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# Images, Perception, and Psychophysics

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## ABSTRACTS

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◆ **Functional range of the human visual system and some of its spatial – temporal characteristics**

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The transcendental psychology approach [Mirakyan, 1999 *Outlines of Transcendental Psychology* (Moscow: IPRAS)] focuses on the way that visual representations need to be created over time. For example, even simple attributes, such as the perceived width of a line, change systematically when the stimulus is first presented. Such phenomena can provide important cues to the spatial and temporal properties of the representation process. We therefore investigated the temporal development of perceived line width by presenting contoured hexagons consisting of 0.3 deg wide lines at a range of short durations, and asking observers to estimate perceived line width by comparison with long-duration figures. Our results confirm that perceived line width increases smoothly between 10 and 50 ms, reaching a maximum rate of about 15 deg s<sup>-1</sup>. This reveals a basic temporal limit to visual processing that can explain why the maximum perceivable speed is about 30–50 deg s<sup>-1</sup> (objects must remain fixed for at least 10 ms for any representation to emerge), and why the maximum speed perceivable without blur is about 4–5 deg s<sup>-1</sup> (objects must remain fixed for at least 50 ms for the perceived width to stabilise). It may also explain other, apparently illusory, phenomena such as the flash-lag effect (Eagleman and Sejnowski, 2000 *Science* 290 1051), in which a stationary flash and a rapidly moving object in the same location appear to be spatially offset. The spatial uncertainty associated with a dynamically changing, rapidly moving object will produce a predictable shift in its perceived position.

◆ **Visually-guided actions are dependent on luminance signals**

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When a visual stimulus is continuously moved behind a small stationary window, the window is perceived to be spatially displaced in the direction of motion (De Valois and De Valois, 1991 *Vision Research* 31 1619–1626). We showed that the magnitude of this illusion is more pronounced when assessed with a visuomotor (pointing) task than with a perceptual task, and argued that this may reflect neural compensation for the physical displacement a moving object would undergo during delays associated with visuomotor processing (Yamagishi et al, 2001 *Proceedings of the Royal Society of London Series B* 268 973–977). Here, we report that this ‘visuomotor illusion’ is specific for luminance-modulated stimuli. Following the presentation of a smooth-windowed horizontal grating 7.5 deg to the right of fixation for 500 ms, subjects were asked to judge its vertical position either by: (i) reporting its perceived position relative to an on-screen ruler, or (ii) touching the screen with their right index finger (without visual feedback of hand position—‘open-loop pointing’). Both equiluminant red–green gratings and luminance-modulated gratings were used, and the vertical position of each target was varied randomly between ±1.5 deg of the horizontal meridian. Note that the visibility of stimuli was matched by using individual direction discrimination thresholds. Our results show that, while perceptual localisation errors for luminance and equiluminance stimuli were similar, visuomotor localisation errors were significantly greater for luminance than for equiluminance stimuli. Differences in perceived speed cannot account for the differences observed in the visuomotor task. Our results support the idea that separate cortical pathways exist for visual perception and visually guided actions, and that the latter are critically dependent on luminance signals.

◆ **Assessing local and global factors in motion perception by means of equivalent noise**

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Our ability to assess in which direction a large object is moving depends on two factors: how well we can assess the motion of any one of its parts (local motion) and how efficiently we can combine these estimates together (global motion). Existing techniques for assessing direction sensitivity are typically based on motion coherence thresholds and cannot separate the influence of these local and global factors. This is a cause for concern when the results of applying such techniques within a clinical context (eg glaucoma, dyslexia, etc) are frequently interpreted in terms of global deficits. I describe a methodology based on equivalent noise that can tease apart global and local limits on motion perception. I then describe how this paradigm has shed light on (a) the influence of spatial factors (eg density) on motion perception, (b) why we are better at judging direction around the cardinal (vertical–horizontal) axes, (c) how eccentricity affects motion perception, and (d) how we see motion transparency.

◆ **Visually induced motion sickness in the fore-and-aft axis**

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Despite the predominance of forward motion in both real and simulated movement, few studies have been reported on the provocativeness of visually simulated ego-motion in the fore-and-aft axis (eg So et al, 2001 *Human Factors* **43** 452–461). In this study, seated subjects viewed monocularly random-dot displays which simulated observer motion through a volume of randomly positioned points (expanding/contracting radial optic flow). Two conditions were employed: (i) forward translation at a constant velocity, and (ii) sinusoidally oscillating (0.025 Hz) forward–backward translation. According to the widely accepted ‘sensory conflict’ theory, the sinusoidally oscillating condition would be expected to generate visually induced motion sickness. This is because self-motion cues provided by the visual system are not accompanied by an expected vestibular signal consistent with varying acceleration. On the other hand, at constant velocity, visual and vestibular self-motion cues are not in conflict, since the vestibular system responds to accelerations only and hence no vestibular signal is expected in this condition. However, according to the ‘subjective vertical-conflict’ model (Bles et al, 1998 *Brain Research Bulletin* **47** 481–487), which states that motion sickness results only when the subjective vertical deviates from the sensed vertical, neither condition should produce symptoms, because the stimuli are neutral with respect to gravity. Preliminary results indicate that, although vection was experienced for approximately 50% of the total exposure time in both conditions, translation in the fore-and-aft axis caused little or no motion sickness. These findings conflict with sensory conflict theory predictions, and provide indirect support for the subjective vertical-conflict theory.

◆ **Fixed or variable noise in contrast discrimination? The jury’s still out**

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The ability to distinguish one visual stimulus from another slightly different one depends on the variability of their internal representations. In a recent paper on human visual-contrast discrimination, Kontsevich et al (2002 *Vision Research* **42** 1771–1784) re-considered the long-standing question whether the internal noise that limits discrimination is fixed (contrast-invariant) or variable (contrast-dependent). They tested discrimination performance for 3 cycles deg<sup>-1</sup> gratings over a wide range of incremental contrast levels at three masking contrasts, and showed that a simple model with an expansive response function and response-dependent noise could fit the data very well. Their conclusion—that noise in visual-discrimination tasks increases markedly with contrast—has profound implications for our understanding and modelling of vision. Here, however, we re-analyse their data, and report that a standard gain-control model with a compressive response function and fixed additive noise can also fit the data remarkably well. Thus these experimental data do not allow us to decide between the two models. The question remains open.

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◆ **Geometric texton theory: The 1-D, 2nd-order jet**

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Much is understood of how quantitative aspects of image structure are measured by V1 simple cells, but less about how qualitative structure is determined from these measurements. Geometric texton theory (GTT) aims to describe this step from quantitative to qualitative. GTT (Griffin et al,

2004 *Vision Research* **44** 407–421) proposes that qualitative feature categories arise through consideration of the maximum likelihood (ML) explanations of image measurements. This posits that a pair of output vectors of an ensemble of co-localised neurons signal the same feature category if and only if the corresponding ML explanations are qualitatively similar. I have studied the mathematics and image statistics relevant to GTT for the limited case of measurement by 1-D Gaussian derivative filters of up to second order. Mathematical analysis has identified the simplest explanations for measurements by such filters, while empirical results have identified the ML. The ML explanations are not the most simple under any of the definitions of ‘simple’ that have been examined. However, the ML explanations are simple and do have properties predicted by GTT. In particular, they change rapidly and qualitatively for certain narrow regions of measurement space, while remaining qualitatively extremely stable between those transition regions. Three feature categories arise naturally from the data: light bars, dark bars, and edges. The results are consistent with GTT.

◆ **Leaky predictive coding: A subtractive and divisive fast/slow gain control model for contrast coding**

7 Keith Langley (Department of Psychology, University College London, Gower Street, London WC1E 6BT, UK; e-mail: [kl@psychol.ucl.ac.uk](mailto:kl@psychol.ucl.ac.uk))

The dynamic on-line adjustment of the visual internal settings of a system to external stimuli is investigated. It is proposed that the observed effects of divisive and subtractive contrast gain control may be understood by an analysis of a leaky predictive coding strategy through an adjustment of the encoding and decoding weights. The proposed model assumes that there exist three noise sources: input noise, channel noise, and reconstruction noise. The purpose of the initial stage of coding is to reduce input noise, while at the same time provide an efficient representation for the signal to be transmitted. The purpose of the stage of decoding is to recover the transmitted signal while maximally reducing the overall contribution made by both the input noise and channel noise sources in the decoding process. Through the introduction of specific constraints on the system studied—for example, hard constraints on the available transmission channel variance and soft constraints on the coding weights themselves—it is shown that a communication system, if optimised online to reduce transmission noise, may be developed that possesses both fast and slow components of divisive and subtractive gain control. More interestingly, the divisive component of the proposed coding strategy exhibits the interesting property of contrast facilitation close to threshold and contrast suppression at high contrast. The proposed model suggests that the fast components of subtractive and divisive contrast adaptation are driven by the need to minimise input and channel noise efficiently. The slow phase of contrast adaptation, on the other hand, is driven by unpredicted visual signals such that the environmental model of the visual signal exploited by the visual system is adapted to match with the input signal itself.

◆ **Memory colours of real, familiar objects under changing illumination**

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Colour constancy is a robust phenomenon most likely mediated by multiple mechanisms, operating at different levels in the visual system. In the natural world, visuo-cognitive factors such as object familiarity, colour diagnosticity, and colour memory may also contribute to constancy. To investigate these factors, we have developed a setup which preserves the natural binocular and monocular cues to 3-D shape, while allowing us to adjust the apparent colour of real objects. In this experiment, the observer’s task was to report whether particular colours ‘matched’ particular objects under different illumination conditions. The objects were solid, matt-white-painted styrofoam fruits and vegetables arrayed on a white board (70 cm × 50 cm) contained within a black box (100 cm × 80 cm × 60 cm) and illuminated by a hidden data projector, which the observers viewed through a fixed aperture. The surface colours of individual objects were applied via projected images and varied between trials. The observer’s task was to respond whether the colours of targeted 3-D objects were appropriate, or whether the colours of flat disks matched the verbally cued object (eg ‘banana’ or ‘carrot’). We found that (i) observers accept a significantly larger range of colours as object-appropriate when they appear as surface colours of congruent 3-D shapes, compared to flat disks; (ii) for 3-D shapes, but not disks, the range of accepted colours varies with illumination; (iii) reaction times are slowest for flat disks, and fastest for 2-D and 3-D shapes. We conclude that 3-D shape influences memory colour and colour constancy.

◆ **Distance judgments based on Rayleigh scattering: The detection of colour changes with distance in blue – yellow opponent channels**

9 P George Lovell, Tom Troscianko, C Alejandro Párraga (Department of Experimental Psychology, University of Bristol, 8 Woodland Road, Bristol BS8 1TN, UK; e-mail: [p.g.lovell@bristol.ac.uk](mailto:p.g.lovell@bristol.ac.uk))

Rayleigh scattering causes distant objects to appear bluer than their nearer counterparts. The phenomenon is exploited by landscape painters who add a blue tint to representations of more distant objects. Using calibrated cameras (Párraga et al, 2002 *Current Biology* **12** 483–487) we measured the chromatic properties of near and far surfaces in natural images of mountains, hills, meadows, and railway tracks. RGB values for pixels were translated into cone-activity values and in turn these were translated into values in blue – yellow opponent space (BY):

$$BY = \frac{S - Lum/2}{S + Lum/2},$$

where S is the short-wavelength cone response and Lum is the sum of the long- and medium-wavelength cone responses. Regressions were calculated for each category of natural scene and the mean slope was derived ( $\Delta BY = 0.000068$  metres), revealing an increase in blue pixel activity of approximately 235% over 4000 metres. In a psychophysical study, the sensitivity of observers ( $n = 3$ ) to these colour changes was measured. The results confirmed that observers could detect changes in colour caused by shifts in distance of as little as 200 metres. We conclude that while L and M cones have wavelength sensitivities optimised for the detection of fruit and for the removal of shadows (Párraga et al, 2002 *ibid.*), the relative wavelength sensitivity of the S cone results in a BY opponent system that is efficient at the discrimination of distance, even when all other cues are removed. This may be related to the benefits, on an evolutionary time-scale, gained from having the ability to discriminate distances where other cues are removed, for example in savannah and desert.

◆ **Size matters, but not for everyone: Individual differences for contrast discrimination**

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It is well known that contrast detection thresholds improve with the size of a grating-type stimulus, but it is thought that the benefit of size is abolished well above threshold (Legge and Foley, 1980 *Journal of the Optical Society of America* **70** 1458–1471). Here we challenge that view. We performed two-interval, forced-choice contrast discrimination (pedestal contrast = 20%) and contrast detection (pedestal contrast = 0%) experiments for circular patches of sine-wave grating (spatial frequency = 1 cycle deg<sup>-1</sup>; duration = 100 ms) with four different diameters (2.7 deg – 12.2 deg) and central fixation. We confirm that sensitivity improves with approximately the fourth-root of stimulus area at detection threshold (a log–log threshold slope of –0.25), but find large individual differences (IDs) for the suprathreshold discrimination task in a group of eleven observers. For several observers, performance was largely unaffected by area; but for others, performance first improved (by as much as a log–log slope of –0.5) and then either reached a plateau or deteriorated again. All of the results were very well fit by extending a recent model of area summation (Meese, 2004 *Journal of Vision* **4** 930–943) to accommodate the multiple stimulus sizes used here. In this model, (i) excitation increased with the fourth-root of stimulus area for all observers, and (ii) IDs in the discrimination data were described by IDs in the relation between suppression and area. According to this formulation, direct empirical observations are good approximations of: (i) the level of summation when the experiment is performed at detection threshold, and (ii) the weight of suppression relative to excitation when the experiment is performed well above detection threshold.

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◆ **Sensitivity to colour gradients and its dependence on complexity of surround**

11 Alexa I Ruppertsberg, Fazila Mayat, Anya Hurlbert ¶, Marina Bloj (Department of Optometry, University of Bradford, Bradford BD7 1DP, UK; ¶ Institute of Neuroscience, Henry Wellcome Building for Neuroecology, University of Newcastle upon Tyne, Newcastle upon Tyne NE2 4HH, UK; e-mail: [a.i.ruppertsberg@bradford.ac.uk](mailto:a.i.ruppertsberg@bradford.ac.uk))

Colour gradients surround us in the natural and encode crucial information about the geometry and reflectance of objects and light sources. Surround complexity might be an important cue for recovering this information by limiting the number of possible interpretations. Consider a corner formed by a white and a green card. If the latter is directly illuminated, the white card

will display a colour gradient due to inter-reflection. On changing the position of the light source the gradient will change. How sensitive are we to these changes? Does sensitivity depend on the contents of the area surrounding the gradient?

The above stimulus configuration was simulated for a range of light-source positions with Radiance [Ward, 1994 *Computer Graphics Proceedings, Annual Conference Series* (New York: ACM Press) p.459] yielding physically accurate results [Ruppertsberg and Bloj, 2004 *1st Symposium on Applied Perception in Graphics and Visualization, Los Angeles* (New York: ACM Press) p.169]. In a roving 2-interval same–different design [Macmillan and Creelman, 1991 *Detection Theory: A User's Guide* (Cambridge: Cambridge University Press)] we measured  $d'$  between the reference scene and all other scenes. Three conditions were tested: intact surround (corner displayed with other objects giving full scene information), scrambled surround (gradient surrounded by 1-by-1 pixel scrambling of intact surround, preserving luminance and colour), and no surround (gradient in isolation giving no additional information).

For three observers and all conditions we found that sensitivity significantly increased as the illumination angle of the comparison scene differed from the reference. Sensitivity was the same for the scrambled and intact surround scenes, and significantly higher than for the no-surround condition. This does not support the hypothesis that a meaningful surround facilitates the discrimination of gradients, but implies that the improvement in sensitivity might be due to contrast effects. [Supported by the EPSRC Grant No. GR/S 13231.]

◆ **The role of texture amplitude in shape from shading**

12 Andrew J Schofield, Gillian Hesse, Mark A Georgeson<sup>¶</sup> (School of Psychology, University of Birmingham, Birmingham B15 2TT, UK; <sup>¶</sup>Neurosciences Research Institute, Aston University, Birmingham B4 7ET, UK; e-mail: [A.J.Schofield@bham.ac.uk](mailto:A.J.Schofield@bham.ac.uk))

When a textured surface is modulated in depth and illuminated, parts of the surface receive different levels of illumination; the resulting variations in luminance can be used to infer the shape of the depth modulations—shape from shading. The changes in illumination also produce changes in the amplitude of the texture, although local contrast remains constant. We investigated the role of texture amplitude in supporting shape from shading. If a luminance plaid is added to a binary noise texture (LM), shape from shading produces perception of corrugations in two directions. If the amplitude of the noise is also modulated (AM) such that it is in-phase with one of the luminance sinusoids and out-of-phase with the other, the resulting surface is seen as corrugated in only one direction—that supported by the in-phase pairing. We confirmed this subjective report experimentally, using a depth-mapping technique. Further, we asked naïve observers to indicate the direction of corrugations in plaids made up of various combinations of LM and AM. LM+AM was seen as having most depth, then LM-only, then LM–AM, and then AM-only. Our results suggest that while LM is required to see depth from shading, its phase relative to any AM component is also important.

◆ **Similar processing in visual search and motion perception?**

13 Nicholas E Scott-Samuel, James J Marsh, Ute Leonards (Department of Experimental Psychology, University of Bristol, 8 Woodland Road, Bristol BS8 1TN, UK; e-mail: [n.e.scott-samuel@bris.ac.uk](mailto:n.e.scott-samuel@bris.ac.uk))

We present evidence that similar processing underpins the analysis of both a well-established motion stimulus (the Ternus display), and a standard visual-search display. Ternus displays were constructed, with Gabor patch elements and a 0 ms interstimulus interval. From frame to frame, carrier orientation, spatial frequency or contrast were varied. Smaller inter-frame differences in each of these parameters resulted in the perception of element motion, larger ones gave group motion. The magnitudes of orientation, spatial frequency, and contrast change at the transition point between the two percepts were far larger than normal discrimination thresholds for these parameters (8° orientation difference; 20% spatial-frequency change; 50% contrast change), implicating high-level processing. To see whether other higher-order visual processes might behave similarly, the same Gabor patches were then used in a visual-search task, and the transition point from efficient to inefficient search was derived. The orientation, spatial frequency, and contrast transition points observed for both types of display were strikingly similar. Combined with previous evidence that low-level motion processing plays no part in the analysis of Ternus displays (Scott-Samuel and Hess, 2001 *Perception* 30 1179–1188), these data suggest that the processes underlying the analysis of the Ternus display are high-level and spatial in nature, with perception driven not by just noticeable differences, but rather by sufficiently large differences to indicate meaningful change. The findings have implications both for pure (ie motion perception) and applied (eg dyslexia) research. In addition, the Ternus display could be used as surrogate for certain search paradigms, as both stimuli may tap into the same processes.

- ◆ **The efficient use classification images for the psychophysical investigation of visual search**  
 14 Abtine Tavassoli, Ian van der Linde<sup>¶</sup>, Lawrence K Cormack<sup>§</sup>, Alan C Bovik (Department of Electrical and Computer Engineering [<sup>§</sup>Department of Psychology], University of Texas at Austin, Austin, TX 78712, USA; <sup>¶</sup>Department of Computing, APU, Chelmsford CMI 1JJ, UK; e-mail: [ianvdl@ece.utexas.edu](mailto:ianvdl@ece.utexas.edu))

One application of the classification image (CI) technique is the study of visual search [for background see Eckstein and Ahumada, 2002 *Journal of Vision* 2(1)]. Observers may be requested to judge the presence or absence of a target embedded in noise. The properties of the noise associated with correct and incorrect responses can provide insight into the underlying strategies deployed, showing how the observer weights the importance of different stimulus features in deciding if the target is present or not. A general drawback of this popular technique in its original form is that it requires the accumulation of a large number of data (to the order of several thousands of trials per observer).

We propose an extension to the CI technique which allows us to reveal more rapidly features used by observers in visual-search tasks. With eye tracking and a grid-like stimulus ensemble, the accumulation of results is accelerated in comparison with earlier methods by up to two orders of magnitude, whilst also providing compatibility with low-accuracy eye trackers. Our method is faster owing to three factors: first, when using a grid of discrete candidate tiles, one of which contains a centred target, the spatial jitter of features, observed when single large noise images are used, is avoided; second, in addition to obtaining hit and miss information, determined by whether the user selected the appropriate tile, a large number of useful data may be assembled from all the tiles fixated en route to the observer's selection, and from tiles never visited; third, the use of  $1/f$  noise increases the level of low-spatial-frequency structure in the tiles, leading to faster CI convergence. We tested our method using three human observers and two target types at 200 trials per target. The CIs obtained show the efficacy of the proposed method in exposing the search behaviour of different human subjects, even with such a small number of trials.

- ◆ **Is the early visual system energy efficient?**  
 15 Ben Vincent, Roland J Baddeley, Ian D Gilchrist, Tom Troscianko (Department of Experimental Psychology, 8 Woodland Road, University of Bristol, Bristol BS8 1TN, UK; e-mail: [ben.vincent@bristol.ac.uk](mailto:ben.vincent@bristol.ac.uk))

We report that a code, which balances natural image coding with metabolic energy efficiency, shows many similarities to the neural organisation observed in the early visual system. A simple two-stage, foveated visual system calculates the optimal receptive fields and finds that centre-surround organisation is optimal when synapses are costly, whereas Gabor-like organisation is optimal when firing rates incur costs. We find that combining natural image coding with energy efficiency goes a long way to account for the organisation of receptive fields across the entire foveated visual field in retina and cortex, but that factors such as the fixation locations of natural scenes may account for discrepancies. This work provides a sound biological justification for why 'sparse' distributions are beneficial in the cortex (Olshausen and Field, 1966 *Nature* 381 607–609) and in the retina (Vincent and Baddeley, 2003 *Vision Research* 43 1283–1290).

- ◆ **The effect of illusory brightness and illusory contours on the detection of target lines superimposed on an Ehrenstein figure**  
 16 Brian Wink, Véronique Salvano-Pardieu<sup>¶</sup>, Alain Taliencio<sup>¶</sup> (Psychology Division, University of Wolverhampton, Wulfruna Street, Wolverhampton WV1 1SB, UK; <sup>¶</sup>Université de Tours, Département de Psychologie, EA Vieillesse et Développement Adulte, 3 rue des Tanneurs, BP 4103, F 37041 Tours Cedex 1, France; e-mail: [b.wink@wlv.ac.uk](mailto:b.wink@wlv.ac.uk))

Evidence exists for subthreshold summation between physical targets and illusory contours (eg Poom, 2001 *Vision Research* 41 3805–3816), but Salvano-Pardieu et al (2001 *Perception* 30 Supplement, 37) were unable to support this using a four-armed Ehrenstein figure. The Ehrenstein illusion is produced by illusory brightness and illusory contours. In this study we investigated the effect of both of these on detection of a target line (four observers, 2AFC staircase procedure). The target was either superimposed on the illusory contour or the target was collinear with two arms of the Ehrenstein figure, where the target was clearly superimposed on the bright illusory surface. The two target locations (contour or collinear) were presented in each of three inducer conditions: (i) an eight-arm Ehrenstein figure, (ii) dots replacing the arms of the Ehrenstein figure, (iii) control—no cue to the spatial location of target. The results show no significant difference between the Ehrenstein or dot conditions with either contour or collinear targets. However, detection was significantly better in the Ehrenstein and dot conditions than in the control for both contour and collinear targets. In a second experiment (seven observers, 4AFC),

with only contour targets, we found that detection was significantly worse in the Ehrenstein condition than in the dot condition. These two experiments do not support the existence of subthreshold summation between illusory contours or illusory brightness and physical targets, but support the view that the improved detection of the target when superimposed on the Ehrenstein figure is due to reduced spatial uncertainty.

◆ **Attention modulates fMRI activation of motion- and form-sensitive areas**

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It is known from fMRI experiments that coherent-motion stimuli activate visual cortical areas including V5 and the MST complex, and that coherent-form stimuli activate regions in the ventral and lateral occipital lobe, as compared with incoherent-motion and incoherent-form stimuli (Braddick et al, 2000 *Current Biology* **10** 731–734). It is also known that selective attention to motion enhances activity in V5 and related areas (O’Craven et al, 1997 *Neuron* **18** 591–598). The present study extends these findings using novel transparent (form + motion) stimuli constructed from orthogonal Glass patterns. The principle is that the stimulus remains identical while the observer attends either to the stationary or the moving pattern. Attention to motion or to form was initiated by a cue at fixation, and maintained by requiring the observer to classify the Glass pattern attended to as random, circular, or radial. Brain images were acquired with a 3 T fMRI scanner with an 8-channel-array head coil and analysed with statistical parametric mapping (SPM). 192 whole brain volumes were collected in each of two sessions per subject (seven stimuli including baseline, presented in  $4 \times 13.16$  s randomised blocks each containing seven scans). Modulatory effects of attention were observed in V5 for attend coherent motion > attend coherent form, and in ventral occipital cortex for attend coherent form > attend coherent motion.

◆ **Integration of spatial-frequency information in localisation and discrimination tasks**

18 Michael J Wright, Louise Lakha (Centre for Cognition and Neuroimaging, School of Social Sciences and Law, Brunel University, Uxbridge UB8 3PH, UK; e-mail: [michael.wright@brunel.ac.uk](mailto:michael.wright@brunel.ac.uk))

We ask how spatial-frequency (SF) information may be combined across discrete temporal intervals in order to locate and identify targets. We have previously analysed SF comparisons across targets and distractors in simple Gabor arrays (Wright and Alston, 2002 *Perception* **31** Supplement, 171–172). Here we extend our analysis to include summation between discrete frames separated by an ISI. Observers indicated the position of a target stimulus differing in SF from uniform distractor stimuli (localisation) and, in different blocks, whether the target was higher or lower in SF than the overall mean value (discrimination). In both types of task, a varying proportion of the target SF increment (the bias) was added to the distractors, in order to determine the interaction of target and distractor stimuli. The way information is combined across the elements in a single-frame display was close to a signal-detection-theory (max rule) prediction for localisation of an odd SF target but not for discrimination (sum rule). Discrimination performance was improved in two-interval tasks more than localisation performance. Combination across frames was consistent with sub-linear summation for both localisation and discrimination. Experiments isolated the contribution of each frame, and of the difference between frames. The best fit to data was obtained if three rather than two sources of information were assumed to contribute to threshold: the signal in each of the two intervals, and the comparison of corresponding elements on the two frames. Thresholds were consistent with a high-level decision process, rather than summation within high-order SF filters.

◆ **The unique hues revisited: estimating the cone inputs to the colour-opponent mechanisms**

19 Sophie M Wuerger, Philip Atkinson¶, Simon Cropper§ (Centre for Cognitive Neuroscience, School of Psychology, Eleanor Rathbone Building, University of Liverpool, Bedford Street South, Liverpool L69 7ZA, UK; ¶The Neurosciences Research Institute, Aston University, Birmingham B4 7ET, UK; §Department of Psychology, University of Melbourne, VIC 3010, Australia; e-mail: [sophiew@liv.ac.uk](mailto:sophiew@liv.ac.uk))

‘Unique hues’ were first mentioned by Hering who proposed that any hue can be described in terms of its redness or greenness and its yellowness or blueness; unique red and unique green are perceived whenever a putative yellow–blue mechanism is silenced; unique yellow and unique blue are perceived whenever a putative red–green mechanism is silenced.

Our aim was to characterise the cone inputs to the chromatic mechanisms that are silenced by the four unique hues by finding the null planes for each unique hue in differential LMS cone space. We report three main findings: (i) The loci of the unique hues do not coincide with the cardinal cone-opponent axes, confirming findings by Webster et al (2000 *Journal of the Optical Society of America* **17** 1445–1455). These cardinal colour directions describe the chromatic tuning

of neurons in the early visual pathway, namely the lateral geniculate nucleus, but do not seem to correlate with higher-order colour mechanisms. (ii) Unique red and unique green are not generated by silencing a single yellow–blue mechanism; two mechanisms with different cone inputs must be postulated to obtain unique red and unique green. In contrast, a single red–green opponent mechanism is sufficient to yield unique yellow and unique blue. (iii) These three chromatic mechanisms (one red–green and two yellow–blue mechanisms) combine the differential L, M, and S cone signals linearly. All three chromatic mechanisms receive L–M (cone-opponent) input.

◆ **Optic flow in natural environments—a downunder perspective**

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Optic flow generated by moving observers is crucial for navigation, and therefore has attracted many theoretical, psychophysical, and physiological studies about estimating ego-motion parameters such as direction of heading from the structure of velocity distributions in artificial stimuli. Little is known, however, about the structure of optic flow under natural operating conditions. To address this issue, we recorded sequences of panoramic images along accurately defined paths in a variety of outdoor locations and used these sequences as input to a two-dimensional array of correlation-based motion detectors (2-DMD model). We find that (a) motion signals are sparsely distributed in the visual field and represent local motion directions with considerable error; (b) motion signal distributions contain oriented patches of high energy (motion streaks); (c) a distinct, dorso-ventral topography reflects the distance anisotropy in the terrestrial environment; (d) the spatiotemporal tuning of the local elements of the 2-DMD model has little influence on the structure of motion-signal distributions; (e) environmental motion (unrelated to observer motion) is noisy throughout the visual field, with little spatial or temporal correlation, can therefore be removed by temporal averaging, and is small compared to image motion caused by observer movement; (f) spatial or temporal integration is required to retrieve reliable information on the local direction and size of motion vectors. These results raise a number of questions about the role of specific environmental and computational constraints in the processing of natural optic flow.

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