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ABSTRACTS

◆ **Human motion perception: Currents in the stream**

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It has become popular to refer to two streams of processing within the hierarchy of cortical areas in the human visual system: a motion-processing stream and a form-processing stream. Given this conception it is important to ask whether the two streams are further subdivided and also to what extent they interact in vision.

One concerted research effort has focused on whether there are sub-streams within the motion-processing system selectively sensitive to first-order and second-order stimulus properties. I present a series of experiments, designed to tap different levels of the motion-processing hierarchy, which show that for at least one specific pair of first-order and second-order properties motion-processing receives separate inputs at all levels tested (D R Badcock, S K Khuu *Psychological Research* in press). In this case it is useful to think of functional sub-streams.

Following this, a series of experiments is presented which question the functional independence of form and motion processing by showing that form-processing mechanisms can provide a significant input to the motion system. Sequences of Glass patterns are displayed which have a common global form but are uncorrelated with each other. These sequences contain motion signals of random velocity but the common global form shapes the perceived motion direction (Ross and Badcock, 1999 *Perception* **28** Supplement, 27). Thus the independence of the form and motion streams seems to have been overstated.

◆ **What and where is adaptation? A contrast gain control model of the tilt aftereffect**

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There seems little doubt that the classical distribution-shift model (in which visual aftereffects arise from an adaptation-induced shift in the activity distribution across an ordered set of neurons) is qualitatively correct, but what can we learn from aftereffects about the selectivity, contrast response, and adaptive properties of visual coding mechanisms? Drawing on several recent models of cortical-cell responses (the contrast gain control models of Heeger; Foley; Wilson and Humanski) I modelled the tilt aftereffect (TAE) by assuming that the response of the ith neuron can be described by:

$$R_i = \frac{(S_{it}\, C_t)^n}{k^n + (A S_{ia}\, C_a)^n + C_t^n},$$

where C is grating contrast, S is orientation-tuned sensitivity, A controls strength of adaptation, and subscripts a and t refer to the adapting and test gratings respectively. Note that the divisive gain term contains a non-selective effect of test contrast and a selective effect of the adapting stimulus. Visually coded orientation was taken as the vector sum of responses across orientation-labelled cells spaced at 5° intervals. The TAE was measured by a staircase nulling method for gratings of 2 cycles deg^{-1} at five adapting orientations, with adapting contrasts of 4%, 16%, 64% and test contrasts of 4%–64%. Results showed that the TAE grew almost linearly with the logarithm of the adapt/test contrast ratio. This effect puts strong constraints on the form of the model's contrast response. The TAE peaked around ±20° adapting orientation. A good fit to the data was obtained with Gaussian orientation tuning of each unit ($\sigma = 7.2°$ for both adaptation and test sensitivities), but only when both k and n were low ($k = 1\%$, $n = 0.37$). This indicates a contrast response quite different from those shown by V1 cells (monkey median values $k = 32\%$, $n = 2.0$) and may reflect a later stage whose role is orientation coding, not contrast coding.

◆ **Is heading information necessary for timing behaviour?**

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The optic flow generated by forward ego-movement contains information about both heading and time-to-contact (TTC) with an object ahead. Estimating TTC with a frontoparallel plane requires information about either the distance of an image element from the focus of expansion and its instantaneous rate of motion or the instantaneous rate of change of the distance between two image elements. Both methods work well with pure expansion. However, when rotation is introduced, the former requires a prior decomposition of the flow while the latter remains unaffected. Here, human sensitivity to heading and TTC were tested with random-dot kinematograms (2, 4, 9, 16, or 25 dots) depicting a rotating surface moving towards the observer. The size and the duration of the display were 17 deg × 17 deg and 1 s, respectively. It was found that increasing the distance of the focus of rotation from the focus of expansion decreased heading sensitivity but left TTC sensitivity intact. A small effect of rate of rotation on both heading and TTC performance was observed, but this effect depended on the focus of rotation angle and display density, respectively. Moreover, heading performance did not improve even when motion parallax was introduced. In addition, observers could estimate heading accurately even with 2-dot displays but their TTC performance deteriorated. Finally, disturbing the spatiotemporal structure of the displays did not substantially affect either heading or TTC. It is concluded that heading and TTC are solved independently and that TTC is based on the instantaneous rate of change of the distance between image elements.

◆ **Fixation could simplify, not complicate, the interpretation of retinal flow**

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It has long been assumed that the visual system analyses retinal flow by decomposing it into rotational and translational flow (Longuet-Higgins and Prazdny, 1980 *Proceedings of the Royal Society of London, Series B* **208** 385 – 397). However, for a fixating observer, these two components are tightly linked to one another. In this case, an alternative method, originally used to describe the binocular disparity field (Gårding et al, 1995 *Vision Research* **35** 703 – 722), is particularly appropriate. Retinal flow is divided into changes in eccentricity ($\Delta\rho$) and changes in meridional angle ($\Delta\theta$). The latter, called 'polar angle disparities' for binocular viewing, can be used to recover the relief structure of the scene. We show how information about the direction of heading can be recovered with the use of a similar hierarchy of heuristics. The maintenance of fixation while the observer moves, far from complicating the interpretation of retinal flow, simplifies these computations.

We show how a reference frame for storing the visual direction and depth of points can be built up with the use of the polar angles (ρ and θ) and changes in polar angles ($\Delta\rho$ and $\Delta\theta$) between pairs and triples of points. The representation is similar to recent computer vision models that record the parallax of points against a frame of distant points (Irani and Anandan, 1998 *Proceedings of the IEEE* **86** 905 – 921). We show how data in the representation could be built up over a series of fixations and for different directions of translation of the observer.

◆ **The extent of motion integration depends upon contrast**

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The conditions under which local motion signals are integrated or differentiated are not fully understood (Braddick 1993 *Trends in Neurosciences* **16** 263 – 268). We examined the effect of contrast, inter-element distance, and the number of elements upon motion integration. Using a 2IFC speed-discrimination task we measured thresholds as a function of contrast (7% and 20%), number of local motion elements (presented in annuli of 2, 4, 8 and 16 Gabor patches), and inter-element distance (rotational distance of 11.25°, 22.5°, 45°, 90°, and 180°). Our stimuli (Gabor patches) were vertical sine-wave gratings windowed by a two-dimensional Gaussian. The carrier frequency of the gratings was kept constant at 1.9 cycles deg^{-1}. The speed of the standard stimulus was 1.6 deg s^{-1} and was always moving from left to right. The Gaussian window (0.53 deg of visual angle) was kept stationary throughout each presentation. Psychometric functions were fitted individually for each observer for each of the fifteen conditions. Thresholds were defined as the 81%-correct point on the fitted Weibull curve.

Our findings are: (i) When the moving stimuli are clearly above threshold (20% contrast), there is no significant decrease in speed discrimination thresholds with increasing number of elements (slope = −0.11). The speed discrimination thresholds asymptote at around 0.4 deg s^{-1}; there is no improvement for more than two elements. (ii) When the moving stimuli are close to detection threshold (7% contrast), speed discrimination thresholds decrease as a function of number of elements (slope = −0.39). Speed discrimination thresholds also asymptote at around 0.4 deg s^{-1}; thresholds decrease up to eight elements. (iii) Contrast detection thresholds decrease as a function of number of elements, but to a lesser extent (slope = −0.15). (iv) Speed discrimination thresholds are independent of the interelement distance.

We conclude that the number of elements used for speed discrimination depends on the contrast: for low-contrast stimuli (close to detection threshold) integration of up to eight elements takes place; for high-contrast stimuli there is no evidence of integration for more then two elements.

◆ **Psychological colour space is physical colour space**

6 L D Griffin (Department of Optometry and Vision Sciences, Aston University, Birmingham B4 7ET, UK; e-mail: l.d.griffin@aston.ac.uk)

Colour space is a set of related perceptual qualities. Its structure can be described from viewpoints either external and physical, or internal and psychological. Descriptions from the external viewpoint are given as the output of a model of the physical processes of colour vision. Description from the internal viewpoint can be made through assertions such as "Yellow is more akin to Red than Blue".

Data on the psychological structure of colour space were gathered with the use of linguistic tasks phrased in terms of the Basic Colour Terms [B Berlin, P Kay, 1969 *Basic Color Terms: Their Universality and Evolution* (Berkeley, CA: University of California Press)]. Similarity and lightness data were collected with the use of questionnaires consisting of questions such as "which is the more similar pair, Blue and Pink or Orange and Green?" and "which is lighter, Brown or Grey?". A total of 47 557 similarity judgments were collected from 195 subjects and 2560 lightness judgments were collected from 47 subjects. Topological data were derived from a colour naming system [*The ISCC–NBS Method of Designating Colors and a Dictionary of Color Names* 1955 (NBS Circular 553)].

A contemporary model of the processes of colour vision was used to determine the physical structure of colour space. This model makes use of the body colour solid [E Schrödinger, 1920 *Annalen der Physik* **62** 603], which represents the gamut of possible cone responses to objects viewed under a fixed illuminant.

Agreement between the psychological and physical structures of colour space is demonstrated by showing the similarity between a pair of approximate symmetries—one of the psychological structure and the other of the physical structure. This supports the hypothesis that the subject of the two descriptions is the same.

◆ **Speed gain control via nulling of opponent and non-opponent processes in a model of motion perception**

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

A computational model of motion perception and adaptive effects is proposed. The model, which is gradient-based, adheres to the neural constraint that transmitted signals are positive-valued functions by posing the problem of motion detection as a linear programming problem. Three possible neural sites for motion aftereffects are identified. The first (V1 simple cells) stems from adjustments of the temporal bandwidth of bandpass filters. Adaptation is motivated by automatic gain control (AGC) processes that increase filter temporal bandwidth as a function of increasing image contrast. The second (V1 complex cells) stems from AGC and adjustments of temporal bandwidth from the squared and pooled response of the raw bandpass filter responses. Coding for image speed at this stage includes both opponent and non-opponent signal combinations. For non-opponent signal combinations, a nulling strategy is proposed. The nulling strategy codes for the space–time product of spatial and temporal gradient signals by scaling the squared sum of these elements and by subtracting the square of each individual element. The nulling scheme posits that adaptive effects stem from suppression of ancillary neurons rather than signal-bearing neurons: a reversal of traditional explanations for adaptive effects as posited by energy-based speed coding. In the final stage (MT cells), motion is detected by iteration and represented by the responses of a small number of speed-tuned neurons. AGC processes again affect motion computations at this final level, which in line with the previous stages is modelled by adjustments of feedback gain. The model may, by virtue of its cascaded stages of processing, explain a variety

of empirically observed motion aftereffects, notably speed increases, speed decreases, direction repulsion, and the manner by which some of these effects can vary as a function of image contrast, frequency, and speed.

◆ **Effect on visual function of laser flash from devices containing optical limiters**

8 E P Liggins (DERA Centre for Human Sciences, Farnborough, Hants, UK; e-mail: epliggins@dera.gov.uk)

The effect of introducing a safe (sub-MPE) laser flash into a subject's visual field was assessed on performance in an aiming task. The aiming task was displayed on a computer monitor and consisted of a fixation cross with an aiming cross controlled by the subject using a joystick. The computer measured how close the subject managed to keep the aiming cross to the fixation cross whilst introducing randomised variations in the aiming cross position to make the task more demanding.

The irradiance distribution of the retinal laser flash was typical of the measured output from an optical device with an inbuilt optical limiter. The laser flash was subjected to spatial filtering such that the resulting retinal irradiance distribution was representative of real-life measured data. Subjects were also asked to comment on the brightness of the flash. Comments were recorded and subsequently used to support and interpret the objective performance results. The presence and size of an afterimage were characterised by comparing pre-flash aiming performance with temporally and spatially resolved post-flash measurements of aiming performance in the computer-based task.

The laser flash was found to impede performance in the aiming task. The effect, which was greatest for early trials in the experiment, was interpreted as being caused by an afterimage that persisted for, typically, less than 5 s. Analysis of aiming scores showed that aiming performance recovered more rapidly at large angular subtenses, which may be interpreted in terms of the retinal irradiance distribution of the flash.

◆ **Blur discrimination and its relation to blur-mediated depth perception**

9 G Mather (Department of Experimental Psychology, School of Biological Sciences, University of Sussex, Brighton BN1 9QG, UK; e-mail: georgem@biols.susx.ac.uk)

Retinal images of three-dimensional scenes are likely to contain regions that are spatially blurred by differing amounts, owing to depth-of-focus limitations in the eye. A difference in blur between one region in the image and another therefore offers a cue that objects in the two regions lie at different depths. However, 'region blur' cannot specify depth ordering, since the more blurred region could lie nearer or further away than the less blurred region. This ambiguity can be resolved by using 'border blur' (the degree of blur in the border between the regions); eg a blurred border would indicate the presence of an occluding edge attached to the more blurred region. Results of experiments to investigate perceived depth ordering in textured images containing only blur depth cues indicate that border blur does influence depth ordering, but only at relatively large blur values. Data from experiments to measure blur discrimination in the same stimuli indicate that thresholds for detecting border blur are significantly higher than thresholds for detecting region blur. The sensory limitations of detecting blur can be related to its perceptual salience in depth judgments.

◆ **Fourth-root summation for stimulus patches that are remote in position and orientation**

10 T Meese (Neurosciences Research Institute, Aston University, Aston Triangle, Birmingham B4 7ET, UK; e-mail: t.s.meese@aston.ac.uk)

Consider a log–log plot of contrast detection threshold versus total area of a single or multiple patches of a sine-wave grating stimulus. On such a plot, the term 'fourth-root summation' is sometimes used when performance improves with a slope of $-\frac{1}{4}$. One possible interpretation of fourth-root summation is probability summation between independent stimulus detectors with finite receptive field sizes. In a recent paper, Bonneh and Sagi (1998 *Vision Research* **38** 3541–3553) reported a series of experimental results on spatial summation using many 12.5 cycles deg^{-1} stimulus patches having full-width at half-heights of 1.4 cycles. They concluded that fourth-root summation occurs only when (i) stimulus patches are placed closer than about 3 stimulus widths apart, and (ii) when the arrangement of the stimulus patches forms smooth contours. For other conditions, summation was found to be less than fourth-root summation. The authors suggest that one interpretation of their results is that fourth-root summation is due to facilitation between contour extracting mechanisms that interact over short distances and along smooth curves. I present results of further summation experiments that are consistent with the probability-summation interpretation of fourth-root summation and challenge the contour-facilitation interpretation. For example, when stimulus patches similar to those used by Bonneh and Sagi, but with a spatial frequency of 4 cycles deg^{-1}, are used, fourth-root summation is found for four patches placed 17

stimulus widths apart, indicating that proximity is not crucial for fourth-root summation. In a second experiment, fourth-root summation was found for a pair of orthogonally oriented step-edges, indicating that contour collinearity is not crucial for fourth-root summation.

◆ **Contrast discrimination and summation**

11 T Meese, D Holmes, C Williams¶, R Hess¶ (Neurosciences Research Institute, Aston University, Aston Triangle, Birmingham B4 7ET, UK; e-mail: t.s.meese@aston.ac.uk; ¶ McGill Vision Research, Department of Ophthalmology, McGill University, 687 Pine Avenue West [H4-14], Montreal, Quebec H3A 1A1, Canada)

At contrast detection threshold, performance improves when either the number of (superimposed) sine-wave stimulus patches (with the same or different spatial frequencies and orientations) is increased, or when the size of a stimulus patch is increased. However, contrast discrimination thresholds do not generally improve in the same way (Legge and Foley, 1980 *Journal of the Optical Society of America* **70** 1458 – 1471). We present a series of suprathreshold summation experiments to examine this issue in more detail. Using 1 cycle deg^{-1} circular stimuli with duration of 100 ms and a pedestal contrast of either 15% or 20%, windowed by a raised cosine function: (i) we found no evidence for summation across orthogonal orientations in a plaid, (ii) we confirmed the absence of summation for a circular patch of grating whose diameter was increased from 2.5 deg to 11.1 deg, and (iii) we found summation (whose magnitude varied across observers), when the number of stimulus patches, equidistant from fixation, was increased from 1 to 4. Findings (ii) and (iii) are broadly consistent with the results of Bonneh and Sagi (1999 *Vision Research* **39** 2597 – 2602), who suggested that, in (ii), short-range inhibitory interactions null the benefits of a summation process. To investigate the temporal dynamics of these putative processes we repeated the experiment in (ii) with stimulus durations of 8 ms and 33 ms. As stimulus diameter was increased from 2.5 deg to 7.4 deg, performance improved with a log – log slope of about $\frac{1}{4}$; a characteristic that is sometimes referred to as fourth-root summation. If an active process is responsible for the absence of summation at longer durations, this last result implies that it acts at least 25 ms more slowly than the mechanism responsible for summation.

◆ **Evidence for object-based selection operating on a grouped array of locations**

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Space-based and object-based selection effects were investigated in two experiments by using variants of the 'ring-cueing' paradigm of Egly and Homa (1984 *Journal of Experimental Psychology: Human Perception and Performance* **10** 778 – 793). The results revealed significant cueing modulation for non-ring configurations of target locations spanning a range of retinal eccentricities, with the cueing effects independent of eccentricity and confined to the configuration of locations (rather than extending to locations within the space enclosed by the cued configuration). These results are consistent with object-based selection operating on a 'grouped spatial array' (Vecera and Farah, 1994 *Journal of Experimental Psychology: General* **123** 146 – 160). Object selection may be based on a supradimensional saliency map representation of the field, modulated by feature-specific segmentation mechanisms (eg an object may be made salient on the basis of its colour). Complex objects may be represented by grouped saliency signals. In this way, a two-dimensional spatial (saliency) representation may provide the common format for object-based selection, prior to full object definition.

◆ **A linear mechanism for Gabor-patch alignment in amblyopia**

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Vernier thresholds and alignment bias were measured for 3-Gabor alignment in the vertical and horizontal meridians. The patches, separated by six carrier periods, were either collinear or orthogonal. In the orthogonal conditions, the outer (reference) patches were aligned with the configuration, the central patch at right angles to it. Data were gathered from a large sample of amblyopic and normal observers, over a range of spatial frequencies from 2.25 to 6 cycles deg^{-1}. In all groups, and under all conditions, collinearity resulted in a small acuity advantage (reduced thresholds). This improvement was generally in the order of about 10% for amblyopic eyes to 20% for non-amblyopic eyes and normal controls, and was statistically significant ($p < 0.05$). Bias was often larger for amblyopic eyes in the vertical meridian, but did not otherwise vary consistently according to conditions.

Although surprising in the light of previous results (eg Keeble and Hess, 1998 *Vision Research* **38** 827 – 840), this intuitive finding (of improved acuity for collinear patches) is backed by a sample

of more than twenty observers (making about 100 data points in all the different conditions). It suggests that an alignment process based on the linear (Fourier) orientations in the stimulus can influence performance even at relatively large separations, and this process, although impaired, is still measurable in amblyopia. Possible substrates for such a process are elongated filters or collators. Sensitivity to the alignment of the collinear stimulus could be modelled by Pythagorean summation of sensitivity to envelope alignment (orthogonal condition) and sensitivity to pure carrier misalignment.

◆ **Heading in the right direction?**

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Analyses of the optic-flow field from J J Gibson onwards have shown that there is information to specify the point of impact in the visual scene if locomotion were to continue along the same path. Locomotion direction can be modified if there is a discrepancy between the actual and desired points of impact. Use of these optic-flow characteristics would be highly desirable if there are forces, such as side winds or cross currents, which result in there being a difference between the observer's direction of heading (with respect to a body or vehicle axis) and his/her actual locomotor path. If there are no such forces, observers could use the visual direction of the intended target (with respect to a body or vehicle axis) to alter their locomotor direction either directly, by changing their walking or swimming direction, or more indirectly by turning a steering wheel. Studies by Rushton et al (1998 *Current Biology* **8** 1191 – 1194) and Rogers and Dalton [1999 *Investigative Ophthalmology & Visual Science* **40**(4) S764] suggest that observers rely more on visual direction than optic flow. Providing richer optic-flow information through motion parallax or the addition of road markings produces locomotor paths which are more consistent with the use of optic-flow information but these results are also consistent with the greater salience of static (rather than dynamic) alignment cues in these situations. Thus the question whether optic flow per se plays any role in the control of locomotor direction remains unanswered.

◆ **What information do we use during interception of an approaching projectile?**

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The ability to intercept or deflect an approaching projectile is critical to survival. What information do we use during projectile interception? In the related actions of reaching for static or laterally moving objects, and walking towards a target, it has been shown that we utilise information about the instantaneous direction of the target relative to the body (egocentric direction), specified by gaze direction and retinal location. However, the models of projectile interception that have been proposed instead rely on projectile trajectory information which is specified in the binocular retinal-flow fields (Regan 1997 *Journal of Sports Sciences* **15** 533 – 558), or by the focus of expansion on the textured surface of the projectile [Lee and Young, 1985, in *Brain Mechanisms and Spatial Vision* Eds D J Ingle et al (Dordrecht: Nijhoff)], or avoid the issue by specifying quantities in the theoretical optic array (Peper et al 1994 *Journal of Experimental Psychology: Human Perception and Performance* **20** 591 – 612). We investigated projectile interception by having observers attempt to deflect approaching balls whilst viewing through horizontally oriented variable prisms. Prisms selectively perturb the perceived direction of an object, relative to the observer, but leave retinal-flow relations such as object speed and relative object position unchanged. We found systematic errors that are compatible with the use of instantaneous direction, relative to the body (egocentric direction), during interception of a projectile. This finding puts projectile interception into the larger class of actions that rely on egocentric direction information.

◆ **Modelling the detection of blur in natural scenes: whitened kurtosis and the rectified contrast spectrum**

16 R J Summers, M G A Thomson (Neurosciences Research Institute, Aston University, Birmingham B7 4ET, UK; e-mail: summerrj@aston.ac.uk)

Two independent psychophysical studies (Thomson, 1996 *Investigative Ophthalmology & Visual Science* **37** 4207; Field and Brady, 1997 *Vision Research* **37** 3367 – 3383) have shown that human observers' ability to detect blur in natural scenes depends strongly on the individual phase spectrum of an image, even though the experimental stimulus parameter was a measure of power-spectral structure. A model observer capable of accounting for human performance must therefore be sensitive to information in both power and phase spectra. Field and Brady described the rectified contrast spectrum (RCS), which measures the spatial-frequency dependence of the contrast of 'detectable structure' in an image. The RCS models human blur-detection performance reasonably

well, predicting that images appear blurred when the contrast of the detectable high-frequency components falls below that of the detectable low-frequency components. The RCS must (by definition) be sensitive to higher-order as well as second-order global image statistics; if it can be placed within a more general higher-order statistical framework, regularities in the phase spectra of natural scenes (Thomson, 1999 *Journal of the Optical Society of America A* **16** 1549 – 1553) could be taken into account. We do this by relating the RCS model to one based on a measure known as the whitened kurtosis, defined here as the kurtosis of an image whose power spectrum has been multiplied by an amount proportional to the square of spatial frequency. The ability of these two blur-detection models to account for human performance is compared, and implications for the arrangement of the neural-coding mechanisms involved in blur detection are discussed.

◆ **Spatial resolution and metamerism in coloured natural scenes**

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Measurements of the spectral reflectance functions of natural surfaces imply that metamerism is rare under natural illumination; that is, there are probably very few pairs of naturally occurring surfaces which, despite being spectrally distinct, give rise to colour signals that would be confused by the human eye. This leaves the possibility, however, that a similar sort of metamerism could arise by combination: a human observer may confuse members of the set of all colour signals which could be produced by illuminating linear combinations of naturally occurring spectral reflectance functions. Such a phenomenon would be of ecological relevance, since the linear combinations required to produce these combined spectra could arise naturally as a result of an observer being unable to resolve two or more spectrally distinct surfaces in an image. To gauge the prevalence of this type of metamerism in natural scenes, CIE ΔE measurements were made on spatially averaged data derived from hyperspectral images. The results, which are discussed in terms of the relationship between the colour-coding properties of the human visual system and the statistics of the natural environment, imply that metamerism-by-combination is possible but unlikely.

◆ **The onset repulsion effect**

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There have been many previous reports of mislocalisation associated with moving objects (eg flashlag effect, Fröhlich effect, representational momentum). Across five experiments, we explore a new effect which is unusual in that the mislocalisation error is always back along the observed path of motion. That is, when observers are asked to localise both the initial and the final position of a moving object, by far the largest and most systematic error they make is in placing the starting point too early along the correct path of motion. Errors orthogonal to the path of motion and errors in localising the stopping point are small by comparison. Errors are also very small when motion is implied rather than continuous. The effect can be observed with and without fixation, and, as with other mislocalisation effects, shows some dependence on direction and velocity. As the most obvious prediction in these studies, based on previous reports of mislocalisation and the known properties of the visual system, would be for forward rather than backward errors, discussion focuses on specific aspects of the current paradigm that might give rise to the observed pattern of results. In particular, the influence of compensation strategies, illusory acceleration effects, and distance versus length errors is discussed.

◆ **Perceived contrast of filtered natural images**

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In previous work which has involved altering the amplitude – spectral slope of natural images and measuring object discrimination in images with different values of the spectral slope, we found optimal object discrimination when the slope values are natural (typically around 1.2). Performance is worse when the slopes are markedly steeper or shallower. Object discrimination was measured within sequences of morphed images.

However, we noticed that the 'natural' images (slopes around 1.2) appeared to have a higher perceived contrast than the blurred or whitened images (with steeper and shallower slopes, respectively). Neither the Fourier amplitude content of these 'natural' images, nor that Fourier amplitude content weighted by the observer's contrast sensitivity function, suggest any kind of maximum for the 'natural' images. Thus, it seems that there is a nontrivial dependence of perceived contrast on the degree to which the spectral characteristics of an image are 'natural'.

A possible model which might account for such a result is the suggestion (D J Field and N Brady, 1997 *Vision Research* **37** 3367 – 3383) that natural images stimulate the bank of cortical filters to a roughly equal extent. We tested this model by selecting images whose unmodified amplitude slopes increasingly departed from the value of 1.2. A simple 'filter bank' model would predict that contrast would peak for slopes around 1.2 even if these were produced by modifying the image. Instead, we found that the unmodified, 'natural' image has the highest contrast even if its slope is markedly different from 1.2. Thus, perceived contrast cannot be simply predicted by second-order image statistics and associated cortical filter models.
[Supported by BBSRC.]

◆ **Psychophysics of change detection in multiple Gabor target arrays**

20 M Wright, A Green, S Baker (Department of Human Sciences, Brunel University, Uxbridge UB8 3PH, UK; e-mail: Michael.Wright@brunel.ac.uk)

The purpose of the study was to investigate how a psychophysical threshold for a spatial-frequency change depends on the number of targets simultaneously present. The stimuli used were two 150 ms frames each containing 1 – 4 Gabor targets. A 'change/no change' discrimination was employed, comparing the stimuli in the two frames. Using a partial report technique (to equalise response variables), we found that the logarithm of the Weber fraction for spatial frequency change discrimination was proportional to the logarithm of the number of targets. The slope of this function (the set-size effect) was greater than has been reported for visual search tasks. The limitation was not a perceptual one affecting the visibility of the stimuli, because pre-cueing one out of four targets restored performance to the level found with a single target. With post-cueing (partial report) there was no difference in performance at 250 ms and 2000 ms inter-stimulus interval (ISI). However, where there was no cueing and only one target could change on a given trial, there was a larger set-size effect at 2000 ms than 250 ms ISI. Parallel division of attentional resources in the encoding of stimuli could account for the set-size effects, but the last finding suggests a memory component as well. It is argued that such low-level effects could account for the phenomenon of 'change blindness'.

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