant response. Changes in size of the Maltese cross elicited convergence response regardless of expansion and contraction. Our hypothesis is that appropriate vergence responses occur as richness of information about expansion or contraction increases. We tentatively conclude that the oculomotor system requires various information about expansion or contraction, such as changes in target area, texture density, etc, to determine the direction of vergence eye movements.

◆ **Tangled eye movements: A new method to quantify human scan paths**

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To date, there is no formal quantitative technique for characterising the entire scan path—the complex sequence of saccades and fixations that are performed as we view an image. Here, we present a new mathematical tool, based on knot theory and modern geometry, which characterises the number of ‘crossings’ in a scan path. Crossings occur when the scan path folds over itself in space, forming a 2-D ‘loop’, providing a quantitative measure of how ‘tangled’ a scan path is. We tested how useful this tool is for characterising both individual observers and different images. Scan paths were recorded with an ASL 504 infrared eyetracker running at 60 Hz. We found that loops occur on two scales. Larger loops are formed by saccades during image viewing, while much smaller loops are formed when fixating. A clear difference was found, for all participants, between the number of crossings recorded when maintaining fixation and when freely viewing images of natural scenes. However, more variability was found, across participants, during fixation than during image viewing. These results suggest that it may be possible to use the number of crossings to characterise participants on the basis of simple fixation.

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◆ **A memory-recency effect in visual search**

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Visual search often involves searching the same environment, consecutively, for a number of different targets. Here, we introduce a paradigm to study such search and investigate the extent to which search benefits from previous exposure to the same display. In the experiments, participants searched the same ten-letter display for three consecutive targets. Simultaneously with the display onset a target was announced through loudspeakers (search 1). When the participant had made a present-absent manual response, a second target was announced (search 2); following a further response, a third target was specified (search 3). Manual responses were faster for search 2 than for search 1; however, there was no additional benefit for search 3. Eye-movement recordings during this task demonstrated that the time necessary to find a target letter depended on when that letter was last fixated in the previous search. This is a classical short-term-memory-recency effect. The results showed that search benefits from fixation recency up to about the last four fixations. This is evidence for a limited-capacity short-term-memory store in visual search.

◆ **Prediction of eye-movement direction in natural stimuli**

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We developed a method to identify the most likely direction of saccades during the inspection of natural stimuli. Eighteen subjects viewed 23 pictures (cartoons, photographs, paintings, etc) for 20 s. For every trial, a Voronoi diagram (Voronoi, 1908 *Journal für die Reine Angewandte Mathematik* **134** 198–287) was constructed from the fixation points. The cells were coded by the direction of the saccade that was made from the cell's fixation point to the next fixation point. For each picture, the Voronoi diagrams of all subjects were combined by vector addition, and the resulting diagram was corrected for directions that were to be expected on the basis of picture dimensions. A threshold was applied to the amplitude of the resulting direction vectors to identify locations where the saccades showed a narrow angular distribution about their average direction. These locations were colour-coded by their average direction and thereby provided information about the locally preferred saccade directions. Therefore, in addition to methods that predict fixation locations (eg salience maps), this method predicts likely directions of eye movements from specific locations in the stimulus. This information may be useful for advertising, websites, and other presentations.

◆ **Effects of gaze-contingent stimulation on eye movements with natural videos**

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We measured the effect of presenting peripheral visual patterns on the subjects' scan paths when viewing 20 s video clips of natural indoor and outdoor environments. Small red squares or looming patterns were overlaid on the video for 200 ms at locations 12° – 20° away from the position of gaze. The actual location was chosen randomly from candidate locations that had some minimal amount of salience (mean spatiotemporal curvature). The red squares had a width of 1 deg of visual angle and their luminance was dependant on local spatial contrast. The looming pattern was presented in squares with a side length of 2 deg. Within that square, the video content was zoomed by a factor that changed from 1 to 3 within 133 ms. Results show that, in videos with relatively low intrinsic salience, about 50% of the peripheral stimuli triggered a saccade to the desired location, while in more salient videos this rate was about 25%. Subjects' verbal reports indicated that only a fraction of the stimuli were perceived consciously. The latencies of the saccades varied between 160 ms and 500 ms. Our research aims at creating new forms of visual communication and vision-based interaction (see <http://www.inb.uni-luebeck.de/Itap>).

◆ **Eye movements in natural environments and with their CRT representations**

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Are eye movements recorded in laboratory conditions with CRT display devices representative of data obtained outdoors in natural conditions? This question was addressed here by comparing

eye movements for data recorded in outdoors, stationary, urban and rural environments with data obtained from observers viewing representations of the same scenes on a colour monitor in the laboratory. Eye-position data were recorded in both viewing conditions with a modified infra-red *xy*-gaze-tracking device. The chromatic specification of the monitor images was obtained from hyperspectral data recorded at the same time as the outdoors eye-movement measurements (Nascimento et al, 2003 *Perception* **32** Supplement, 110). In both conditions, observers were instructed to look at the scene for 5 min so that they could answer a question about its composition afterwards. Eye-position data were analysed for speed and spatial distribution, and in relation to the chromaticity and luminance of the images. We found that, although the distribution of velocities was slightly different between the two viewing conditions, with larger values obtained for outdoors measurements the spatial patterns were similar, suggesting little influence of overall luminance and three-dimensionality.

◆ **Temporal decoupling in eye – hand coordination: Effects of task and stimulus**

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Saccadic eye movements are altered by simultaneous execution of hand movements towards the same visual target. Latency increase as well as latency decrease has been reported for saccades accompanied by hand movements (eg Bekkering et al, 1995 *Experimental Brain Research* **106** 475–484; Lünenburger et al, 2000 *European Journal of Neuroscience* **12** 4107–4116). Lünenburger et al attribute the increase of saccadic latencies to a prolongation of hand-movement latencies elicited by complicated experimental demands. In contrast, we assume that saccadic-latency increase is elicited by the experimental design directly. To test this hypothesis, we measured saccades and pointing movements towards visual stimuli to the left and right. Resting positions of the index fingers were 3 cm in front of the visual targets. In all eight subjects tested we found a significant increase in saccadic latencies, together with an increase in manual latencies in five subjects. From our results we conclude that saccadic latencies decrease when the performance of the hand movement can be improved by prior fixation of the target, whereas in other cases (eg large targets, auditory targets) a latency increase may appear. This increase in mean saccadic latency may be caused by those saccades which are elicited after the hand movements are executed.

◆ **Fixation duration and proximity**

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Owing to the complexity of measuring fixation duration, this parameter is still quite unknown, and the experimental results found in the literature are controversial. After studying the effect of task difficulty on the increase of the number of fixations and their duration, some authors (eg Salthouse and Ellis, 1980 *American Journal of Psychology* **93** 207–234), found that the greater the task difficulty the greater the number of fixations and their duration. Others, such as González and Kolars [1985, in *Eye Movements and Human Information Processing* Eds R Groner, G W McConkie, C Menz (New York: North-Holland/Elsevier Science) pp 251–259], suggest that the number of fixations is affected but not their duration. We recorded eye movements of thirty-four students during a task based on the perception of dot configurations under two experimental conditions: (i) perceptual organisation according to the Gestalt principle of proximity, and (ii) an organisation contrary to this principle. Our results suggest that the proximity principle makes the task easier, which is reflected in a shorter response time ($F_{1,33} = 43.920$, $p < 0.01$), smaller number of fixations ($F_{1,33} = 30.647$, $p < 0.01$), and shorter fixation durations ($F_{1,33} = 54.241$, $p < 0.01$) in (i) than in (ii). Therefore, we agree with Salthouse and Ellis that both the number and duration of fixations are affected by task difficulty.

◆ **Eye movements and good continuation: Figural goodness or relatability?**

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Eye-movement recording was used to study the difficulty of having to make a perceptual organisation contrary to the good-continuation principle, by measuring the number of fixations and their duration. Wertheimer's figures were used in two experimental conditions: one with a perceptual organisation according to the good-continuation principle, and the other contrary to that principle. The subjects were thirty-four students. Our results show that the difficulty of having to make a perceptual organisation contrary to the good-continuation principle leads to an increase of the number of fixations, but not of their duration. A second goal was to contrast the figural goodness notion [Palmer, 1991, in *The Perception of Structure. Essays in Honor of Wendell R. Garner* Eds G R Lockhead, J R Pomerantz (Washington, DC: American Psychological Association)

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pp 23–39], based on global factors, with the reliability notion [Kellman, 2000, in *Perception, Cognition, and Language: Essays in Honor of Henry and Lila Gleitman* Eds B Landau, J Sabini (Cambridge, MA: MIT Press) pp 157–190], based on local factors. Our data, based on eye-movement recording, are explained by the latter not by the former, providing experimental evidence in favour of the reliability model.

◆ **Eye-movement patterns in solving inductive reasoning problems**

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Inductive reasoning problems, such as analogies, series completions, or matrices, are commonly used in psychological assessment procedures. Item difficulty depends on the type and number of rules required to solve a problem and the salience of elements that are governed by the same rule. To investigate the influence of these components on the cognitive processes underlying inductive reasoning, an eye-tracking experiment was carried out. Materials were a set of 20 items from two problem domains: geometric matrices and number series completions. For both domains, the type of rules (easy versus difficult), the number of rules (one, two, or three), and their salience (high versus low) were varied. The fixation paths for each step in the solution process and the number of fixations and their duration dependent on item difficulty were predicted. The results show a good agreement of participants' eye movements with the predicted solution steps and the difficulty of the components. The established relationship between problem components and eye movements provides design criteria for improved item constructions, which can also be used in adaptive testing procedures.

◆ **Perception and motor control: The link between fixational eye movements and postural sway**

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During fixation, eye position is imperceptibly altered by small involuntary eye movements. Two important types of these 'fixational' eye movements (FEMs) are drift and microsaccades. Recently, we investigated statistical behaviour of FEMs using a random-walk analysis (Engbert and Kliegl, 2004 *Psychological Science* 15 431–435). Scaling exponents obtained by this analysis indicated a separation of time scales in FEMs. Here, we investigate how microsaccades interact with postural sway in three conditions: sitting with the head positioned on a chin-rest, normal sitting, and standing. Using the same analysis, we replicated the findings of our first study in the sitting with chin-rest condition: microsaccades enhance fixation errors on a short time scale, a phenomenon known as persistence and control fixation errors on a longer time scale (anti-persistence). On the short time scale, scaling exponents are very similar across conditions. On the long time scale, fewer fixation errors can be observed (more antipersistence), although postural sway contributes to the noise level in gaze position. The interaction of FEMs with postural control indicates a global coupling of perceptual motor systems. FEMs constitute visual fixation, the platform on which almost all visual perception depends—understanding their properties has potential impact on fundamental mechanisms of perception.

LEARNING, MEMORY, AND PLASTICITY

◆ **The tricky disks: Non-sensory factors modulate size discriminability**

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Experience-induced statistical context modulates perceptual judgments in tasks with many response categories and clearly distinct stimuli (eg Sokolov et al, 2000 *Perception & Psychophysics* 62 998–1007). Here, we examine if the non-sensory variables (serial order and frequency of stimuli) affect sensory discrimination of disks that only slightly (by 5%) differ in their size. Using two categories ('small', 'large'), four groups of participants judged two grey disks presented one per trial. The disk sets varied between the groups in the base rate (with frequent small or large disks; ratio 3 : 1) and serial order of stimuli (either frequent or infrequent disks occurred mainly on the initial trials). The data indicate that (i) the frequent small disks induce more liberal criteria than the frequent large disks, and (ii) the concordant base rates and serial orders (frequent stimuli presented early in a series) yield a greater discriminability than the discordant ones (when mainly infrequent stimuli occur earlier). The effects are of early onset, persisting over the entire experiment. The findings suggest that in standard signal detection tasks, the non-sensory experience-related context alters the sensory representation of stimuli irrespective of their physical properties. We discuss putative neural mechanisms of these effects.

◆ **The effect of figure – ground segregation on visual search and implicit learning**

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Three experiments were conducted to investigate the effect of the difficulty of figure–ground segregation on implicit learning of the task-irrelevant background and on visual search. In all experiments, contextual cueing paradigm was used and the difficulty of figure–ground segregation was defined by similarity of features between background and search items. The results of experiment 1 showed that repeated background helped search target, indicating that the background was implicitly learned. As similarity of features increased, the implicit learning of background became stronger. Experiment 2 was performed with the figure and background separated by binocular depth cue. The implicit learning of the background also occurred when the background was repeatedly presented and a feature of the background was similar to one of the search items, whereas when it was dissimilar implicit learning became weaker. In experiment 3, with random dots, implicit learning of the background disappeared, indicating that the background without form information could not be learned implicitly. These results mean that task-irrelevant background can be learned implicitly, and figure–ground segregation has an important role in visual search and implicit learning.

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◆ **Cross-dimensional transfer and specificity of perceptual learning effects**

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Ahissar and Hochstein (*Nature* 1997 **387** 401–406) found that learning effects transfer for easy tasks (large target–distractor difference) but are quite specific with harder conditions. These differences are related to cerebral modification site: hard tasks are seen as requiring low-level representations, easy tasks as using high-cortical-level mechanisms. We now ask if learning effects will transfer also across visual dimensions (from orientation to or from colour) and if this transfer depends on task difficulty. Low-level task learning might not transfer, since neurons at these levels are reported to be specific to colour or orientation. On the other hand, high-level learning might transfer, since here neurons combine aspects of both dimensions to represent complex objects. Subjects were trained on one dimension and then tested—and retrained—on the other dimension. Alternatively, subjects trained on colour, orientation, or gap feature search, each with arrays in one hemifield. Following training, we switched the sides of the tasks or introduced a new dimension. We found nearly complete cross-dimensional transfer for easy conditions, and considerably less with difficult conditions. Our results support the notion that feature search with easy conditions is performed at high cortical levels where representations are multi-dimensional.

◆ **Priming faces around the clock: effects of intervening sleep and time in the day at study and test**

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Forming memory traces for new faces is a common, automatic, and socially important ability. Little is known, however, how time of the day and periods of sleep affect storage of such traces. Recent research suggests a role of sleep in memory consolidation (Peigneux et al, 2001 *Neuro-Report* **12** A111–A124) and enhanced face-familiarity recognition following a 3 h-period of REM sleep (Wagner et al, 2003 *Biological Psychology* **62** 197–210). We examined whether time of the day and intervening sleep periods influence repetition priming for unfamiliar faces after incidental learning. Subjects studied 3 lists of 48 faces, given in two different sessions at a 12-h interval, first in the morning then in the evening (group 1), or vice versa (group 2). Each group studied lists 1 and 2 in the first session, and list 3 in the second, being tested on list 1 in the first session, and on lists 2 and 3 in the second session. Participants judged pleasantness at study, and gender at test. A preliminary analysis of reaction times showed a significant interaction of priming × session × group ($p = 0.01$), indicating faster responses to ‘old’ than ‘new’ faces only when study occurred in the evening, while intervening periods of sleep had no differential effects.

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◆ **Visual inference of population means with the use of sequential and simultaneous samplings**

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We investigated properties of visual inference of population means in sequential and simultaneous sampling tasks. We prepared two sets of luminance patches as stimuli. The luminance of the patches in each set had Gaussian distribution, $N(m_1, \sigma^2)$ or $N(m_2, \sigma^2)$ and $m_1 > m_2$. In the sequential sampling task, pairs of luminance patches were presented one pair at a time, side by side, at the centre of a display. Participants were required to terminate the sequential presentation of the pairs at a proper time and determine which side of patches was selected from brighter sets (ie mean luminance, m_1). In the simultaneous sampling task, 20 patches selected from each of the luminance sets were presented in the upper and lower parts of the display. Participants determined which part consisted of the patches from the brighter set. Results showed that about only 6 pairs (or samples) produced the same percentage of correct responses in the sequential task as in the simultaneous task. In addition, the percentage of correct responses in a dual-task situation (ie sequential + simultaneous tasks) was almost the same as in the single-task situation. These results suggest that separate mechanisms are involved in these inference processes.

◆ **The time series of attentional requirement for visual learning**

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We investigated the time series of attentional requirement for visual learning. Participants performed two tasks simultaneously. The main task was a supervised learning of target and distractor patterns. The patterns consisted of 4×4 mosaic patches, and were presented side by side at the centre of the display. Participants were required to choose the target. The patterns presented in each trial had a luminance of gray scale such that a different normal noise was added to original black-and-white patterns. Feedback of responses enabled the participants to learn the characteristics of the patterns through trials. The sub-task was luminance discrimination. Two groups of 40 luminance patches were presented in upper and lower areas of the display. The luminance of the patches was normally distributed in each group. Participants were required to choose the group in which the mean luminance was higher. The result showed that the time series of performance in the sub-task was out of phase with that in the main task, and the phase difference was larger when the learning was difficult. This suggests that the attentional requirement changes along with the learning process, and the time lag of attentional allocation depends on the difficulty of learning.

◆ **Visual short-term memory during smooth-pursuit eye movements**

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We investigated whether spatial and retinal target positions are encoded in visual short-term memory (VSTM). With this in mind, we examined the effects of continuous displacement of the spatial or retinal target position, while some experimental conditions involved smooth-pursuit eye movements (SPEM). First, we tested whether VSTM for position would suffer when targets were presented during SPEM. VSTM capacity for position was actually reduced during SPEM compared to a fixation condition. There was no difference between a SPEM condition in which the targets moved with the pursuit target such that they were stabilised on the retina, and a SPEM condition in which the targets were stationary such that they moved across the retina. However, performance in SPEM conditions may not only be governed by spatial or retinal stability. It may be that the execution of SPEM binds attentional resources. In this case, the execution of SPEM would lead to impairments in performance that would be unrelated to changes in an item's position. The reduction of capacity for position during SPEM was actually eliminated when miniature targets were presented foveally. The results suggest that visuospatial attention is tied to the target during SPEM such that VSTM for the position of peripheral objects is impaired.

◆ **Testing sequence effects in visual memory: Clues for a structural model**

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Memory tests were performed in which the subjects, after memorising 2 to 5 constantly renewed random abstract patterns, passed recognition tests in all possible testing permutations. Over 300 000 tests were performed, generating more than 40 000 errors. The results for both the 3-image and the 4-image experiments are compatible with the presence of just four typical accuracy levels. However, the reaction time (RT) results revealed surprisingly rich patterns. The RT for recognising image i at testing stage $t > 1$ depends upon which image (j) was tested just before. The ranking of the RTs for (j, i) couples evolves from one testing stage to the next. It is suggested that these RTs reflect, in part, the time needed to localise the trace in memory of a given image, starting from the position at which the previous test occurred. The configurations formed by items memorised in the visual memory store can then be deduced from the error rates and the RT patterns. A hypothetical minimal model, involving several rows of slots on a triangular mesh, is proposed to account for the error rates and the RT results. The model also helps to explain earlier paradoxical findings (Ninio, 1998 *Cognitive Brain Research* 7 57–68).

◆ **Limitation in maintenance of multiple object representations revealed by cuing effects**

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Contrary to the widely held view of maintenance of multiple object representations, we recently found that our capacity to hold feature binding is limited (Saiki, 2003 *Vision Research* 43 2107–2123). Using a paradigm called multiple-object permanence tracking (MOPT) we investigated memory for feature binding by requiring observers to identify a violation in feature combination of multiple objects occurring during an occlusion. A sequence in MOPT contains constant sets of features and locations, and changes occur only in their combinations. To test whether task performance reflects limitation in the maintenance of object memory or in its retrieval, we provided a 100% valid cue indicating an object with a change either just before or just after the change. If the previous data reflect the difficulty in retrieval of object representation, a cue just after the change (post-cue), as well as a pre-cue, will facilitate the task performance. However, only the pre-cue condition showed significant facilitation, and there was no facilitation in the post-cue condition compared with no-cue control. The results suggest that representation of the pre-cued object is maintained with focused attention, and without attention, as in the post-cue condition multiple object representations are either not formed or destroyed during the 470 ms occlusion period.

◆ **Iso-salient colour and luminance information in infant visual working memory**

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Infants were shown to be able to encode a certain type of featural information in visual working memory (VWM) tasks (Kaldy and Leslie, 2003 *Developmental Science* 6 360–373; Wilcox, 1999 *Cognition* 72 125–166). Features that infants could readily use were based on edge information (shape, size). Infants seemed to have difficulties in using surface features (colour, pattern). In this study, we tested the visual working memory (VWM) for two surface features: colour and luminance in young (6.5-month-old) infants using computer-generated stimuli. First, a preferential-looking study was conducted to determine the luminance difference that is equally salient for a predetermined colour difference. Calibrating iso-salient stimuli is essential for a sound comparison of different featural dimensions. The second step consisted of a VWM test for the iso-salient colour versus luminance pair by using standard looking-time techniques. Infants were capable of recognising objects by colour, but not by luminance, where, crucially, the perceptual differences along those dimensions were equally salient. This demonstrates that infants can use surface features early on and it brings infants' abilities into line with those of adults (Wichmann et al, 2002 *Journal of Experimental Psychology: Learning, Memory, and Cognition* 28 509–520; Sachtler and Zaidi, 1992 *Journal of the Optical Society of America A* 9 877–894). We speculate that the better memory of infants for colour is adaptive, since the colour of an object is a more reliable identifier than its luminance (which is subject to the vagaries of shadows and illuminants).

◆ **Boundary extension: Proportional versus non-proportional transformations in visual memory**

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Boundary extension (BE) is a spatial-memory error in which recall and recognition of depicted scenes reveal an extension of scene boundaries and a reduction of object sizes. In this study,

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we asked whether the transformations of objects and inter-object spaces involved in BE are proportional or not. To investigate how objects and their relations inside the pictorial space are represented in memory, we created four versions of several three-object compositions by combining two views (wide-angle versus close-up) and two object separations (small versus large). Participants were shown a sequence of 32 photographs of such scenes (exposure time: 15 s) and estimated the similarity of 32 comparison pictures shown, in the same order, in the test phase. Comparison pictures derived from four transformations: null; change of spaces between unchanged objects; proportional change of objects and inter-object spaces; non-proportional changes of objects and spaces. We considered several hypotheses: proportional transformation; object minimisation (reduction of figural areas); configural minimisation (reduction of separations between constant objects); scene compression (reduction of object sizes and more-than-proportional reduction of spaces). Data support the proportional-transformation hypothesis and suggest a possible role of object minimisation.

- ◆ **Categorisation learning procedures influence the representation structure of new concepts**
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We evaluated a prototype model and an exemplar model for different procedures of training in a categorisation task. In the categorisation literature, artificial stimuli are always learnt individually, sequentially presented one after another. We examined group presentation of artificial stimuli during the learning phase. The stimuli consisted of artificial sheep, visually distinguishable in features according to the linearly separable 5-4 category structure of Medin and Schaffer (1978 *Psychological Review* **85** 207–238). A group presentation during learning slightly favoured a prototype representation on condition that no individual feedback on exemplars was available (experiment 2). Group presentation with individual feedback still provided an advantage to the exemplar model (experiment 1). The results show that learning procedures could influence the representation of visually distinguishable categories. The fitted results are also in line with the meta-analysis of Smith and Minda (2000 *Journal of Experimental Psychology: Learning, Memory, and Cognition* **26** 3–27). The advantage of the exemplar model lies in the trained stimuli. New stimuli are equally fitted by prototype and exemplar models. A higher sensitivity parameter in the exemplar model explains the fit advantage for trained stimuli.

- ◆ **Long-lasting prism-adaptation aftereffects: Shift in open-loop midsagittal pointing involves more than just visual and proprioceptive components**
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Prism adaptation and its aftereffects are useful tools to investigate how we integrate different spatial maps of various modalities. To dissociate visual proprioceptive, and motor contributions to midsagittal pointing, powerful prism-adaptation training was used for normal subjects, by gradually increasing the leftward optical shift (2°, 4°, 6°, 8°, 10°, 12°, 15°) for 1.25 hours. After-effects were measured up to 7 days. After this prism training, the total shift in open-loop midsagittal pointing without visual feedback (OLP) showed summation of visual shift (VSH) and proprioceptive shift measured by straight head pointing without vision (SHP) for 2 days. However, after 3 days Wilkinson's additive hypothesis ($OLP = -VSH + SHP$) no longer fits the data. Surprisingly, the SHP shifted up to 7 days after training, while shifts in VSH and OLP returned to original level. To remove motor component in SHP, an original method to measure arm proprioceptive midsagittal judgment (PSH) was employed: the arm was passively brought from right and left direction. This revealed that the proprioceptive component disappeared well before the end of SHP. This suggests that generation of aftereffects involves different time scales (minutes, hours, days) of neural plastic mechanisms in different modalities.

MULTISENSORY INTEGRATION

- ◆ **Audio – visual interactions reveal both mandatory and cognitive integrative processes**
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Cross-modal interactions between vision and audition have been demonstrated in both spatial and temporal domains. The direction of such effects is often thought to reflect modality appropriate 'capture', with vision dominating spatial judgments and audition dominating temporal judgments. However, recent studies of spatial localisation have shown that by manipulating relative signal uncertainty in the two modalities, visual dominance can be attenuated (Battaglia et al, 2003 *Journal of the Optical Society of America A* **20** 1391–1397) or even reversed (Alais and

Burr, 2004 *Current Biology* **14** 1–20). We investigated the integration of auditory and visual temporal rate information using a simple rate-discrimination paradigm. The visual stimulus was a flickering LED; auditory stimuli were bursts of white noise, amplitude-modulated by a square wave around a fixed mean intensity. Auditory unimodal discrimination thresholds varied as a function of modulation depth, allowing systematic control of the balance between visual and auditory sensitivity. In cross-modal conditions, observers were required to make rate judgments in one modality while ignoring conflicting rate information presented in the other. Integration weights varied with relative uncertainty, but were significantly biased towards the task-relevant modality. Results suggest a mandatory integrative process where the weighting of information can be substantially influenced by the behavioural goals of the observer.

◆ **No low-level foveal or extra-foveal enhancement of visual sensitivity by auditory stimuli**

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Previous studies have reported enhanced visual detection when visual stimuli are coupled with coincident auditory stimuli. Furthermore, recent cortical-connectivity studies in primates suggest that the degree of audio–visual interaction may depend upon retinal eccentricity (Falchier et al, 2002 *Journal of Neuroscience* **22** 5749–5759). Here we employ a spatial-scaling paradigm to investigate the relationship between visual detection thresholds for a Gabor patch, measured at two retinal locations (0° and 15°), and show a marked but consistent enhancement when sound stimuli are present. This effect may potentially be explained by a heightened visual awareness during auditory stimulus presentation. In order to establish the nature of this enhancement, we conducted an orientation-discrimination experiment where such cognitive factors were minimised. In this second experiment, observers judged the orientation (45° or 135°) of a Gabor patch in the presence or absence of sound. If auditory stimuli increase the perceived contrast of the Gabor patch, observer's performance should improve. The results reveal no difference in contrast thresholds for discrimination, either with or without an accompanying sound. These data suggest that auditory influences on visual performance may be based on a high-level modulation, rather than any low-level amplification of the visual signal.

◆ **The role of audio-visual congruence in discrimination of visual events**

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A previous study [Gerbino, 1997, in *Human and Machine Perception* Eds Cantoni et al (New York: Plenum Press) pp 147–154], in which the launch effect was used [Michotte, 1963 *The Perception of Causality* (London: Methuen)] shows that auditory information affects visual discrimination. Here I investigated the role of audio-visual congruence in time in discrimination of visual events. In the first experiment, a sequence of two continuous sounds (523 and 659 Hz) accompanied the visually moving objects. Two different time gaps (0 or 40 ms) between the stopping of the first moving object and the start of the second one and three different pauses (0, 40, or 200 ms) between the two sounds were used. Participants were asked to discriminate the events only visually. The signal detection theory was adopted. Data analysis showed that the performance of visual discrimination is worse when the auditory information is physically congruent with the visual event. When the pause between the two sounds is 200 ms, the performance improves. In the second experiment I used an undiscriminable visual time gap (0 or 10 ms) to demonstrate that auditory information is not enough to improve the performance. I conclude that the visual discrimination is largely influenced by the global structure of events.

◆ **Time alignment for visual and auditory stimuli**

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Simultaneous changes in stimulus attributes (such as motion or colour) are perceived to occur at different times, a fact often attributed to differences in neural processing times for those attributes. However, other studies suggest that the perceptual asynchrony is not due to attribute-specific latencies, but to the type of change: first-order or second-order. To test whether this idea generalises across modalities, we studied perceptual synchrony of acoustic and visuo-acoustic cross-modal stimuli, caused to vary in a first-order or second-order fashion. First-order changes could be an abrupt change in tone intensity or frequency, or spatial position, while a second-order change is an inversion of change direction, such as a turning point when a rising tone or a visual blob starts falling. For pure acoustic and cross-modal stimuli, first-order changes were perceived before

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second-order changes (by 70 to 150 ms). However, temporal alignments of pairs of first-order or second-order changes yielded little or no perceptual asynchrony (no more than 40 ms) regardless of the attribute or modality involved. This shows that perceptual synchrony is not determined solely by neural latencies, and points to a role for complicated and little-understood temporal markers in stimulus alignment.

◆ **Visual exploration and attention distribution in motion sickness**

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Motion sickness (MS) is a discomfort that occurs during real or simulated passive displacements. If perception includes an anticipation of action consequences, MS could be linked to the violation of expectation principle. This hypothesis was tested by simulating a passive displacement in a virtual environment. We compared a measure of MS in participants controlling their virtual gaze movements (self-directed visual exploration task) to that in participants whose exploration was under the experimenter's control. We also tested whether the simulation background noise and commentary (auditory information) could generate MS according to a specific attentional demand (double task). Results showed that MS increases during the exposure to the simulation and depends on the attentional demand. A higher degree of MS occurs after only 150 s of simulation when participants do not control their gaze. First, it is reasonable to assume that motion sickness is highly linked to the participants' ability to make correct perceptive expectations and anticipations of their own visual exploration. Second, auditory attentional demand or distraction seem to modulate the massive effect of visual information and visuo-proprioceptive conflicts on motion sickness.

◆ **Visual – auditory fusion and frames of reference**

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From investigations of multisensory spatial interaction mostly based on selective localisation tasks underlying cross-modal bias phenomena, vision appears as the predominant modality in visual – auditory space perception. Recent studies assessing tolerance to spatial disparity between visual and auditory stimuli in azimuth and elevation (Godfroy et al, 2003 *Perception* **32** 1233 – 1245) have shown that perceptual fusion was, conversely, essentially determined by the less accurate modality (ie audition). The question arises what are the relative contributions of visual and auditory reference frames (respectively, oculocentric and craniocentric) to perceptual fusion. The effect of referential dissociation was investigated in a visual – auditory fusion task in two dimensions. A broadband noise burst and a 1 deg spot of light, 500 ms duration, were simultaneously presented with a random spatial disparity. Participants had to judge about their unity. Spatial dissociation between the visual and the auditory references was introduced as an independent variable. The subject's head was maintained and the gaze, under eye-tracker control, oriented either straight ahead or 20° laterally shifted. Results showed that fusion thresholds varied, according to the referential positions (superimposed or dissociated). They support evidence that reference frame for visual – auditory space is neither visual, nor auditory, but results from cross-modal dynamic interaction.

◆ **Noninformative vision improves haptic recognition of a scene**

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We examined whether providing noninformative vision would help improve haptic scene recognition. In experiment 1, we used a factorial design to compare scene recognition performance across two groups of participants, one blindfolded and the other able to view their surroundings. We also tested performance across changes in rotation of a scene in order to investigate whether noninformative vision provides an allocentric reference frame for encoding haptic scenes. We found that the noninformative vision group performed significantly better at our haptic scene recognition task than the blindfolded group. When the blindfolds were removed, haptic scene perception did not improve. Interestingly, performance was better to familiar orientations of the scene for both groups, suggesting that spatial layout of objects is encoded according to an egocentric reference frame for both vision and touch. Previewing the laboratory did not affect performance in the blindfolded condition (experiment 2). Our findings suggest that vision helps locate the hand in space which in turn improves the encoding of spatial layout. They also demonstrate the influential role of vision in the encoding and representation of familiar objects through touch.

◆ **Feeling what you hear: Auditory signals can modulate the perception of tactile taps**

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Investigating multisensory integration, Shams et al (2000 *Nature* **408** 788) recently found that the number of perceived visual flashes could be altered by a sequence of beeps presented simultaneously. Here, we tested whether auditory sequences of beeps can modulate the tactile perception of sequences of taps (2 to 4 taps per sequence). In experiment 1, the auditory and tactile sequences were presented simultaneously. The number of beeps delivered in the auditory sequence was either the same as, less than, or more than the number of tactile taps. Though task-irrelevant (subjects were instructed to focus on the tactile stimuli), the auditory stimuli significantly modulated subjects' tactile perception. Such modulation occurred only when the auditory and tactile stimuli were structurally similar. In experiment 2, we tested whether auditory-tactile interaction depends on simultaneity or whether a bias can be evoked without temporal overlap between the auditory and tactile sequences. Audition significantly modulated tactile perception when the stimuli were presented simultaneously, but this effect gradually disappeared when a temporal asynchrony was introduced between auditory and tactile stimuli. These results show that when provided with auditory and tactile signals that are likely to be generated by the same stimulus, the brain tends to automatically combine these signals.

◆ **Visuo-tactile cortical network defined on graph-theoretical ground**

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Cross-modal integration, similarly to other functions of the cerebral cortex, is based on parallel distributed processing across the cortical areas. However, the elements of such a cross-modal network and their relationships have not been exactly defined. We analysed the connectional pattern and topographical arrangement of visual and somatosensory cortices of primates to identify areas involved in visuo-tactile integration and to characterise the architecture of the network of these areas using graph-theoretical methods. Visuo-tactile network is characterised by a high incidence of nonreciprocal connections (82.4%). The network is densely connected with all areas separated by short distances. Areas 7b/MT/7a/LIP/46/FEF occupy a central position in the network. This was confirmed by multi-dimensional scaling and cluster analysis in the whole set of visuomotor and somatomotor areas. MT was the most frequently occurring area in cliques defined by mutual connections between the areas. Virtual lesions further supported the central role of MT in the formation of cliques. The shortest paths from early somatosensory cortices to early visual areas V1/V2 were through MT from areas 3a/1/2. These results suggest a central role for MT in visuo-tactile integration and in cross-modal compensational plasticity.

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◆ **Differences in visual perception of 'Mach's Figure' contingent on touching solid figures**

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Two types of solid figure imaging 'Mach's Figure' were used: one (F1) was made of wooden frames with no surfaces and no edge, the other (F2) was made of wooden plates with two surfaces and one edge. In the first experiment, subjects watched F1; 28% of them could perceive the differences of shading on the two surfaces and the edge, but the others could not. In the second experiment, subjects were divided into two groups: one (G1) watched F1 touching another F1, and the other (G2) watched F1 touching F2. 26% of the G1 group and 56% of the G2 group could perceive the differences of shading on the two surfaces. The conclusion is that the subjects of the G2 group developed their perception of shading and edge more than those of the G1 group. The difference was statistically significant.

◆ **Contribution of balance training in the rehabilitation of age-related macular degeneration patients**

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The balance involves three sensory systems: visual, vestibular, and somesthetic. With aging, the efficiency of sensory and motor functions decreases, resulting in falls. In addition to central

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visual loss, two-thirds of patients with age-related macular degeneration (AMD) present balance deficits. Balance can be restored by training. Brain plasticity allows sensory reorganisation in young people but also in the elderly. We investigated first the effect of AMD on balance, and then studied the effects of multi-sensory training on postural stability and sensory organisation in elderly adult controls and in AMD patients. In these patients, the impact on stabilisation of an eccentric retinal fixation was measured. We carried out balance training on a postural platform (Multitest), stressing sensorimotor coordination by selectively inhibiting or stimulating either visual, vestibular, or somesthetic information. Blocking inputs from a system forces subjects to rely more heavily on other systems. Producing a conflict between two systems leads to reinforcement of the other system. We expect that an improvement of the visuo-vestibulo-proprioceptive loop will shorten rehabilitation procedures. Preliminary results indicate that balance training leads to a sensory reorganisation, and for AMD patients improves visual information integration used in stabilisation of eccentric fixation and visually guided movements.

◆ **Effects of rotation speed of yaw, roll, and pitch on visually induced motion sickness**

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We investigated the effect of rotation speed on visually induced motion sickness, with a moving image virtually simulating yawing, rolling, and pitching. To do this, we virtually produced a rectangular solid in which the observer's vantage point was centrally located. The visual stimulus ($82 \text{ deg} \times 67 \text{ deg}$) was such that observers virtually rotated along any of the three axes: yaw, roll, and pitch. Rotating speed was one of six in a range from 2.6° to 360° s^{-1} . The inner wall of the rectangular solid was set so that an ordinary room was simulated (RR condition), or a room textured with random dots (RD condition). Observers' task was to subjectively evaluate motion sickness and also the intensity of vection on eleven values on a scale. The results showed that: (a) the average subjective scores of motion sickness across observers showed the highest value at around 30° to 60° s^{-1} regardless of rotation axes; (b) the highest subjective score of motion sickness was obtained with rolling, pitching, and yawing in this order; and (c) the average subjective scores of vection intensity across observers showed the same tendency as those of motion sickness. We postulate that counterbalancing information on vision and vection yields the highest subjective scores.

◆ **Role of perceptive expectations and structural visual flow on motion sickness**

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The aim of the study was to understand how motion sickness (MS) is linked to simulated visual flow according to perceptive expectations. The structure of visual flow was altered by both observation and fixation point. This visual information could yield a conflict between expectations (based on visual invariants) and sensorial signals that lead to MS. In the experiment, a virtual scene depicting an observer walking around three trees on a circular path was projected on a large screen. Participants were instructed to look at a particular tree and repeatedly estimated their motion sickness. Visual flow was modified by using different virtual camera fixations (path centre or not, always corresponding to one of the trees). The perceptive expectations of the participants were modified by asking them to look at the tree that was not fixed by the camera. Results indicate an increase of MS over time. Postural data show an effect of the fixation point congruence; participants are more unstable when they look at the tree not fixed by the camera. These results suggest that perspective expectations are involved in MS appearance.

◆ **Can synaesthetic tendencies be grasped in the preattentive task?**

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Synaesthetic tendencies have been studied by means of the semantic differential technique. By the affect primacy hypothesis (Zajonc, 1980 *American Psychologist* **35** 151–175), affective processes take place preattentively, without conscious cognitive analysis of the stimulus. We investigated the synaesthetic tendencies in preattentive process with the use of the affective priming task. We created 4 computer-generated abstract forms associated with the emotional words such as happiness, surprise, sadness, and anger by the word–form association method. As prime stimulus in the affective priming task, we used those forms, the 4 emotional words, and 4 prototypical schematic facial expressions corresponding to those words, reported by Yamada (1993 *Applied Cognitive Psychology* **7** 257–270). As target stimuli, we used these facial expressions and these

forms. We asked participants to judge the affective tone of target, whether the target looked pleasant or unpleasant, as well as active or inactive, one at a time as quickly as possible. The affective priming effect was observed in the judgment of pleasantness, which means the facilitation of reaction time, irrespective of stimulus attribute. We can study this in relation to synaesthesia.

SACCADES

◆ Remembering a location affects saccade trajectory

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Previous research has shown that saccade trajectories are affected by the presence of visible stimuli (eg Godijn and Theeuwes, 2002 *Journal of Experimental Psychology: Human Perception and Performance* **28** 1039–1054). In the current study we asked whether maintaining a location in spatial working memory can also affect saccade trajectory. Subjects were instructed to fixate at a central point and make a saccade in the direction of an arrow to a target: up or down. At the same time, subjects had to remember the location of a previously presented circle. Eye-position data were recorded and angular deviations of saccade trajectory were analysed. It was found that the eyes curved away from the memorised location when the memory task coincided spatially with the direction of the saccade. This can be interpreted as a link between visual working memory, attention, and eye movements. We argue that curvature is the result of the need to inhibit memory-based eye-movement activity in the superior colliculus, in order to allow an accurate saccade to the visual target. Where previous research has shown that the eyes may deviate away from visually presented stimuli, we show that the eyes also curve away from remembered stimuli.

◆ Eye movements and the natural image statistics as seen by VI

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Gabor-type models of VI neurons are often used to study the relationship between statistical properties of natural images and the characteristics of those neurons. However, such studies have not taken into account the non-uniform sampling due to eye movements. Twenty-five subjects viewed a set of 70 calibrated natural images (8-bit grey scale—van Hateren et al, 1998 *Proceedings of the Royal Society of London, Series B* **265** 359–366), presented for 5 s each (VSG 2/5). Eye positions were recorded at 60 Hz with an infrared eye tracker. Local oriented contrast was calculated at all locations in the 70 images with the use of 80 Gabor operators (8 orientations, 5 spatial scales, even/odd) whose output was normalised with their respective Gaussian envelope to give contrast. The results indicate: (i) dominant orientations and spatial scales at fixated locations follow the distributions obtained with random sampling, but a bias toward horizontal and vertical orientations is apparent; (ii) fixated positions avoid equivalent Michelson contrasts below 20%–25%. This adds weight to the argument that any realistic estimate of the visual diet and its impact on neuronal coding must take eye movements into account (Martin et al, 2003 *Perception* **32** Supplement, 168).

◆ Intrasaccadic gamma EEG in blindfolded subjects: Saccade-direction-dependent hemispheric differences

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We investigated if the direction of voluntary saccades is associated with hemispheric gamma power differences. Ten subjects were studied. Twelve EEG channels over the posterior cortex and horizontal EOG were recorded. For better saccadic accuracy measures, EOG was calibrated against infrared scanning (ISCAN). Saccades were executed between two markers 17.5–17.5 deg from midline. Perisaccadic EEG was analysed in four time windows (pre-saccade, two intra-saccades, and post-saccade). Gamma power (38.4 Hz) was evaluated by applying continuous wavelet transform followed by Hilbert transform. General linear model for ANOVA was used. Contrasts given by higher-level ANOVA interactions were used to determine saccadic-direction-dependent hemispheric differences for 5 homologous electrode pairs. Saccade direction and electrode position interaction was found to be significant ($F_{11,57000} = 2.39$, $p = 0.0060$). Contrasts for electrode pairs were significant in the first half of the saccade (parieto-temporal electrode pair, $p = 0.0026$), in the second half (lateral occipital electrode pair, $p = 0.0346$), and after the saccade (lateral occipital electrodes, $p = 0.0313$; medial occipital electrodes, $p < 0.0001$).

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We conclude that, in the absence of visual input saccade, direction-dependent hemispheric difference shifts from parietal to occipital electrodes as the saccade progresses. The results suggest an intrinsic role of gamma in updating visual space representation, or in shifting visuospatial attention.

◆ **Intrasaccadic perception of gratings with low and high spatial frequency**

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A static vertical grating briefly displayed during a horizontal saccade is perceived either as moving against the saccade direction [at low spatial frequencies (SFs)] or as a static blurred image (at high SFs) (Castet et al, 2002 *Proceedings of the National Academy of Sciences of the USA* **99** 15159–15163), suggesting an intact ability of the visual system to process intrasaccadic stimulation. To investigate further intrasaccadic processing, we tested the ability of observers to discriminate two intrasaccadic vertical gratings (duration: 18 ms) separated by a short temporal delay (12 ms), thus producing slightly different retinal temporal profiles. Each of the two gratings was displayed on one half of the screen (2AFC). The two gratings had the same SF. With low SFs ($0.18 \text{ cycle deg}^{-1}$), observers reported which of the two gratings produced the strongest motion percept, while with high SFs ($1.81 \text{ cycles deg}^{-1}$), they reported which of the gratings was most blurred. Off-line analysis of ocular movements allowed us to assess the temporal course of performance. Results show that: (a) observers are remarkably good at these discrimination tasks; (b) the temporal course of performance is not the same for the two different SFs, indicating that observers use visual cues based on the retinal spatiotemporal content of intrasaccadic stimulation.

◆ **Saccadic suppression of motion of the entire visual field**

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During visual exploration of a natural scene, saccades must be used to direct the fovea to areas of interest in the scene. During these saccades, images of objects will be streaming across the retina at hundreds of degrees per second. Despite this disjoint motion of the retina, the world does not appear disjoint or unstable, and motion blur during saccades is not apparent. Sensitivity to many visual stimuli is known to be reduced during a change in fixation compared to when the eye is still. For example, motion of a small object is harder to detect during a saccade than during a fixation. We asked whether this saccadic suppression generalises to suppression of motion of the entire visual scene. Eye movements were measured with a video-based eye tracker. Saccade-contingent translations of 0.4, 0.8, or 1.2 deg were imposed on wide-field-of-view images of natural scenes. The changes were seldom noticed during saccades and detection rate for the smallest translation was just 6.25%. Qualitatively, even when trans-saccadic scene changes were detectable, they were less disturbing than equivalent changes in the absence of a saccade.

◆ **Stimulus-driven and goal-directed control in saccadic target selection**

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Three experiments were conducted to investigate the role of stimulus-driven and goal-directed control in saccadic eye movements. Participants were required to make a speeded saccade towards a target defined by a unique orientation presented concurrently with multiple non-targets and one distractor singleton. The relative salience of the target and distractor singleton was manipulated within a dimension (orientation) or across dimensions (orientation and colour). The results uniformly demonstrated that fast eye movements were completely stimulus-driven, whereas slower eye movements were goal-directed. Furthermore, slow eye movements were not affected by target or distractor salience suggesting that no contingency exists between stimulus-driven and goal-directed influences. The results are in line with models that assume that oculomotor behaviour is controlled independently by stimulus-driven and goal-directed processes, operating in different time windows.

◆ **The remote distractor effect in saccade programming: Long-range channel interactions and lateral inhibition**

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When a distractor appears in close temporal proximity to a target, the target-directed saccade is delayed. We explored the role of spatial-frequency (SF)-specific visual channels in the generation

of this remote distractor effect (RDE). A target Gabor patch appeared at 4° or 8° eccentricity on the horizontal midline. On the majority of trials a contralateral distractor appeared simultaneously with the target. The task of the observer was to saccade to the target (saccade direction was blocked). In various experiments, SF contents of the target and distractor were systematically manipulated. We obtained a robust RDE with low-to-medium SF distractors ($1-4$ cycles deg^{-1}), regardless of the SF of the target ($2, 4,$ or 8 cycles deg^{-1}). A similar distractor effect was obtained with high-SF distractors (8 cycles deg^{-1}) only when the target was of the same SF. We propose a neurophysiologically plausible framework to explain these results. The framework is based on SF-tuned, long-range interactions at the level of the visual channels, and lateral inhibition between target and distractor activity at the level of an oculomotor decision unit.

SEARCH

◆ **Category effects in visual search for colour: Evidence from eye-movement latencies**

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Categorical perception (CP) is shown when stimuli from the same category (within-category) are discriminated slower or less accurately than equivalently spaced stimuli from different categories (between-category) [Harnad, 1987 *Categorical Perception: The Groundwork of Cognition* (New York: Cambridge University Press)]. The nature of CP is under debate (Pilling et al, 2003 *Memory & Cognition* **31** 538–551). If CP is perceptual, then CP should affect visual search. This was tested in two experiments. In experiment 1, adults eye-movement latencies to a coloured target defined by chromatic difference from the background were on average 40 ms faster when the target and background were between-category rather than within-category. In experiment 2, eye-movement latencies to a single target, with varying number of distractors, were on average 118 ms faster when the target and distractors were between-category rather than within-category. For both between-category and within-category conditions, eye-movement latencies did not increase as the number of distractors was increased, indicating parallel search for both conditions. The within-category search slope (15 ms) and between-category slope (2 ms), did not differ significantly. These results suggest that CP affects the time taken to detect a target but not the type of search strategy used.

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◆ **Visual search for a motion singleton among coherently moving distractors**

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We tested whether search for a visual motion singleton presented among several coherently moving distractors can be more efficient than search for a motion stimulus presented with a single distractor. Under a variety of different conditions, a multitude of spatially distributed and coherently moving distractors facilitated search for a uniquely moving target as compared with a single motion distractor (experiments 1, 2, and 4–6). Colour coherences among static distractors were not equally effective (experiments 2 and 3). Results confirm that humans are highly sensitive to antagonistically directed motion signals in backgrounds as compared with spatially more confined regions of visual images.

◆ **Visual search and foraging compared in an automated large-scale search task**

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A number of researchers have argued that visual search is a valid model for human foraging. Here, we introduce a novel automated foraging apparatus that enables a direct comparison between visually guided foraging (as studied in visual search tasks) and foraging that is not based upon a visually distinct target. The foraging room consisted of a grid of 49 search locations, each containing two coloured lights and a switch. The room was devoid of obvious landmarks. In three conditions, participants searched for a target defined by (i) a single feature (red target amongst green distractors); (ii) the absence of a feature (green target amongst red and green distractors); and (iii) participants foraged for a target that was only visible once the switch was activated. Visually guided foraging (conditions i and ii) followed the pattern found in conventional visual search: feature searches had equal latencies across display size, whereas feature-absent searches were longer as the number of distractors increased. In comparison, non-visually guided foraging resulted in far longer latencies that rose markedly with display size. This demonstrates the important distinction between visually guided and non-visually guided foraging processes, and established a paradigm for the study of foraging in humans.

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◆ **Effects of phenomenal transparency in visual search**

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We investigated, using the visual search paradigm, whether phenomenal transparency has an effect on the recovery of superimposed surfaces. A stimulus was composed of long and short bars. Three stimulus configurations were made: (i) short vertical bars overlapped long horizontal bars, (ii) short horizontal bars overlapped long vertical bars, and (iii) long vertical bars overlapped long horizontal bars which appeared as a grid. The appearances (ie transparency versus opacity) of overlapped parts were adjusted with the use of a gray-level control. Observers were required to detect a transparent intersection among opaque intersections in the transparent-target condition or an opaque intersection among transparent intersections in the opaque-target condition. The search displays consisted of 9, 16, or 25 intersections. Six search tasks (three configurations \times two target conditions) were run. In any configuration, the result of search efficiency (the slope of reaction times \times display-size function) was asymmetrical between target conditions: the transparent target (5.75 ms item⁻¹) versus the opaque target (29.85 ms item⁻¹). The results suggest that phenomenal transparency has perceptual ambiguity for the recovery of overlapping surfaces when the transparency exists as distractors in the visual search.

◆ **Conjunction search with motion and stereo depth is harder with smaller set size**

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Conjunction-search performance for motion versus stereo depth was investigated. It was assumed that the search time for a conjunctive target would increase with the set size if the two cues were processed serially, or would not change if processed in parallel. However, the results showed neither. Stimuli consisted of 6 or 12 Gabor patches, equally spaced on a circumference of 1.5 deg in radius. The patch size was 0.6 deg with spatial frequency of 2.5 or 5.0 cycles deg⁻¹, and the stimuli moved at either vertical, 45°, horizontal, or 135° direction, with a speed of 7.5 deg s⁻¹. Half of the patches were presented on a 5 min crossed disparity, moving to one direction. The other half were on a 5 min uncrossed disparity, moving in the opposite direction. The target was the patch moving in the opposite direction to the others in either depth. The subjects were required to respond as soon as possible whether there was a target or not. The search time was found to be longer in the smaller set size (6) than in the larger set size (12) for all three naïve subjects and a trained subject. The results show that the present conjunctive search requires stereo grouping before motion search.

◆ **Visual search of contrast modulation**

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To detect contrast modulation, a mechanism describing distribution of activity of filters which are selective for brightness modulation is needed. The nature of this mechanism (preattentive or attentive) can be defined by using the visual-search task. In our experiments, distractor stimuli were random-dot patterns with 1 deg diameter and constant contrast. The target stimulus was the same pattern with the contrast modulated by a circular Gabor function. The target and the distractors had the same average brightness and the same spatial-frequency spectrum. The number of stimuli presented simultaneously varied from 2 to 10. Subjects looked for the target stimulus among distractor stimuli. The slope of the function relating reaction time to the number of items was found to be near zero (about 3 ms per item). Similar results are typical when the visual search is parallel to one that is preattentive (Treisman and Gelade, 1980 *Cognitive Psychology* 12 97–136). It has been established that the reaction time increases at a rate of about 25–35 ms per item when the visual search is successive (Kwak et al, 1991 *Perception & Psychophysics* 49 473–480). Our results show therefore that the detection of contrast modulation is realised preattentively.

VISUOMOTOR CONTROL

◆ **Visual information of both target object and moving hand in the early phase of prehension affects the control of grasping**

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We investigated the role of visual information provided by the target object and the moving hand of the participant in the early phase of prehension. We manipulated separately the visibility of the moving hand and of the object using two liquid-crystal shutter plates. Two conditions of

the view of the hand during a trial were designed: the hand-visible condition (HV) and hand-invisible (HI) condition. We manipulated the amount of time in which the participant could not use the view of the target object after movement initiation. Three timings were adopted, 0 ms (0T), 150 ms (150T), and 350 ms (350T). These six viewing conditions (hand \times target) were tested randomly. Participants were told to reach for and grasp a cylinder. The duration of movement was controlled (approximately 1000 ms). The results showed that maximal finger apertures (MFAs) in HI/150T and HI/350T were significantly larger than those in HV/150T and HV/350T, respectively. Target-invisible time also affected MFA; MFA at 350T was significantly larger than that at 150T. The present study demonstrates that visual information about both the hand and the target is critical during a relatively early phase of grasping control.

◆ **Alcohol selectively impairs countermanding of automatic corrective movements**

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There are several studies of the effect of alcohol on controlled and automatic processes. However, none has examined these effects in the visuomotor domain. Here, we employed a countermanding paradigm in order to compare the effects of alcohol consumption on automatic visuomotor corrections, and the ability to countermand corrective movements. Separate groups of subjects were assigned to correction and countermanding conditions. In the correction condition, subjects were asked to point at a series of LED targets. On some trials, movement initiation triggered a displacement of the target to a new location. On these trials, subjects were instructed to amend the trajectory of their movements in order to account for the new target location. In the countermanding condition, subjects were asked to terminate their movements in response to target displacement. All subjects took part in both alcohol (0.08% BAC) and no-alcohol sessions, which were run on separate days. Subjects were able to make corrective movements to target displacements equally well in the alcohol and no-alcohol conditions. In the countermanding condition, however, subjects in the alcohol group were less effective at terminating their movements in response to target displacement. These data suggest that alcohol selectively impairs controlled processes in the visuomotor domain.

◆ **Alpha power of the brain correlates with optokinetic nystagmus**

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Optokinetic nystagmus (OKN) is a reflexive periodic eye movement which helps to hold the image of a moving target on the fovea. While in frog this mechanism is controlled by the tectum and OKN is maintained while a rotating drum is moving, in man OKN is controlled not only by the brainstem but also by cortical structures. In man OKN is influenced by orientation, attention, and fatigue. We assumed that human OKN appears predominantly in relaxed state. Attentional state can be estimated by the measurement of relative alpha power of the EEG. Analysis of the two physiological parameters provides clarification of structural and functional backgrounds of OKN. We examined OKN in parallel with EEG of the posterior part of the brain in five healthy subjects. We stimulated OKN with a computerised rotating drum and registered eye movements and brain activity. OKN and EEG recordings were analysed mathematically. The relative alpha activity decreased directly before OKN, whereas at the beginning of OKN alpha activity increased on posterior channels. When OKN became irregular, alpha power also decreased. Alpha synchronisation correlates with the augmentation of OKN, and alpha desynchronisation correlates with the exhaustion of OKN.

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LETTERS AND READING

◆ **Can crowding and repetition-priming effects account for facilitation of initial, medial, and terminal letters in visual-search tasks?**

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When searching for a target amongst a random five-letter string, response time and accuracy is typically facilitated for skilled readers of English when the target appears in the initial, medial, and terminal positions. The resulting M-shaped function is specific to letters, as other shapes generate a U-shaped function (Green et al, 1996 *British Journal of Psychology* **87** 311–326). We investigated if facilitation occurs from (1) less crowding of exterior letters, and (2) repetition priming of the medial letter, by varying (i) the nature of the visual stimuli (letters versus shapes) and (ii) the modality of the target-letter cue (visual versus auditory), in three visual search tasks, given to three groups of skilled readers. Results showed an M-shaped function was generated when the visual target was preceded by either a visual or auditory (as a spoken letter name) cue compared to a U-shaped function for other shapes. This suggests that (a) facilitation of the initial and terminal letters does not result from reduced crowding as other shapes are disadvantaged in these positions; and (b) facilitation of the medial position does not arise from repetition priming as the medial letter is advantaged even when the target is preceded by an auditory cue.

◆ **Band-limited noise suppresses contour perception not only of letters but of any objects**

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Band-spectrum noise has been shown to suppress the visual perception of printed letters. The suppression exhibits a specific dependence on the spatial frequency of the noise, and the frequency domain of most-effective inhibition has been related to the letter size (Solomon and Pelli, 1994 *Nature* **369** 395–397). In a series of psychophysical experiments, we demonstrated that the effect is not specific to the recognition of letters, but also applies to other objects and even to single bars. We also showed that the frequency domain of most effective inhibition depends on the letter stroke width rather than on the letter size (Petkov and Westenberg, 2003 *Biological Cybernetics* **88** 236–246). We attribute the observed effect to non-classical receptive field (non-CRF) inhibition in visual area V1 (Nothdurft et al, 1999 *Visual Neuroscience* **16** 15–34). We introduce a computational model that is based on a Gabor-energy filter extended by surround suppression. The results of computer simulations show a dependence of the inhibition effect on the spatial frequency of the noise that is similar to the one measured in the psychophysical experiments and confirm the hypothesis for a possible functional role of non-CRF inhibition in the observed suppression effect.

◆ **Evidence for serial and global encoding of letter identity and position in a visual-search task by skilled and dyslexic adult readers**

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Letter processing is qualitatively different from that of other visual shapes (Hammond and Green, 1982 *Canadian Journal of Psychology* **36** 67–82). When detecting a target letter (or shape) in a visual array of five different letters (or shapes), skilled readers of English produce an upwards sloping M-shaped function for letters but a U-shaped function for other shapes. We investigated the underlying nature of the linear (upwards sloping) and quartic (M-shape) components characterising visual letter search by administering a letter-search task to three groups of adult readers with varying reading abilities: skilled readers ($N = 28$); surface dyslexics ($N = 12$) with poor whole-word reading; and phonological dyslexics ($N = 12$) with poor sub-word reading. Results showed that both skilled readers and surface dyslexics produced significant linear and quartic components, although the slope direction differed across groups. In contrast, only the quartic component was significant for phonological dyslexics; no significant linear component was exhibited. We suggest the visual letter search function arises from two distinct reading processes: the linear component stems from serial decoding of letters in a systematic left to right direction, whereas the quartic component reflects global processing of letter strings at the whole-word level, consistent with dual-route models of reading.

◆ **Role of configurational structure in perceptual organisation of Chinese characters**

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We have demonstrated previously that configurational structure plays a greater role in the visual similarity of Chinese characters than has been hitherto considered (Yeh and Li, 2002 *Journal of Experimental Psychology: Human Perception and Performance* **28** 933–947). For the five structure types [L-shaped, P-shaped, enclosed (E), horizontal (H), and vertical (V)], Americans could perceive the first three with the aid of salient structural components but not the last two (Yeh et al, 2003 *Visual Cognition* **10** 729–764), suggesting that the extraction of structure involves both top–down and bottom–up processes. Here, we further examined whether these two subgroups of structure, (L, P, E) versus (H, V), were processed differently during early formation of perceptual organisation in perceiving Chinese characters. The microgenesis analysis of the primed-matching paradigm was used to explore the time course of the formation of the five structure types. A prime character or a neutral pattern was presented first, followed by two target characters after different SOAs. Participants made speeded judgments whether the target characters matched. The results clearly showed different patterns for the two subgroups of structure, indicating differences in extracting structural information during early formation of perceptual organisation for Chinese characters.

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◆ **The contrasting demand for Chinese and alphabetic scripts: Automatic semantic activation by phonetic components in Chinese character recognition**

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The majority of Chinese characters can be classified as phonetic compounds that include a meaning-conveying semantic component and a sound-conveying phonetic component. Past studies have mainly focused on whether, how, and when the phonetic component provides the phonological cue in character recognition. We asked, instead, whether the phonetic component also automatically activates its semantic representation. As the meaning of the phonetic component (if present) is different from that of the character, its activation should lead to interference and should thus be avoided, unless it has become automatic and is unavoidable. We used a Stroop colour-naming task and found robust Stroop effects for compound characters containing a phonetic component that has a meaning related to colour when the character as a whole is unrelated to any colour names in either pronunciation or meaning. Several confounding factors were ruled out. Because the sublexical processing in alphabetic systems seems to be a purely phonological event (eg no priming effect between boycott and girl in English and Dutch), the strong evidence we provide here for the automatic semantic activation of the phonetic component in Chinese characters reflects one contrasting demand between Chinese and alphabetic scripts.

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◆ **Are Chinese characters picture-like?**

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We examined whether Chinese characters are like pictures in the sense that the form-meaning relationship is much closer than that in English, when using the repetition blindness (RB) paradigm. RB occurs when the second instance of a repeated item is undetected owing to the failure to create or stabilise the second spatiotemporal token for the same type. Previous studies found RB for semantically related pictures, but not when these items were presented as English words. Meaning thus seems necessary for picture identification, whereas word recognition proceeds too quickly on the basis of orthography for its meaning to exert any effect. On this basis, we examined whether Chinese characters are processed like pictures or like English words (Reeves and Harris, personal communication). If Chinese characters are like pictures, RB should be found when the two critical characters are synonyms. In four experiments, series of characters (or two-character words) and symbols were presented in rapid serial visual presentation, and participants were asked to write down or articulate the characters (or words). Robust RB was found for orthographically identical characters, but not for synonyms. This indicates that Chinese characters are processed more like English words than like pictures.

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◆ **Capacity limitations in the perception of letters**

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Comparing the performance of observers under the conditions of successive and simultaneous presentation of visual stimuli can reveal capacity limitations of information processing (eg Duncan, 1980 *Psychological Review* **87** 272–300). In earlier studies, no or relatively small differences have been found between successive and simultaneous presentation of alphanumeric characters. Usually, small sets of letters (2 and 4) have been used in these studies. Here, I used a visual-search experiment where observers had to detect a target letter among 4, 8, or 12 random letters. The letters were presented briefly (20–100 ms) either simultaneously, or in two successive groups with an interval of about 1 s. Sensory factors (eccentricity, lateral masking) were held approximately equal across the two conditions. A very large advantage of successive presentation was found for set sizes of 8 and 12 letters. The results support the view that there is a processing capacity limit on average of about 4 letters per brief presentation (which is curiously similar to the estimated capacity of visual short-term memory).

◆ **how important is punctuation**

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It seems clear that some punctuation is necessary for quick and clear reading if a full-stop at the end of a sentence and the capital at the beginning of the next are omitted this may make it difficult to read. recently, however, there has been a trend for email messages to lack capitalisation but perhaps use full stops. does this affect reading speed and comprehension or doesn't it matter? we measured reading speed in passages 222–227 words in length written in 7 different punctuation styles. These were: (i) all punctuation, (ii) mid-sentence punctuation and capitals removed, (iii) mid-sentence capitals removed, (iv) all punctuation and capitalisation apart from full stops removed, (v) full stops removed, (vi) initial capitals removed, (vii) all punctuation and capitalisation removed. We used forty-two subjects in all, and both fast and natural reading speeds. In all cases removing punctuation reduced reading speed, to differing levels of significance. Either full-stops alone (fast condition) or full-stops and initial capitals (natural condition) were necessary for maximum reading speed in each condition. This suggests that some form of sentence delineation is important in achieving maximum reading speeds.

[Supported by the College of Optometrists.]

◆ **Recognition sensitivity in homonymous hemianopia**

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Brain infarct is a common cause of visual field loss. However, it is possible to improve vision with intensive long-lasting training. We studied how well form perception improved in hemianopic patients. Two men with hemianopia participated in the experiments. Subjects were trained with luminance flicker, presented on a computer screen, twice a week during one year. Eccentricities of 10° and 30° in the hemianopic visual field were trained. Recognition sensitivity was measured with flickering letters T, L, H, and U. Letter size was 4 deg. Eye movements were monitored with a video camera. Before training, neither of the subjects was able to recognise flickering letters at 10° eccentricity. After 31 sessions, the recognition sensitivity of subject 1 became equal to that of the normal half-field and that of subject 2 in 50th session at 10° eccentricity. However, their recognition sensitivity improved still with time. After a training period of one year, both men could recognise flickering letters in their hemianopic field as well as in the normal half-field even at the eccentricity of 35°. The results suggest that not only flicker detection, but also form perception can be improved with flicker training.

◆ **An ERP study of featural and abstractive repetition priming of written names in the cerebral hemispheres**

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We assessed hemispheric differences in feature-specific and abstractive repetition priming for the names of famous persons. Participants performed speeded familiarity judgments for famous and unfamiliar names. Centrally presented famous target names were preceded by primes (150 ms) in the left or right visual field (LVF or RVF). Primes were either the same name as the target, the same name in a different font, or a different name (unprimed condition). For RTs,

left hemisphere (LH) superiority was strong for abstractive priming across fonts, but was reduced to insignificance for feature-specific priming. We observed 3 topographically different ERP modulations of priming for target names. A small posterior N200 (160–220 ms) and a reduced N400 (300–500 ms) were seen for primed names. In addition, a left temporal negativity between 220 and 300 ms (N250r) exhibited abstractive priming for RVF primes, but more feature-specific priming for LVF primes. With respect to previous findings that these ERP components reflect facilitation at the levels of font-specific encoding, lexical entries for names, and semantic integration, respectively (Pickering and Schweinberger, 2003 *Journal of Experimental Psychology: Learning, Memory, and Cognition* **29** 1298–1311), these findings suggest a LH superiority for name processing, which is particularly pronounced for the access to abstractive lexical entries for written names.

MOTION

◆ **Kansas**

L M Nolan, J Intriligator¶, A Gilchrist§ (School of Arts and Social Sciences, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK; ¶ School of Psychology, University of Wales – Bangor, Gwynedd LL57 2AS, Wales, UK; § Department of Psychology, Rutgers University, Newark, NJ 07102, USA; e-mail: LMN419@aol.com)

We present an exhibit called Kansas, which is both an art installation and a visual perception apparatus. The observer steps into a small room containing a number of windows. Computer-generated flow fields projected onto screens located beyond each window create the visual impression that both the observer and the room are moving through space. As an art installation, Kansas demonstrates that a sense of immersion depends on the nature of the visual stimulation, and that immersive art forms can be achieved without complex virtual reality/interactive technology. As a vision experiment, Kansas is being used to investigate the rules of anchoring in the motion domain. It is known that the largest framework appears stationary and serves as the anchor for relative motion. But largest can be defined in retinal or perceived terms. The interior of the room fills most of the observer's visual field, but the flow fields create the experience of a larger framework outside the room. We find that this phenomenal framework functions as the anchor. As an art/science collaboration, the exhibit suggests the individual benefits of installation artists and visual scientists working together.

◆ **No evidence of perceptual dimorphism in the Fraser – Wilcox illusion**

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Radial patterns comprising a sawtooth luminance gradient elicit compelling illusions of rotational motion when viewed in the visual periphery. Differences in the direction of perceived motion for a given stimulus have been reported for different observers (Fraser and Wilcox, 1979 *Nature* **281** 565–566; Naor-Raz and Sekuler, 2000 *Perception* **29** 325–35), which poses serious problems for an explanation grounded in traditional theories of motion perception. The only attempts to quantify the strength and direction of the illusion have been through the use of subjective rating scales. Using a motion-nulling technique, we found that the direction of the luminance gradient strongly influences the direction of perceived motion ($p < 0.001$), and found no support for claims that this illusion is subject to perception dimorphism, with all eighteen individuals consistently reporting illusory motion in the direction of the luminance gradient. The illusion was also experienced by a small sample of older participants (aged 55 years), which extends a previous finding indicating that accommodative fluctuations, absent in older individuals, do not play a role in eliciting this illusion. Our findings pave the way for a mechanistic explanation on the basis of contrast reversals associated with small eye movements, which has been successfully applied to similar illusions in the past.

◆ **The dynamics of vertically biased apparent motion**

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In two experiments we analysed the effect of vertical separation on the perception of apparent motion of the 'motion quartet' stimulus; assessing vertically biased apparent motion and hysteresis. Experiment 1 was a replication of Gengerelli's study (1948 *Journal of Experimental Psychology* **38** 592–599) which addressed vertically biased apparent motion on the vertical visual midline, but we included controls for eccentricity and new methods of logging subject responses. Our findings extend Gengerelli's by demonstrating that fatigue is neither a relevant factor for producing vertical bias nor necessary for perceptual switching. The current results also indicate that differences in eccentricity do not significantly affect vertical bias on the vertical midline. In experiment 2

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we investigated the effect of perceptual hysteresis on apparent-motion perception of the 'motion quartet' by isolating hysteresis from the competitive effect of neural fatigue. We found that apparent motion of the 'motion quartet' was significantly affected by its position in the visual field, and that the stimulus elicited perceptual hysteresis. The presence of hysteresis is consistent with other investigations of visual inertia (eg Anstis and Ramachandran, 1987 *Vision Research* 27 755–764), and provides further evidence for the generality of this dynamic phenomenon.

◆ **Temporal properties of chromatic and luminance motion mechanisms inferred from a masking paradigm**

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Our previous studies (Yoshizawa et al, 2000 *Vision Research* 40 1993–2010; Mullen et al, 2003 *Vision Research* 43 1237–1249) suggested the absence of a first-order chromatic motion mechanism. To clarify whether first-order chromatic motion is mediated by an identical mechanism to that which codes first-order luminance motion signal, we compared temporal properties derived from chromatic and luminance motion discrimination performance in the presence of luminance masking noises. We calculated impulse response functions for mechanisms generating chromatic and luminance motion signals. We found that (i) impulse response functions for luminance motion discrimination are of a band-pass type, consistent with a number of previous studies on motion mechanisms; and (ii) functions for chromatic motion discrimination change from a band-pass to a low-pass type increasing contrast of the masking noise. The results indicate that a mechanism for first-order motion has access to signals produced by luminance and chromatic stimuli under conditions of low contrast of luminance masking, but in the presence of high contrast of luminance noise another mechanism mediates chromatic motion.

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◆ **Movement of isoluminant red – green gratings and of random-dot stereo depth gratings is perceived by the same salience motion-perception mechanism**

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In the Lu–Sperling theory of three orders of motion systems, the third-order motion system computes the motion of figures defined on a salience map. Two motion stimuli have previously been shown to be perceived exclusively by the third-order motion system: a translating isoluminant red or green grating and a depth-grating defined by a dynamic random-dot stereogram (DRDS). Consider two such gratings translating in the same direction: when they stimulate the same motion system, perceived motion will increase or cancel depending on the relative phase. When they stimulate different systems, perceived motion is always greater than for either grating alone. These predictions were tested with a translating random-dot stereo grating in which small amounts of isoluminant red or green (in DKL space) were added to either the foreground or background stripes. In five out of six observers, we found a phase in same-direction colour and stereo motion partially or completely cancelled each other. We conclude that isoluminant colour and DRDS motion are processed by the same motion system. A three-stage motion model consisting of (i) representation of cues in a salience map, (ii) an elaborated Reichardt detector to extract motion from salience, and (iii) a decision rule accounts for our data very well.

◆ **Variation of chromatic and luminance motion-onset VEPs as a function of lateral electrode location**

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When motion-onset VEPs are elicited by moving luminance patterns, the motion-specific component of the response, N2, is more prominent at electrode sites that overlay the lateral occipito-parietal cortex close to area V5/MT than over the primary visual cortex (Bach and Ullrich, 1997 *Vision Research* 37 1845–1849). We wished to examine whether VEPs elicited by chromatic motion exhibited a similar topographical variation. This is because functional segregation, in its strict form, suggests that colour and motion processing should take place along different ventral occipito-temporal and lateral occipito-parietal pathways, respectively. Hence, a different topographical distribution might be expected for the chromatic and luminance

responses. We recorded motion-onset VEPs from five electrode sites located at Oz, and at four locations (T1–T4) lateral to Oz, at intervals of 5% of the head circumference. The stimuli were either luminance (black–white) or isoluminant chromatic (red–green) sinusoidal gratings and responses were recorded from six subjects at velocities of 2, 5, and 10 deg s⁻¹ over a range of contrasts. The results showed that the N2 component was maximal at similar lateral electrode locations (T1–T2) for both types of stimuli. This similar topographical distribution suggests a common rather than a segregated processing pathway for chromatic and luminance motion.

- ◆ **Grayer than gray: Achromatic contrast of perceptually lagging flashed object is preserved**
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A yellow line flashed on a green bar moving on a black background is seen as a red line lagging the green bar (Nijhawan, 1997 *Nature* **386** 66–69). Cavanagh (1997 *Nature* **386** 19–21) speculated that a dark line flashed on a moving green bar, seen lagging the green bar, ought to appear 'blacker than black'. We explored this conjecture. Observers viewed a line of medium luminance flashed on either a darker or a lighter bar moving on a background equal in luminance to the line. Intriguingly, the flashed line did not disappear against the equal-luminance background. Observers adjusted (ascending and descending trials) the luminance of a flashed comparison line until it matched the perceived lightness of the lagging flashed line. Matches revealed that the contrast polarity of the flashed line relative to the moving bar was carried over when the flashed line was seen against the background. Thus, a flashed line can be rendered visible against a background of equal luminance. If the flashed line is defined by a luminance decrement (increment) relative to the moving bar, it will be seen as a dark (light) line against a background of equal luminance.

- ◆ **Spontaneous patterns in the perceived direction of motion in ambiguous motion quartets: Effect of perception or judgment?**
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In a motion quartet (MQ), perceived direction of rotation is bistable, sometimes clockwise (C) sometimes counterclockwise (c). We reported (Martello et al, 2004 *Journal of Vision* **4** in press, abstract) that observers exhibited spontaneous patterns across time in their responses. Our results could be explained as completion of two kinds of patterns: (i) sequences (eg CCCC > C), and (ii) alternations (eg CcCc > C). We report an experiment intended to determine whether the effect of past perceptions is present even when the observer does not overtly judge the direction of MQs. We collected psychometric functions $P(C|\text{angle})$ for sixteen subjects who viewed almost 2000 MQ trials each. The trials were organised in groups of four (tetrads) and the angles in the MQs for the first three trials in each tetrad were chosen so that we could control the perceived direction of motion on these trials. The observer did not respond to these trials but simply observed them. On the fourth trial of each tetrad, the subject saw an MQ whose direction he judged. We found that the alternating sequences CcC and cCc still led to a strong bias to completion but that the effect of the cumulative sequences ccc and CCC had vanished.

- ◆ **A second moving object influences the flash-lag effect**
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When a stationary object is flashed near a moving one we perceive the flashed object displaced relative to the moving one (flash-lag effect, FLE). Two main categories of explanation have been proposed: those which rely on neural processes underlying motion (extrapolation hypothesis, Nijhawan, 1997 *Nature* **386** 66–69) and those which assume that visual awareness is related to what happens after the flash (postdiction accounts, Eagleman and Sejnowski, 2000 *Science* **287** 2036–2038). According to postdiction, the magnitude of the FLE should not be affected by a second moving object introduced before the flash. We used a classical flash-lag paradigm, where a second object (besides the ring in which the FLE would occur) moved perpendicularly to the ring in such a way that they would intersect just after the flash. Contrary to the predictions of the postdiction theory we found that, when the second moving object was present, the magnitude of the FLE increased by 20% as predicted by motion-extrapolation theory. Our data supports the

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idea that a sensed location needs to be assigned to some cells, and that location is linked to further areas in the visual cortex. This function may be performed by long-range horizontal connections. [This research was partially supported by a grant from the Ministerio de Ciencia y Tecnología of the Spanish Government (number BSO 2001-2008).]

◆ **Representational momentum with complex objects**

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Nested radial objects (NEROs) were used to assess interactions between global and local motion during a representational-momentum task. NEROs consist of concentric rings of dots, with phase shifts between rings leading to structural variation. The NEROs were animated by making the rings locally rotate clockwise (CW) or counterclockwise (CCW) around their own centre. Global motion involved the rotation of the whole object around the centre of the screen, again either CW or CCW. When the object vanished, observers localised the remembered disappearance point, and then reported either the local or global motion direction, as cued at the start of each trial. Eye position (fixate/track), task (report local or global), and local–global congruence were the main factors of interest. Both angular error and deviations towards the screen centre were measured. Strong forward shifts in the remembered angle, regardless of eye position, with a congruent decrease only for fixated trials, were found. Fixation gave rise to a much larger bias towards the centre than tracked trials, but there was a clear increase in the size of this bias for congruent trials of both types. Reporting global or local motion did not influence responding in any way.

◆ **Does representational momentum contribute to the flash-lag effect?**

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In the flash-lag effect, a briefly presented stationary stimulus aligned with a moving target is perceived to lag behind the moving target (Krekelberg and Lappe, 2001 *Trends in Neurosciences* 24 335–339). In representational momentum, memory for a moving target is displaced forward [Thornton and Hubbard, 2002 *Representational Momentum: New Findings, New Directions* (New York: Psychology Press/Taylor and Francis)], but it is possible the flash-lag effect reflects forward displacement of a moving target rather than lagging of a flashed stimulus. In experiment 1, memory for flashed stimuli aligned with the final position of moving targets was displaced forward. In experiment 2, memory for flashed stimuli aligned with the mid-trajectories of moving targets was displaced backward. In experiment 3, memory for flashed stimuli aligned with the final position of moving targets and memory for the final position of moving targets were both displaced forward. In experiment 4, forward displacement of flashed stimuli decreased with increases in distance of the flashed stimuli from the moving targets. Although theories of the flash-lag effect typically emphasise lagging of the flashed stimulus, data suggest that representational momentum for the moving target contributes to the flash-lag effect.

◆ **Dramatic shifts in perceived motion direction reveal multiple simultaneous solutions**

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The literature supports two hypothesised rules for combining 1-D moving Fourier components: the intersection of constraints (IOC) and the vector average (VA). We have previously reported data showing that stimuli perceived in the IOC direction shifted in the direction of the VA following adaptation by a plaid or grating moving in the IOC direction. Here, we repeated the experiments at short durations using patterns that were perceived in either the IOC or the VA direction prior to adaptation. Adapting out the initial perceived direction led to a dramatic shift (40°–60°) in the alternative direction. In an attempt to understand this large shift we varied the duration of the adaptor, and the spatiotemporal characteristic of the adaptor. The results showed that the shift required only 1 s of adaptation, and was unaffected by the spatiotemporal properties of the adaptor over a range of spatial and temporal frequencies. We conclude that both solutions are encoded, and that the mechanism underlying the two solutions is not dependent on spatial or temporal tuning.

◆ **Attention does not modulate local motion detectors**

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Although it is widely accepted that attention modulates neural activity in the extrastriate visual cortex, there is a debate on whether attention modulates the primary visual cortex (V1).

The aim of this study was to investigate whether attention modulates local motion detectors located at V1. Observers viewed a rotating logarithmic spiral during the adaptation phase. A second task was presented at the centre of the spiral and the task was either performed (distracting observers' attention) or ignored. After the adaptation phase, either the same spiral or its mirror-image was presented as the test stimulus. While viewing the same spiral shows the amount of adaptation of both local and global motion detectors, viewing the mirror-image spiral activates another set of local detectors, thereby illustrating adaptation of global motion detectors. MAE duration was used as an indicator of adaptation strength. The difference in MAE duration between attention-distracted and attention-not-distracted conditions was compared in same-test and mirror-image-test conditions, which were not statistically different. Therefore the difference was only due to the effect of attention on global motion detectors, and attention did not affect local motion detectors. Since local motion detectors are located in the visual area V1, we conclude that V1 is not modulated by attention.

◆ **Competition between opposing motion directions in 2-flash apparent motion: Implications for correlational motion detection**

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Hock et al (2002 *Journal of Experimental Psychology: Human Perception and Performance* **28** 93–112) found that counter-changing luminance provides the informational basis for the perception of luminance-defined apparent motion (AM). For light elements on a dark background, the start of the motion path is specified by a luminance decrement at one location and the end of the motion path by a luminance increment at another location. In addition, Gilroy and Hock (submitted) found that AM proceeds from offset to onset irrespective of the order of offset/onset presentation, and, further, that motion is best perceived when offsets and onsets are simultaneous. These results are relevant to the typical 2-flash AM paradigm, for which an onset–offset sequence at one location is followed by an onset–offset sequence at another location. Evidence that AM is best perceived in the 2-flash paradigm for non-zero inter-flash-intervals previously has been interpreted as supportive of Reichardt/Barlow motion detection—the effect of the first flash would be delayed prior to being combined with the effect of the second flash. We show, instead, that the 2-flash results are due to inhibitory competition between motion detectors with opposing directional selectivity (one offset/onset pair specifies leftward, the other rightward motion), supporting a correlational motion detector model, but without delay.

◆ **D_{\max} for low-level motion processing does not depend on dot density**

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Several studies have found that the maximum displacement (D_{\max}) for motion in random-dot kinematograms (RDKs) depends on dot density. This creates problems for low-level motion models, eg motion energy, in which D_{\max} depends on the lowest spatial-frequency channel activated by the stimulus. Since changing dot density does not change RDK spatial-frequency content, it should have no effect on D_{\max} . This study shows that the effect of density on D_{\max} in two-frame RDKs depends on the temporal parameters of the stimulus. With short (16.7 ms) frames separated by a long (200 ms) interval, D_{\max} decreases with density; while for short frames with no interval, D_{\max} is constant. Long (116.7 ms) frames and no interval produce a combination of decreasing D_{\max} at low densities, and constant D_{\max} at high densities. These results indicate that two different motion systems contribute to D_{\max} . One responds to brief stimuli, but is disrupted by long inter-frame intervals; the other requires longer stimulus durations, but can tolerate long intervals. These properties parallel the distinction between short-range and long-range motion processes. Only the long-range process is affected by density. As predicted by motion-energy models, D_{\max} for the short-range process does not depend on dot density.

◆ **Spatial-frequency tuning of post-adaptation plaid coherence?**

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Physiological evidence for the direct detection of the motion of 'blobs' in plaid patterns by V1 receptive fields with broad orientation tuning has recently been provided by Tinsley et al (2003 *Journal of Neurophysiology* **90** 930–937). This finding suggests that some V1 neurons may contribute to the coherent percept of a plaid stimulus by directly detecting the motion of the blobs in a plaid stimulus. Subjects were adapted to moving gratings and a plaid was presented subsequently to test the reduction in coherence post-adaptation. Subjects made a forced-choice

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decision regarding the perceived coherence or transparency of the test plaid. Coherence reduction was hypothesised to demonstrate tuning around the spatial frequency (SF) of the plaid blobs. Movshon et al [1985, in *Pattern Recognition Mechanisms* Eds C Chagas, R Gatass, C G Gross (New York: Springer)] showed that adaptation to a moving grating reduces perceived coherence of a plaid and found a negative linear relationship between the SF of the test plaid and its post-adaptation coherence. However, the test plaids employed by Movshon et al, being asymmetric in contrast, would not ideally stimulate the proposed 'blob detecting' mechanism. Contrary to this earlier research, the preliminary results presented here show SF-tuning of post-adaptation plaid coherence.

◆ **A single population of velocity detectors can account for the adaptation differences to fast and slow motion**

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Motion aftereffects (MAEs) are illusory perceptions of motion after prolonged viewing of drifting patterns. MAEs are different for static and dynamic test stimuli. For example, static test stimuli cause MAEs for slow adaptation motion whereas dynamic test stimuli do so for fast adaptation motion (Verstraten et al 1999 *Vision Research* **39** 803–810; van der Smagt, 1999 *Nature Neuroscience* **2** 595–596). The authors interpreted these (and other) findings as supporting evidence for the idea that different populations of neurons process slow and fast motions. Verstraten et al used test stimuli that were either static or dynamic; no intermediate stimuli were used. Van der Smagt et al used two adaptation speeds. We investigated whether the use of two comparison points (static/dynamic or two velocities) may have caused the dichotomy in the data. We used the distribution-shift model (including velocity and direction adaptation, and explicit modeling of the test phase), and were able to reproduce the experimental data by assuming that there is just a single population of velocity-sensitive cells. An important assumption of the model was that the distribution of velocities in static test stimuli was narrower than in dynamic test stimuli.

◆ **Perceived velocity decreases with time: The case of interrupted motion**

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When a target is moving in the frontal plane with constant velocity, the perceived velocity decreases with time. This phenomenon could be explained with Bachmann et al's concept of perceptual acceleration (2003 *Consciousness and Cognition* **12** 279–297). Here, we examined how velocity perception is affected by a short interruption of motion. The target travelled across the computer screen and disappeared for a short time during motion. Velocities before and after motion interruption were varied and the point of subjective equality of velocities was measured. We found that perceived velocity after the interruption was lower than the one before the interruption. On the other hand, in the control condition, where after interruption the target reappeared at the initial onset position and thus travelled the same path twice, perceived velocity after motion interruption was similar to that before the interruption. The results indicate that, when a target travels behind an invisible occluder for a short time, it can preserve its identity owing to motion extrapolation and then its velocity can be effectively represented as soon as it reappears again. Perceptual acceleration is therefore most likely restricted to cases where representations of new objects are formed.

◆ **Accelerating self-motion displays produce the most compelling vection**

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We examined the vection induced when two very different types of simulated self-acceleration were added to displays simulating constant-velocity self-motion in depth. Contrary to the predictions of visual-vestibular conflict theory, coherent perspective jitter (random, high frequency) and coherent perspective oscillation (systematic, lower frequency) were both found to improve vection relative to non-accelerating controls. While only horizontal and vertical self-accelerations reduced vection onsets, self-accelerations along all three axes were found to increase the perceived speed of self-motion in depth and reduce motion aftereffects. These results are clearly incompatible with the notion that constant-velocity displays produce optimal vection. Rather, it appears that simulated self-acceleration not only facilitates the induction of vection, but it also produces a more compelling experience of self-motion in depth by reducing adaptation to the radial component of the optic flow.

◆ **Can the Ternus display be used as a probe for phonological dyslexia?**

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It has been suggested that the Ternus display can be used to distinguish between phonological dyslexics and controls, and that this lends support to the magnocellular-deficit hypothesis of dyslexia. Previous experiments have demonstrated that Ternus displays do not dissociate low-level and high-level motion processing (Scott-Samuel and Hess, 2001 *Perception* **30** 1179–1188), and thus may not be useful when examining a potential link between motion perception and dyslexia. Here, we used two manipulations of the Ternus display to investigate whether such stimuli might discriminate between phonological dyslexics and controls. The degree of phonological dyslexia of the subjects was assessed via the Castles and Coltheart method (1993 *Cognition* **47** 149–180), resulting in a classification based upon relative latencies in the pronunciation of non-words and irregular words. The stimuli were (i) a standard Ternus display, where interstimulus interval (ISI) was manipulated, and (ii) a Ternus display where ISI was fixed at 0 ms and the carrier orientation of the Gabor patches which constituted the Ternus elements was changed from frame to frame. In both cases, there was scant evidence of any correlation between degree of phonological dyslexia and performance. We conclude that the Ternus display is an inappropriate stimulus for the investigation of dyslexia.

◆ **Snow motion**

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While developing visual perception applets (posted at <http://lite.bu.edu>) for Project LITE (Light Inquiry Through Experiments), we observed a striking phenomenon. Overlaying regular grid patterns on top of dynamic random-dot visual noise elicits the percept of coherent motion. This apparent motion can be seen either along or orthogonal to the guiding channels. The same effect can be observed when viewing TV snow through regular grid patterns. We subsequently learned that this type of effect was first reported by D M MacKay (1957 *Nature* **180** 849–850). He named the organised perceived motion of dynamic random dots in circular channels ‘the omega effect’ and discussed its possible cause. The most detailed recent treatment of this effect seems to have been the one by Rose and Blake (1998 *Philosophical Transactions of the Royal Society of London, Series B* **353** 967–980). In this presentation, we explore the rich variety of snow motion effects. We have also found the opposite effect, the suppression of coherent random-dot motion by regular grids. We discuss possible connections of these phenomena to the kind of subjective motion observed in Isia Leviant’s Enigma paintings (traffic illusion) and other visual illusions. Snow-motion effects may help probe motion perception, much as random-dot stereograms probe the nature of depth perception.

◆ **Direction selectivity and the contrast response function of cortical neurons to first-order and second-order motion**

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Visual neurons selective for movement often exhibit some limited response to motion in their non-preferred directions. We examined whether neuronal direction selectivity depends on stimulus contrast, using both first-order (luminance-modulated) and second-order (contrast-modulated) stimuli. We recorded extracellular responses from individual area-18 neurons ($n = 58$) in anaesthetised cats to moving stimuli, optimised for each cell, over a range of contrasts (1.25% to 80%). Direction-selective contrast response functions (CRFs) were calculated as preferred-minus-null differences in mean firing rate. We also applied receiver operating characteristic analysis to derive neurometric functions, characterising the potential of each cell to discriminate direction at each contrast. CRFs for first-order gratings were usually monotonic, sigmoidal and often saturating; however, a substantial minority (35%) were non-monotonic (peaking at intermediate contrasts). The underlying preferred and non-preferred direction CRFs were diverse, often having different shapes in a given neuron. Neurometric functions showed similar heterogeneity, including instances of non-monotonicity. For second-order stimuli, however, CRFs for either carrier or envelope contrast were always monotonic, convex and never showed saturation. For the same neurons, neurometric thresholds were typically higher for second-order than for first-order stimuli.

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Thus the direction selectivity of a cell is not a characteristic parameter, but depends on the contrast at which it is measured.

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◆ **High-frequency neuronal synchronisation in the human visual motion pathway**

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Synchronisation of high-frequency (>30 Hz) oscillatory neuronal activity has been implied in various aspects of sensory information processing. Several areas of the primate extrastriate visual cortex, particularly area MT, are specialised in processing of stimulus motion. Using magnetoencephalography (MEG), we investigated whether high-frequency oscillations in the human brain are modulated by stimulus motion and, more specifically, whether such a modulation occurs in human area MT. Subjects viewed moving random-dot and static stimuli while MEG was recorded with a 151-channel whole-head system. An adaptive spatial filtering technique known as 'linear beamforming' was applied to the MEG data in order to identify the sources of oscillatory activity. This method allows to image the frequency-specific spatial distribution of oscillatory neuronal activity within the entire brain volume. We demonstrate that high-frequency oscillations in area MT significantly increase when subjects view moving as compared to static stimuli. Furthermore, oscillatory responses to peripheral stimuli are stronger in the MT subregion contralateral to the visual hemifield where moving stimuli are displayed. These results suggest that (i) visual motion modulates high-frequency oscillatory synchronisation within human area MT, and (ii) that these oscillatory responses reflect the coarse retinotopic organisation of area MT.

◆ **Differential effects of test stimulus configuration on magnitude of MAE generated by first-order and second-order motion**

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First-order and second-order rotating logarithmic spirals were presented to subjects (adapting stimuli) and the magnitude of MAE was measured. The test stimulus was either the same as the adapting spiral (SS) or its mirror image (MS). Since in the MS condition all contours of the adapting and test stimuli are 90° apart, local motion detectors tuned to the directions of the mirror-image spiral fail to respond and therefore do not contribute to the observed MAE. The difference between the MAE strength generated by the SS and MS was then calculated and normalised. The normalised difference of magnitude of MAEs generated by first-order motion was significantly larger than that generated by second-order motion: when first-order spirals were used, subjects reported a weaker MAE with MS than with SS. In contrast, the difference between the MAEs with SS and MS was slight when second-order motion was used as the adapting stimulus. These results may indicate that, contrary to previous suggestions (Chubb and Sperling, 1989 *Proceedings of the National Academy of Sciences of the USA* **86** 2985–2989), first-order and second-order motion are not computed by a similar algorithm, ie the processing of second-order motion does not depend on extracting local edges while the processing of first-order motion does.

◆ **Static motion aftereffect does not modulate positional representations in early visual areas**

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A stationary stimulus is perceived to drift in the opposite direction after adaptation to a moving stimulus (static motion aftereffect, MAE). There are substantial controversies about the level of visual processing at which static MAE is encoded; however, it is commonly assumed that positional effects from the static MAE are mediated by early visual areas. Here, psychophysical evidence is provided to the contrary, demonstrating that these positional effects do not occur in early visual areas. The processing level of static MAE was compared to that of another previously known illusion whose level of processing had been fairly well determined and illusory line-tilt aftereffect (TAE) was chosen for this comparison. An adaptation paradigm was used to investigate the interaction between static MAE and illusory line-TAE. In this paradigm an illusory contour was physically induced by abutting gratings, but perceptually made invisible to the viewer by apparent position shifts due to static MAE. The results showed that such illusory

contour is capable of inducing (maintaining) the TAE. Since illusory contours are represented at relatively early stages of visual hierarchy, it is suggested that static MAE modulates positional representations in higher visual areas.

◆ **Effects of dot density and displacement size on motion-detection performance in random-dot kinematograms**

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Threshold coherence for detecting motion in random-dot kinematograms is largely independent of dot density over a wide range of densities, provided displacement size has been optimised (Downing and Movshon, 1989 *Investigative Ophthalmology & Visual Science* **30** Supplement, 72; Barlow and Tripathy, 1997 *Journal of Neuroscience* **17** 7954–7966). We investigated the effects of dot density on performance when the displacement size is varied. In experiment 1, for each displacement size (10–70 min of arc), the dot density was varied (0.74–74 dots deg⁻²), with coherence fixed at 30%. At this coherence level, the direction of motion was correctly identified on 80%–90% of the trials for the lowest density and the smallest displacement. As displacement size increased, the proportion of correct responses fell for the lowest dot density. However, for a given displacement size, the influence of dot density was minor. In experiment 2, the dot density was varied, keeping the coherence fixed at a level for which performance was 80%–90% correct for the lowest dot density tested at each displacement. At small displacements, the effects of dot density are small. For larger displacements, performance drops as dot density is increased, as predicted by the correspondence noise hypothesis (Tripathy and Barlow, 2001 *Perception* **30** Supplement, 32).

◆ **Contours from motion: The effect of speed and density reveals an integrative mechanism**

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We studied the effects of speed and dot density on the perception of illusory contours produced by manipulating the modulation of luminance on a random-dot pattern. The stimulus consisted of a circular patch surrounded by an annulus, both containing the same kind of modulated dot pattern. The background of the stimulus was homogeneous and no dots ever moved relative to the background. We used a Vernier acuity test between the central patch and the surround annulus to evaluate how sharp the contour was perceived in each condition. To do this, we manipulated the phase of the modulation in both the central patch and the surround annulus. Results show that the Vernier threshold decreases with increasing speed up to a saturation value that depends on density: the lower is the density the higher is the speed of saturation. This result suggests that there is a finite temporal window in which the rate of sampling must exceed a threshold for the contour to be perceived. Importantly, when the dot density is too low, the saturation speed cannot be reached, perhaps because the distances between dots exceed a certain amount—range limit of lateral interaction of neural mechanisms.

◆ **Temporal dynamics of motion integration for smooth pursuit**

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We measured smooth-pursuit eye movements in response to two types of translating diamond-shaped stimuli. For type I stimuli, the direction of motion was consistent between the true object motion and the vector average of the local motions of the contours of the object. For type II stimuli, the vector average of the local motions of the contours deviates $\pm 44^\circ$ from the object motion. Eye movements in response to these two stimuli were recorded with the high-resolution search-coil technique (Skalar Med, The Netherlands). While tracking was accurate for type I stimuli, for type II stimuli the eye movements initially deviated in the direction of the vector average and were aligned with the correct object direction over a period of ~ 200 ms, consistently over four cardinal target directions. The effect is dependent on speed, is maximal at low contrasts, and depends on the relative amount of 1-D and 2-D information in the stimulus. The combined results suggest that motion integration is a dynamic process where a coarse initial estimate that drives the initiation of the pursuit response is refined over time.

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◆ **Motion-induced overestimation**

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Subjects were asked to report the number of items in a display as the items moved along a circular path around a fixation point. As the rotation speed increased, the reported number of items also increased. This motion-induced overestimation (MIO) illusion was investigated in two experiments. In the first experiment, the effect of rotation speed and set size was explored with an enumeration task. The overestimation error increased with an increase in speed or number of items in the display. In the second experiment, using an adjustment paradigm, we measured the speed threshold of the onset of the MIO effect. The temporal rate of the display, which was defined as a product of the rotation speed and the number of rotating items, was the determining factor of the onset of MIO.

◆ **Asymmetric mislocalisation of a visual flash ahead of and behind a moving object**

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When subjects localise a flash relative to another stationary stimulus, the flash appears displaced in the direction of nearby motion signals (position-capture—Whitney and Cavanagh, 2000 *Nature Neuroscience* 3 954–959). Our previous study suggested that the position-capture effect is larger for a flash presented ahead of a moving stimulus than behind it (Watanabe et al, 2003 *Perception* 32 545–559). Here, the asymmetry of position-capture was further investigated. The position of a flash relative to a moving stimulus and to the fovea was systematically manipulated (experiment 1). The results showed that the asymmetric position-capture occurs in a moving-object-centred coordinate, not the fovea-centred coordinate. In experiment 2, it was found that the asymmetry becomes negligibly small when two flashes are simultaneously presented both ahead of and behind a moving object. Subsequent experiments with reaction-time and temporal-order judgment measures showed that there is no significant difference in temporal processing between space ahead of and behind the moving stimulus. These results indicate that the asymmetric position-capture is a spatial, not temporal, effect and is based on visual representations of isolated objects, which points to the possibility that high-level visual representations are involved in the position-capture effect.

◆ **Final position of a gradually disappearing moving object is spatially extrapolated**

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Accurate localisation of the motion-termination position of a moving object has been deemed contradictory to the notion of visual compensation for neural delays. We postulate that the visual system uses strong retinal input (eg OFF-signals) in achieving this accuracy. To test this, we employed a stimulus, which ‘terminated’ but did not provide a strong OFF-signal. A dot, moving on a circular path, gradually became dimmer until it disappeared. Observers viewed a short segment of motion (SSM), pre-cued by a radial line at 10 different angles. They determined the angle at which the dot in this condition was at visibility threshold. Next, the dot was visible during a long trajectory motion (LTM). In a 2AFC task, subjects judged whether the dot disappeared before or past a radial line. During LTM, observers on average saw the dot disappear ‘ahead’ of the angle at which the SSM dot was at visibility threshold, ie when its intensity was half that of the SSM dot. We conclude that the visible position of the LTM dot is based on cortical signals that compensate for visual delays. Motion-termination of objects is perceived correctly because of the retinal OFF-signal. Here, the LTM dot is seen in an ‘extrapolated’ position because the OFF-signal is absent.

◆ **Local and global integration of individual motions in locally paired dot stimuli**

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Recent psychophysical studies showed there are two types of motion integration processes in human visual system: global motion perception in random-dot kinematograms (RDKs) and vector-average perception in locally paired dot (LPD) stimuli (Curran and Braddick, 2000 *Vision Research* 40 2115–2124). We investigated the relationship between the two motion integration

processes by comparing the coherence thresholds for signal motion detections in three corresponding stimuli: (i) RDKs, (ii) LPD stimuli the component motions of which are identical to those of RDKs, and (iii) pairwise-averaged stimuli the component motions of which correspond to the vector-average of locally paired motions in LPD stimuli. Psychophysical experiments showed there were significant differences between the signal-detection performances in RDKs and LPD stimuli. When moving dots were paired appropriately, observers could detect coherent motions in LPD stimuli, even if the proportions of signal dots were less than the detection thresholds of RDKs. The thresholds of LPD stimuli could be predicted by the pairwise-averaged stimuli. The result suggests that paired motions in LPD stimuli are integrated prior to the global motion perception, and this process is unaffected by proportions of motion signals. We conclude that the global and local integrations of individual motions are carried out by different mechanisms.

◆ **Modelling the influence of visual motion on perceived position**

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We developed a computational model to investigate whether perceptual shifts in position can be explained by changes in the relative firing rates of neurons in V1 under the influence of motion feedback. Spatiotemporal filter outputs in the McGM (Johnston et al, 1999 *Proceedings of the Royal Society of London, Series B* 266 509–518) motion model can be used to form a labile representation of visual input, enabling input reconstruction if required. The McGM velocity calculation can be used to re-weight the additive components of this spatial and temporal representation. This feedback loop can generate movement-induced spatial shifts (De Valois and De Valois, 1991 *Vision Research* 31 1619–1626; Whitney and Cavanagh, 2000 *Nature Neuroscience* 3 954–959). The spatial extent of the local influence of motion on position can be altered by spatially aggregating motion signals. The model exploits the properties of a Taylor series reconstruction to provide a mechanism by which changes in the firing rate of V1 cells in place can mimic the effect of a spatial translation. The biological advantage of this system is flexibility, in that it allows both interpolation and extrapolation of visual information in both space and time.

◆ **Wagon-wheel illusion revisited**

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Rotating wheels sometimes seem to turn backwards when observed in stroboscopic light. This is called the wagon-wheel illusion (WWI). Yet another phenomenon of illusory multiplication of the number of the spokes may accompany WWI. This work was aimed to eliminate the shortcomings of the putative mechanism of WWI by carefully considering the phenomenon of illusory multiplication of spokes. According to the popularly accepted mechanism of WWI, periodic loss of visual information due to the intermittency of the stroboscopic light is responsible for the reverse matching of the spokes. This reverse matching is an erroneous solution to the correspondence problem and leads to the misperception of direction of rotation. This hypothesis does not suffice to describe a couple of phenomena. One is the multiplication of spokes by various integer coefficients while the wheel is rotating at different speeds. Another is the frequency of the occurrence of WWI during the time a stationary, say a 4-spoke, wheel starts rotating and picks up speed to reach the corresponding angular speed of 90° per strobe period. A model analogous to the tetralogy of sequential flickering, apparent motion, simultaneous flickering, and flicker fusion originally described for two alternating light spots is proposed to describe the aforementioned phenomena.

◆ **Motion-induced colour mixture: objective evaluation by colour matching**

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We recently reported that different colours presented at separate retinal locations can be perceptually mixed when they are temporally integrated through rapid apparent motion (Nishida et al, 2004 *Journal of Vision* 4 forthcoming). To make objective evaluation of this phenomenon, we conducted a colour-matching experiment. Our stimulus consisted of vertical red–green stripes (6 min of arc in width for each), masked by a black field, and seen only through an array of bar-shaped slits (12 min of arc in width for each). While the red–green stripes were stationary, the slits repetitively made a horizontal 6-min jump at short temporal intervals (say, 6.25 ms). Even when the exposure duration was too short to evoke observer's tracking eye movements (200 ms), the observer perceived yellow bars instead of retinally veridical bicoloured bars. In the

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present experiment, subjects were asked to adjust the colour (red–green ratio) of comparison stimulus to match with the motion-induced colour. The results indicate that the motion-induced colour changed progressively as the relative intensity of red–green stripes changed. The PSE (perceptual point of equality) and variability of colour matching were comparable to those obtained in a control experiment where bars with physically mixed colours moved. This provides objective evidence that retinally separated colours can be perceptually mixed by motion processing.

◆ **Recognising faces in motion**

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In addition to the nonrigid and rigid motions of the head, both of which have been shown to facilitate face recognition, another familiar type of movement occurs whenever a person approaches you. We investigated whether this kind of looming motion has any effect on recognition performance. We used 12 different male head models from the MPI face database and placed them on the same 3-D body model. These figures were animated to approach the observer. Subjects were familiarised either with the last frame out of the rendered sequence, which basically showed the head and shoulders of the person, or the entire video sequence. To facilitate learning, observers filled out a questionnaire relating to the facial features and the personality of each individual, a facilitation phase that lasted approximately 1 h. After a brief intervening task, observers were shown 12 pairs of static faces, one old and one new in each pair, and asked to identify the familiar individual. These test faces were rendered from a novel viewpoint to increase the demands of the recognition task. Our initial results indicate a robust advantage for dynamic familiarisation.

◆ **Visual extrapolation and motion imagery: The role of the two-thirds power law**

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The relation between curvature and velocity of several human movements is constrained by the two-thirds power law (TTPL) (Viviani and Terzuolo, 1982 *Neuroscience* 7 431–437). Visual and kinesthetic perception is attuned to this motor rule. We asked whether TTPL constrains also motion imagery. We presented a spot moving along an elliptical path, whose velocity either followed (TTPL motion) or violated (non-TTPL motion) the TTPL. When this template disappeared, subjects had to mentally continue the motion, either in conditions of free viewing or central fixation, and to indicate the imagined position of the spot at the time of a tone presented at various stimulus onset asynchronies (SOAs). With both TTPL motion and non-TTPL motion, subjects showed an increasing phase lag relative to the stimulus for increasing SOAs, suggesting that the imagined motion was slower than the template. In the fixation condition, a different phase modulation emerged between the two motion conditions, indicating that mental extrapolations for TTPL motion or non-TTPL motion are not equivalent. We then measured spontaneous eye movements during motion imagery. Saccade sequences reproduced the to-be-imagined trajectory, and their tempo was significantly different between the two motion conditions, suggesting that motion imagery can be rather flexible.

◆ **Motion-induced shift and navigation in virtual reality**

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De Valois and De Valois (1991 *Vision Research* 31 1619–1626) showed that moving Gabors (cosine gratings windowed by a stationary two-dimensional Gaussian envelope) are locally misperceived in their direction of motion. In a pointing task, Yamagishi et al (2001 *Proceedings of the Royal Society, Section B* 268 973–977) reported an even stronger visuo-motor localisation error, especially when participants had to make a speeded response. Here, we examined motion-induced bias in the context of an active navigation task, a situation in which perception and action are tightly coupled. Participants were presented with a bird's-eye view of a vertically moving contour that simulated observer motion along a path. Observers centrally fixated while the path and a moving Gabor target were presented peripherally. The task was to follow the path with the moving Gabor, whose position (left/right) and direction (towards left/right) were varied in separate blocks. Gabor eccentricity was constant relative to fixation, with observers adjusting their simulated position with a joystick. Deviations from the path were analysed as a function of Gabor direction.

We found large and consistent misalignment in the direction of the moving Gabor, indicating that global position/motion judgments during action can be strongly affected by irrelevant local-motion signals.

- ◆ **Spatial-frequency correlates of perceived temporal aliasing in simulated real-world imagery**
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We have compared the spectral characteristics of simulated imagery with the appearance of spatiotemporal aliasing in order to establish the practical limitations on the visual cues required to simulate motion over complex terrains. Imagery was produced by a PC, and displayed on the front channel (55 deg × 50 deg) of an operational jet-aircraft flight simulator. Observers flew passively over a low-pass random-noise texture (4 texture elements/m² at an altitude of 30 m and speeds of between 50 and 500 m s⁻¹). They were asked to indicate the farthest location in the database where the simulated image motion became either discontinuous or incoherent. Owing primarily to image perspective, the vertical spectra (V) were generally flatter than the horizontal spectra (H) (mean values were V: 1/f = 1.41 and H: 1/f = 1.11). The pattern of perceived image coherence coincided with image spatial frequencies in the range 0.5–2.0 cycles deg⁻¹, indicating that the perception of self-motion can be mediated by restricted portions of a wide-field image, although these lower frequencies may not provide robust cues to motion. In addition, the presence of motion incoherence, mostly in the visual periphery, did not significantly affect the perception of self-motion.

- ◆ **Cognitive effects on representational momentum: The role of knowledge about the intention of an object**

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Representational momentum is the systematic tendency to remember the final position of a moving object shifted in the direction of the preceding motion. Cognitive factors, like knowledge about an object's function, influence the amount of representational momentum (Reed and Vinson, 1996 *Journal of Experimental Psychology: Human Perception and Performance* **22** 839–850). In two experiments, the intention of a moving object was varied and representational momentum was measured with a touchscreen paradigm. In experiment 1, a mouse moved either towards a cheese or a waiting cat and then disappeared. Speed and motion direction were varied. Participants' task was to indicate the final position of the mouse on a touchscreen with the index finger of their right hand. In experiment 2, which was more abstract, a small dot moved towards a rectangular area of orange or blue colour. One colour was characterised to be attracting, the other one to be repelling. The colours of the objects and areas were varied systematically. In both experiments, participants produced a larger representational momentum in the attracting than in the repelling conditions. This indicates that conceptual knowledge about the intention of a moving object can affect the magnitude of representational momentum, independently of the visual context.

PERCEPTION AND ACTION

- ◆ **Posterior parietal contributions in motor programming for peripheral visual targets**

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To study the neural basis for the distinct visuomotor systems involved in central vision and peripheral vision, we tested patients with posterior-parietal lesion causing optic ataxia. We measured reaction times (RTs) of both a finger lift and manual aiming at a visual target appearing on a touch-panel monitor while manipulating the target position in the visual field. Participants were asked to either quickly lift the index finger from a starting position or to reach to the centre of the target by quickly moving the finger from the same position upon target onset. To explore temporal characteristics of motor programming, differential RTs (DRTs) calculated by subtracting the finger-lift RTs from aiming RTs were evaluated. Because the stimulus-detection and movement-triggering times are subtracted, DRTs can be thought to reflect the information-processing time needed for preparing motor action per se. Results showed that DRTs for

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peripheral-visual-field conditions in the affected side of patients were longer than those in normals. This indicates that patients with focal lesions of the superior-parietal lobule, part of the visuomotor module heralded by Milner and Goodale [1995 *The Visual Brain in Action* (Oxford: Oxford University Press)], are specifically impaired for programming actions toward targets presented in peripheral vision. Implications for the ventral/dorsal-stream theory are discussed.

◆ **Visual receptive field organisation and spatial reference transformation in macaque posterior parietal cortex**

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A number of neurons in the ventral intra-parietal area (VIP) show visual receptive field placements that are independent of eye position (Duhamel et al, 1997 *Nature* **389** 845–848). This observation was taken as evidence of visual information encoding, ie space representation, in the parietal lobe in frames of reference other than retinal coordinates, eg head-centred ones. However, these data did not cover all possible reference-frame transformations between various reference systems (eye, head, body, environment). We have investigated this by mapping the visual receptive field of VIP neurons during different combinations of eye and head positions. A macaque monkey was trained to fix a point on a screen at different spatial coordinates, with the head fixed centred on the body, or with the head turned at corresponding eccentricities to the coordinates of the presented fixation point. Neurons were recorded extracellularly with single electrodes in VIP or the lateral intra-parietal (LIP) area. Our initial results indicate the presence of head-centred (craniotopic) and possibly also body-centred reference frames in VIP neurons. Craniotopic reference frames could also be shown in the saccade-related area LIP. The interaction between reference frames seems to be dependent on the input gain between the differentially positioned body parts.

◆ **Saccadic and perceptual classification images have similar receptive-field shapes in a contrast-discrimination visual-search task**

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In a visual-search task, we compared saccadic and perceptual processing by computing classification images from incorrect decisions. Two observers searched for the brightest circle in a spatial, 8-alternative forced choice (8AFC) contrast-discrimination task. The target (contrast 18%) and distractors (contrast 15%) were equally spaced (eccentricity 5.8 deg) blurred (8 min of arc) circles (57 min of arc radius), with added external, white, Gaussian noise (24% rms contrast). In the saccadic processing condition (duration 4 s), observers searched with eye movements. The 8AFC saccadic decision was defined as the element location nearest the 1st saccade's endpoint. In the separate perceptual processing condition, observers made an 8AFC perceptual decision with the stimulus duration (117–150 ms) chosen so that the perceptual processing time was similar to the processing time available for the 1st saccade. Radial difference of Gaussian (DOG) functions containing both excitatory and inhibitory regions fit both the saccadic and perceptual classification images well (mean reduced $\chi^2 = 1.07, 0.99$, respectively). The shapes of the saccadic and perceptual receptive fields were nearly identical for both observers (dot product of normalised DOG fits were > 0.99), but were both significantly different from that of the target. These results suggest that saccades and perception share visual information about search-target shape. [Supported by NASA Airspace Operations System Program, NASA WBS 21-711-80-

◆ **Visual form/motion binding: Comparable biases for perception and action**

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We investigated whether perceptual visual motion analysis and sensori-motor control of manual pointing movement rely on different ventral and dorsal pathways, using moving aperture stimuli that require integration of form and motion across space and time. Performance in both perceptual and sensori-motor tasks has been measured as a function of perceptual integration difficulty (ie perceived coherence), object shape (diamond, cross, chevron), and trajectories (circular versus horizontal/vertical ellipses). In perceptual tasks, observers either discriminated object direction (clockwise/anticlockwise) or indicated in which of the four quadrants the elliptical motion ended. In the sensori-motor task, observers used a graphical pen to point to the final position of the centre of the invisible object. The results indicate that performance and spatial accuracy depend on difficulty, object shape, and trajectories in a comparable way for all tasks, although specific,

object-related cues, also yield differences. Overall, the data suggest that form/motion binding is not modulated by the task at hand. Perceptual and sensori-motor control appear to use the same shared representation of visual information.

◆ **Learning time-to-contact: How a neural network combines information and reflects human strategies**

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It has been shown that visual angle and rate of expansion may be combined in different ways in time-to-contact tasks giving place to different monocular strategies (Smith et al, 2001 *Journal of Experimental Psychology: Human Perception and Performance* **27** 395–410). These strategies can be defined either by different computational algorithms or by a more general algorithm that can adaptively combine visual angle and rate of expansion. The latter would be consistent with a single learning mechanism (Karanka and Luque, in press) instead of different independent mechanisms. A neural network can be used to test whether different strategies, resembling those reported in humans, arise from a single learning mechanism. By using an error-correcting algorithm, we trained a simple recurrent network to respond to simulated incoming objects at a specific time. The analysis on the response time at different training epochs suggests the development of successive strategies. While early in training, responses missed large and slow objects; with practice, network responses converged to a tau-like strategy. Thus, the way the network adapts to reduce its global error orderly reflects the sequence of strategies found in humans. These results cast some doubts on the idea that independent algorithms are implemented for dealing with monocular optical variables.

◆ **Comparison of the perceived distance traveled by an approaching object with the theoretically calculated distance**

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We investigated whether the perceived distance traveled by an approaching object was equal to the theoretically calculated distance. Two expanding squares [the first square (FS) and the second square (SS)] were continually presented on a CRT display, which simulated approaching squares. The squares approached at constant velocity. Each FS and SS had three initial sizes (0.2 deg, 0.3 deg, and 0.4 deg). There were nine combinations of FS and SS used. Subjects perceived that the initial position of the square with the large initial size was closer than that of the smaller square (case 1), or that the initial positions of the large square and the small square were same (case 2). In case 2, the physical size of the two squares was different. Subjects were required to estimate the ratio of the perceived distance traveled by the FS and that of the SS. Theoretically, the ratio of the perceived distance traveled by FS and SS decreased (case 1) or was constant (case 2), as the initial size of SS increased. The results were that the ratio of the perceived distance of FS and SS increased as the initial size of SS increased. This indicates that the perceived distance traveled by an approaching object is different from the calculated distance.

◆ **Direction-of-heading judgments are poorer under more naturalistic conditions**

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The optic flow created when we move through the environment contains information about our point of impact in the scene. Regan and Beverley (1982 *Science* **215** 194–196) reported the precision of such judgments was as small as 2 min of arc whilst Warren et al (1988 *Journal of Experimental Psychology: Human Perception and Performance* **14** 646–660) reported precisions of around 1 deg for simulated translation over a ground-plane surface. A significant problem with any experiment that requires observers to judge their heading direction on a 2-D display is that observers might base their judgments on some proximal characteristic of the flow. To circumvent this problem, 3-D movies were used in which it was very difficult to detect the characteristics of the proximal stimulation. Observers viewed movie sequences on a large (60 inch by 45 inch) non-depolarising screen and on each 2.5 s trial they judged whether the direction of heading was to the right or left of a randomly positioned marker. Although observers reported a powerful impression of self-motion, the precision of observers' heading judgments was typically a factor of two poorer compared with judgments under non-stereoscopic conditions. This suggests that optic flow may not be as precise a source of heading information as previous experimental work suggested.

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◆ **The directional bias in children's line copying does not generalise to pointing actions**

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When young children copy lines that protrude at an angle of 45° from the midpoint of baselines, the line is drawn as more perpendicular than it actually is relative to the baseline. We addressed the question whether or not this bias is a general spatial bias by measuring its effect on pointing accuracy. We transformed the standard stimulus (baseline 8 cm, testline 4 cm) into a computer-presented motion stimulus where a fixed left-oblique baseline (ie 45°) was present and the path of a vertically moving dot represented the testline. At the end of the motion, the children were asked to indicate, by pointing on a touchscreen, the point at which the dot disappeared. In direct contrast to tasks in which children were asked to draw the testline, the results from the pointing tasks showed that 5–6-year-old children ($N = 62$) were remarkably accurate and did not make the perpendicular bias in predicting the position of the target. These results suggest that perpendicular bias is modality-specific.

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◆ **Concurrent perception and action: Minimal interference between visual identification and pointing**

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Milner and Goodale [1995 *The Visual Brain in Action* (Oxford: Oxford University Press)] propose independent streams of visual processing: a ventral stream for conscious perception and a dorsal stream for online guidance of action. The theory suggests that each stream has separate attention systems. We investigated interference between concurrent ventral and dorsal tasks. In experiment 1, participants identified letters (ventral) that were preceded or followed by a pointing target (dorsal) that could unexpectedly jump to a new location upon initiation of pointing. In a single-task control, participants ignored the letter and only pointed to the target. In experiment 2, participants responded within a deadline to ensure that pointing was undertaken during letter presentation. In both experiments, pointing reaction time was longest when the pointing target preceded the letter target, and it decreased as the pointing target onset was delayed relative to the letter. Most importantly, movement time was unaffected in the dual task, even when movements were concurrent with letter identification. These results indicate that (i) initiation of visually guided action is delayed by a concurrent ventral task, but (ii) online control of pointing, once initiated, is unaffected by this same task, even under severe time pressure.

◆ **Transformation of body-centred spatial memory representation for pointing after body rotation**

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We examined the transformation process of body-centred spatial representation after body rotation using a pointing task in far space. Participants memorised the location of one of five targets, which was presented for 2 s at a distance of 2 m in the forward direction in complete darkness. During a 3 s delay period they rotated their entire body, including their head, by either 10° or 140° to either the right or the left, and then pointed to the presented location of the memorised target. For all conditions, the pointing errors were indicated along the counter direction of body rotation. The magnitude of pointing errors increased as a linear function of the target location relative to the body position before rotation. Furthermore, the reproduced area in which participants pointed to all targets shrunk as the rotation angle of the body increased: after body rotations of 10° and 140° , participants reproduced all targets within approximately 90% and 45% of the space which was actually presented, respectively. These results suggest that body-centred spatial memory representation was transformed at the location displaced along the counter direction of body rotation, and that the size of the memorised space shrunk. In addition, on the basis of previous results that fewer pointing errors occurred after body rotation in the light than in the dark (Yoshida and Inui, 2003 *Perception* 32 Supplement, 63), when the participants utilised also the environment-centred spatial representation of target location, the visuospatial memory was transformed to the appropriate location after body rotation.

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◆ **How visually perceived surface slant influences the way we put objects on the surface**

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In order to place an object gently on a surface, it is obviously advantageous to place it perpendicularly to the surface at the moment of contact. Here, we examined whether placing an object on a surface could be controlled exclusively by two more-or-less independent actions: orienting the object so that it is perpendicular to the surface, and transporting it to the desired position on that surface.

In particular, we examined whether the path also depends on the surface's orientation. Subjects were asked to place a flat cylinder (like the lid of a jar) at an indicated position on a slanted surface. We measured the position and orientation of the cylinder throughout the movement. The orientation of the cylinder in the final part of the movement was approximately perpendicular to the surface slant. The approach angle of the path does not only depend on the final position, but also on the slant at that position. For a given surface slant, the approach angle and the orientation of the cylinder were not related. This suggests that the path of the cylinder and its orientation are independently influenced by the surface slant.

◆ **Localisation of the plane of regard in space**

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Position of objects relative to the plane of regard is perceived accurately, irrespective of eye or head orientation (Poljac et al, submitted). To create a correct representation of objects in space, orientation of the plane of regard in space is required. Subjects pointed to the intersection of their plane of regard and the touch-screen positioned on their right. The pointing distance to subject's eyes varied from 10 to 40 cm. Subjects were sitting upright and fixating one of nine randomly presented targets in the dark, ranging from 20° left-down to 20° right-up. Subjects underestimated the elevation of their plane of regard (4.11 cm, SD = 1.02 cm), regardless of the fixation direction or pointing distance. When the targets were shown on a display mounted on a table, to provide support of the subject's hand throughout the trial, subjects pointed accurately (0.3 cm, SD = 0.8 cm). The bias observed in the first task could be caused by maintained tonus in arm muscles when the arm is raised, that might interfere with the transformation from visual to motor signal needed to perform the pointing movement. We conclude that the plane of regard is correctly localised in space and provides a good starting point for representing objects in head-centric coordinates.

◆ **Effects of the visual jitter aftereffect on the control of posture**

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To assess what visual information is used to control posture, we examined whether postural stability varies with the occurrence of illusory visual motion. Ten observers were exposed to five types of adaptation stimuli (30 s). (a) A central square region (17 deg × 17 deg) was filled with dynamic random noise and the surrounding region (46 deg × 38 deg) was static noise. (b) The central region was static and the surrounding region was dynamic. The whole region was (c) uniform gray, (d) static noise, or (e) dynamic noise. Adaptation was followed by a test period (20 s), during which the whole region was filled with static noise. In (a) and (b), the test stimulus was perceived to 'jitter' in the surrounding and central regions, respectively (Murakami and Cavanagh, 1998 *Nature* **395** 798–801); otherwise no illusion occurred. The observer's postural sway was measured by a force plate. In the jitter-aftereffect conditions (a) and (b), the sway amplitude (0.2–0.5 Hz) was larger during the test period than during the adaptation period. Since the jitter aftereffect is considered to reflect undercompensation of retinal motion due to fixational eye movements, these results suggest that some perceptual representation of motion, not retinal motion itself, is used to stabilise our body.

◆ **The effect of perceptual motion repulsion on action is task-dependent**

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Exactly how perceptual illusions affect actions like pointing or grasping is an issue of much debate. Here, I report results of an experiment in which a touch-screen was used to evaluate the effect of visually misperceived motion direction (the motion repulsion phenomenon) on three types of action (i) pointing to the end of the motion path, (ii) pointing to the start and the end of the motion, and (iii) tracing the motion path. Pointing to the end of the motion path did not show a directional bias and confirms results from induced-motion studies that argue in favour of a mismatch between perception and action. However, in two novel multi-pointing tasks, pointing to start and end as well as tracing the motion path, action was influenced by the misperceived motion direction with directional biases of more than 20°. For the latter tasks, perception does affect action. These results show that the effect perception can have on action is task-dependent.

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◆ **Vection and body sway induced by various visual characteristics of a large-field stimulus**

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It is known that both vection and body sway are induced when one is watching moving stimulus with a large visual field. Although measurement of body sway was proposed as an objective method to estimate the amount of vection, there has been no systematic investigation to compare visual characteristics that induce vection and body sway. Here, vection and body sway were measured for three different kinds of stimulus characteristics: (a) foreground–background depth relationship, (b) presence of a stationary frame, and (c) a stimulus with visually induced motion. It was found that (i) vection and body sway were induced only when visual stimulus was presented as background, (ii) the amount of vection and the magnitude of body sway were significantly reduced when stationary frame was presented in the peripheral field, and (iii) vection and body sway were induced with the direction of visually induced motion. It was also found that, although all observers reported vection, about half of them showed body sway in these experiments. These results suggest that vection and body sway are controlled by a common mechanism in our spatial vision, and that sensitivity for vection is significantly higher than that for body sway.

◆ **Internal representation of gravity for visual prediction of an approaching 3-D object**

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Internal knowledge of the physical world often plays an important role in interpreting ambiguous sensory information. Gravity is a powerful physical constraint, since all objects receive 1g on the Earth. Does the human visual system use any knowledge of gravity when predicting time-to-contact (TTC) and point-of-contact (POC) of an approaching object? A study was carried out to examine how gravitational acceleration affects the spatiotemporal prediction of an approaching object in a 3-D environment. In the experiments, a computer-generated spherical object was displayed on a large binocular-stereo screen system and projected from a distant point toward a subject along a simulated parabolic trajectory. The subject tried to catch the virtual object, after the object disappeared at a distance of 2.4 m from the subject. The gravitational acceleration internally assumed by the visual system was estimated from the measured position and timing data of each catch. The results indicate that the estimated value of an internal gravitational acceleration did not change much even when the simulated gravity changed significantly. The results suggest that the human visual system does not directly estimate gravitational acceleration from retinal images, but uses an internal representation of gravity for visual motion prediction. [Supported in part by the Telecommunications Advancement Organization of Japan.]

◆ **Neutral primes can modify subliminal priming effect**

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In a recent study (Jaskowski et al, 2003 *Journal of Cognitive Neuroscience* 15 911–920), a well visible pair of squares (main stimulus) was preceded by a sequence of four pairs of squares (primes). Each following pair was a little larger than the preceding pair, masking it by metacontrast. Participants had to react to the side of the target (a square with small gaps). One of the four primes contained a smaller copy of the target on the same side (congruent) or the opposite side (incongruent) of the target. A benefit for reaction times for congruent and a detrimental effect for incongruent trials was found. The priming effect depends on stimulus onset asynchrony (SOA) between target-like prime and the target. We checked if the number of neutral primes modify the priming effect. For the four primes in the priming sequence (one target-like prime and three neutral primes) the priming effect was largest for 70 ms–100 ms SOAs and smaller for longer SOAs. If the priming sequence contained only a target-like prime followed by one neutral mask, the priming effect gradually increased with SOA. Non-informative primes changed results. We plan to augment these conclusions by analysing brain activity in such tasks (event-related lateralisation).

◆ **How do we perceive distances in a driving simulator?**

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The car body often occludes lateral vision of a driver who still has to assess his own position efficiently with restricted visual information about surrounding vehicles and road limits. Our goal was to test how the approach towards simulated car targets is controlled. We assume that their increasing complexity may influence driving performance according to the difficulty in

perceiving distances properly. The first task consisted in placing the car at an equal distance between two cars separated either by 40 m or 60 m (bisection). In a second task the subjects had to level their front bumper with the front bumper of the preceding car (alignment). Target cars were either static or running at 40 km h⁻¹ or 60 km h⁻¹. Results show a more precise distance perception when the task difficulty decreases. Both tasks were easier with a static simulation, and in any other conditions the subjects underestimated distances. Subjects are better at adjusting their own position at 60 km h⁻¹ than at 40 km h⁻¹, and in bisection tasks the performance improves with smaller car distances. The alignment tasks produce better performances than bisection tasks as a consequence of their lower complexity. Physical constraints due to velocity and distances between vehicles also play a major role.

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◆ **Effects of illusory position on hand and eye movements**

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The perceived position of a stationary Gabor window is displaced in the direction of motion of a sine-wave grating drifting inside the window. In previous studies, it was demonstrated that there was larger displacement when the perceived position was estimated by manual pointing movements compared to perceptual judgments. We re-examined this situation using relatively small target patches. We did not observe dissociation between perception and action. The illusion was the same for manual estimation, saccades, and probe judgments. Depending on the probe stimulus used, the illusion was actually larger with perceptual measures than with manual pointing. Further, we investigated whether the time course of the illusion could explain the discrepancy. To this end, probe stimuli were presented either simultaneously with the target patch, or some time after target offset. The results show that the illusion was present throughout the intervals investigated and did not build up gradually. Across the experimental manipulations, various biases to localise the target were observed: with saccades and manual pointing, a bias toward the fovea was observed. With relative judgments and line probes, a bias away from the fovea was observed. This bias was not present with a probe containing low spatial frequencies.

◆ **Interpupillary distance is accurately perceived but overestimated in a drawing task**

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Thompson (2002 *Perception* 31 651–656) reported that humans overestimate their interpupillary distance (IPD) by around 30% in a drawing task. We measured estimated IPD using Thompson's protocol and the method of constant stimuli, whereby subjects indicated whether the distance between two points was greater or less than their IPD. The results of the drawing task were in agreement with Thompson's; however, under conditions where subjects did not draw their estimates, perceived IPD was veridical. As previously reported by Thompson, we found no significant correlation between physical and estimated IPD. The absence of such correlation is suggestive of a scheme whereby subjects' internal representation of IPD may be based upon some 'average', rather than their own IPD. The overestimation observed in the drawing task may be a result of some (non-veridical) representation of space peculiar to drawing. Alternatively, it may be mediated by a more general spatial representation used by the motor system. We conclude that the overestimation of IPD previously reported is not a robust effect and may be due to non-coincident spatial representations in visual and motor modalities. When a measurement technique that does not require manual reproduction of IPD is used, no bias in IPD estimates is found.

◆ **Eye movements during text entry for small devices**

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Most studies with hand-held mobile devices such as mobile telephones have been conducted by measuring reaction times or the number of mistakes. With small devices, more precise methods are needed which are sensitive enough to detect small movements of the eye, head, and body and could explain potential causal connections more explicitly. We studied text-entry performance with three different mobile devices, each of which had a different keypad/keyboard arrangement. To provide more detailed information on the perceptual processes, we measured the participants' eye movements with a fast high-resolution eye-tracking system. The main effect of the device on typing time was significant. Basic eye-movement-derived measures could also differentiate between the three types of devices. The primary effect of device on fixation and saccade duration

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and fixation number was significant, and of all the possible contrasts of eye-movement-based measurements, 40% were significant. Analysis of the scan paths showed that text-entry behaviour varied considerably between devices. Our results suggest that eye-movement analysis can indeed support more traditional evaluations of small-screen interfaces, and that eye-tracking methodology is valuable in the comparison of different arrangements of keys and in comparing the designs of different products.

◆ **Where the self controls its brain?**

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Effect of subliminal primes on subjects' performance is limited by the frequency with which primes conflict with consciously perceived target stimuli (Jaskowski et al, 2003 *Journal of Cognitive Neuroscience* 15 911–920). We employed metacontrast masking paradigm of geometrical shapes placed on each side of fixation. The proportion of compatible (target and target-like primes presented on the same side of fixation) and incompatible (target and target-like primes presented on different sides of fixation) trials was manipulated across blocks. 80/20 blocks contained 80% compatible and 20% incompatible trials, and vice versa in the 20/80 blocks. Longer reaction times to target and lower error rates for incompatible than for compatible trials were found. Moreover, the error rate differences for incompatible trials between 80/20 and 20/80 blocks clearly showed the intervention of the subjects' strategic control: in 20/80 blocks these error rates substantially decreased. Neuroimaging data revealed performance-dependent effects in inferior parietal, inferior temporo-occipital, and prefrontal regions. These areas showed increasing activation with increasing reaction times, thus indicating the emergence of strategic control processes which seems to intervene simultaneously at the level of visual discrimination of the primes and at motor activation evoked by the primes, thereby shielding observers from unwanted information.

◆ **The best action time for a goalkeeper engaged in penalties**

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It is very important for an athlete and, in particular, for a soccer goalkeeper defending against a penalty kick, to choose the right time of motor action. Goalkeepers usually try to make a save moving their legs before the kicker touches the ball. In a preliminary experiment, we obtained data showing that the performance of goalkeepers improves when the temporal gap between the goalkeeper action and the beginning of the kick is near to zero. By using acoustic stimuli, twenty goalkeepers were tested in order to study the possibility to induce them to start the save at the right time. The experimental variable was the temporal gap between the acoustic stimulus and the beginning of the penalty kick (anticipation: none, 300 ms, and 600 ms from the beginning of the kick). Results confirm the improvement of the performance of the goalkeepers when acoustic stimulus induced them to move only when the kicker touched the ball and not before: the number of saves almost doubled. The method used in our experiments, and the results obtained, underline the possibility to implement specific training sessions for goalkeepers based on individual strategy aimed to determine the best timing for each athlete.

◆ **Ideal deceleration: A flexible alternative to taudot in the control of braking**

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Models of braking control are conventionally based on maintaining a constant value of $\dot{\tau}$, the rate at which time-to-contact with the target, τ , declines. $\dot{\tau}$ is an appealing perceptual variable because τ is easily extracted from optic flow, bypassing the need to estimate current speed and target distance. However, it is less appealing as a control variable for many reasons; for instance deviations from the required, constant value do not map simply onto the required brake adjustment. Here, we investigate an alternative model in which ideal deceleration is explicitly compared with actual deceleration, having the important advantage from the control viewpoint that deviations are proportional to the required braking correction. We show empirically that this model provides a better account than $\dot{\tau}$ of braking behaviour both in real-world driving and in laboratory-based visual simulations. We also show, given reasonable contextual assumptions, how deceleration might be recovered from visual estimates of speed and distance. A further advantage of the model is in allowing flexible use of non-visual as well as visual information, and we speculate that observed differences between real-world and laboratory data may arise from the use of non-visual acceleration cues in the former case.

◆ **Can the hand act on the far visual space before approaching it?**

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Evidence of a difference between left-handers (LHs) and right-handers (RHs) in representing the horizontal dimension of the outer space has suggested that how we are used to moving affects how we perceive the near space (Marino and Stucchi, 2001 *Perception* 30 Supplement, 25). Here, we investigated whether motor habits influence the visual representation of the far space by comparing LHs and RHs in a remote-distance reproduction task. Virtual reality was used to transfer participants in an amphitheatre, over the tiers of seats, facing a distant screen on which a radial distance was presented. Participants indicated the point on the screen that defined the mirror image of the radial distance. Distances of 1.71, 6.88, and 13.69 deg with eight different orientations (from 0° to 315° in 45° steps) were used. In accordance with results previously obtained for the near space, subjects' accuracy in reproducing remote distances was modulated by both distance and orientation. Furthermore, participants were very accurate in reproducing distance orientations. Contrary to previous results, RHs did not differ from LHs in reproducing more accurately distances presented to the left than distances displayed to the right. We conclude that motor habits cannot affect the visual processing of the far space.

SPATIAL VISION

◆ **Nonlinear interactions between gaps and contrast determine apparent contrast**

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We have previously shown that a thin circular gap introduced in a uniform-contrast grating patch reduces the apparent contrast of the grating enclosed by the gap. Here, we asked how the gap-induced suppression interacts with more typical contrast-defined surround suppression. We measured the apparent contrast of a circular grating patch (diameter 1.5 deg or 3 deg) surrounded by a similar surround grating patch (diameter 6 deg). The stimuli were vertical, 4 cycles deg⁻¹ sinusoidal gratings, with centre contrast of 0.1. Surround contrast varied. In a second condition, we repeated the measurements with a thin unmodulated gap (width 7.2 min of arc) introduced either within the centre, at the centre-surround border, or in the surround (0.75, 2.0, or 5.0 deg). In the no-gap condition, apparent contrast decreased with increasing surround contrast. Introducing a gap further increased suppression, but contrast-dependent differences were reduced, with one exception at the smallest diameter. Except for this smallest gap diameter, the magnitude of suppression did not depend upon gap diameter. These data have many possible interpretations. At the very least, however, they indicate some type of nonlinear interaction between the presence of a gap and surround contrast.

◆ **Using fMRI to isolate spatial-frequency channels**

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Psychophysical research has identified channels selective for stimulus spatial frequency (SF) (eg Blakemore and Campbell, 1969 *Journal of Physiology* 203 237–260). The functional characteristics of these channels have been shown to match the electrophysiologically observed properties of V1 cells (eg De Valois et al, 1982 *Vision Research* 22 545–559). Here we extend the fMRI-adaptation method, reported by Grill-Spector and Malach (2001 *Acta Psychologica* 107 293–321) to more directly link psychophysically identified SF channels to the underlying neural substrate in the same human observers. First, we used the retinotopic mapping technique to identify V1 in our observers (Serenio et al, 1995 *Science* 268 889–893). Then, using a blocked design, we adapted observers to repeatedly presented grating patterns in stimulation blocks, interspersed with fixation blocks. In some stimulation blocks, all patterns had the same SF. In other blocks, patterns with a variety of SFs were presented sequentially, spanning either a 0.25, 0.5, 1, 2, or 3 octave range. We observed adaptation of the BOLD response in V1. Calculation of an adaptation ratio showed that, as the bandwidth of SFs in a stimulation block increased, the adaptation of the BOLD response decreased, paralleling psychophysical estimates of SF tuning.

◆ **Retinotopic specificity of flexible spatial-frequency processing**

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In a previous study during 'sensitisation' observers identified city versus highway scenes that were high-pass (H) or low-pass (L) spatial-frequency (SF) filtered, depending on visual field position, and combined with noise at the orthogonal scale. Perception of subsequent, unexpected,

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hybrid stimuli combining a HSF city with a LSF highway (or vice versa) was biased to match the SF content of the filtered scenes previously presented at that location (Özgen et al, 2002 *Perception* 31 Supplement, 111). Findings were consistent with the possibility that flexible spatial-scale usage is mediated by SF and retinal-location-selective mechanisms in early vision. However, our hybrid stimuli left open the possibility that observers perceived both hybrid components, but chose to report the component matching the SF content of the sensitisation stimuli viewed at that location: a response bias. Here, we used a new method that ruled out response-bias explanations of our findings. We sensitised observers as before, but, in a test stage, 'incongruent' filtered images, orthogonal to the observers' initial sensitisation pattern were randomly interleaved. Decrements in recognition on incongruent trials are difficult to attribute to response bias, since valid scene information is never presented at both scales.

◆ **Spatial frequency difference between textures interferes with brightness spreading**

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Previously we have shown that superimposing a texture pattern over a luminance border disturbs brightness perception beyond the textured area (Salmela et al, 2003 *Perception* 32 Supplement, 152). Here, we studied the effect of texture borders within a uniform luminance patch. The stimulus was a large (6 deg diameter) incremental luminance disk (36 cd m^{-2}) on a grey background (33 cd m^{-2}). The centre (3 deg) and surround regions of the disk contained different one-octave band-pass noise textures, but had same mean luminance (36 cd m^{-2}). The spatial frequency (SF) of the textures was varied ($0-7.5 \text{ cycles deg}^{-1}$). The brightness of the disk centre was measured with the 2AFC method of constant stimuli. The comparison stimulus was identical to the disk centre. Brightness matches were veridical when the centre and the surround regions were similar. When the surround was unmodulated or had a high SF texture, the brightness of the centre was reduced 50% regardless of the centre content. Brightness was also reduced (50%) if the surround had low SF texture and the centre texture SF differed at least one octave. The results are in favour of brightness filling-in and suggest that brightness signal is mediated by narrowly tuned SF-specific mechanisms activated within the uniform luminance field.

◆ **Perceived length distortions at isoluminance**

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Müller-Lyer figures, 120 min of arc long with no shaft line, were generated by CRS VSG 2/3 and presented as stimuli on an EIZO T562 monitor with gamma correction. The CRT primary colours provided chromatic contrast between the stimulus and the background areas. Prior to the experiments, the method of two-colour gratings was used to detect isoluminance for each colour pair. In experiments with monocular viewing, subjects estimated the perceived length of the test part of the Müller-Lyer figure by adjusting it so that it would be equal to that of the reference part in the absence and presence of luminance contrast (0.0 and 0.7), respectively. The illusion was measured as the functions of length and internal angle of the wings varying from 7 to 35 min of arc and from 20° to 180° , respectively. The experimental curves showed a significant ($p < 0.05$) increase of the illusion strength, up to 20%–60% at isoluminance, within the ranges of wing length 20–35 min of arc and internal angle $40^\circ-80^\circ$, irrespective of the colours combined. The five subjects tested have demonstrated similar results. The data obtained are interpreted in terms of spatial-frequency filtering and low-pass chromatic filters.

◆ **Short-time effect of prisms and/or convex lenses on size perception**

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Spectacle lenses are known to modify short-time size perception owing to their prismatic power (S.I.L.O. effect) and dioptric power (magnification). We measured size perception as a function of prismatic power with and without a +1.50 diopter lens on ten subjects with normal or corrected-to-normal vision. Size perception was measured by means of a staircase protocol on a 7.5 cm VGA monitor placed 40 cm from the subject. Observers had to compare perceived size of a randomly chosen 5-letter word with and without lenses inducing prismatic or prismatic and dioptric power. With lenses, letter size displayed on screen was constant, whereas without lenses letter size was adjusted by the computer program. Short-time size perception varied linearly from +6.7% for 10 prismatic diopters base-in to -5.8% for 10 prismatic diopters base-out. Perceived magnification induced by the +1.50 diopter lens (+4%) was independent of the one induced by prismatic power. Results are discussed in terms of extra-ocular muscle feedback on binocular fusion, space, and size perception.

◆ **Dynamics of orientation discrimination assessed with reverse correlation**

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We used a classification-image (CI) technique to examine the tuning of detectors mediating orientation discrimination at various stimulus durations. A Gabor target appeared for 1–6 frames in the middle of a 32-frame sequence of dynamic white noise (500 ms duration). Subjects performed a 2AFC judgment of the target orientation ($+11^\circ$ or -11° of vertical). The contrast of the Gabor was determined by a staircase procedure that maintained 79% correct discrimination. Noise sequences leading to an incorrect response were averaged and subtracted from the average sequence producing a correct response, to yield a CI. We found that the Gabor functions that provide the best fit to the CIs had narrower bandwidths than the target (more so at long durations than short ones), and that their peak orientations were approximately 10° more tilted from vertical than the true target orientation. Our changes in estimated bandwidth may arise from the operation of cortical neurons, whose tuning is known to sharpen during the first ~ 100 ms of stimulus presentation. We propose that the observed shift in peak orientation results from off-orientation looking where overlap between the channels tuned to the two possible target orientations leads observers to rely on more widely separated channels.

◆ **Spatial localisation: Interpolation of first-order and second-order visual structure**

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Human observers are able to localise the relative position of objects defined by Gaussian variations in either luminance (1st order) or contrast (2nd order). However, positional sensitivity is significantly poorer for 2nd-order stimuli than for 1st-order stimuli. These judgments require the visual system to construct a representation of pertinent variation from a number of individual retinal samples—a process known as interpolation. We compared 1st-order and 2nd-order interpolation mechanisms to examine whether differences in this process underlie differences in positional sensitivity. Observers were required to judge the relative position of two vertically separated 1st-order or 2nd-order Gaussian distributions. The distributions were discretely sampled, and both sample number and separation were systematically varied. Results showed that for a fixed sample separation (1.9 or 7.7 min of arc), optimum localisation thresholds were obtained with a minimum of 4–6 samples, for both 1st-order and 2nd-order stimuli. When sample number is maintained above this critical value, marked changes in sample separation (0 to 9 min of arc) had relatively little impact on thresholds for both 1st-order and 2nd-order stimuli. These results suggest that both 1st-order and 2nd-order interpolation mechanisms are limited by sample number rather than separation, and require a similar number of samples to mediate positional judgments.

◆ **Predicting contrast masking by natural images**

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While contrast masking by a simple sine-wave grating is easily predicted by the contrast of the grating, the amount of masking produced by a complex image, such as a photograph of a natural scene, cannot be predicted so easily. We compared the masking effects of photographs of natural images on vertical Gabor-patch targets with that expected if natural images behaved like sine-wave gratings with respect to contrast masking. The contrast in the natural images was calculated as local band-limited contrast of the same spatial frequency and orientation as the target. In all cases, the natural images produced significantly more masking than a sine-wave grating of the calculated equivalent contrast. To investigate the source of this additional masking, we then filtered the frequency spectra of the masking images to produce band-pass and notch-filtered masks. The most striking result of these experiments was that the notch-filtered images, which contained little or no contrast in the target frequency and orientation band, still produced substantial levels of masking. These results can be explained by applying a simple contrast-gain control model based on divisive normalisation to adjust the contrast of the mask and the target stimulus.

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◆ **Natural scenes and the dipper function**

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The traditional dipper experiment measures contrast discrimination thresholds for sinusoidal gratings at different base contrasts. It has repeatedly been shown that, for the lowest base contrasts, discrimination threshold drops below the detection threshold (facilitation), and rises as base contrast increases (masking), to give the dipper shape. We present the results of three observers for novel dipper experiments that used natural-image stimuli. The five natural-image stimuli were digitised, linearised black-and-white photographs. They were chosen to represent a wide selection of possible image structures. For comparison, discrimination thresholds were measured for gratings, and for two $1/f$ filtered random-dot images, the latter experiment conducted in order to test the hypothesis that it is the Fourier statistics that predict the experimental result. A two-alternative forced-choice procedure was used. For all sinusoidal, natural, and random-dot images, and for all observers, the results showed the dipper effect. The random-dot results could easily be distinguished by the upward and rightward displacement of the dipper. Results for the natural scenes resembled more those of the gratings, though the different natural scenes produced markedly different amounts of facilitation. Fourier analysis could not predict these differences, but the low Fourier energy of the random-dot stimuli did account for those results.

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◆ **Straight and inverse subliminal priming effect in metacontrast masking**

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Subliminal primes can affect motor performance. The direction of the effect is, however, controversial. In some studies a straight priming effect was reported (ie reaction time to an imperative stimulus was slower when prime was mapped to the same response as the imperative stimulus), whereas in other studies an inverse priming effect was described. We performed an experiment to determine the role of the mask in subliminal priming. Three pairs of geometrical figures (prime followed by mask followed by imperative stimulus) were presented in each trial. One of the figures was defined as a target and the task of the participants was to respond to the imperative stimulus by the hand on the target's side. Metacontrast masking was employed. Three types of neutral mask were used: target-like (T), non-target-like (NT), or neutral (N, neither target nor non-target) figures. The sign and the magnitude of the priming effect depended on the mask type. A straight priming effect was observed for NT and T, being larger for NT than for T, while an inverse effect was observed for N. Our finding suggests that the mask (even neutral) interferes with prime and target modulating the priming effect.

◆ **Time-course of surround suppression: Supersonic inhibition in the contrast – contrast phenomenon**

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Neural processes underlying the contrast–contrast phenomenon should inevitably involve a delay. Here, we measured psychophysically the latency of surround suppression. All stimuli were 4 cycles deg^{-1} sinusoidal gratings. The apparent contrast of a circular 1 deg patch with an adjacently surrounding 0.5 deg annulus was measured in a 2IFC interwoven double-staircase procedure. The stimulus onset asynchrony (SOA) of centre and surround was varied (-400 to $+200$ ms in 12.5 ms steps). There were three conditions: (i) centre and surround had the same duration (100–200 ms); (ii) they had different durations, centre 100 ms, surround 25 ms; and (iii) as condition (ii), except that the centre had a Gaussian time envelope, the slope of which was varied. Unexpectedly, the suppression was strongest when the surround was presented 12–25 ms after the centre. Presentation duration had no effect on suppression latency. The short duration surround caused maximum suppression when presented 12.5 ms after centre onset. With Gaussian time envelope the maximal suppression occurred 12–25 ms after centre contrast peak. There are no current explanations for negative latencies such as presented above. However, our results suggest that the contrast rise duration of a stimulus has a critical effect on the susceptibility of the stimulus to surround suppression. Some preliminary models based on this assumption are considered.

◆ **Investigating collinear facilitation by classification images**

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The detection threshold for a Gabor patch can be decreased by placing collinear masks (flankers) well beyond the target Gabor. Different models for this long-range facilitation have been proposed. Whilst some theories assume complex nonlinear interactions between the perceptual filters, a simpler approach explains the facilitation by classical summation in a perceptual filter extending beyond the target (Solomon et al, 1999 *Vision Research* 39 987–992). We tested the latter approach by measuring classification images in two conditions: (i) for a 1.5 cycles deg⁻¹ horizontal Gabor target, and (ii) the same target flanked by two collinear Gabors horizontally displaced, by 1.7 deg, from the target. The target was masked by a 2 deg × 2 deg low-contrast white-noise mask. Finally, obtained classification images were fitted by Gabor functions. The results show that flankers increased the length (along collinear axis) of the perceptual filter. Further, the facilitation was quite prominent in spite of the noise mask. Thus, we found support for the idea that changes in the spatial properties of the perceptual filter may play a role in collinear facilitation. However, as the overlap between the estimated perceptual filter and the flankers was minimal, classical summation alone can hardly explain the observed facilitation.

◆ **Lateral interactions: Orientation and spatial frequency bandwidths in fine spatial discriminations**

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We measured the range of orientations and spatial frequencies over which lateral interactions occur, while performing fine discriminations between two gratings that differed slightly in orientation or spatial frequency. The patterns were 40 min of arc patches of vertical 4 cycles deg⁻¹ grating, modulated sinusoidally around a mean luminance of 19.8 cd m⁻². Modulated surrounds subtending 3 deg were added to the display in test conditions. Contrast was held constant in both test patterns and surrounds at 0.10%. A signal detection rating paradigm was used to measure the range of interactions. Results were similar, though not identical, for orientation and spatial-frequency judgments with one notable exception. Performance was maximally impaired by surrounds nearly identical in spatial frequency and orientation. Both orientation and spatial-frequency bandwidths depended upon the judgment. In one case (orientation judgments, orientation bandwidth), two minima were observed. Spatial-frequency bandwidths were greater than ±1 octave. Masking effects were observed even at 90 deg separations. We conclude that the lateral processes affecting apparent contrast are different from those which affect fine spatial discriminations, and that multiple processes may underlie the lateral interactions involved in orientation judgments.

◆ **Lateral interactions in the visual perception can be explained on the basis of LGN cell array output**

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Previously, we found that the perception of flicker strength in a circular stimulus can be changed by altering the relative temporal phase of a simultaneously flickering surrounding annulus: flicker is perceived as weak when the two stimuli are modulated in phase and strong when the two are modulated in counterphase. The stimulus is encoded by an array of LGN neurons, the receptive fields (RFs) of which are covered by the stimulus. We studied the responses of marmoset LGN neurons to such stimuli as a function of relative phases and of spatial displacements between the stimulus and the RF. The responses strongly depend upon the spatial displacement when the relative phase is large, but not when the relative phase is small. The responses of the cells can be described by a difference-of-Gaussians (DOG) model with an RF surround delay. The DOG model responses at different displacements can be considered as the output of an array of ideal and identical LGN cells with different RF locations. We applied a peak-to-trough detector to the model responses to simulate a simple cortical decision mechanism. The outputs of such a detector, combined with a threshold and saturation, are in good quantitative agreement with psychophysical data.

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◆ **Manipulating contour smoothness: Evidence that the association-field model underlies contour integration in the periphery**

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Field et al (1993 *Vision Research* **33** 173–193) proposed that an association-field model (AFM) underlies performance in path-paradigm (PP) tasks. The AFM integrates dynamically the outputs of filters with different orientation preferences. In the current study, simulations were used to examine whether PP tasks could be solved by a simple-filter model (SFM). The SFM posits that 2AFC decisions are based upon the maximum length of zero-bounded regions after convolution of stimuli with elongated filters—integration only occurs between the outputs of co-oriented filters. In contrast to Hess and Dakin (1997 *Nature* **390** 602–604; 1999 *Vision Research* **39** 947–959), initial simulations showed that manipulations of Gabor patch phase were an inadequate control for the contribution of the SFM towards PP performance. In a further simulation, the angular difference between neighbouring contour elements was held constant, while the global smoothness of contours was varied. The SFM favoured jagged contours and was relatively impaired in the detection of smoother contours. Conversely, human observers favoured smoother contours in the fovea and parafovea (13°). Whilst the SFM could account for the detection of jagged and randomly structured contours, it is inadequate as an account of the detection of smooth contours. Consequently, the AFM may provide a parsimonious account of contour integration across the whole visual field.

◆ **Contour interaction with picture optotypes**

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Isolated optotype acuity in picture tests may not be equivalent to normal Snellen acuity unless the effects of contour interaction have been considered. We assessed the influence of flanking bars on performance using the Kay Picture optotypes. Five visually normal adult observers participated in the study. Isolated Kay Picture optotypes were presented, at random, on a standard PC platform, either with or without four flanking bars. The flanking bars were presented at one of five distances from the optotype, corresponding to a proportion of the symbol size (abutting, 0.25, 0.5, 1.0, 2.0). Performance was assessed by recording the proportion of correctly identified symbols. For comparison, measurements were also obtained for the traditional isolated Landolt C optotype. Consistent with previous studies, our results showed a decrease in performance depending on the distance of the bars from the symbol. Performance was most affected when the flanking bars were abutting or at 0.25 distance. However, the decrease in performance with the Kay Pictures was relatively small, much less than that observed with the Landolt C. Although contour interaction does occur with the Kay Pictures, more research is needed to determine whether the effects observed have any useful clinical application.

◆ **Empirical performance of optimal Bayesian adaptive psychophysical methods**

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Simulation studies (Alcalá-Quintana and García-Pérez, 2004 *Psychological Methods* **9** 250–271) showed how Bayesian methods should be set up for optimal performance. We assessed whether these results hold for human observers, who are more subject to failure than simulation subjects. Discrimination and detection tasks, both with two-alternative forced-choice trials, were used that yielded psychometric functions P , respectively, ranging from near 0 to near 1 and from 0.5 to near 1. Thirty measurements of the point of subjective equality (PSE, the 50% point on P in discrimination tasks) and threshold (the 80% point in detection tasks) were taken for four observers by optimal Bayesian methods while P was measured concurrently with the use of fixed-step-size (FSS) staircases. In the discrimination task, PSEs for each observer were distributed around the actual 50% point on P but their variability was slightly larger than what simulations indicated it should be. In the detection task, the distribution of thresholds was consistently above the 80% point on P and its spread was also larger than expected from simulations. The larger variability of Bayesian estimates for human observers seems to arise from variations in human performance over time, while the apparent bias in detection tasks seems to reflect the inappropriateness of the use of FSS staircases.

◆ **Distribution of sensitivity measures in magnitude estimation**

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When magnitude estimation [Stevens, 1975 *Psychophysics: Introduction to Its Perceptual, Neural and Social Prospects* (New York: John Wiley)] is applied, and individual differences are analysed, usually two measures are examined: the exponent of Stevens's power function (K) and Pearson's product moment correlation between the logarithm of the stimulus and the logarithm of the response (R). We studied the distribution of these measures in visual modality (line length and squares) across different stimulus ranges by using a large sample (more than one hundred subjects). Our results show that K is normally distributed, but R is not. We suggest that R could be corrected by applying a logarithmic transformation (the same was proposed by Fisher when determining a statistical inference about Pearson's product moment correlation). When R is corrected (F), we obtain a normal distribution, and, what is more important, the capacity of F to distinguish between different experimental conditions is greatly improved. Since R is employed as a sensitivity measure [Garriga-Trillo, 1985, PhD thesis (Madrid: UAM); 1987 *Progress in Mathematical Psychology* 1 343–349], we conclude that F could be used instead of R for this purpose.

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◆ **Age-related changes in perception of verticality with a static or kinetic visual-field disturbance**

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While there have been several investigations of age-related changes in static visual field dependence, few results deal with age-related changes in kinetic visual-field dependence. We aimed to complete previous findings by comparing the performances in the rod-and-frame test (RFT) and rod-and-disc test (RDT) of forty-two young subjects (21–31 years old) to those of thirty-four older subjects (44–60 years old). First, observers were asked to adjust a luminous rod to the apparent direction of gravitational vertical while the rod was surrounded by a white luminous tilted square. Second, the same task was performed while the square was replaced with a ring composed of white luminous dots driven by a circular motion. The results showed that, whatever the test, rod-setting mean error and inter-individual dispersion were significantly larger for the older age group. Moreover, RFT and RDT scores were more correlated in the older age group. Compared to the RFT, the RDT allowed better discrimination among young subjects whereas the opposite result was observed for the older subjects. Nevertheless, given the RFT or RDT score variation curve, one may doubt the relevance of the usual distinction method dividing subjects into two categories of visual-field dependence.

◆ **Does shading affect size illusions in simple line drawings?**

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Geometric illusions can be observed in a number of simple line drawings like the Müller-Lyer or Judd figures. Perspective explanations, such as the 'inappropriate constancy scaling' theory, advocate that the size of line drawing components may be adjusted by the perceptual system with reference to the inferred three-dimensional structure of the pictured object. This theory would predict that additional depth cues, for instance shading added to line drawings, should affect these illusions by manipulating the three-dimensional appearance. We measured the magnitude of length misjudgments for horizontal Müller-Lyer and Judd figures in the pure line drawings, and with shading attached to the top or bottom of the figures, which are interpreted as 'folded' configurations with a horizontal edge behind or in front of the image plane, respectively. While we could not find any effect of shading, we did observe a length misjudgment in Judd figures that corresponds to the asymmetry found for the Müller-Lyer illusion for inward and outward directed fins. This pattern of results is not consistent with notions of inappropriate constancy scaling but fully coherent with the view that neural filtering mechanisms, affecting the perceived position of line intersections, are responsible for this type of geometrical illusions.

◆ **Evaluation of the perceptual image quality of compressed images with a model of the human visual system**

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The need for the evaluation of perceptual image quality has become much greater with introduction of multi-media communication and image compression formats. Our aim was to design

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and test a tool for image quality evaluation corresponding to the perceptual image quality. Objective methods, eg mean square error (MSE), are simple but they do not take account of the properties of the human visual system (HVS). Subjective tests, based on many observers, provide the best results but the procedures are very time-consuming and costly. Therefore, we devised a model of HVS. The model has 60 channels and is based on Frese's approach (West Lafayette, USA). It involves Gaussian pyramidal decomposition, contrast and oriented response computation, and differential metrics calculation. Evaluation of the accuracy of the model was based on the results of subjective testing in our subjective testing laboratory, conforming to ITU-R recommendations BT.500-10, by the double-stimulus continuous-quality scale method, with fifteen observers and five different image types. The results show very good agreement of the quality predicted by the HVS model with the subjective testing, unlike the MSE method. Using the model for perceptual quality assessment is precise enough for a variety of tested images and a wide range of compression rates of the images.

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◆ **Layout from texture in a panorama**

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Shape-from-texture studies for large visual fields suggest that the human observer may refer surface orientation to local visual direction instead of the global 'forward' direction. Sixty naïve observers sketched the apparent profile of a horizontal section of a texture-defined surface. The stimulus was a transillumined hemisphere of 120 cm diameter, on which 1000 black polka dots (5.7 deg diameter) were pasted randomly. The display was viewed monocularly through a peephole at the centre of the sphere that prevented binocular viewing. Observers were set up for the task but kept fully ignorant of the true layout. The data were subjected to a clustering algorithm. Three major groups of roughly similar size were encountered: the first (small) group experienced a veridical impression, the second group a flat frontoparallel plane of 20–40 deg, and the third group a curved surface of about 90 deg extent. The second group clearly referred local surface orientation to local visual direction, whereas the first group did not. The third group may be understood from Helmholtz's model for subjective curvatures in the visual field. This reveals a remarkable diversity in the way the observers experience a truly panoramic, monocular visual field.

TEMPORAL VISION

◆ **Reaction time to S-cone increments and decrements**

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Temporal integration of blue-on-yellow short wavelength (S-cone) selective luminance signals depends on signal polarity (Murzac et al, 2003 *Comptes Rendus of the Academy of Sciences of Bulgaria* **12** 91–96). The question posed in this study is whether the differences in temporal characteristics will be preserved at suprathreshold level, while using reaction time (RT) as an indicator. The background consisted of 415 cd m⁻² yellow light and 1.4 cd m⁻² blue light. The test stimuli were either luminance increase or decrease of the blue light over a circular area 2 deg in diameter centred at 1.5 deg, or 4 deg in diameter at 15 deg from fovea along the temporal meridian. Stimulus duration was 106 ms. Stimulus contrast spanned 3 to 9 times above threshold. RTs to decrements were shorter by 10–40 ms than to increments at our central location. Shorter RTs to S-cone decrements for isoluminant stimuli modulated along the tritanopic axis were reported (McKeefry et al, 2003 *Investigative Ophthalmology & Visual Science* **44** 2267–2276); however, the differences we found were an order of magnitude smaller. Our peripheral presentation yielded no systematic difference between RTs to increments and decrements. Three possible explanations are considered: S-cone system isolation, unequal sensitivity to increments and decrements, or separate S-cone ON and OFF pathways.

◆ **The phenomenon of increase of perceived brightness of the drifting light spot**

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As a result of our modeling of the dynamic processes in primary stages of the human visual system, we have predicted a new phenomenon. A drifting test light spot over a limited range of

angular speeds is perceived to be brighter than when it is stationary. This phenomenon was first found theoretically and later observed and investigated experimentally. We found that, when the angular speed of a drifting test light spot is increased, its perceived brightness at first increases, reaches maximum, and then decreases monotonically tending to the perceived brightness of the stationary spot. This phenomenon is observed only when the diameter of the drifting test light spot is not less than 0.5–1 deg. The phenomenon does not occur when the background and the drifting test light spot have only colour contrast. We found that the mechanism of this phenomenon is due to the delay of inhibitory signals relative to the excitatory signals, as in the case of processes giving rise to the Broca–Sulzer effect.

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◆ **Contrast dependence of the flash-lag effect**

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A moving object that is presented very briefly (a flash) is mislocalised relative to a moving object of longer duration (flash-lag effect—FLE). Our stimulus paradigm employed low-speed stimuli and limited their spatial-frequency content. Previously, we probed the significant frequency-tuning of the FLE [Cantor and Schor, 2003 *Journal of Vision* 3(9) abstract 211], reporting a progressive increase in the FLE for stimuli of lower spatial-frequency and speed. This is consistent with our hypothesis that the temporal impulse response (TIR) produces the flash-lag effect. Here, we probed the contrast dependence of the FLE. Changing the contrast of the display should affect the TIR of the visual system (Stromeyer and Martini, 2003 *Vision Research* 43 285–298). If the FLE is due to interaction between the TIR function and the high temporal frequencies introduced by flashing a stimulus, then compression of the TIR at high contrast will enhance the contribution of these high temporal frequencies, increasing the magnitude of the FLE. Our results confirm a contrast dependence consistent with the TIR hypothesis.

◆ **The structure of visual hallucinatory experiences induced by flickering light**

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Conscious visual states are generally assumed to be based upon the interaction of spatially structured information in the environment with the visual nervous system. This stands in contradiction to the fact that visual hallucinations can be generated by temporally, but not spatially, defined electrical and optical stimulation (Benham, 1895 *Nature* 2 321; Knoll and Kugler, 1959 *Nature* 184 1823–1824). Here, we show that complex colour (red, green, blue, yellow, purple) and form hallucinations (eg circles, radial patterns, spirals, rectangles) are evoked when subjects are presented with flickering light in the frequency range of 5–56 Hz. The different hallucinatory experiences are distributed differentially over flicker frequencies, while the onset of hallucinations can relate to a particular phase of the periodic stimulus (eg hallucinations have a specific frequency and phase of occurrence). What is more, specific patterns of co-occurrence determine which hallucinations will be experienced, ie the experience of a given hallucination seems to depend on the occurrence or the probability of occurrence of others. These results suggest that conscious visual experiences may be evoked by particular temporal variations of a spatially unstructured stimulus; this provides support for theories assuming the generation of consciousness to be mediated by a dynamic psychophysical structure.

◆ **Optic flow estimation by means of the polynomial transform**

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We present a spatiotemporal energy-based method to estimate movement from an image sequence. A directional energy is defined in terms of the Radon projections of the Hermite transform. Radon transform provides a suitable representation for image orientation analysis, while Hermite transform describes image features locally in terms of Gaussian derivatives. These operators have been used in computer vision for feature extraction and are relevant in visual system modeling. The responses of these operators have been found to be very accurate when modeling the human vision, and the results contain characteristics not found by traditional methods. The proposed algorithm incorporates the knowledge of the visual system which makes an attractive alternative to analyse image sequences. Here, it is shown that the cascaded Radon/Hermite transformation is readily computed as a linear mapping of the 3-D Hermite transform coefficients through some steering functions. A directional response defined from the directional energy is used to estimate local motion of 1-D and 2-D patterns as well as to

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compute a confidence matrix. This matrix provides a confidence measure for our estimate and is used to propagate the velocity information toward directions with high uncertainty.

◆ **Absence of representational momentum for rotating objects**

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In apparent-motion displays, the remembered final position of a moving object is often displaced in the motion direction. This forward displacement has been called representational momentum, and has led to the hypothesis that subjects automatically predict the object's future path, on the basis of an internalised representation of the object's physical properties. To test this hypothesis, we investigated whether representational momentum occurs not only for translating motion, but also for rotation. Observers saw three sequentially presented images (presentation duration and interstimulus interval of 250 ms each), implying rotation around a vertical axis through the object's centre of gravity. They were followed by a test image, which the subjects had to adjust to match the last (third) position. Stimuli were rendered from 3-D models of either a simple rotating cuboid or a complex rotating face. Responses were measured as displacement from the position of the last presented image. For simple objects, there was no significant effect: subjects reported the final object's position accurately. For complex objects, we found an unexpected backward displacement, incompatible with the representational-momentum hypothesis. We explore alternative explanations that do not rely exclusively on representational momentum, and that account for the dependence of the results on the complexity of the object.

◆ **Shape complexity and goodness affect synchrony coding in perceptual grouping**

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Previous psychophysical studies reveal that detection of a target Kanizsa-type figure within a matrix of distractor junctions is expedited when the target display is preceded by a 40-Hz modulated matrix of premask crosses, with the synchronised repetition of four crosses at the subsequent target location (Elliott and Müller, 1998 *Psychological Science* 9 277–283). In the current study, two experiments were performed to examine whether this 40-Hz 'priming' effect was influenced by shape complexity, shape goodness, or both. In experiment 1, different priming effects were compared among three different shape matrices (triangle, square, and hexagon). Results showed that synchrony priming was facilitated by shape complexity (ie the magnitude of priming increased monotonically as a function of an increase in the number of sides defining the shapes). In experiment 2 we further examined this relationship within the same structure of matrix by comparing the effect of different shapes in the same matrix. Results were consistent with those of the first experiment and also indicated that synchrony priming may be a function of figural goodness.

◆ **Dynamics of nonlinear feedback control**

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We are reporting on the mathematical behaviour of systems for gain control in which the dynamic output $O(t)$ of the system equals the input $I(t)$ to the system either multiplied by a gain control $G(t)$: $O(t) = I(t) \cdot G(t)$ (multiplicative control), or divided by an attenuation signal $A(t)$: $O(t) = I(t)/A(t)$ (divisive control). The control signal $G(t)$, respectively $A(t)$, is derived from the output $O(t)$ (ie we are dealing with feedback control) through a concatenation of an instantaneous nonlinearity $f(O)$ and a linear low-pass filtering. Such control systems have been used to describe the dynamics of both light adaptation and contrast gain control in the visual system. We find that the dynamic behaviour of multiplicative and divisive control can be very different. For instance, for inputs $I(t)$ that consist of low-pass filtered step signals, the output $O(t)$ of a multiplicative control system shows large overshoots under conditions where the divisive control system attains steady state without overshoot. Also, the order of the operations in the feedback path is important: a nonlinearity $f(O)$ followed by low-pass filtering yields a smooth (monotonic) output $O(t)$, whereas the reversed order can yield an output $O(t)$ with many oscillations. Finally, we discuss the implications of our results for psychophysics and physiology.

◆ **Effects of rapid stimulus onset and offset on the identification of fast moving achromatic and isoluminant chromatic stimuli**

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The influence of rapid stimulus onset and offset on the subject's ability to identify the orientation of achromatic and isoluminant red-green gratings was tested. The 1 cycle deg^{-1} stimuli were either horizontally or vertically oriented and moved at a velocity of 36 cycles s^{-1} . The onset and offset of the stimulus presentation was either abrupt or ramped. In the ramped condition the stimulus contrast was constantly increased or decreased over 80 ms or 8 frames. Full contrast of the stimuli was present for 160 ms or 16 frames. Three onset-offset conditions were tested over a broad range of stimulus contrasts: (i) rapid onset followed by rapid offset, (ii) rapid onset followed by ramped offset, and (iii) ramped onset followed by rapid offset. For achromatic as for isoluminant chromatic stimuli it was found that contrast sensitivity for the identification task was highest for the rapid onset-rapid offset condition followed by the rapid onset-ramped offset and the ramped onset-rapid offset condition. The results suggest that there is a transient response not only to the fast moving achromatic but also to the isoluminant chromatic stimuli which contributes to the visibility of the stimuli.

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