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Seeing the bigger picture: an amblyopic advantage in the global integration of moving visual information?

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Abstract

Devices used to incorporate global information by normal and amblyopic eyes were investigated using the Classification Image (CI) technique. An orientation task with randomly orientated tilting Gabor patches and a motion-direction task using randomly directed moving discs were utilized. Participants judged the near-threshold average global orientation or motion-direction in each. CIs were calculated, adding noise samples eliciting correct responses and subtracting noise samples producing incorrect responses. Results illustrated normal participants had consistently narrow perceptive fields as was the case for amblyopes in the orientation task. For global motion-direction judgements, amblyopic perceptive fields were far wider, illustrating sparse sampling of elements. This reflected reduced inhibition for amblyopic motion processing mechanisms; a diminished suppression device proving advantageous for this type of observer.

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Ethical Statement

All ethical procedures have been complied with by providing informed consent and right to withdraw information through briefing and information sheets. Participants were provided with contact details on a paper debrief in the event they chose to withdraw data. All data gathered remained anonymous and confidential, participants were informed of this through the brief and de-brief. Experimenters were open and honest and participants were fully informed, no deception was used in the experiment. Participants were protected from harm by a researcher being present in the room at all times during the experiment. An ethical committee approved the study, classifying it to be ethically sound with any ethical issues categorized as simple and straightforward.

The author shared the responsibility of data collection equally with two other researchers. The author personally collected the data of 28 participants and collated this together with the 58 participants whose data the other researchers collected.

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Introduction

The human visual processing mechanism at large is considered to necessitate initial local analyses that are subsequently integrated globally to derive functional representations of structure, enabling observers to derive object movement and orientation information. This broadens over considerable areas of visual space and provides observers with the means to make a variety of perceptual judgements in everyday life (Allman, Miezin & McGuiness, 1985). A condition named amblyopia, colloquially referred to as ‘lazy-eye’ is a common developmental deficit in human spatial vision, resulting in a loss of visual acuity which produces marked deficits in the visual techniques used by the observer to make perceptual assessments (Hess, France & Tulunay-Keesey, 1981). The visual disorder is instigated by either a lack of transmission or poor conduction of the visual image to the brain for a prolonged period of dysfunction, commonly during early infancy. Amblyopia normally only affects one of the eyes, but in rare cases it is possible to be amblyopic in both eyes (Moke, Turpin, Beck, Holmes, Repka, Birch, Hertle, Kraker, Miller & Johnson, 2001). Amblyopia affects approximately 3 per cent of the population and carries a projected lifetime risk of visual loss of at least 1.2 per cent (Weber & Wood, 2005). Whilst this visual disorder is a frequent cause of lifelong unilateral visual impairment, the nature of the disorder is poorly understood, highlighting a critical need for research in this domain. The expansion of current knowledge regarding amblyopia and its deficits will aid in treatment and help clinicians provide the best level of care for their

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amblyopic patients.

Various types of amblyopia have been medically classified but the two most common types of amblyopia are strabismic and anisometropic, both involving nepotism of one of the eyes. In strabismic amblyopia, the eyes are not aligned properly, resulting in one eye being used less by the observer. As a result, the non preferred eye is not adequately stimulated. The two differing scenes from each eye cannot be fused into a single central image, so, to avoid confusion, image from the amblyopic eye is suppressed. In the case of anisometropic amblyopia, the eyes have different refractive powers. To illustrate, one eye may be farsighted and one nearsighted. It becomes problematical for the brain to balance the difference consequently favouring input from the stronger eye. A review of recent psychophysical studies of naturally occurring amblyopia in humans by Levi (2006) presented good evidence for deficits exclusive to each form but the present study is interested in the universal visual performance for all classifications and does not differentiate between types. The review surmised a key factor in determining the nature of amblyopic loss is presence or absence of binocularity. Furthermore, it was construed that dysfunction within the amblyopic visual system first occurred in area V1 of the visual cortex, with effects being amplified downstream further in the visual system.

Our developing understanding of amblyopia has been focussed by our broadening knowledge of normal visual systems. It is commonly understood that early visual mechanisms have receptive fields which are slight and selective for stimulus attributes such as spatial frequency, orientation and motion-direction.

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Positional information concerning large objects and their movements can be extracted by integrating the local representations across the visual field (Braddick, 1997). Unfortunately, little has been established with reference to what devices higher levels of the visual system use to incorporate global information by either normal or amblyopic eyes. In the last five years, various exciting new methods have been implemented to rectify this lack of scientific comprehension.

Early research originally suggested that amblyopic observers were exclusively poor at detecting spatially simple targets, in other words an inadequacy in the detection of high spatial frequencies (Gstalder, 1971; Lawwill & Burian, 1966; Levi & Harwerth, 1977). Explicitly, a study conducted by Hess & Howell (1977) noted contrast sensitivity greatly depressed in 10 strabismic adult amblyopes. This initial inference was substantiated physiologically with animal model evidence (Crewther & Crewther, 1990) which suggested the neural deficit involved in amblyopia originated in sensory insufficiency at the single cell level. Eggers & Blakemore (1978) examined the physiological basis of this visual disorder by artificially inducing amblyopia in kittens. The study discovered that most neurons in the brain were dominated by input from the normal eye. Furthermore, contrast sensitivity and resolving power were inferior for stimulation through the originally defocused eye, mimicking psychophysical results from human amblyopes. It was concluded that the fundamental discrepancy lied in amblyopic contrast sensitivity functions derived from the spatial properties of high spatial frequency responsive neurons in area V1 of the visual cortex.

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In contrast to these initial implications, more recent evidence suggests that amblyopia involves a much more extensive set of visual processing deficits. Of specific significance, an insufficiency has been discovered in the amblyopic observer's ability to process global motion. Simmers, Ledgeway, Hess & McGraw (2003) utilized a method which enabled the factoring out of any influence of the recognized contrast sensitivity deficit to examine this mechanism in adult amblyopes. They illustrated independent global motion processing deficits in human amblyopia which were more extensive for contrast-defined than for luminance-defined stimuli. It was suggested that the site of these deficits must include the extra-striate cortex and in particular the dorsal pathway, therefore not limited to a subset of neurons in V1 as first assumed.

In expansion of this finding, Simmers, Ledgeway, Hess & McGraw (2005) employed directly analogous global orientation and global motion stimuli to investigate whether amblyopes demonstrated general irregularities in processes of global image integration or whether the anomalies presented were stimulus specific. The combination of orientation and motion coherence thresholds reported supplied easily comparable psychophysical measures of global processing by spatial-sensitive and motion-sensitive mechanisms in the amblyopic visual system. The results illustrated deficits in both global orientation and global motion processing in amblyopia, which appeared independent of any low-level visibility loss. The most acute deficit influenced the extraction of global motion. This provided evidence for the existence of a universal dominant temporal processing deficit in amblyopia.

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However, the former papers (Simmers et al 2003; 2005) have been criticized for overlooking the detail that a typical global motion task involves not only the integration of local activity but also the segregation of the local motion signal from spatially coextensive noise (Hess, Mansouri, Dakin & Allen, 2006). It is recognized that visual perception as a holistic mechanism is limited by both the strength of the neural signals it receives, and by noise present in the visual nervous system (Pelli & Farell, 1999). However, until recently, little was realised about what characteristics of input noise the human visual system was sensitive to and how our individual internal representations of structure can be influenced by this visual noise.

The Classification Image (CI) technique has been found to provide a powerful and effectual tool for examining how observers detect objects within noise and model the behavioural templates used to make perceptual judgements. Beard & Ahumada first demonstrated this method in 1998. The images they produced provided functional information regarding the stimulus aspects the observer used to segregate images into discrete response categories. Firstly, the experimenters collected data on a discrimination task containing low contrast noise. The noises were then averaged separately for the stimulus-response categories. These averages were then summed with appropriate signs to obtain an overall CI. This method was found to be successful for determining behavioural templates used by observers to visualize stimulus features and subsequently make precise position discriminations in

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vernier acuity tasks. The resulting images rejected the idea that the discrimination is performed by the single best discriminating cortical unit.

Alongside straightforward positional judgements, the visual system is continually faced with the problem of distinguishing partially occluded objects from incomplete images cast on the retina. Phenomenalogically, the visual system seems to fill in absent information by interpolating illusory and occluded contours at points of occlusion, in order to realize complete objects. A compelling study by Gold, Murray, Bennett & Sekular (2000) illustrated that illusory and occluded contours appear in observers' CIs, providing the first direct evidence that observers use perceptually interpolated contours to recognize objects. These results offered a convincing demonstration of how visual processing acts on completed representations, and illustrated the CI technique as a powerful new technique for constraining models of visual completion.

More recently, Gosselin & Schyns (2003) used the CI technique alongside superstitious perceptions to reveal the properties of unobservable object representations in human memory. They presented observers with 20,000 noise samples. The participants were informed that the letter “S” was present on 50% of the trials but no more detail was given regarding the shape of the letter. However, no “S” letter was ever presented; therefore there was no signal to be obtained within the white noise. This in effect stimulated the visual system with unstructured white noise and due to this; observers firmly believed that they perceived the letter “S”. The CIs computed resembled the letter “S” indicating the

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weighting of the “S” shaped information and their own internal representations and templates used to make their perceptual decisions.

This discovery about the significance of internal representations captivating the form of behavioural templates to extract signal from noise has led to a number of experiments utilizing this approach in an attempt to better understand the nature of the neural losses in amblyopia.

In order to examine which noise factors in particular limits a typical normal observers behavioural templates, Levi, Klein & Chen (2005) asked participants to discriminate differences in the strength of presented one-dimensional white noise. They measured observer’s response consistency and produced CI templates which were compared with an ideal energy detector. The study was able to illustrate that discrimination of noise was limited by the observer’s template. In particular they identified the most significant factors as the weighted combination of energy in each stimulus component plus higher order nonlinearities referred to as systematic noise, and sources of random internal noise. They discovered this systematic noise to be present only near detection threshold. Surprisingly, they also found the human template to be an adaptive mechanism, its shape dependent on the spatial frequency band of the noise. They concluded that sensitivity to spatial noise is not simply determined via passive, inert filtering by the observer.

Realising the potential of the CI technique, a study by Levi & Klein (2003) used noise to compare the templates that normal and amblyopic observers used to detect a target and discriminate its position. They discovered that some

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amblyopic observers show markedly abnormal templates for the position task and moderately abnormal CIs for the detection task. However, the abnormal template could not abundantly account for the loss of efficiency and poor performance illustrated. Predictably, amblyopes demonstrated a much higher fraction of stimulus-dependent internal noise than normals. As a result, the loss of efficiency in amblyopia was attributed in part to a poorly matched template, but to a greater degree, to a high fraction of relative to external noise.

These discoveries suggesting the strong effect of noise within the amblyopic visual system has led to a different angle of investigation from researchers. In apparent conflict with the deficits pronounced by the previous studies (Simmers et al., 2003; 2005) suggesting amblyopic global motion processing was defective in global coherence tasks, Hess, Mansouri, Dakin & Allen (2006) hypothesised that the deficits in amblyopia were not due to anomalous global integration of local motion signals but segregation of local motion signals from spatially coextensive noise. Performance was equated between normal and amblyopic eyes at the single element level and an equivalent noise model was utilized. The study was able to illustrate global motion processing to be normal in amblyopia, suggesting any discrepancies point to a selective problem in separating signal from noise in the typical global coherence task.

Alongside the research into global motion processing, amblyopic deficits have been identified in the processing mechanism used for making global judgements concerning object orientation (Simmers et al, 2003). Focusing on

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normal observers, Jones, Anderson & Murphy (2002) supplied evidence to suggest that human orientation discrimination is mediated by pooling local responses of low-level neural mechanisms which is limited by two stages of intrinsic neural noise. Using two types of high contrast, broadband stimuli, they discovered that discrimination thresholds are better for local stimuli, in which the orientation signal is spatially limited, than for global stimuli, in which the orientation signal extended across the entire stimulus. Observer performance improved with increasing stimulus area but thresholds were not influenced by either brief presentation times or practice.

To determine whether amblyopes are affected by the same factors when integrating local orientation signals, Mansouri, Allen, Hess, Dakin & Ehrt (2004) examined the efficiency at which the amblyopic system can integrate information of a purely spatial character. The study assessed performance for an orientation integration task in which the orientations of static signals were integrated across visual space. In contrast with recent reports suggesting that amblyopes are deficient in processing local orientation at supra-threshold contrasts (Simmers et al. 2005) the results suggested that amblyopic visual systems can integrate local static oriented signals with the same level of efficiency as normal visual systems. Although internal noise was shown to be slightly elevated, there was no indication that fewer samples were used to achieve optimal performance. This finding suggests normal integration of local orientation signals in amblyopia.

As a result of the conflicting nature of the evidence surrounding amblyopic deficits for tasks involving global integration of information Mansouri & Hess

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(2006) suggested that overall signal integration is normal, but noise segregation is not. Using comparable global orientation and motion direction discrimination tasks results suggested that amblyopic eyes can integrate orientation and motion direction similarly to normals when all the information is signal and no pedestal noise present. The introduction of pedestal noise perturbs the performance of the amblyopic eyes significantly more than that of the normal eyes.

Until 2006, only an equivalent amblyopic performance in global integration tasks had been suggested. However, an exciting discovery by Shahani, Manahilov & Simpson (2006) applying the CI technique suggested an amblyopic advantage in global motion processing. Two differential tasks were employed, both requiring an average global judgement. The stimulus for the orientation task consisted of an array of Gabor patches and the chosen stimulus for the motion direction task consisted of moving discs. Each element had an orientation or direction that diverged randomly about the mean. Observers judged whether the near-threshold global orientation or motion-direction were to the left or right of vertical. The experimenters then calculated CIs by adding element-by-element noise samples eliciting correct responses and subtracting noise samples producing incorrect responses. The CIs obtained illustrated normal observers had a surprisingly narrow perceptive field, weighting information from the central 1-2 deg of their visual fields to make judgements for both tasks. Although a similar picture was illustrated in amblyopes for the global orientation task, the performances of the amblyopic eyes were higher for integrating global motion compared to normal eyes. It was noted that the amblyopic eye’s corresponding

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perceptive fields were wider than that of normal or fellow eyes, with sparse sampling of stimulus elements. This sparse sampling over a more considerable area of the visual field was a distinct advantage in efficiently making judgements for global motion judgement tasks.

It could be considered that this effect was merely due to the generally reduced visual acuity of the amblyopic eye; the blurred retinal images of the moving dots responsible for reducing the central localised perceptive field. However, to test this possibility, two normal observers performed the global motion direction experiment with lenses which reduced their visual acuity. The results suggested that blurred vision does not alter localised forms of the perceptive fields.

The current experiment applied the same CI technique in an attempt to replicate and examine the particular patterns of suppression within the visual templates used by both normal and amblyopic eyes in tasks that required the global integration of either motion-direction or orientation information over substantial areas of the visual field. The orientation task implemented required a global judgement of an array of Gabor patches having some average orientation. The motion direction task employed required a judgement of global motion-direction of moving discs. Observers judged whether the near-threshold global orientation or motion-direction were to the left or right of vertical. CIs were calculated by adding element-by-element noise samples eliciting correct responses and subtracting noise samples producing incorrect responses. The behavioural templates this created provided the means to investigate the

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separate patterns of suppression applied by observers to suggest evidence as to whether the strategies used by amblyopes creates an advantage in global motion-direction tasks.

Method

Participants

Eighty-six (65 women and 21 men) psychology undergraduates at the University of Plymouth participated in the study. All participants possessed at least basic computer skills. No other biographical data was recorded. All participants completed the Frisby Stereotest (Near) (Frisby, 1978) and the 5 participants who failed this were classified as having amblyopia. All other participants possessed normal to corrected vision.

Materials

Instructions for each of the two tasks (orientation or motion-direction) were given in separate printed handouts containing information on participants' right to withdraw and the anonymity of their results. A standard consent form was used to certify participant's involvement. Furthermore, participants were supplied with a paper copy de-brief regarding the aims of the experiment, confidentiality issues, their right to withdraw data and contact details of the experimenters. Full details of instructions, briefing and debrief sheets are given in Appendix A. A standard recording spreadsheet was used to chronicle biographical and visual impairment information as well as performance on the Frisby Stereotest (Near)

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(Frisby, 1978) (See Appendix B). A softly lit room accommodated one Retail Machines Pentium II PC running MS DOS. All stimuli were presented on a ViewSonic Professional Series P227f 21” monitor. The monitor was connected to a RGB splitter box (basic idea from Pelli & Zhang, 1991) to ensure accurate control of contrast and produce a grey display. There was a small black focal point affixed to the centre of the monitor to ensure concentration of attention during trials. An adjustable chin rest with eye patch was utilized to standardize the distance from the monitor (870mm) and provide the means of blocking the vision in one eye as the main trials were carried out monocularly.

The Frisby Stereotest (Near) (Frisby, 1978) was used to classify participants as amblyopes. The test consisted of 2 transparent plates which were divided into four patterned quadrants. A 'target' cluster of randomly arranged blue arrowheads of differing sizes was printed on one side of each plate within one of the four quadrants (see Appendix C for an example of the plate and ‘target’ illustration). The two plates were of differing thickness; both 6mm and 3mm consecutively, presenting different sizes of disparity cues and enabling the stereoacuity of the participant to be calculated. A stud was present in each corner of the transparent plate apart from the corner of the quadrant with the target pattern in order for the experimenter to discreetly check whether a correct judgement has been made. The box used for storing the plates supplied a fold-out flap for providing a clear background against which the plates were presented. A measuring tape was used to assist in controlling eye-to-plate distance. Participants used a standard computer mouse to indicate their left or right judgement during the task.

Custom software written in Pascal (Manahilov, 2000) with two separate tasks for each condition was used to govern the experiment and attain results. The visual angle for both task durations was approximately 12.79 degrees. Each of the two tasks presented three straightforward practice trials. The orientation task presented 400 trials with a midway break after 200. The stimulus contained a 9x9 grid of 81 Gabor patches having a spatial frequency of 4 c/deg and standard deviation of the Gaussian envelop of 12 minutes of arc. The distance between the Gabor patches was 1.3 deg and the size of the stimulus was 10.6x10.6 deg. The orientation of all elements, referred as signal, was positive (clockwise) or negative (counter-clockwise). The signal orientation of elements was added to orientation noise selected from a Gaussian distribution with a mean equal to zero (vertical) and a standard deviation of 10 deg. (See Appendix D for a stimulus illustration).

In the motion-direction task 224 trials were presented with a midway break after 112. The stimulus consisted of a 9x9 grid of 81 moving black dots of diameters of 20’ and speed of 5 deg/s. The motion was created by presenting four frames of 50 ms in which the dots were displaced in order to create the impression of motion. The standard deviation for the level of noise present was 20 deg. for this task. (See Appendix D for a stimulus illustration).

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Design and Procedure

A between-subjects design was implemented whereby each participant was exposed to only one out of two task durations, either orientation or motion-direction. Allocation to the different conditions was carried out on a random basis prior to the experiment whereby every other person was tested on each, beginning with motion-direction. Participants were tested individually and task duration was approximately 30 minutes. Participants entered a softly lit room which contained a copy of the specific task instructions, a chair and chin rest which had been measured to an exact 870mm away from the monitor and a standard computer with the software preloaded. The experimenter instructed the participant to read the brief, concerning the procedure and what was expected of them, providing them with the right to withdraw and guaranteeing their anonymity. When participants were happy to continue, they signed a consent form. Participants were asked whether they had any visual impairments or dyslexia and this was recorded on a pre-printed sheet. The chin rest was then adjusted to a comfortable position and the Frisby Stereotest (Near) (Frisby, 1978) was administered binocularly to determine whether or not to classify the participant as an amblyope. Participants were told this was a test of their 3D vision and were presented with a target pattern of randomly arranged blue arrowheads of differing sizes in a circular cluster. From their position, they were asked to identify which of the four quadrants of the transparent plate in front of them contained the target. The plates were presented in a random orientation for every participant and each consecutive plate. A fold-down flap on the test box

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was used to provide a white background against which the plates were viewed. The 6mm plate was used initially then followed by the 3mm plate. The experimenter held the plates during the test and discretely felt the studs to discern where the target was. Correct or incorrect identification was documented on the standard recording sheet. If the participant identified the target incorrectly for both plates, the 6mm plate was used once more and upon incorrect judgement amblyopia was classified.

One of the two main tasks (orientation or motion-direction) was then administered to participants, which they performed monocularly, beginning with the left eye. Before this stage, participants were orally briefed in which they were made aware of the significance of focusing attention on the central black focal point, the provision of feedback in the form of a +/- between each trial and clarification of what the individual tasks require. Particular emphasis was made for instructing how the direction of the striped Gabor patches should be classified in the orientation task, either up to the left or right using hand signals to indicate an upward motion. In each session, observers were presented with three practice trials. For each trial of the orientation task, participants made a global judgement of an array of the presented Gabor patches. Similarly, if they were completing the motion direction task, they made a judgement of the global motion-direction of the presented moving discs. Participants judged whether the near-threshold global orientation or motion-direction were to the left or right of vertical and used the left or right mouse button to indicate their judgement. The eye patch was swapped half way through each task. This point was indicated an auditory beep

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and the software returning to a feedback screen. Participants were informed that they may take a break or continue with the other half of the trials by clicking the mouse key. Upon completion, participants were fully de-briefed orally by means of the aim of the experiment and a paper debrief was provided. CIs were then calculated by adding (element-by-element) noise samples eliciting correct responses and subtracting noise samples producing incorrect responses. This provided the behavioural templates for normal and amblyopic observers.

Analysis and Discussion

CIs for three sets of normal observers for both tasks are illustrated in Figure 1. The classification images (CIs) obtained from the three sets of normals show a consistent pattern for both the global motion-direction and orientation tasks. This adds strength to any conclusions made about the behavioural templates and consequently the strategies used by normal observers within the two tasks. The CI of an ideal observer should illustrate bright white for the whole distance of the image. This would indicate that all elements of the presented display are being utilized to make the most efficient perceptual judgement. However, it appears that from the templates obtained from the study, an average normal observer utilizes a method to derive global representations of orientation and motion-direction which is far from this complete ideal. The CIs provided for the global orientation task present a comprehensible and consistent behavioural template employed by normal observers to reach their decision concerning the global orientation of objects across all three of the images.

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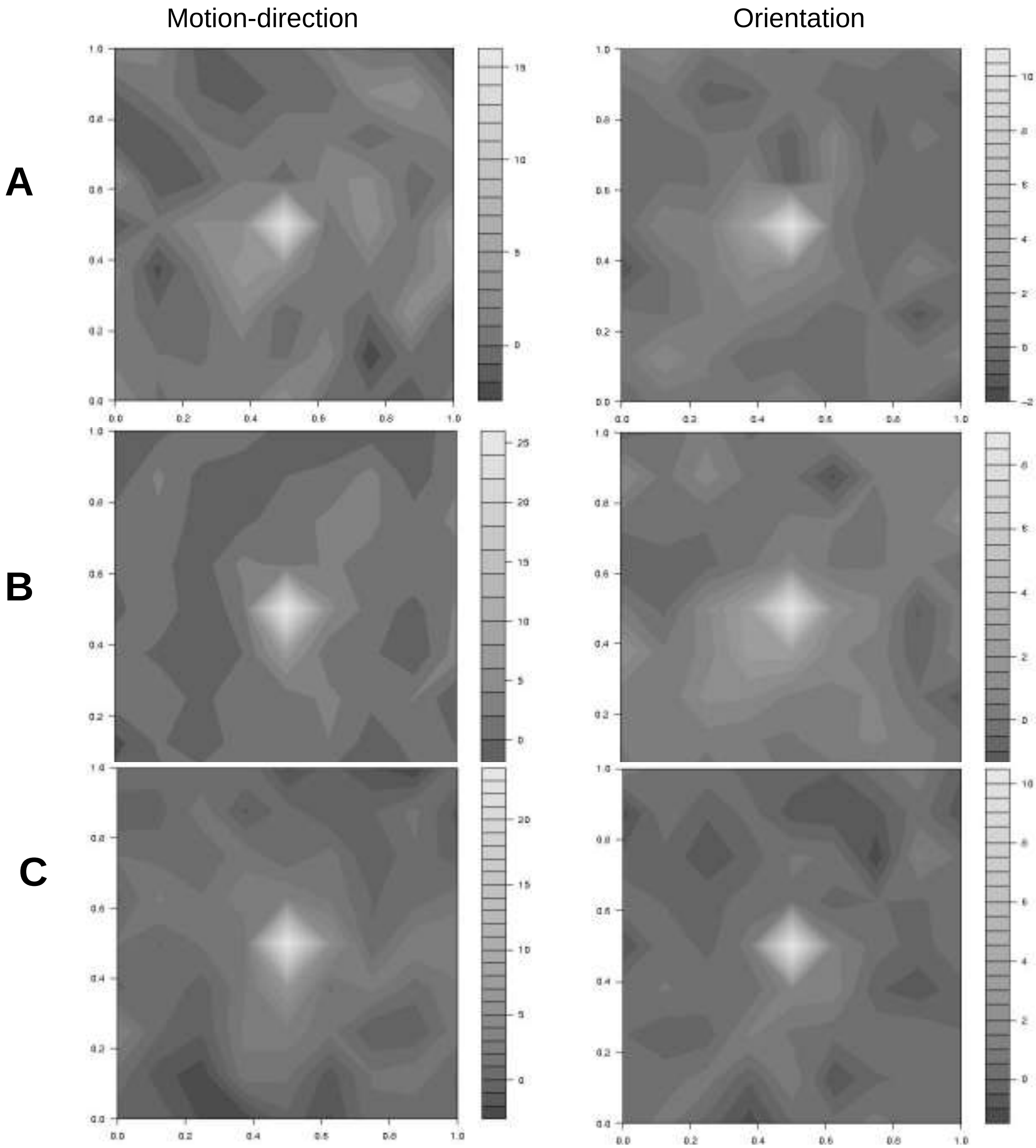

Figure 1. Normal CIs for the two tasks. Each row corresponds to a set of normal observers (A, n= 30, B n=26, C n=25). x and y axis indicate visual distance in degrees. The white areas of the CI indicate which part of the image the observer weighted to make their judgement. Grey areas were not used significantly by the observer. Random noise has been superimposed on the CIs.

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The estimates are clearly somewhat noisy, but nevertheless a clear area of activation can be observed on the images. A bright, diamond shaped facilitatory region is present in the centre of the average normal observers' template for this task. This suggests increased intensity in this area and indicates that only the innermost stimuli (tilting Gabor patches) were weighted as important in reaching a perceptual decision about the average global orientation of the whole presented 9x9 grids. Careful inspections of the CIs reveal that all three appear to have inhibitory surrounding regions of varying strengths, indicated by varying colours of grey. The same picture has been provided by the CIs obtained for the motion-direction task. Again, a central white diamond is present on the image, with a surrounding grey inhibitory area for peripheral items. The technique used by normal observers for both tasks presented here suggests that periphery information is suppressed. It could be construed that this is due to the random elements in the display creating high levels of noise deemed to be confusing. Consequently, concentration and attention is focused in on the middle of the display, a heuristic which lessens ambiguity. This correlates with previous findings on the human visual system's sensitivity to noise and the adaptive nature of visual templates dealing with distracters (Levi et al., 2005). The average behavioural templates indicated by the CIs suggest a two stage local to global strategy applied by normal observers to integrate global information. Within the first stage observers extract motion or orientation information from central moving discs or orientated items, only weighting the information derived from the central 1-2 degrees of the visual field to make a perceptual judgement.

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The second stage involves suppression and inhibition of attentionally absorbing peripheral items. Consequently, on the whole, the normal observers' perceptive fields are surprisingly narrow and constricted. These findings add weight to the conclusions derived from the previous experiment by Shahani at al. (2006) emphasizing the importance of behavioural templates to obtain global representations of the direction of motion of objects and positional judgements or orientation. Normal observers' behavioural templates can now be compared to amblyopes to highlight differences in their perceptive fields and visual representations of global information. The average behavioural templates used by the two amblyopic observers for each eye (left and right) in the motion-direction task are presented in Figure 2.

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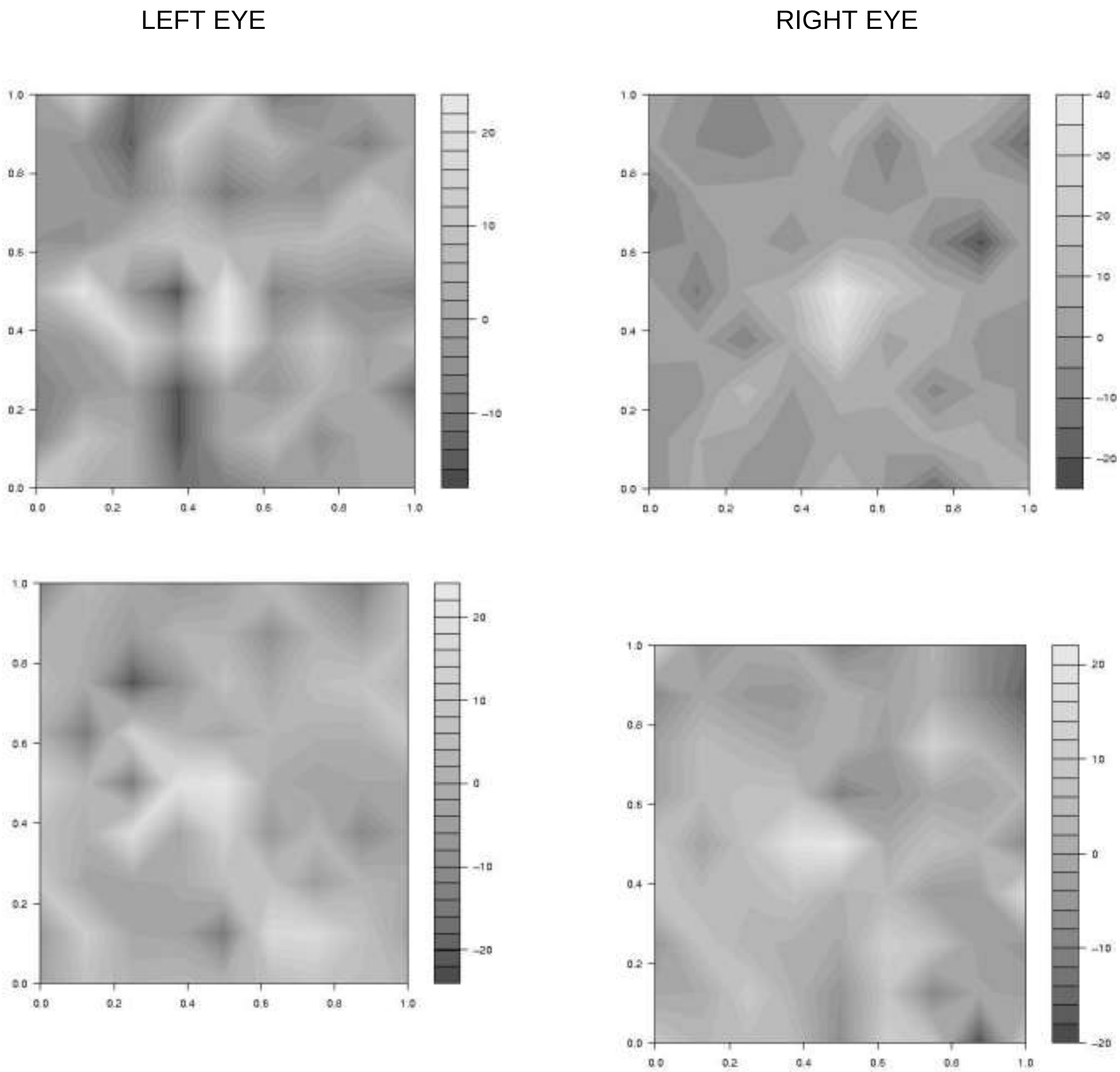

Figure 2. CIs from the global motion-direction task illustrating the behavioural templates used by the left and right eye for two amblyopic observers (presented on each separate row). The x and y axis indicate visual distance in degrees. The scales of colour are used to interpret the pattern of suppression and which parts of the display are most weighted in order to reach a decision about the global motion-direction of the presented stimulus. White indicating highly stimulated areas and grey areas indicating suppression of items.

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In comparison with the CIs obtained for normal observers' in the motion-direction task, a stark contrast is illustrated in the behavioural templates used by the amblyopic observer.

Examining the first observer's CI (presented on the top row of the page) it can be seen that the right eye has used a similar technique to the normal observers illustrated previously. A bright white activation spot is visible in the centre of the image, indicating that information from this area was most heavily weighted in the decision making process regarding the global motion-direction of the presented stimuli. Drawing parallel with normal observers, grey areas of suppression are present surrounding this facilitatory area, comprising a localised form. It could therefore be assumed that this is the fellow, normal eye and not the amblyopic eye.

Therefore, presuming the left eye is the amblyopic eye, more conclusive inferences can be made. A stark contrast in perceptive pattern can be seen when comparing this CI to not only the results from the fellow eye but the results obtained from normal observers. In place of any distinguishable central peak, indicated by the bright white diamond on the previous motion-direction CIs, there is a notable area of grey suppression just off centre. Furthermore, there is a much further expanse of white, indicating a much wider perceptive field. The CI suggests that items with a much more random distribution were weighted to make a decision about the global motion-direction, including areas in the periphery which in comparison were suppressed and inhibited by the normal observer and fellow eye. On the whole, there are few grey areas present on the image, indicating suppression

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to be limited for the amblyopic eye. This technique suggests amblyopic superiority in this type of task.

Examining the second amblyopic observer (presented on the second row) the derivation of which is the fellow versus amblyopic eye is more problematical. This concern aside, the white pattern of activation illustrates a much larger sampling of items in the visual display for both the left and right eyes. This suggests that more items from the periphery were used to weight the overall decision about the direction of motion on a global scale. This adds further evidence to suggest that an amblyopes perceptive field for the global-motion direction task is considerably wider than that of a normal observer. The pattern of white is far closer to that of a normal observer for this task, suggesting the technique and behavioural template used by the amblyopic observer to be advantageous in judgements of global motion-direction. Unfortunately, these results are not as conclusive as the previous findings by Shahani at al. (2006). Binomial analysis of overall task efficiency compared to normals using the performance percentages (61% for normals, 62% for amblyopes) revealed only a 1% increase that was not statistically significant. It could be suggested that the results illustrated here and previously reported (Shahani et al., 2006) are merely a reflection of the fovea of the amblyopic eye being generally poorer, resulting in a reduction in visual acuity. Detailed, central vision is therefore depressed in general. However, as there are no clearly defined grey areas of central depression found in the CIs for the amblyopic eye this adds weight to an independent effect with no relation to this deficit. Furthermore, the global orientation task provided a clear

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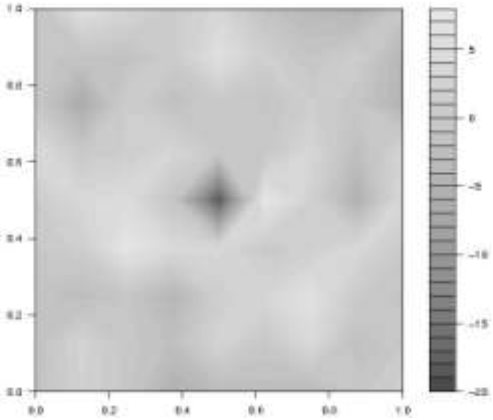
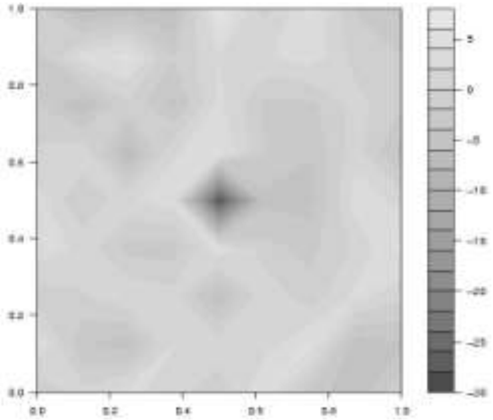
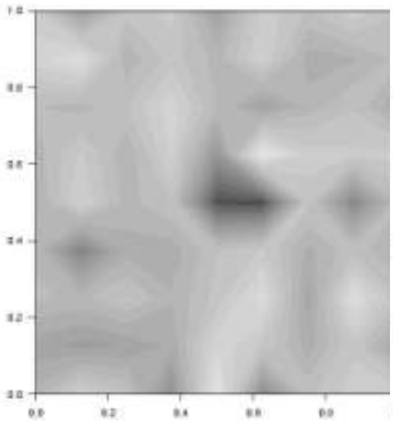
comparison for effect. If this central suppression is not evidenced in this task then the effect must be autonomous. CIs of three amblyopic observers for each eye (left and right) for the global orientation task are presented in Figure 3.

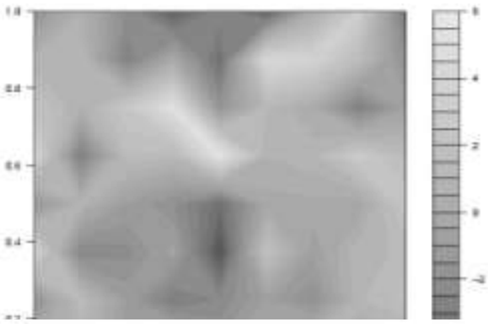
LEFT EYE

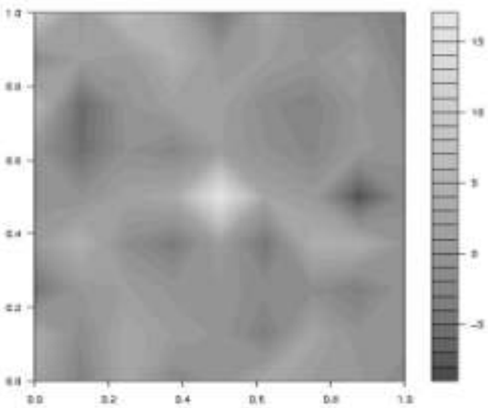




RIGHT EYE







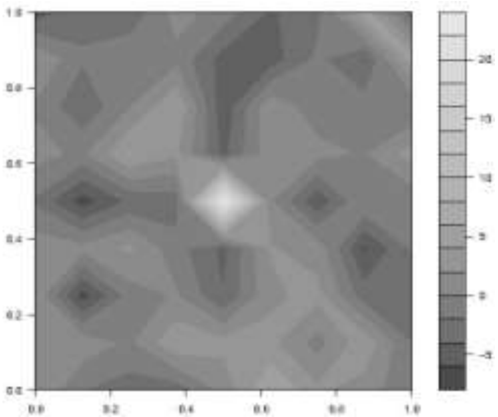


Figure 3. Amblyopic CIs found in the global orientation task. Each row corresponds to one of the amblyopic observers. The column corresponds to the eye used, either left or right. The x and y axis are again visual distance in degrees. The white areas of the images indicate which part of the stimulus the observer used to make their judgement. The grey areas were not used significantly by the observer.

The CIs presented for the orientation task show varied results. The first two amblyopic observers, presented on the first and second rows indicate some surprising results. There appears to be a trough in the centre of the image instead of a peak, this Illustrates the opposite of what was predicted and illustrated by the previous study (Shahani et al, 2006). It has been deduced that the reason for this may have the systematic misinterpreted of the instructions given to the observer. In order to investigate this unanticipated effect more trials would need to be carried out to investigate whether this was in fact a misinterpretation or true effect. Therefore, these CIs should be treated with caution and no inferences can be made about their significance to the overall conclusions of the experiment.

However, the third amblyope (presented on the last row of the CIs) illustrates the predicted behavioural template, comparable for both eyes. A white, central attentional peak illustrates that the central items of the display were most weighted when making judgements on the global orientation of the presented stimulus (Gabor patches). This is surrounded with the customary grey areas of suppression, illustrating that items within the periphery were not weighted during the decision making process by the observer. This illustrates

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the same template utilized by a normal observer for the global orientation task and suggests the two stage local to global strategy is applied by amblyopic observers to integrate global information of an orientation nature; only weighting the information derived from the central 1-2 degrees of the visual field and suppressing attentionally absorbing noisy items in the periphery to make a global representation of stimulus orientation.

The Classification Image technique has provided a useful and efficient method for estimating observers' perceptive fields for processing global information. The behavioural templates obtained by the current study provided a fascinating insight into the differing techniques normal and amblyopic observers use to make perceptual judgements. Further elaborations into the functions of the CI technique suggest it to be a constructive measure of internal representations, perceptive fields and covert attention for visual tasks.

To recapitulate, we found that normal observers used localised perceptive fields when integrating both the global orientation of Gabor patches and the global direction of moving dots embedded in motion noise. The overall size of the normal observer's perceptive field was surprisingly narrow and constrained for these types of task and sampling of items was central and deliberate. Items within the periphery were suppressed by the normal observer, illustrating resourceful inhibition of unwanted distracters.

The reverse was witnessed when examining the behavioural templates used by the amblyopic observers for the global motion-direction task. The CIs indicated the reliance and application of peripheral items in the visual scene to construct visual representations of global movement. This suggests that there is overall reduced suppression of the global, attentional mechanisms in

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amblyopic vision which allow amblyopes to integrate information over a much larger visual field than a normal observer. Amblyopes are therefore able to use more of the presented items in order to make their judgements, increasing task efficiency. It could be concluded that this technique provides an advantage in making global motion judgements compared with a normal observer. This provides evidence against the conclusions made in previous studies (Simmers et al. 2003; 2005) that amblyopes were deficient in tasks involving global integration of information across the visual field. In fact, elevated performance was witnessed (with normals obtaining 61% accuracy and amblyopes 62% accuracy) but unfortunately, using binomial analysis this proved not to be statistically significant. It is recommended that a larger sample of amblyopes would be beneficial in order to investigate the true extent of this increased performance. Replication of the study should also entail an increased amount of trials for each amblyopic observer in order for true efficiency rates to be calculated. The general results obtained provide further evidence for the conclusions derived in the previous study by Shahani et al. (2006).

The results obtained for the orientation task were inconclusive due to a presumable observer error. The possible misinterpretation of instructions highlighted the need to alter the difficulty of specifically the global orientation task used. Low performance percentages were witnessed within both conditions for both groups of observers. The modification of the software to decrease the difficulty of the trials along with a larger amblyopic sample would enable more decisive and convincing analysis.

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A further area of improvement within the study would be the appropriate classification of amblyopic and fellow eye. Shahani et al (2006) previously discovered that when amblyopic observers completed the global motion task with the fellow eyes, the perceptive fields had a localised form similar to normals. Although this was speculatively suggested after interpretation of the appropriate CIs, in order to enhance the study and obtain more categorical results, an accurate classification of fellow and amblyopic eye would need to be achieved. This would enable true comparisons and an assessment of correct response percentages obtained with the amblyopic eye compared to fellow eye. This would add certainty to any conclusions made.

Other approaches to the analysis of classification images have been suggested in detail in a paper by Abbey & Eckstein (2002). Among various procedures for estimating and performing statistical hypothesis testing on classification images, the researchers have identified radial averages as particularly useful. The plots these provide could present a method to obtain more exhaustive results from our data.

Alongside these suggested improvements, various areas of research expansion have been identified. General performance was investigated by the current experiment, across all medically classified types of amblyopia. It is suggested that the subdivision of amblyopes into categories such as strabismus, anisometropic, form-deprivation and occlusion would provide specific CIs which could be interpreted to derive the deficits explicit to each differing type compared to normal observer performance.

Although the advantages of the lack of visual suppression illustrated by amblyopes are clear from the obtained results, further research is needed in

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order to investigate the real world disadvantages amblyopic observers could face in cases including the presence of unwanted environmental noise. Additional research should be made into the extent and consequences of the deficits for the exclusion of unwanted distracters for other visual tasks where

sparse sampling of elements in the stimulus is not a proficient method.

Furthermore, research should be applied to investigating abnormalities in global judgement tasks for other types of abnormal observer. Elevated global-motion processing performance for observers with both persistent migraine aura and dyslexia was illustrated by Shahani et al., 2006. It was hypothesized by the study that disrupted perceptive fields in the global motion task may be related to impaired suppression in motion-sensitive neurones, if this is the case then various other abnormal observers could provide similar CIs and over excitation on this type of task. Autism, Williams syndrome and hemiplegia are an example of conditions which need to be further investigated to derive the behavioural templates and techniques used to investigate whether these prove to be advantageous compared to normal observers.

The CI technique could also be further utilized to compare visual performance with age. Due to the naturally occurring reduction in visual acuity among the elderly population, it could be suggested that due to less inhibition and consequent wider perceptive fields, the elderly will have an advantage in global-motion tasks compared to younger observers.

In summary, the CI technique has provided a proficient and influential tool for estimating observer’s templates for detecting a variety of objects in a diversity of positional ways. Conclusive evidence has been provided to

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suggest normal observers use localised perceptive fields when integrating information of a global nature whilst suppressing peripheral information. The perceptive fields of an individual with amblyopia are much wider than normals, with sparse sampling of elements including those in the visual periphery. Task difficulty adjustments and the appropriate classification of fellow and amblyopic eye would substantiate results further, providing supplementary evidence for the effect of the human behavioural template in a variety of visual and clinical disorders.

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