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ABSTRACTS

◆ **Monoptic, dichoptic, and binocular masking in strabismic amblyopia**

1 Daniel H Baker, Tim S Meese, Behzad Mansouri ¶, Robert F Hess ¶ (School of Life and Health Sciences, Aston University, Birmingham B4 7ET, UK; ¶ McGill Vision Research, McGill University, Montréal, Québec H3A 1A1, Canada; e-mail: bakerdh@aston.ac.uk)

Contrast vision in strabismic amblyopia is characterised by (i) threshold elevation in the amblyopic eye, (ii) poor binocular summation at threshold, and (iii) abnormal dichoptic masking (Harrad and Hess, 1992 *Vision Research* **32** 2135–2150). We develop this here by reporting contrast masking functions for five strabismic amblyopes. Patches of horizontal grating with spatial frequencies of 0.5 or 3 cycles deg^{-1} were presented to the same (monoptic, left and right), different (dichoptic, left and right), or both (binocular) eyes (five conditions in total). All subjects had higher thresholds in the amblyopic eye and typically showed substantial levels of dichoptic masking in each eye. Otherwise, the subjects fell into two groups. In one group ($n = 2$), small levels of dichoptic facilitation were found, similar to normal observers (Meese et al, 2006 *Journal of Vision* **6** 1224–1243). The results from this group were strikingly similar to those of a normal observer with a neutral density filter in front of one eye. In all cases, the loss of binocular summation could be attributed to the low sensitivity in the affected eye. The other group ($n = 3$) showed no evidence of dichoptic facilitation and their loss of binocular summation could not be attributed to a loss of contrast sensitivity in the affected eye. One possibility is that their eyes operate independently, with perceived stimulus strength determined by the most active ocular channel (be that mask or test), resulting in dichoptic masking (without suppression) and no binocular summation. Our findings suggest that the visual architectures amongst strabismic amblyopes might vary considerably.

◆ **Detection of feature displacements in familiar and unfamiliar faces**

2 Kevin R Brooks ¶§, Richard I Kemp ¶ (¶ School of Psychology, University of New South Wales, Sydney, NSW 2052, Australia; § School of Psychology, University of Plymouth, Plymouth PL4 8AA, UK; e-mail: krbrooks@plymouth.ac.uk)

Familiar and unfamiliar faces are processed in quite different ways, as demonstrated by studies that have isolated the internal (eg eyes, nose, mouth) and the external (eg ears, hair, chin) features of these faces. As a face becomes more familiar, performance in both matching and recognition tasks improves markedly for intact faces, or when only the internal features are available. In contrast, when only external features are shown, little or no change in performance with increasing familiarity is observed (Ellis et al, 1979 *Perception* **8** 431–439; Young et al, 1985 *Perception* **14** 737–746). We sought to further investigate the differences between familiar and unfamiliar face processing while isolating the contribution of specific features (nose, mouth) or feature pairs (eyes, ears) in four separate experiments. Using a staircase procedure, we analysed observers' thresholds for the detection of displacements of these internal and external features in pictures of either unfamiliar or highly familiar faces. We found that, for displacements involving either the eyes or the nose, observers' thresholds were significantly lower for familiar than unfamiliar faces, but that this differential sensitivity was not apparent with another internal feature—the mouth—or with external features—the ears. These results are consistent with the view that the processing of familiar faces is aided by the formation of a robust representation of the more invariant aspects of faces. Our data are inconsistent with accounts of face processing through featural cues alone, and lend support to models which emphasise the use of configural or holistic information in face processing.

◆ **Coding contrast as brightness to convert colour images to grey-scale**

- 3 David Connah, Graham Finlayson, Marina Bloj ¶ (School of Computing Sciences, University of East Anglia, Norwich NR4 7TJ, UK; ¶ Bradford Optometry Colour and Lighting Laboratory, School of Life Sciences, University of Bradford, Bradford BD7 1DP, UK; e-mail: dc@cmp.uea.ac.uk)

In terms of human and machine vision it is often assumed that grey-scale is simply the weighted sum of three colour responses. Thinking of grey-scale (or luminance) in this way occasionally causes practical problems: details in pictures or graphics can be lost in grey-scale reproductions if two different colours share the same weighted response. An alternative way to envisage the grey-scale is as brightness encoding, whereby, rather than using the luminance value at each pixel, the grey-scale image represents the colour-contrast of the colour image as luminance-contrast. Socolinsky and Wolff (2002 *IEEE Transactions on Image Processing* **11** 923–931) have proposed an algorithm that achieves this goal. The algorithm consists of two stages: computing a gradient field using DiZenko's (1986 *Computer Vision Graphics and Image Processing* **33** 116–125) structure tensor, and then reintegrating the gradient field to produce a grey-scale image whose local luminance-contrast reflects the colour-contrast of the original image. This approach has two problems: first, there is no guarantee that it is possible to preserve colour contrasts perfectly in a grey-scale reproduction; second, the range of grey-scale values required to maintain colour contrasts may exceed the range displayable on a given display device. In this work we mitigate the second problem using a tone reproduction curve, which maps the grey-level histogram of the reintegrated image towards that of the luminance image. We show images and numerical measures that demonstrate the advantages of this new method and discuss the future implications for both image processing (eg digital photocopying) and displaying accurate grey-scale reproductions of colour images.

◆ **Zipf's law distribution of local structure in natural images**

- 4 Michael S Crosier, Lewis D Griffin (Computer Science, University College London, Gower Street, London WC1E 6BT, UK; e-mail: m.crosier@cs.ucl.ac.uk)

Zipf's law [1949 *Human Behavior and the Principle of Least Effort* (Reading, MA: Addison-Wesley)] describes a power law between the frequency and rank of an event. For instance, in English text, for which the law was first noted, the r th most common word occurs with frequency proportional to $r^{-\alpha}$, where $\alpha \sim 1$. Zipf's law holds for a wide range of data sets including non-human language (McCowan et al, 1999 *Animal Behaviour* **57** 409–419), city populations, and earthquake magnitudes (Li, 2002 *Glottometrics* **5** 14–21). Here we show that the distribution of micropatterns in natural images also exhibits this property. We counted small squares of sizes up to 9×9 from a database of natural images (van Hateren and van der Schaaf, 1998 *Proceedings of the Royal Society of London, Series B* **265** 359–366), binarised by taking the sign of the Laplacian. For each size, we found that the frequencies of occurrence could be described by a Zipf's law distribution. The linearity of the fit on a log–log plot improves, and the slope steepens (and so approaches closer to the Zipf ideal of -1) as square size increases, reaching -0.8 for size 9×9 . We resist drawing inferences about the 'natural language-likeness' of the data (Suzuki et al, 2004 *Animal Behaviour* **69** F9–F17). Instead, the interest lies in the precision of the description of the full variation of rarity/commonality of micropatterns: because of the adherence of the data to Zipf's law, this information is encoded in the single parameter α . For example, knowing that for 9×9 squares $\alpha = 0.8$, allows us readily to calculate that the 10% most common 9×9 patterns account for 63% of images, while the 10% least common account for 2.1%.

◆ **No role for attention in orientation crowding**

- 5 Steven C Dakin, Peter J Bex, John Cass, Roger J Watt ¶ (Institute of Ophthalmology, University College London, Bath Street, London EC1V 9EL, UK; ¶ Department of Psychology, University of Stirling, Stirling FK9 4LA, Scotland, UK; e-mail: s.dakin@ucl.ac.uk)

Visual crowding—the tendency of irrelevant nearby structure to interfere with object recognition—limits human visual performance across more than 95% of the visual field. It has been proposed that crowding reflects the spatial resolution of visual attention. We tested this hypothesis by comparing the effects of crowding and/or attentional load on subjects' ability to judge the mean orientation of a set of six patches of spatially band-pass oriented-noise. Patches were presented, iso-eccentrically, either in isolation, or crowded by the presence of six randomly oriented iso-eccentric patches falling between fixation and the target locations. By measuring orientation discrimination at various levels of target-orientation variability, equivalent noise analysis yields (a) the precision with which subjects can estimate the orientation of any one patch (local noise), and (b) the number of samples over which they are averaging (global sampling). In some conditions,

subjects also performed an attentionally demanding 'dual-task' (to report the orientation of a white 'T' amongst a stream of randomly oriented black 'T's). We report that crowding increases local noise, but attentional load induces global under-sampling. A dual-pass experiment shows that crowding does not affect the relationship between percent-agreement (across runs) and percent-correct performance, further supporting the notion that crowding does not induce more stimulus-independent variability in responses (as an account based on attention would predict). That crowding and attentional load are psychophysically dissociable, suggests distinct neural mechanisms for both.

◆ **Visual memory for people's body shape**

- 6 Noémy Daury, Serge Brédart (Department of Cognitive Sciences, University of Liège, boulevard du Rectorat 5B, Bâtiment B32, 4000 Liège, Belgium; e-mail: noemy.daury@ulg.ac.be)

Previous studies showed that people's ability to detect, from memory, alterations in highly familiar faces (eg a change in interocular distance) is excellent. Indeed, just-noticeable differences for the detection of alterations in a recognition-memory task were not significantly different from the corresponding measures in a perceptual-discrimination task (Ge et al, 2003 *Perception* 32 601–614; Brédart and Devue, 2006 *Perception* 35 101–106). The perceptual-discrimination task provides an estimation of the efficacy of our perceptual system to discriminate between the original stimulus and altered ones. This estimation in turn serves as a benchmark to which data from the recognition task may be compared. The present study was aimed at evaluating whether people's perceptual memory for body shapes of very familiar persons reaches the high level of accuracy that was reported for face memory. The participants' task was to detect body-shape alterations (ie an increase or a decrease of 2% to 10% of the waist-to-hip ratio) on pictures depicting either themselves or a friend. All participants were females. Body-shape alterations were carried out with image-manipulation software. Results showed that the detection of body-shape alterations was significantly better in a perceptual-discrimination task than in a recognition-memory task. Perceptual memory for familiar body shapes does not appear to be as accurate, relative to perceptual-discrimination performance, as that of perceptual memory for familiar faces. However, other studies involving other kinds of body-shape alterations are needed to evaluate this statement further.

◆ **Determining effective motion-defined contours for the human visual system**

- 7 Szonya Durant, Johannes M Zanker (Department of Psychology, Royal Holloway University of London, Egham TW20 0EX, UK; e-mail: szonya.durant@rhul.ac.uk)

Motion discontinuities can signal object boundaries where few or no other cues, such as luminance, colour, or texture, are available. Hence, motion-defined contours are an ecologically important counterpart to luminance contours. We developed a novel motion-defined Gabor stimulus to investigate the nature of neural operators analysing visual motion fields in order to draw parallels with known luminance operators. Luminance-defined Gabors have been successfully used to discern the spatial-extent and spatial-frequency specificity of possible visual contour detectors. We now extend these studies into the motion domain. We define a stimulus using limited-lifetime moving dots whose velocity is described over 2-D space by a Gabor pattern surrounded by randomly moving dots. Participants were asked to determine whether the orientation of the Gabor pattern (and hence of the motion contours) was vertical or horizontal in a 2AFC task, and the proportion of correct responses was recorded. We found that with practice participants became highly proficient at this task, able in certain cases to reach 90% accuracy with only 12 limited-lifetime dots. However, for both practised and novice participants we found that the ability to detect a single boundary saturates with the size of the Gaussian envelope of the Gabor at approximately 5 deg full-width at half-height. At this optimal size we then varied spatial frequency and found the optimum was at the lowest measured spatial frequency (0.1 cycle deg⁻¹) and then steadily decreased with higher spatial frequencies, suggesting that motion contour detectors may be specifically tuned to a single, isolated edge.

◆ **Depth propagation and surface construction in 3-D vision**

- 8 Mark A Georgeson, Tim A Yates, Andrew J Schofield¶ (School of Life and Health Sciences, Aston University, Birmingham B4 7ET, UK; ¶ School of Psychology, Birmingham University, Birmingham B15 2TT, UK; e-mail: m.a.georgeson@aston.ac.uk)

In stereo vision, regions with ambiguous disparity can acquire perceived depth from unambiguous regions. This has been called stereo capture, depth interpolation, or surface completion. We studied some striking induced depth effects suggesting that depth interpolation and surface completion are distinct stages of visual processing. An inducing texture (2-D Gaussian noise) had sinusoidal modulation of disparity (0.15 or 0.3 cycle deg⁻¹), creating a smooth horizontal corrugation. The central region of this surface was replaced by various test patterns whose perceived

corrugation was quantified by adjusting the apparent slant of a monocular gauge figure at 8 test points. For horizontal 1-D noise, a strong in-phase corrugation was induced, but with 2-D noise, or 1-D vertical noise, little or no depth was induced. This held for both binocular and monocular tests, suggesting that horizontal orientation, not simply indeterminate disparity, was a key factor. For a horizontal sine-wave grating (same spatial frequency as the inducer), strong depth was induced at all phase offsets (0° , 90° , 180° , 270°). But for a corresponding square-wave grating, depth was induced only when its edges were aligned with the peaks and troughs of the flanking surface, and now the induced corrugation was a triangle-wave, not a sine-wave. These and related results suggest that disparity (or local depth) propagates along horizontal 1-D features, and then a 3-D surface is constructed from the depth samples acquired. The shape of the constructed surface can be different from the inducer, and so surface construction appears to operate on the results of the more local depth-propagation process.

◆ **Perceived roughness of textured surfaces**

- 9 Patrick R Green, Stefano M Padilla ¶, Ondrej Drbohlav ¶, Mike J Chantler ¶ (School of Life Sciences [¶ School of Mathematical and Computer Sciences], Heriot-Watt University, Edinburgh EH14 4AS, Scotland, UK; e-mail: P.R.Green@hw.ac.uk)

What dimensions underlie our perception of visually presented textures, and can they be mapped to physical dimensions of surfaces? We describe a new method for studying these problems, which uses graphics techniques to create synthetic textured surfaces, rendered under specified illumination. The effect of varying parameters of such surfaces on observers' judgments of specific qualities of their texture is then determined. We created random-phase fractal surfaces, defined by two parameters of the height power spectrum: root-mean-square (RMS) height (σ) and slope (β). Both parameters were varied across the largest ranges consistent with creating surfaces that appeared realistic. In the first experiment, five observers judged the roughness of surfaces by adjusting the RMS height of one surface to match the roughness of a sample. The data were used to plot contours of equal perceived roughness in $\sigma - \beta$ space. In the second experiment, the observers adjusted the RMS height of a surface until they judged its roughness to be equidistant between two samples. This was repeated with all combinations of three values of β and three widely spaced pairs of values of σ . The midpoint σ values obtained were consistent across observers (maximum coefficient of variation = 0.12) and were close to values predicted from the first experiment (maximum discrepancy 10%). These results show that: (i) the perceived roughness of fractal surfaces is a function of both σ and β , and (ii) at a particular value of β , perceived roughness is in metric agreement with σ .

◆ **'Reading the game': judgments of pass trajectory in football are made in both egocentric and allocentric frames of reference**

- 10 John Harris, Lucy Campbell, Laura Dale, Debra Parker (Department of Psychology, University of Reading, Whiteknights, Reading RG6 6AL, UK; e-mail: j.p.harris@reading.ac.uk)

Part of the skill of an accomplished footballer lies in judging whether a pass made by another player will reach its intended target. To study the nature of such judgments, we presented to fifteen observers 80 video clips of one player kicking a ball to another player. In half the clips, the pass was successful (hit part of the target player's body), and in the other half it was not. Each clip was terminated when the ball was halfway along its trajectory. The task was to judge whether the pass was going to hit the target, and rate confidence in the judgment. We investigated in which frame(s) of reference such judgments are made by varying the orientation of the monitor (upright or on its side), and the observer (upright or lying on their side). Accuracy was higher when the orientations of both screen and observer were aligned (both upright or both on their sides), than when they were not (one upright, the other on its side). There was also an additional increase in accuracy when the observer was upright. The confidence ratings followed a similar pattern to the accuracy data. The findings suggest that both egocentric and allocentric frames of reference are important contributors to judgments of pass trajectory.

◆ **Response to combined first-order and second-order motion in visual cortex neurons**

- 11 Claire V Hutchinson, Curtis L Baker Jr ¶, Tim Ledgeway (Nottingham Visual Neuroscience Group, School of Psychology, University of Nottingham, University Park, Nottingham NG7 2RD, UK; ¶ McGill Vision Research, Department of Ophthalmology, McGill University, Montréal, Québec, Canada; e-mail: lpxcvh@psychology.nottingham.ac.uk)

Preliminary results are reported of an investigation into how neurons in area 18 of feline visual cortex respond to combined first-order (luminance grating) and second-order (contrast envelope) motion by quantifying the spatial phase and amplitude dependence of neural responses to combinations of these stimuli. Drifting first-order and second-order patterns, individually optimised

for each neuron, were spatially superimposed within the receptive field at amplitudes which were equated for responsivity to each stimulus presented in isolation. Neural responses were measured as a function of the relative spatial phase difference ($0^\circ - 360^\circ$) between the two moving patterns. Neural responses were highly dependent on the spatial-phase relationship between the two patterns, typically exhibiting a maximal response to in-phase patterns and a minimal ('null') response to patterns presented in anti-phase. To measure dependence on amplitude (ie Michelson contrast), we superimposed the patterns at their 'null' phase, fixed the contrast envelope amplitude at 70%, and varied the luminance grating amplitude from $\sim 0\%$ to a maximum of 30%. Neural responses decreased as the amplitude of the two patterns approached a level at which they were of equivalent 'strengths' (ie elicited the same degree of response from the neuron when presented in isolation) and increased thereafter. This phase dependence and amplitude dependence suggests that these neurons combine the convergent input they receive from separate neural pathways that encode first-order and second-order motion.

◆ **Effects of feedback on the timing of interception**

12 Joni Karanka, Simon K Rushton, Tom C A Freeman (School of Psychology, Cardiff University, Tower Building, Park Place, Cardiff CF10 3AT, Wales, UK; e-mail: karankajt@Cardiff.ac.uk)

We investigated how the timing of interception is learnt. Observers viewed a simulated approaching ball that disappeared prior to arrival. Observers were instructed to press a button to indicate the time the ball would have reached them. Actual arrival time varied at random in each trial between 300 and 820 ms and was indicated by the flash of LEDs placed at either side of the head. We were interested in the consistency of the response (precision) and its relation to the actual arrival time (accuracy). In the first experiment five participants were trained for a total of 1440 trials during 4 separate days. The training resulted in an increase in both the precision and the accuracy of the response. Both changes persisted in tests a month after the initial training. In the second experiment we investigated whether these improvements were due to the feedback given or if they were practice effects. If feedback has an effect in setting the timing of the response, it follows that temporally biased feedback should result in biased timing. We therefore manipulated the temporal relationship between the feedback and actual arrival time, creating three feedback conditions: the LED flashed either at the correct time (unbiased feedback), 150 ms before actual arrival time, or 150 ms after. Three groups of different observers ran in each of the feedback conditions. The results showed rapid changes in timing in accordance with the type of feedback given. Taken together, these results provide evidence of the influence of feedback on the timing of interceptive actions.

◆ **The generalised Bayesian homunculus: an illustration using a model of direct and indirect tilt aftereffects**

13 Keith Langley, Stephen J Anderson ¶, Peter J Bex § (Department of Psychology, University College London, Gower Street, London WC1E 6BT, UK; ¶ Neurosciences, School of Life and Health Sciences, Aston University, Birmingham B4 7ET, UK; § Institute of Ophthalmology, University College London, 11-43 Bath Street, London EC1V 9EL, UK; e-mail: k.langley@ucl.ac.uk)

Many researchers in the visual sciences have focused on signal encoding transformations as a primary goal of sensory processing while ignoring the inverse decoding transformations that are necessary in order to fully recover encoded information. By placing our focus on signal encoding-transmission-decoding (E-T-D) transformations, we argue that an E-T-D model of visual processing may be viewed as a generalised Bayesian computation in which the stages of signal encoding and decoding (extraction or homunculus) are controlled by the statistical properties of the underlying visual signal and the constraints placed upon the propagation of visual information. Using the Bayesian perspective, we demonstrate that the process of signal encoding, when constrained by bandwidth across a communication channel, leads to a leaky difference (inversion) between the statistical expectations and the actual signals that are transmitted. In contrast, the signal decoding transformation required to recover the encoded signal (the Bayes prior) should both invert and average the encoded signal, again using the statistics of the underlying signal. With these ideas in place, we propose an explanation for tilt aftereffects in which direct (repulsive) and indirect (attractive) biases in perceived orientation are respectively explained by information loss owing to adaptation of an encoder and averaging from the signal decoder (the Bayes prior). Our modeling further demonstrates that under redundant signal encoding conditions, it is possible for effects of adaptation to be described by purely subtractive processes. Our analysis raises the interesting possibility that cortical adaptive processes may be subtractive, whereas retinal adaptation processes may be divisive.

◆ **Asymmetric spatial-frequency tuning in the human visual motion system**

- 14 Tim Ledgeway, Claire V Hutchinson (Nottingham Visual Neuroscience Group, School of Psychology, University of Nottingham, Nottingham NG7 2RD, UK; e-mail: txl@psychology.nottingham.ac.uk)

We explored the spatial-frequency tuning of the human motion system using visual masking and adaptation. In a masking experiment, we measured modulation-depth thresholds for identifying the direction of a sinusoidal test pattern (0.25 to 2 cycles deg^{-1}) in the absence and presence of a temporally jittering (temporally broadband) mask. At low test frequencies (0.25 cycle deg^{-1}), maximum threshold elevation occurred when test and mask shared the same frequency, decreasing as the spatial-frequency difference between them increased. However, as test frequency increased, maximum threshold elevation occurred when the mask was ~ 1 octave below the test. We found comparable effects when we examined the spatial-frequency tuning of the motion aftereffect (MAE), using duration as an index of aftereffect magnitude. Observers adapted to the motion of two oppositely drifting gratings (0.25 to 2 cycles deg^{-1}), spatially separated in the vertical dimension. Following adaptation, two stationary test patterns appeared, and MAE duration was measured as a function of the spatial-frequency difference between the adaptation and test patterns. Tuning functions at 0.25 cycle deg^{-1} were bandpass and symmetric. However, as the spatial frequency of the adaptation patterns increased, MAE tuning functions became markedly asymmetric. This asymmetry was accompanied by a peak MAE ~ 1 octave below the adaptation frequency. The asymmetric tuning of our masking functions and of the MAE may reflect either asymmetric spatial-frequency selectivity of underlying motion units or inhibition between mechanisms tuned to different spatial frequencies.

◆ **Subtractive suppression underlies contrast processing of visual stimuli**

- 15 Velitchko Manahilov, Gael Gordon, Julie Calvert, William A Simpson¶ (Vision Sciences Department, Glasgow Caledonian University, Cowcaddens Road, Glasgow G4 0BA, Scotland, UK; ¶ Simulation & Modelling Section, DRDC Toronto, 1133 Sheppard Avenue West, PO Box 2000, Toronto, Ontario M3M 3B9, Canada; e-mail: vma@gcal.ac.uk)

Simple and complex cells of primary visual cortex exhibit nonlinear behaviour, eg their responses saturate at high contrasts; the responses to an optimal test grating are reduced by a superimposed grating of non-optimal orientation or spatial frequency. Some nonlinear cell properties have been explained by a threshold model (Tolhurst and Dean, 1987 *Experimental Brain Research* **66** 607–620), which assumes that cortical cells respond when their linear excitation exceeds some threshold level. The nonlinear features of cortical-cell behaviour have been accounted for more successfully by contrast-normalisation models (Heeger, 1992 *Visual Neuroscience* **9** 181–197). These propose that the underlying linear responses are normalised (divided) by a quantity proportional to the pooled activity of a large number of other neurons. Here we propose a model which assumes that the linear excitatory responses of cortical cells are normalised by subtractive suppression which is proportional to a nonlinear (power) quantity of the pooled activity of neurons selective to a wide range of spatial frequencies and orientations. This elaborated threshold model successfully predicts the saturation of the response as a function of stimulus contrast and the 'divisive' behaviour of the contrast-response function for non-optimal stimuli. The neural correlate of divisive normalisation has been associated with the mechanism of shunting inhibition; this mechanism remains controversial (Berman et al, 1991 *Journal of Physiology* **440** 697–722). Subtractive normalisation can be implemented by hyperpolarising inhibition, a fundamental property of cortical neurons. The proposed subtractive-suppression model is physiologically plausible and provides a new look at the organisation of excitatory and inhibitory processes within the early cortical processing stages.

◆ **Integration of ordinal and metric cues in depth processing as a function of contour salience**

- 16 Jasna Martinovic, Marco Bertamini¶, Sophie Wuerger¶, Christopher Nolan¶ (School of Psychology, University of Liverpool, Eleanor Rathbone Building, Bedford Street South, Liverpool L7 7AD, UK; ¶ Institute of Experimental Psychology, University of Leipzig, Seeburgstrasse 14–20, D 04103 Leipzig, Germany; e-mail: jasn@liv.ac.uk)

Burge et al (2005 *Journal of Vision* **5** 534–542) reported that ordinal, configural cues of familiarity and convexity influence perceived depth even when unambiguous metric information is present (binocular disparity). Convex and familiar shapes increased perceived depth if they were shown in the foreground and decreased it if they were shown in the background. It is generally assumed that luminance cues are necessary for this pre-figural shape representation to be processed in parallel with depth information, and therefore to influence figure-ground computations (Peterson and Gibson, 1993 *Cognitive Psychology* **25** 383–429). In our current study, we tested this simple prediction that configural cues need to be defined by luminance. We first replicated

Burge et al's findings and confirmed that configural cues can affect the perceived depth in the presence of disparity information. Then we examined the effect on perceived depth when the configural cues were defined by disparity only, without any luminance cue. We found that, for a sufficiently large disparity pedestal (about 2.5 min of arc), binocularly defined configural cues also exert influence on perceived depth. In conclusion, the integration of ordinal and metric cues is driven by general salience of the contours and not only by luminance information.

◆ **Sudden disappearance of moving objects overrides motion extrapolation**

17 Gerrit W Maus, Romi Nijhawan (Department of Psychology, School of Life Sciences, University of Sussex, Brighton BN1 9QH, UK; e-mail: G.W.Maus@sussex.ac.uk)

Mislocalisation phenomena (Fröhlich, flash-lag, and representational momentum illusions) have sparked a debate into what mechanisms underlie the perception of the positions of moving objects. Proposed models include temporal integration and spatial extrapolation (Krekelberg and Lappe, 2001 *Trends in Neurosciences* **24** 335–339). Here we report a new effect in which two bars, one directly above the other, moved horizontally across the screen. One of the bars disappeared abruptly while the other one continued to move. Observers were asked to judge the apparent alignment of the two bars at the time of disappearance (a) with an adjustment method, and (b) in a 2AFC task. Observers perceived the stopping position as lagging behind the position of the continuing bar, even when the two bars were physically aligned until the sudden offset. In a control experiment, we confirmed that stopping positions are perceived accurately (with a small undershoot), so the misalignment is caused by a forward displacement of the instantaneous position of the continuously moving object. Our account of the present misalignment assigns special significance to the transient off-signal. We propose that the position of a moving object is based on extrapolation from the previous trajectory, whereas in the case of an abrupt offset the transient signal retroactively masks this percept and facilitates accurate localisation (Maus and Nijhawan, 2006 *Vision Research* **46** 4375–4381). Temporal integration models (eg Roulston et al, 2006 *Proceedings of the Royal Society, Series B* **273** 2507–2512) would need to incorporate information about future positions and the exact time of disappearance to account for the present findings.

◆ **Flexible target representations underlie priming in visual search**

18 Jennifer McBride, Ute Leonard, Iain D Gilchrist (Department of Experimental Psychology, University of Bristol, 12A Priory Road, Bristol BS8 1TU, UK; e-mail: Jen.Mcbride@bristol.ac.uk)

When target features are repeated across consecutive search trials, response times (RTs) are faster compared to trials in which target features have changed. However, it remains unclear what representation of the target, stored across trials, leads to this priming. To investigate how priming is affected by feature type and the roles that features play in target definition, we manipulated the roles of colour and orientation in defining the search target. In experiment 1, the target bar differed from distractor bars in orientation while target colour was irrelevant to the search. Repeating irrelevant target colour produced significantly faster RTs, but repeating target-relevant orientation slowed RTs. In experiment 2, the roles of colour and orientation were reversed: the target now differed from distractors by its colour while target orientation was irrelevant. Again, a significant RT advantage was found for repeating target colour, but no significant cost or benefit was found for repeating target orientation. These results indicate that the nature of the target representation stored across trials critically depends on the role of target features in the task, and that different features impact differently on this representation. Existing feature-based (eg Maljkovic and Nakayama, 1994 *Memory & Cognition* **22** 657–672) and episodic-memory-based (Huang et al, 2004 *Memory & Cognition* **32** 12–20) explanations of priming cannot account for such effects.

◆ **Contrast discrimination, sampling, and area summation**

19 William McIlhagga (Department of Optometry, University of Bradford, Bradford BD7 1DP, UK; e-mail: w.h.mcilhagga@bradford.ac.uk)

Recently, McIlhagga and Peterson (2006 *Vision Research* **46** 1934–1945) suggested that contrast discrimination was the result of a pointwise early nonlinearity together with multiplicative noise in the decision variable. Multiplicative noise also explains the effect of contrast on Vernier acuity (McIlhagga and Pääkkönen, 2003 *Vision Research* **43** 707–716). Here I suggest a mechanism for this multiplicative noise, based on the idea that an observer randomly samples a subset of relevant neurons and sums their outputs to produce a decision variable. If c is the average output of the relevant neurons, and n the sample size, then the decision variable is cn ; but n is a binomial random variable, so the standard deviation of the decision variable is c times the standard deviation of n , ie multiplicative noise. The sampling observer model is also relevant to

area summation. The expected sample size introduces a limit on the amount of summation, yielding a critical area, which scales inversely with the density of relevant neurons, allowing us to estimate the number of relevant neurons per square degree. This in turn yields an explanation for the reduction in critical area with plaids (Rovamo et al, 1994 *Investigative Ophthalmology & Visual Science* 35 2611–2619), though not all aspects of these data are explained. Finally, the sampling observer predicts correctly that area summation vanishes in contrast discrimination (when pedestal and test are the same size).

◆ **Human vision sums luminance contrast over area at detection threshold and above**

20 Tim S Meese (School of Life and Health Sciences, Aston University, Birmingham B4 7ET, UK; e-mail: t.s.meese@aston.ac.uk)

Contrast detection thresholds decrease as a decelerating function of grating area (on log–log axes), consistent with linear summation of signal and noise over the filtered image after a nonlinear local contrast transformation ($c^{2.4}$), and with retinal inhomogeneity. However, when the target is placed on a pedestal, dipper functions converge for gratings of different diameter, suggesting a loss of summation above threshold. But this confounds target area with pedestal area and so the advantage of area summation might be offset by a corresponding increase in suppression from the pedestal. Fixing the diameter of the pedestal and varying only that of the target reduces this problem, but possibly invokes the use of different mechanisms with different suppressive characteristics across the conditions (Meese, 2004 *Journal of Vision* 4 930–943). Here, (i) the observer was forced into a consistent strategy by using fixed-diameter targets, and (ii) signal area was controlled by modulating a ‘full’ target with a blurred checkerboard (~ 3.5 carrier cycles per check) in either cosine or $-\cosine$ phase. This produced ‘patchy’ gratings with either a target patch or blank patch in the centre of the display. Sensitivity to these two patchy stimuli was identical. However, sensitivity to a full target on a full pedestal was nearly twice as high as that to a patchy target on the same full pedestal over the entire dipper function. These results provide evidence for a process that sums contrast (and noise) over a substantial area—at least two checks—consistent with a simple extension of our threshold model with no extra free parameters.

◆ **Perceived motion transparency from integrating motion and non-motion transparency cues**

21 Andrew I Meso, Johannes M Zanker (Department of Psychology, Royal Holloway University of London, Egham TW20 0EX, UK; e-mail: a.i.meso@rhul.ac.uk)

We investigated the mechanisms underlying the transparent perception of moving patterns which combine motion with other pattern features. First, we established experimentally a reference scale for measuring perceived transparency, based on the observation that moving paired luminance gratings appear increasingly transparent as each grating is composed of a larger number of Fourier harmonics. A set of reference stimuli spanning the range of perceived transparency strength was compared with a test stimulus in repeated presentations by means of a two-interval 2AFC task to identify the more transparent stimulus. Both test and reference stimuli were made of a pair of gratings transparently moving in the same direction. The degree of transparency of the test stimulus was estimated as the number of Fourier harmonics at the PSE of a psychometric function fit to the comparison data. A computer model of global motion detection, based on arrays of local correlation type motion detectors was used to predict the expected level of perceived transparency for test stimuli from separability of global motion signals across spatiotemporal channels. Perceived transparency strength was studied in four participants with test stimuli with components in which we varied differences in speed, spatial frequency, or contrast. When speed difference was varied, perceived transparency was consistent with model prediction. When contrast and spatial frequency differences were varied, however, there was a deviation from predictions such that measured modulation of perceived transparency could not be explained by the contribution of these differences to global-motion signals alone, suggesting additional modulation by non-motion cues. We discuss this in the context of a possible integration of cues beyond the local-detection and global-pooling stages in the perception of motion transparency.

◆ **The ‘uncurved lines’ on Helmholtz’s ‘celestial sphere’⁽¹⁾**

22 Brian J Rogers (Department of Experimental Psychology, University of Oxford, South Parks Road, Oxford OX1 3UD, UK; e-mail: bjr@psy.ox.ac.uk)

In his *Handbuch der Physiologischen Optik* published in 1867, Hermann von Helmholtz asked the apparently straightforward question: “What are the uncurved lines on the visual globe?”—in other words, on what basis do we judge the straightness of a straight line in the world? His answer was that the ‘uncurved lines’ could not be the great circles on a spherical projection surface, since lines that stimulate great circles are typically not seen as straight and parallel. Instead, he argued that the ‘uncurved lines’ must correspond to ‘direction circles’⁽²⁾ and, in support of this idea,

he devised his famous pin-cushioned chessboard figure in which the curved hyperbolic contours appear straight and parallel when seen from a close viewing distance. However, a little thought shows that there cannot be any ‘uncurved lines’, because we also need to know the 3-D characteristics of a line in order to judge whether it is straight. Our experimental results support this point. The perceived 3-D shape of Helmholtz’s chessboard figure and the straightness of its contours are different under monocular and binocular viewing and can be manipulated by changing the pattern of disparities in the latter case. These observations lead us to the conclusion that two factors are responsible for the Helmholtz’s chessboard illusion: (i) a lack of information about the distance of peripherally viewed objects, and (ii) the preference of the visual system for seeing the pin-cushion squares as similar in size.

(1) Helmholtz defined his ‘celestial sphere’ or visual globe as “nothing but the retina itself with all its images and special characteristics projected outside”.

(2) The term ‘direction circle’ was initially used by Helmholtz to describe the “circular arcs which are described by the line of fixation in turning around a fixed axis according to Listing’s law”.

◆ **Characterisation of a high-dynamic-range display**

23 Alexa I Ruppertsberg, Alan Chalmers ¶, Marina Bloj
(Optometry Colour and Lighting Laboratory, School of Life Sciences, University of Bradford, Bradford BD7 1DP, UK; ¶ Department of Computer Science, University of Bristol, Bristol BS8 1UB, UK; e-mail: a.i.ruppertsberg@bradford.ac.uk)

When looking from inside a house towards a window, the ratio between the brightest area outside the window and the darkest area inside the room, the so-called contrast ratio, could be many thousands to one. A typical computer monitor has a contrast ratio of about 100 : 1 and is thus incapable of accurately displaying such a scene. A display device offering higher contrast ratios is now available in the form of a high-dynamic-range display (HDR) (Seetzen et al, 2004 *ACM Transactions on Graphics* **23** 760–768). HDRs can have a maximum luminance output of up to 3000 cd m⁻². This is accomplished by adding a fourth layer of LEDs as backlight to an LCD display. When characterising an HDR colorimetrically one is faced with several problems: the channels may not be constant; they may not be independent; there may be a significant radiant output at the black level, but crucially colour transforms are underdetermined, which means that the number of colorimetric dimensions is smaller than the number of device channels. While the first three problems are associated with the LCD, the fourth problem stems from the additional channel in the HDR—the backlight. A 37 inch flat-panel Brightside DP37 HDR display controlled by a PC with a NVidia GeForce 7900GTX graphics card was characterised. Using a spectroradiometer, we recorded spectral radiance, chromaticities, and luminance, and estimated the true increase in the gamut of the display due to the additional LED layer. The effective contrast ratio of this monitor is currently 1300 : 1, closer to the light levels found in the real world. We present all steps of a basic characterisation, and propose a method for accurately presenting a desired luminance and chromaticity output despite the underdetermined problem that ensures that full advantage can be taken of the increased capabilities of the monitor for use in controlled visual psychophysical experiments.

◆ **Estimating the 2AFC psychometric function: effects of lapsing, psychophysical procedure, and method of curve-fitting**

24 Robert J Summers, Tim S Meese (School of Life and Health Sciences, Aston University, Birmingham B47ET, UK; e-mail: t.s.meese@aston.ac.uk)

Psychophysical performance in an *n*AFC task is often expressed in terms of a two-parameter model that represents threshold and slope. The effects of observer lapses such as missing a trial interval during an eye-blink or pressing the wrong response-button by mistake can bias estimates of both of these parameters. Wichmann and Hill (2001 *Perception & Psychophysics* **63** 1293–1313) showed that for the method of constant stimuli (MCS) the addition of a lapse parameter in a maximum-likelihood (ML) fit to simulated psychometric functions could offset the effects of lapsing if the number of trials was sufficiently large ($N = 480$). But as two-parameter models are widely used with adaptive staircases in practice, we investigated the effects of lapsing under these conditions. Threshold bias increased with lapse rate but its magnitude and variability were very similar for two-parameter fits by probit analysis and two- or three-parameter fits by ML. Slope estimation was less dependent on lapse rate but was biased upwards for shallow simulated slopes (Weibull $\beta = 1.3$, step-size = 1.5, 2, or 3 dB) particularly for the three-parameter model. However, we did confirm that the lapse parameter helped to ameliorate the effects of lapsing when using MCS. We conclude that experimenters would be well advised to try and reduce observer lapses in the first place rather than account for their effects afterwards.

◆ **Depth perception when virtual objects behind opaque real objects are not occluded in mixed reality**

25 Masahiro Suzuki, Kazutake Uehira (Human Media Research Center, Kanagawa Institute of Technology, 1030 Shimo-ogino, Atsugi, Kanagawa 243-0292, Japan; e-mail: msuzuki@ctr.kanagawa-it.ac.jp)

One of the ways for mixed reality is that images of real objects are projected onto an observer's retina with transmission of a beam splitter and the images of virtual objects are projected onto the retina with reflection of the beam splitter. Because the beam splitter is closer to the observer than the real objects, the virtual objects behind the real objects are not occluded, even if the real objects are opaque. In such situations, the visual system does not meet the occlusion constraint that the opaque objects occlude behind them. In this study, we investigate depth perception in the situations. The experiment was conducted in a semi-dark room. The real object was a white wall or textured wallpaper. There were two conditions of illumination for the real object: the illumination condition and the no-illumination condition. (The real object was visible in the no-illumination condition.) The virtual object was a photo presented with a computer monitor. We found (a) the virtual photo was seen and it was behind the white wall or the textured wallpaper, (b) the perceived distance to the virtual photo was not different between the white wall and the textured wallpaper, or between the illumination condition and the no-illumination condition, (c) the perceived distance to the white wall or to the textured wallpaper was not different between the illumination condition and the no-illumination condition. These results indicate that the virtual objects are perceived behind the opaque real objects when the virtual objects are not occluded.

◆ **Summation of suprathreshold cues in complex visual discriminations using natural scene stimuli**

26 Michelle To, P George Lovell¶, Tom Troscianko¶, David J Tolhurst (Department of Physiology, Development and Neuroscience, Physiological Laboratory, University of Cambridge, Downing Street, Cambridge CB2 3EG, UK; ¶ Department of Experimental Psychology, University of Bristol, 12A Priory Road, Bristol BS8 1TU, UK; e-mail: mpst2@cam.ac.uk)

Quick's vector magnitude model (1974 *Kybernetik* **16** 65–67) suggests that the detectability of a compound visual stimulus can be calculated by nonlinearly summing the detectability of the component elements. While this theory has been supported by detection-threshold experiments and has been explained as 'probability summation' (Robson and Graham, 1981 *Vision Research* **21** 409–418; Rohaly et al, 1997 *Vision Research* **37** 3225–3235), we investigated whether summation of cues follows a similar pattern in suprathreshold tasks with complex natural images. In a discrimination experiment, eleven observers were asked to make subjective ratings of the difference between 900 different naturalistic image pairs. Among these were 136 combination groups, composed of three image pairs: in two pairs the images differed along a single dimension A or B, respectively; the third pair was a composite, differing along both dimensions A and B (eg change of object colour in pair 1; change of object position in pair 2; and changes of both colour and position in pair 3). We investigated whether the ratings for composite pairs could be predicted by combining the ratings from their respective component pairs. We found that, similar to the probability-summation theory, the ratings for component pairs could accurately predict the ratings for the combination pairs by Minkowski summation with an exponent of 2.78 (a value comparable to that found in compound-grating-detection experiments). This suggests that elegant vision theories for simple visual stimuli can also be extended to more complex types of visual processing.

◆ **Trying to model grating-contrast discrimination dippers and natural-scene discriminations**

27 David J Tolhurst (Department of Physiology, Development and Neuroscience, Downing Street, Cambridge, CB2 3EG, UK; e-mail: djt12@cam.ac.uk)

Campbell and Kulikowski (1966 *Journal of Physiology* **187** 437–445) first described the contrast discrimination 'dipper' for gratings. Since 1966, there has been increased quantification of dippers and increasingly sophisticated modeling that attempts to relate dipper form to the contrast responses of neurons in visual cortex and to nonlinear interactions between neurons. Understanding contrast discrimination is fundamental to models that attempt to explain the perceptual differences between complex 2-D stimuli such as photographs of natural scenes (eg Lovell et al, 2006 *ACM Transactions on Applied Perception* **3** 155–178). To develop such a model, we start with a model of grating detection performance which maps the behaviour of arrays of 'simple cells' across the two dimensions of the stimuli and which includes untuned contrast normalisation (Watson and Solomon, 1997 *Journal of the Optical Society of America A* **14** 2379–2391); we add

convincing ideas about surround masking (Meese, 2004 *Journal of Vision* **4** 930–943). Meese's surround model is needed to explain some unusual features in the form of dippers for different grating stimulus configurations, but seems initially incompatible with suggestions (eg Petrov et al, 2005 *Journal of Neuroscience* **25** 8704–8707) that there is no surround masking in foveal vision. The incompatibility might be resolved with a full multi-channel 2-D model (with several million stylised 'simple cells') of the visual discriminations. A realistic spatial geometry of the receptive fields is crucial, along with the geometry of the suppressive surround. This would give the correct balance between the proposed surround masking and the counter effects of length summation between centre and surround stimuli.

◆ **No role for colour in symmetry perception?**

28 Tom Troscianko, Devin Martin, Innes Cuthill (Department of Experimental Psychology, University of Bristol, 12A Priory Road, Bristol BS8 1TNU, UK; e-mail: tom.troscianko@bris.ac.uk)

The detection of inconspicuous objects against complex backgrounds is a critical task for many animals, including humans. Symmetry is a potent cue in visual search because biologically relevant objects (prey, predators, competitors, mates) tend to be bilaterally symmetrical whereas natural backgrounds are not. Recent research (Morales and Pashler, 1999 *Nature* **399** 115–116; Huang and Pashler, 2002 *Vision Research* **42** 1421–1430) suggests the counter-intuitive proposition that the ability to detect symmetry is solely a function of brightness differences and "colour has no role in symmetry perception". This runs counter to earlier findings (Troscianko, 1987 *Vision Research* **27** 547–554), which suggest that colour has a strong input to symmetry perception. We propose that the more recent conclusions result from an artifact in experimental design, whereby the task could only be solved by serial search. In this way the alleged effect of colour on the difficulty of the task was simply a byproduct of greater task complexity. In a series of experiments we show the same performance differences are observed in entirely achromatic displays, leading to the patently absurd conclusion that "luminance has no role in symmetry perception". We argue that symmetry detection in nature is intimately tied to figure-ground segregation and, in experiments involving more naturalistic search tasks, we show that symmetry can be detected rapidly and pre-attentively by using colour cues alone.

◆ **Retinal ganglion cell properties at low scotopic light levels**

29 John B Troy, Jie Chen (Department of Biomedical Engineering, Northwestern University, Evanston, IL 60208, USA; e-mail: j-troy@northwestern.edu)

The classical description of the receptive field of an ON or OFF centre ganglion cell under low scotopic conditions is that it lacks a surround. Data that we have collected recently from single-unit studies of cat retinal ganglion cells indicate that this description is inaccurate. Spatial-frequency response measurements were obtained from X and Y cells for mean light levels ranging from where a rod captures a photon every 10 s to one where a rod captures a photon every 5 min. The latter corresponds to the dark light level. At these very low light levels, the surround mechanism moves from being antagonistic to the centre to being more synergistic in behaviour. This shift in receptive-field structure with light level was predicted by Atick and Redlich (1990 *Neural Computation* **2** 308–320) in their model of signal processing by retinal ganglion cells. Their model implies greater synergy between centre and surround at low light levels, like those we studied, where photon noise contributes significantly to the signal-to-noise ratio. We also found changes in the receptive-field centre consistent with a mechanism operating on noisy signals.

◆ **A post-Bayesian analysis of perceptual estimation**

30 Christopher W Tyler (Smith-Kettlewell Eye Research Institute, 2318 Fillmore Street, San Francisco, CA 94115, USA; e-mail: cwt@ski.org)

In its most general sense, Bayesian analysis of perceptual estimation means taking account of prior knowledge of the probabilities of sensory cues in interpreting their meaning in terms of external objects and events. The more experience you have had, the better equipped you are to interpret the meaning of what you are seeing, hearing, and feeling. However, Bayesian theory implies a specific formalism in which this knowledge is incorporated as the product of conditional probabilities. This formalism has a number of undesirable consequences for a theory of perception. First, if something has never been previously experienced, it has zero probability of being perceived. This is clearly unacceptable as a theory of perceptual development. Second, it implies that perception of everything will be biased toward the percept of the most commonly occurring thing, whereas the perceptual landscape is clearly a multifold diversity of local peak biases (verbal object categories) among which there is probabilistic competition. Third, the reliance on occurrence probabilities leaves no room for organismic preferences that enhance the perception of rare and desirable objects over common objects. Such considerations lead to a

post-Bayesian analysis that percepts are biased toward prior feature clusters when the sensory information is in their vicinity, but that there is competition among feature clusters to attach a label to the percept that corresponds to active hypothesis testing even for low-probability percepts, and the concatenation can break away from any prior interpretation to form a new cluster when the evidence is sufficiently strong. This elaboration of role of perception priors may be termed a Generalized Gregorian Attractor, and is instantiated for the 3-D interpretation of spatial configurations as the 'attentional shroud', which is an adaptive prior for the surfaces in the world. Examples of the operation of these post-Bayesian processes are drawn from contrast, texture, and depth perception.

◆ **Accommodation depth for overlapping 3-D images presented by two stereoscopic displays at different depths**

31 Kazutake Uehira, Marie Shimizu, Masahiro Suzuki (Human Media Research Center, Kanagawa Institute of Technology, 1030 Shimo-ogino, Atsugi, Kanagawa 243-0292, Japan; e-mail: uehira@nw.kanagawa-it.ac.jp)

We studied the accommodation depth of observers' eyes when they were watching two overlapping images with the same shape, presented by two stereoscopic displays at different depths. Both images were displayed so that the observers perceived them at the same depth. Since images displayed by the back display are obstructed by the front display, we used a half-mirror to split the optical path and place both displays in their respective paths in the experimental system so that observers could see the two screens at different depths in the same area. We used a 15 inch parallax-barrier-based stereoscopic display with 1024 (H) × 768 (W) pixels for both displays. The equivalent distance between their two screens was 10 cm and the distance between the front screen and the observer was 50 cm. We used a binocular accommodation auto ref/keratometer to measure the accommodation depth. The observers reported that they could see the two images presented by the two displays as one fused image. We found that the accommodation depth when observers saw the overlapping images differed from that when each stereoscopic display presented a single image by itself. It was between them, although it was behind the perceived depth of the fused image. These results indicate that the accommodation depth was determined by the reciprocal effect of the two displays, although the back one had a larger effect. We also clarified the dependence of accommodation depth on the perceived depth of the overlapping images.

◆ **Is there a need to redefine the motion aftereffect?**

32 Frans A J Verstraten (Helmholtz Institute, Universiteit Utrecht, Heidelberglaan 2, NL 3584 CS Utrecht, The Netherlands; and F.C.Donders Centre for Cognitive Neuroimaging, Radboud University Nijmegen, NL 6500 HB Nijmegen, The Netherlands; e-mail: f.a.j.verstraten@fss.uu.nl)

The motion aftereffect (MAE) is one of the oldest documented visual phenomena. After Barlow and Hill (1963 *Science* **139** 412–424) published their seminal paper on ganglion-cell response characteristics in the retina of a rabbit, many researchers have tried to relate the perceptual experience of illusory motion to neuronal activity in the cortex, first in the cat and monkey, and after the introduction of neuro-imaging techniques, in humans. MAE is considered the perceptual correlate of the recovery-from-adaptation process. In experiment 1, it is shown that the visible MAE does not reflect the recovery from adaptation process at all. Only part of the recovery process is accompanied by illusory movement. This might suggest that we have to redefine the MAE as “that part of the recovery from adaptation process, that can actually be perceived as illusory motion”. Successively presented orthogonal patterns (eg Riggs and Day, 1980 *Science* **208** 416–418) are used, whose MAE, as for orthogonal transparent motion, is unidirectional and hence shows the relative contribution of both directions. For example, if adapting pattern A normally shows an aftereffect of x seconds, the orthogonal motion B is presented for a shorter, the same, and a longer period of time, immediately after pattern A is stopped. Although the aftereffect due to pattern A might be below perceptual threshold, it integrates with the visible aftereffect of pattern B, if it is still there in terms of recovering neurons. In subsequent experiments, an attempt was made to find out where this unperceived subthreshold activity can be found in the visual cortex. fMRI shows that area MT is not the best candidate. MT was only active when the illusory motion was actually perceived, suggesting that other areas are involved.

◆ **Evaluating the weighted-saliency account of eye movements**

- 33 Ben T Vincent, Tom Troscianko, Iain D Gilchrist (Department of Experimental Psychology, University of Bristol, 12A Priory Road, Bristol, BS8 1TU, UK; e-mail: ben.vincent@bris.ac.uk)

The 'weighted saliency' model is a prominent account of image-driven visual attention (Itti and Koch, 2000 *Vision Research* **40** 1489–506). This model operates by sampling the visual environment, calculating feature maps, combining them in a weighted sum, and using this to refixate the eye. We examined all of these stages, starting by accounting for the non-uniform retinal sampling and find spatial aliasing causes feature-coding unreliability. From a theoretical standpoint, the linear weighted-sum operation is a satisfactory model to account for how feature maps are combined; efficient searches should be possible for any targets and distractors that are linearly separable in feature space. In conjunction searches, differences between predicted and actual visual-search performance can be explained by joint feature statistics and an inbuilt independence assumption. We find good discrimination between targets and non-targets in the weighted-sum 'saliency' map using signal-detection-theory methods. However, when we analyse the fixation criterion toward 'peak saliency', we find the strategy poor when distractor heterogeneity is high, a situation which might be expected in real complex natural scenes. In summary, we find a number of aspects of the 'weighted saliency' model need to be reconsidered, but that if the natural statistics of image features are taken into account, predictions of the model are closer fits to psychophysical data. A continuing challenge for this class of model, however, is to account for other factors in eye-movement control such as spatial prior knowledge (Torralba, 2003 *International Journal of Computer Vision* **53** 169–191).

◆ **The role of high-level motion in natural-scene perception**

- 34 Quoc C Vuong, Ian M Thornton¶ (Max Planck Institute for Biological Cybernetics, Spemannstrasse 38, D 72076 Tübingen, Germany; ¶ Department of Psychology, University of Wales Swansea, Singleton Park, Swansea SA2 8PP, Wales, UK; e-mail: quoc.vuong@tuebingen.mpg.de)

There are large amounts of motion in scenes but only some are relevant to an observer, as these may indicate objects of interest (eg prey or predator). Here we used a visual-search paradigm to investigate the extent to which such motion plays a role in the perception of natural scenes. Observers were presented with circular arrays of 2, 4, 6, or 8 static or dynamic scenes containing either human, animal, or machine movements. In experiment 1, observers searched for human targets among machine distractors on one block and machine targets among human distractors on another block. The order of the blocks was counterbalanced. In experiment 2, we used humans and animals in the same design. In both experiments, half the observers were tested with static scenes and the other half were tested with dynamic scenes ($N=12$ per condition). We found that observers were faster at searching for dynamic targets than for static targets. We also found category effects on search times. For both static and dynamic conditions, observers were faster at searching for humans among machines than they were at searching for machines among humans. However, there was no difference in search times between human and animal targets for dynamic conditions but there was a difference in search times for static conditions. Overall, the present results point to the importance of high-level interpretations of motion (eg as biological versus mechanical motion) in processing natural scenes.

◆ **Mach edges: a key role for 3rd derivative filters in spatial vision**

- 35 Stuart Wallis, Mark A Georgeson (School of Life and Health Sciences, Aston University, Birmingham B4 7ET, UK; e-mail: wallissa@aston.ac.uk)

Edges are key points of information in visual scenes. One important class of models supposes that edges correspond to the steepest parts of the luminance profile, implying that they can be found as peaks and troughs in the response of a gradient (first-derivative) filter, or as zero-crossings (ZCs) in the second-derivative. A variety of multi-scale models are based on this idea. We tested this approach by devising a stimulus that has no local peaks of gradient and no ZCs, at any scale. Our stimulus profile is analogous to the classic Mach-band stimulus, but it is the local luminance gradient (not the absolute luminance) that increases as a linear ramp between two plateaux. The luminance profile is a smoothed triangle wave and is obtained by integrating the gradient profile. Subjects used a cursor to mark the position and polarity of perceived edges. For all the ramp-widths tested, observers marked edges at or close to the corner points in the gradient profile, even though these were not gradient maxima. These new Mach edges correspond to peaks and troughs in the third-derivative. They are analogous to Mach bands—light and dark bars are seen where there are no luminance peaks but there are peaks in the second derivative.

Here, peaks in the third derivative were seen as light-to-dark edges, troughs as dark-to-light edges. Thus Mach edges are inconsistent with many standard edge detectors, but are nicely predicted by a new model that uses a (nonlinear) third-derivative operator to find edge points.

◆ **Infantile nystagmus adapts to visual demand**

- 36 Debbie Wiggins, J Margaret Woodhouse, Tom H Margrain, Christopher M Harris ¶, Jonathan T Erichsen (School of Optometry and Vision Sciences, Cardiff University, Cardiff CF10 3NB, Wales, UK; ¶ SensoriMotor Laboratory, Centre for Theoretical and Computational Neuroscience, University of Plymouth, Plymouth PL4 8AA, UK; e-mail: wigginsD1@cardiff.ac.uk)

Individuals with infantile nystagmus syndrome (INS) commonly report that making an “effort to see” can intensify their nystagmus and adversely affect vision. However, such an effect has never been confirmed experimentally. In this study we examined the effect of visual demand on the nystagmus waveform. The eye-movement behaviours of eleven subjects with INS were recorded at their null zone (gaze direction in which the intensity of oscillations is minimal) while viewing targets under two conditions: above and then at their visual-resolution threshold. Eye movements were recorded by infrared oculography (Skalar IRIS), and visual acuity (VA) was measured with Landolt C targets and a 2AFC staircase procedure. Analysis revealed a significant reduction in nystagmus amplitude ($p < 0.05$), frequency ($p < 0.05$), and intensity ($p < 0.01$) when target size was at visual threshold. The percentage of time the eye spent within the low-velocity window (ie foveation) significantly increased when target size was at visual threshold ($p < 0.05$). Furthermore, a change in waveform type with increased visual demand was exhibited by two subjects. This study indicates that increased visual demand modifies the nystagmus waveform favourably (and possibly adaptively), producing a significant reduction in nystagmus intensity and prolonged foveation. These findings contradict previous anecdotal reports that visual effort intensifies the nystagmus eye movement at the cost of visual performance. This discrepancy may be attributed to the lack of psychological stress involved in the visual task reported here. Further studies are needed to investigate quantitatively the effects of stress and psychological factors on INS waveforms.

◆ **A ‘portholes’ experiment for probing perception of small patches of natural images**

- 37 Yu Xie, Lewis D Griffin (Computer Science, University College London, Gower Street, London WC1E 6BT, UK; e-mail: l.griffin@cs.ucl.ac.uk)

Each trial of the ‘portholes’ experiment that we have developed makes use of three circular patches from a natural-image database. Two patches are from one image, while the third is from another. One half of a display shows the single-image patch-pair, presented on a grey background, in the configuration that they had in the source image; the other half shows a mixed-image patch-pair in the same configuration. The subject’s task is to judge which is the single-image pair ie which half of the screen appears most to show portholes onto an underlying image? The correct rate drops towards chance as patch separation increases. On the basis of 200 trials at each of ten separations we can estimate the separation that gives a 75%-correct rate. For example, for patches of radius $r = 16$ pixels (a visual angle of 1.16 deg), d_{75} is 210 pixels (95% confidence interval = [120, 310]). By applying blur to the natural images before patch extraction we can alter the information content of patches without the confound of changing patch size. For example, a blur of $\sigma = 2$ makes $r = 16$ patches have the information content of $r = 6$ patches and reduces d_{75} to 130 [90, 220]. Patch information can be degraded in other ways; for example, by subtracting the patch mean. For unblurred patches, this reduces d_{75} to 180 [120, 350]; while for the blurred patches it reduces d_{75} to 20 [10, 30]. Our results indicate that for $r \leq 4$, judgments are based on patch mean luminance only, but, beyond that size, use of structural information dramatically improves performance.

◆ **Assessing motion transparency in space time**

- 38 Johannes M Zanker, Andrew I Meso (Department of Psychology, Royal Holloway University of London, Egham TW20 0EX, UK; e-mail: j.zanker@rhul.ac.uk)

Motion transparency, ie the ability to see two or more different motions within the same region of the visual field, allows us to study how local motion signals are integrated into larger-scale entities such as object boundaries or surfaces. Transparency is a challenging problem both in terms of testing experimentally the performance of human observers, and of developing computational models that can solve the problem and/or can explain human observer data. We recently developed a psychophysical measure of transparency strength (see Meso and Zanker, abstract 21), which is based on the observation that a pair of superimposed moving square-wave gratings can look transparent for parameter combinations that do not allow an observer to separate a pair of moving sine-wave gratings. For the limiting case of vertical gratings moving horizontally at

different velocities, we investigate here how the spatial distribution of signals provided by a motion detector depends on the profiles ('squared-index') of two superimposed gratings. Stimuli and responses of an elementary motion detector of the correlation type are plotted as a space-time function, and the split of these signals into two groups of motion signals is studied for a wide range of conditions. A motion detector sufficiently well tuned to a particular grating combination does retain local motion signals reflecting the motion characteristics of each of the components. Furthermore, the peak separation of the bimodal distribution of response values is larger for square-wave than for sine-wave profiles. We suggest that this observation is related to motion signals being localised near the edges of square-wave gratings.

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