PERCEPTION

Perception
2018, Vol. 47(1) 115–122

DOI: 10.1177/0301006617715527
journals.sagepub.com/home/pec
SAGE

AVA Spring Meeting, Farnborough, UK, April 3, 2017

Keynote Lectures

Colour Night Vision: System Development and Observer Evaluation Studies

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The increasing availability of imaging sensors operating in multiple spectral bands, in combination with lenses that cover a broad spectral range and dedicated image fusion hardware has spurred the development of colour fusion schemes that aim to convey the information from these sensors to the human operator. Inspired by previously developed colour opponent fusing schemes, we initially derived a simple pixel-based false colour mapping scheme that yields fused false colour images with large colour contrast and preserves the identity of the input signals, but does not produce realistic colours. A subsequent statistical colour mapping procedure that transfers the colour distribution of a given example image to a multiband night-time image yielded a more realistic colour rendering. However, it is computationally expensive and achieves no colour constancy, since the mapping depends on the relative amounts of the different materials in the scene. By applying the statistical mapping approach in a colour look-up-table framework, we finally achieved both colour constancy and computational simplicity. This sample-based colour transfer method is specific for different types of materials in the scene and is easily adapted for the intended background and the task at hand. The method can be implemented as a look-up-table transform and is highly suited to real-time implementations. We show some prototype real-time multi-band colour night vision systems and examples of recordings made with these systems during night-time field trials, along with the results of several validation studies that were performed to assess the added value of colour night vision.

CRS Lecture

The Perceptual Combination of Colour and Luminance Contrast

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The study of interactions between color and luminance contrast is fundamental to a complete understanding of visual processing. I will discuss my work on how color contrast affects the perception of luminance contrast and vice versa. We use an arrangement in which red–green color and luminance contrast Gabors are overlaid to form a cross-oriented plaid, designed to

reveal interactions mediated by contrast normalization. Using methods of constant stimuli, we measure the effect of the luminance contrast in the plaid on the perception of color contrast and vice versa, determining both detection thresholds and the perception of perceived suprathreshold contrasts. In general, results show that luminance contrast enhances perceived color contrast in the plaid by around 30% under normal binocular or monocular viewing conditions, with effects consistent across spatial frequency and over a range of component contrasts. Conversely, color contrast has no effect on perceived luminance contrast. (Dichoptic viewing conditions, on the other hand, produce very different results.) In conclusion, we find asymmetric effects in contrast normalization: While perceived luminance contrast is relatively unaffected by color contrast, luminance contrast tends to enhance perceived color contrast.

The Geoffrey J Burton Lecture

Hyperspectral Imaging and Visual Inference

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The light signal reflected from scenes in the real world is complex, spatially and spectrally inhomogeneous, and subject to uncontrolled variation. Hyperspectral imaging can, however, capture the full spatial and spectral properties of the light signal incident on the eye, and is essential for accurate and comprehensive modelling of visual performance in unconstrained settings, sometimes called vision in the wild. Four such applications are considered here. First, the remote characterization of local illumination colour in natural scenes and the effect of its variation on surface colour judgements. Second, the optimum visual detection of target objects defined by their reflecting properties. Third, the existence of universal limits on colour constancy in natural scenes. And fourth, the extent to which a surface colour distribution at one instant provides a guide to its distribution at another. All four applications illustrate the fact that achievable levels of visual inference fall short of what might be expected from laboratory experiments in simple, constrained settings. This performance gap is argued to be a consequence of the unpredictability of real-world light signals.

Talks

1. Visualising Glare in the Human Eye

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Glare is a significant, debilitating problem, affecting detection and discrimination performance. With an ageing population and greater effects of glare sources in older individuals, it is important to understand how it affects performance. Traditional (CIE) approaches to predicting glare effects are parametric, using human measurements to define a glare spread function, which is then used to predict thresholds. The approach, while very effective, incorporates no effects of individual differences in eye optics quality or scattering. It also has no model of the retinal processes and their ability to adapt to light levels. We have developed a radiometric model for visualising glare sources. The model takes as input calibrated hyperspectral images and calculates the optical image

at the retina using a wave optics approach. It incorporates the effects of wavefront aberrations allowing individual or population effects to be explored. In addition, it models the scattering in the different components of the eye optics (Ritschel et al., 2009, *Eurographics, 28*(2), 1–). The resulting optical image can then be converted into photoreceptor signals using a model of temporal adaptation. The simulation generates the appearance of a glare source in the scene and also predicts the time course of the retinal signals when a glare source is turned on. We will describe the model and illustrate the visualisations it produces for both narrowband and broadband sources.

2. Predictability of Melanopsin Signals From Luminance Signals in Natural Scenes

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The response of the human eye to incident light has two components: one image-forming and one non-image-forming. The image-forming response follows luminance spectral sensitivity, peaking at approximately 550 nm, and the non-image-forming response follows melanopsin spectral sensitivity, peaking at approximately 480 nm. But the two signals may be interdependent, especially in natural scenes with large illumination variations. To test this hypothesis, luminance and melanopsin signals were computed in over 32 hyperspectral radiance images of vegetated and non-vegetated outdoor scenes under natural lighting, with correlated colour temperature 3,000 K to 20,000 K within scenes, and in time-lapse images with daylight correlated colour temperature 3,000 K to 7,500 K. With allowance for prereceptoral lens absorption, luminance and melanopsin signals were computed at each pixel and grouped into 64 patches of 155×125 pixels within each 1240×1000 pixel image, corresponding at the camera to approximately 7° visual angle, and their correlation quantified. Across scenes, mean R^2 over patches ranged from 76% to 99%. Within scenes, R^2 varied more widely, with minimum less than 10%. These results suggest that although the two signals are broadly correlated, the predictability of melanopsin signals from luminance signals in any given scene is limited, presumably owing to the complexity of natural scenes. A partial report of these findings was presented at the January meeting of the Colour Group of Great Britain, London, 2017.

3. Individual Variations in Cortical GABA Levels Are Associated With Contrast Adaptation Magnitude

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Individuals vary in performance on cognitive and perceptual tasks, but drivers of such variability are poorly understood. It was recently reported that cognitive performance is associated with surround suppression magnitude. We previously showed that this association could be explained by variations in cortical levels of gamma-aminobutyric acid (GABA), which were found to be strongly predictive both of surround suppression magnitude and visuospatial IQ in normal subjects. Surround suppression is often considered a form of gain control mediated by inhibitory interactions between cortical neurons. Here, we investigated whether gain control in the temporal domain, contrast adaptation, is also associated with GABA levels. Contrast adaptation to sinusoidal grating patterns was measured in nine volunteer subjects using a temporal 2AFC task at three different visual eccentricities (3°, 6°, and 9°). Cortical GABA levels were measured by MRS using a

MEGAPRESS sequence in the visual cortex centred on the calcarine sulcus. GABA levels were significantly associated with contrast adaptation thresholds: Higher levels of GABA predicted greater adaptation magnitude. First-order surround suppression was also significantly correlated with contrast adaptation magnitude. The associations between visuospatial IQ and contrast adaptation were weaker, although the direction of the (non-significant) association was consistent with predictions based on GABA levels. However, GABA did not predict performance on a shape matching task, suggesting the effect could not be accounted for by a general modulation of behavioural task performance. The association between GABA and adaptation suggests contrast adaptation may be in part mediated by cortical inhibition.

4. A Feedforward-Feedback-Verify-Weight Process for Analysis-by-Synthesis Explains a Difference Between Central and Peripheral Vision in Ambiguous Perception

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Central and peripheral vision should have different functional roles. Here, we use observations of visual perception under dichoptic stimuli to infer that there is a difference in the top-down feedback from higher brain centres to primary visual cortex. Visual stimuli to the two eyes were designed such that the sum and difference of the binocular input from the two eyes have the form of two different gratings. These gratings differed in their motion direction, tilt direction, or colour, and duly evoked ambiguous percepts for the corresponding feature. Observers were more likely to perceive the feature in the binocular summation rather than the difference channel. However, this perceptual bias towards the binocular summation signal was weaker or absent in peripheral vision, even when central and peripheral vision showed no difference in contrast sensitivity to the binocular summation signal relative to that to the binocular difference signal. We propose that this bias can arise from top-down feedback as part of an analysis-by-synthesis computation. The feedback is of the input predicted using prior information by the upper level perceptual hypothesis about the visual scene; the hypothesis is verified by comparing the feedback with the actual visual input. We illustrate this process using a conceptual circuit model. In this framework, a bias towards binocular summation can arise from the prior knowledge that inputs are usually correlated between the two eyes. Accordingly, a weaker bias in the periphery implies that the top-down feedback is weaker there.

5. Linking Position Shifts, Frequency Shifts, and Smoothing in the Visual System

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Under impoverished viewing conditions, such as low image contrast, low luminance, or after periods of prolonged adaptation, the perceived spatial frequency of a sinusoidal pattern can

increase by orders that exceed 20%. This increase is thought to reflect a mismatch between a spatial frequency label tied with an individual spatial frequency channel's tuning characteristics (Georgeson, 1980, *Philosophical Transactions of the Royal Society London B, 290*, 11–22). Here, we show that a change in perceived spatial frequency can be explained by an alteration (increase or decrease) in the spatial sampling rate of visual mechanisms or equivalently the 'slope' of 1D convolution in a 2D convolution matrix. We further show that adjustments in expected spatial frequency can be implemented simply in the spatial domain by a neural system, by a positional dependent shift of linear filter weights, by interpolation and the transpose of interpolation (decimation) that propagates from a given image location. Such treatment is again made possible when considering convolution of a 1D signal with the 2D convolution matrix – a representation that encompasses the Radio Detection And Ranging (RADAR) ambiguity function, as a potentially Doppler (spatial frequency) and position shift tolerant representation. The collective effect of the proposed spatial variation in position shifts are to both re-scale and adjust net smoothing on the input signal. Collectively, our computations provide a link between scaling and smoothing by the visual system, such that increased degrees of physical smoothing under the poorer signal conditions are tied with increased degrees of perceptual scaling, from which one can seek to 'reconstruct' as opposed to 'estimate' visual experience.

6. Comparing Drivers' Gap Acceptance Thresholds for Cars and Motorcycles at Junctions

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Many road crashes are caused by inappropriate gap selection by drivers. A disproportionate amount of these crashes occur when the oncoming vehicle is a motorcycle. Previous research investigating drivers' responses to different gaps has predominantly recorded responses to vehicles presented at a limited and predetermined set of distances and has not systematically varied the type of vehicles presented.

The current study compared drivers' gap acceptance when either a car or motorcycle was approaching at a simulated junction. We used a QUEST adaptive staircase to estimate gap acceptance thresholds for cars and motorcycles separately. Twenty-seven participants completed the task in a car unit (steering wheel and pedals for vehicle control) with a 180° screen and 27 completed the task in a full instrumented car with a 360° screen. On each trial, drivers saw a car approaching from the left and a vehicle (car or motorcycle) approaching from the right. The vehicles were timed such that the driver always had to stop for the car from the left, but could choose to pull out in front of the vehicle from the right, or to wait for it to pass. Despite the fact that motorcycles and cars were approaching at identical speeds, participants accepted significantly smaller (riskier) gaps in front of motorcycles than in front of cars. The difference between car and motorcycle gap acceptance was significantly larger when measured in the 360° simulator than in the 180° simulator. These results help to explain the disproportionate involvement of motorcycles in real junction crashes.

7. Towards Insect-Inspired Navigational Aids for Blind and Visually Impaired People

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Blind and visually impaired (BVI) people face difficulties in leading independent lives, including navigating unfamiliar routes alone. Computer vision approaches hold promise for assistive technologies that help to guide BVI people along routes, but the computational complexity of such approaches may limit their accessibility and usability through the cost and power consumption of necessary hardware.

Inspired by ants, we have developed a parsimonious algorithm for visually guided navigation that stores low-resolution panoramic views from locations along a route. On subsequent trips, heading directions are recovered by rotating the currently experienced view until it best matches a stored view. To date, tests of the algorithm have been limited to controlled environments. We therefore sought to investigate its performance in urban environments relevant to BVI users.

We collected panoramic photo and video data for outdoor urban routes with differing visual and spatial complexity. Performance was quantified as the error between the true and retrieved heading directions. Even with this naïve algorithm, median heading error was only 7.0° on straight sections and 18.0° on corners, with 90.6% and 76.8% of errors, respectively, within 45°. These results suggest that using insect-inspired algorithms, we can develop robust and effective assistive navigational technologies with minimal hardware requirements.

Posters

1. Situational Factors Influence Performance on the Useful-Field-of-View Test

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The Useful-Field-of-View (UFOV) test measures processing-speed, divided-attention, and selective-attention. It is a simple computer test that has been linked to performance in driving (Charman, 1997, *Ophthalmic and Physiological Optics*, *17*(5), 371–) and sport (Wilkins & Gray, 2015, *Perceptual and Motor Skills*, *121*, 57–). Traditionally it is completed in a light room, in silence, whilst seated, and with no incentive. In this study, 60 participants completed the UFOV test under nine different conditions that varied on factors of light, noise, posture, and incentive. Divided-attention and selective-attention were significantly worse when performed in the silent condition compared to a background noise and distracting noise condition. Processing speed was significantly better in the seated condition compared to the standing and stepping conditions, and in the incentive condition compared to the non-incentive condition. No significant differences were found between light and dark conditions. These findings highlight how variations in test conditions can produce significantly different outcomes. Given the growing call for research testing methods to have high task representativeness (Pinder, 2011, *Journal of Sport & Exercise Psychology*, *33*, 146–), combined with the nature of the domains in which the UFOV test is regularly used, it is important that these differences are explored further.

2. Stroboscopic Visual Training: A Case Study Using Elite Youth Football Goalkeepers

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Stroboscopic visual training (SVT) involves athletes performing sports drills whilst wearing specialised glasses with lenses that flicker to produce a strobe effect. Research suggests that it can improve a range of visual functions (Appelbaum & Erickson, 2016, *International Review of Sport and Exercise Psychology*), whilst there are anecdotal reports that these benefits transfer to sporting performance. Here, the case study approach involved six elite youth goalkeepers, three of whom underwent 7 weeks of SVT and three of whom were controls (C). Various visual measures were assessed pre-training, post-training, and at a 4-week retention, whilst semi-structured interviews were conducted post-training. Data showed improvements in response time from pre-post and from pre-retention for the SVT but not the C. The groups did not differ in measures of attention, anticipation, hand-eye coordination, inhibition response, visual memory, and cognitive functioning. A thematic analysis of the qualitative data identified three themes: (a) that ST improved 'focus', 'reactions', and 'judgement'; (b) that ST improved on-field performance; and (c) that ST was effortful and enjoyable. This study is the first of its kind to use elite youth football players whilst also being novel in its use of qualitative methods. Further research should attempt to measure on-field performance.

3. Disrupting Target Detection With Iridescence

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Biological iridescence is a particularly striking phenomenon found in a wide variety of organisms. It is produced by structure, rather than pigment, and is defined as a change in hue corresponding to a change in viewing or illuminant angle. Iridescence is generally considered to have a signalling function, and plays a role in diverse situations including plant-pollinator interactions and sexual displays. One potential function of iridescence that has received far less attention is protective colouration. While the variable signals associated with iridescence have been hypothesised to interfere with object recognition, the brightness of the colours intuitively suggests that iridescent targets should be highly conspicuous and easy to detect. We investigated the effects of iridescence on target detection using a real-world visual search paradigm with human participants foraging for iridescent (diffraction grating), multi-coloured, or plain beetle-like plastic targets on a background of artificial leaves. Detection was performed under both steady and dappled light conditions, mimicking conditions in a forest or natural setting. We present two experiments, the first using targets with a flat upper surface that results in a strong directionally dependent signal, and the second using targets with a curved upper surface that more accurately mimics the shape of real beetles. Evidence from both experiments indicates that iridescent targets are less conspicuous than targets displaying bright static colours and, under dappled light conditions, iridescent targets may be as difficult to detect as plain black targets. We therefore conclude that iridescence has the potential to be useful for defence against predation.

4. Testing Possible Motion Camouflage Schemes for Military Rotorcraft

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Dazzle camouflage (or motion dazzle camouflage) consists of high-contrast geometric patterns, and is hypothesised to disrupt an observer's ability to accurately assess target movement. Historically, this concerned bearing and trajectory, an aspect recently dissected by Hughes et al. (2017, *Proceedings of the Royal Society of London B, 284*, 1850–), but has now largely focused upon estimations of speed. Scott-Samuel et al. (2011, *PLoS One, 6*(6), e20233–) found that two-dimensional static dazzle patterns introduced significant errors for speed assessments and suggested that these results could apply to military jeeps facing projectile threats. Hall et al. (2016, *PLoS One, 11*(5), e0155162–) recently expanded this concept, finding that the effect was accentuated when striped patterning was dynamic (passing over the surface either with or against the motion of an object) and matched the speed of the object. Here, we test these results in a more realistic context; military helicopters frequently bear camouflage colourations based upon traditional camouflage schemes that are designed to make detection difficult when stationary. Yet, when in active military service, helicopters are rarely exposed to danger when stationary. Our investigation therefore addresses, via a gamified computer task, the application of dazzle camouflage patterns to helicopters.