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Eye movements are made to the centre of gravity of texture-defined targets

Shumetha K. Sidhu[a,b,c,*], Harriet A. Allen[d], David R.T. Keeble[c]

[a] School of Psychology and Clinical Language Sciences, University of Reading Malaysia, Iskandar Puteri, Malaysia
[b] School of Psychology and Clinical Language Sciences, University of Reading, Reading, Berkshire, UK
[c] School of Psychology, University of Nottingham Malaysia, Semenyih, Malaysia
[d] School of Psychology, University of Nottingham, Nottingham NG7 2RD, UK

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ABSTRACT

Saccadic localisation of targets of various properties has been extensively studied, but rarely for texture-defined figures. In this paper, three experiments that investigate the way information from a texture target is processed in order to provide a signal for eye movement control are presented. Participants made saccades to target regions embedded in a background structure, and the saccade landing position and latency were measured. The textures comprised line elements, with orientations of the lines configured to form the figure and ground. Various orientation profile configurations (Block, Blur, and Cornsweet), were used in order to measure the role of edge profiles in driving eye movements and producing salience. We found that in all cases the visual system is in fact able to effectively segregate a texture figure from the ground in order to accurately plan a saccade to the target-figure. While saccadic latency was the highest for the Blur profile, the mean saccadic landing position was mostly unaffected by the various profiles (Experiment 1). More specifically, we showed that saccades were directed to the centre-of-gravity of the target (Experiment 2). We also found that figures with information of orientation contrast at both the edge and centre of figure (i.e. Block) produced the highest level of saliency in attracting eye movements (Experiment 3). Overall, the results show that saccades are planned on the representation of the whole target shape rather than a local salient region based on orientation contrast cues, and that the various texture profiles were important only to the extent that they affected the time to programme a saccade.

1. Introduction

A phenomenon of particular interest is the segregation of regions of texture, based on feature characteristics present in the texture stimuli. Among these local feature characteristics are differences in orientation, colour, luminance, motion, and contrast. Within the field of texture segregation, the notion of a gradient is a prominent concept (Beck, 1966; Julesz, 1981; Nothdurft, 1993; Bach & Meigen, 1997). Texture stimuli are effortlessly segregated or grouped together into coherent parts based on rapid changes in the spatial distribution of local feature characteristics. However, there is disagreement in the literature about the importance of texture edges (a region where a texture property changes abruptly) in the segregation process. Some studies suggest that texture edges are crucial for figure-ground segregation (e.g. Landy & Bergen, 1991; Wolfson & Landy, 1998), while others have shown that texture segregation is still possible in the absence of a texture edge (e.g. Kingdom & Keeble, 1996; Ben-Shahar & Zucker, 2004).

The most popular accounts of texture segregation employ either an edge-based or region-based mechanism. Edge-based mechanisms detect discontinuities within a texture image, and segmentation occurs subsequent to the formation of an explicit edge boundary. On the other hand, region-based mechanisms operate by grouping together neighbouring elements that are similar, thus forming an implicit boundary between coherent regions. Some studies have found that these mechanisms operate exclusively (e.g. Landy & Bergen, 1991), while others found that they function together (e.g. Wolfson & Landy, 1998). It is worth noting that the overwhelming number of studies that investigate texture segregation use texture stimuli with abrupt edges rather than smooth variations.

Research involving orientation-based figure-ground segregation has typically taken either a psychophysical (e.g. Landy & Bergen, 1991; Kingdom & Keeble, 1996; Wolfson & Landy, 1998; Ben-Shahar & Zucker, 2004; Norman, Heywood, & Kentridge, 2011) or neurophysiological approach (e.g. Lamme, 1995; Lamme, Rodriguez-Rodriguez, & Spekreijse, 1999; Caputo & Casco, 1999; Rossi, Desimone, & Ungerleider, 2001; Scholte, Jolij, Fahrenfort, & Lamme, 2008; Poort et al.,

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* Corresponding author at: University of Reading Malaysia, Persiaran Graduan, Kota Ilmu, EduCity, 79200 Iskandar Puteri, Johor, Malaysia.
E-mail address: co922442@reading.ac.uk (S.K. Sidhu).

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2012). However, saccades, especially those that direct the fovea to regions of importance within a texture pattern, are able to improve performance at discriminating texture patterns that do not segregate easily (He & Kowler, 1992). This suggests that investigating eye movements during texture-based segregation could provide insights that have yet to be found with other approaches.

Past research has already revealed several important characteristics of saccade programming for luminance-defined stimuli. For example, saccades are more accurate and precise for smaller targets, with saccade latencies also being shorter (Ploner, Ostendorf, & Dick, 2004). Additionally, when presented with two targets simultaneously on the same visual hemifield, saccades land at an intermediate position between the two targets. Interestingly, if one target is larger, then the saccade will land closer to the larger target. This result has been explained in terms of the notion of a ‘global effect’, as the saccade is influenced by the greater weight of the larger target (Coren & Hoenig, 1972; Findlay, 1982).

Melcher and Kowler (1999), on the other hand, differentiated between the centre of gravity (the average dot location that made up the boundary of the shape) and the centre of area (the centre of mass of the shape assuming that the shape is of a uniform density). They found that saccades landed on average at the centre of area of the target shape, rather than at the centre of gravity. That is, changes in the spacing or even addition of the dot clusters did not affect the saccade landing position, so long as the shape of the target is maintained. Their results evidence that saccades are planned post representation of the entire target shape, rather than any distribution of local elements.

The aforementioned studies investigated eye movements to isolated targets in an otherwise empty visual environment. This leaves the question open of whether or not the mechanisms used to plan saccades are similar for different types of visual scene. Arguably, targets in the real world are never, in practice, isolated, but are part of an extremely complex background structure from which objects must be segmented. Thus, investigating how information from a texture target is processed in order to provide a signal for eye movement control is informative for real world scene processing.

Differences in orientation have been shown to guide eye movements. However, these studies were of single line elements (Nothdurft & Parlitz, 1993) or spatially small texture arrays with abrupt texture edges (Deubel, Findlay, Jacobs & Brogan, 1988; Deubel & Frank, 1991). Nothdurft and Parlitz (1993) found that orientation-defined targets did not elicit fast express saccades in the same way that luminance-defined targets did. They attributed this to the weaker signal strength produced by an orientation-defined target. Additionally, Deubel et al. (1988) found that saccade latencies were increased when a target is embedded within a background structure compared to when it was presented alone i.e. in the absence of a background structure. This corroborates our point above that studying eye movements to targets in an impoverished environment does not necessarily reflect the same processes involved in viewing a natural scene which is almost always going to involve a complex visual image. Deubel et al. (1988) also found that when a distractor is presented along with a target, the saccade landing position was to a point in between the distractor and target, suggesting a global processing mechanism that spatially integrates information across a relatively large area.

To our knowledge, the above studies are the only research that has been done on eye movements and texture segregation. However, there has also been research into the neuronal activation in the visual cortex with respect to figure-ground texture stimuli. Specifically, these studies look into the guidance of saccadic eye movements by investigating the role of figure-ground activity in the primary visual cortex (V1) of non-human primates. Lamme (1995) described *figure-ground contextual modulation*, where V1 single unit responses are stronger to line elements when the neuron’s receptive field is overlaid on the figure portion instead of the ground portion of the figure-ground stimuli. Further research by Lamme, Rodriguez-Rodriguez, and Spekreijse (1999) explored the temporal aspects of neuronal activation in V1 during figure-ground segmentation. They found that neuronal responses to the stimulus began at 20–30 ms, while figure-ground responses only began at 70–80 ms, with strongest responses occurring at receptive fields near boundaries of the figure. Peak responses to boundaries are observed only at 115–125 ms, with responses to the figure centre receptive fields still being weak. Responses for the whole figure surface (boundary + figure centre) only appear at 150–160 ms (see Fig. 3a in their paper). The early stage of this initial feature extraction is associated with feed forward processing, while the later stage of perceptual grouping and segmentation is associated with recurrent processing (Lamme & Roelfsema, 2000).

Interestingly, studies with non-human primates have shown a direct link between figure-ground contextual modulation and the percept, whereby contextual modulation is observed **only** when the subject sees/perceives the presence of the figure. If the subject fails to see/perceive the figure, contextual modulation is not observed (Supèr, Spekreijse & Lamme, 2001). Likewise, when the subject is anaesthetised, contextual modulation is not observed, but the tuning properties (i.e. orientation and direction selectivity) of the receptive fields were unaffected (Lamme, Zipser & Spekreijse, 1998). This suggests that local and global processing in V1 operate by different mechanisms, and figure-ground contextual modulation relies on a more global processing that requires the subject to not only be awake, but also perceive the stimuli.

Additionally, Supèr, Spekreijse and Lamme (2003) found that it was the strength of the contextual modulation, not the latency, that resulted in shorter saccadic latencies to a figure-ground stimuli. Similarly, contextual modulation was found to be stronger, and saccadic latencies shorter, with figure-ground stimuli that were made more salient by means of shorter line lengths. Therefore, saliency of the figure-ground stimuli affects the contextual modulation activity in V1, which subsequently reflects the behavioural response of eye movements.

1.1. *Present research*

The question we therefore ask, is how are saccade destinations computed for spatially extended targets embedded in a background structure? Could it be based on a global effect, where endpoints of the target figure are averaged (e.g. Deubel et al., 1988; Findlay, 1982; Ploner et al, 2004), or perhaps based on the representation of the whole segmented figure shape (e.g. Melcher & Kowler, 1999)? Alternatively, if eye movements are driven by the most salient features in a scene (e.g. Itti & Koch, 2000; Parkhurst, Law, & Niebur, 2002), could eye movements be drawn to specific locations of high feature discontinuity within a target itself?

In Experiment 1, we varied the target profile to determine whether saccades land on regions of the target with the highest degree of orientation contrast or on some specific point within the target irrespective of the orientation contrast cue available. This experimental design is in contrast to that used by Deubel and colleagues, in which they used narrow texture stimuli with a target profile that only had an abrupt texture edge. In Experiment 2, we used a texture target with an asymmetrical shape to determine whether saccades are planned in reference to the centre (i.e. midpoint) of the target or the geometric centre of the figure (i.e. the centre of gravity). Evidence favouring the centre of gravity would imply that saccade destinations are computed based on the representation of the entire shape of the texture figure post figure-ground segregation. In Experiment 3, we aimed to investigate the subjective saliency of various texture profiles to test the role texture edges play in guiding eye movements.

2. General methods

Aspects of Experiments 1–3 that differ from this general method will be described in their respective sections.

2.1. Participation

Participants were recruited from the University of Nottingham Malaysia, and provided written informed consent before the experiments. All participants had self-reported normal or corrected-to-normal vision. The three studies were approved by the Ethics Lead, School of Psychology, University of Nottingham Malaysia.

2.2. Apparatus & display

A Tobii T60 Eye-Tracker running Tobii Studio 3.2 was used to present the stimuli and record participants' eye movements. Participants sat 60 cm away from monitor, which produced a resolution of 1.52 arcminute per pixel. All participants performed a nine-point calibration before the experimental tasks.

2.3. Stimuli

The stimuli were pre-generated using PsychoPy 1.83.04 (Pierce, 2007) on an Apple Mac Mini. The overall texture array comprised 50 × 68 anti-aliased white line elements on a grey background, with a figure patch embedded within the array (See Fig. 1). The texture arrays had a

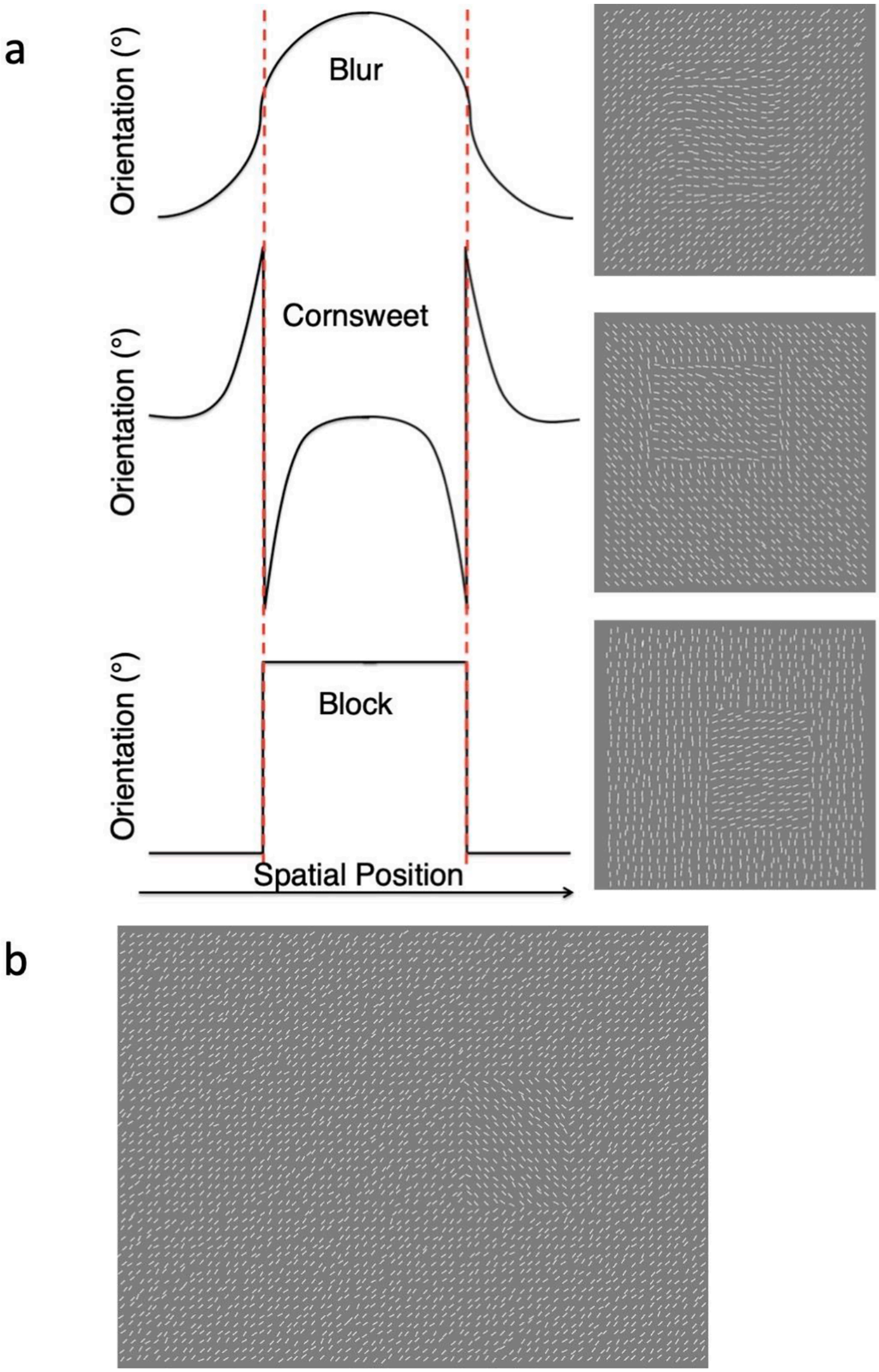

Fig. 1. a) A schematic representation of the orientation change as a function of space for the three different orientation profiles used (left), with examples stimuli of each edge orientation profiles (rights). b) Example stimulus used in Experiment 1 of the Block profile at 4.6° eccentricity to the right of fixation.

visual angle of 25.9°×19.5°, while the fixation point spanned 0.4°.

The anti-aliasing in PsychoPy was achieved by using a mask on each of the individual line elements, which creates an anti-aliased gradient ¼ the width of the line. The length of each line element was 10 pixels long and 2 pixels wide, with an average space of 15 pixels between the centres of the line elements when the elements were positioned in a grid pattern. The orientations of the line elements could form three different types of orientation profile of the target figure – Block, Blur, and Cornsweet (see Fig. 1a for a schematic representation). The red dashed line in Fig. 1a represents the location of the border (or edge) of the figure. The region beyond the border is the ground, while the region within the border is the figure.

For the Block profile, the border of the figure defined the orientation change of the line elements. The orientation of the line elements of the figure region (within the border) was different from that of the ground region by the value of the orientation contrast. The mean orientation (an orientation jitter is added to each element: see below) of the line elements for the Blur (Equation 1) and Cornsweet (Equation 2 & 3) profiles is defined as follows:

$$\theta = \frac{\Delta\theta}{1 + e^{-x/k}} \quad [1]$$

$$\theta i = -\frac{\Delta\theta}{2} + \frac{\Delta\theta}{2}\sin\left[f\left(x - \frac{s}{2}\right)\right] \quad [2]$$

$$\theta o = \frac{\Delta\theta}{2} + \frac{\Delta\theta}{2}\sin\left[f\left(x + \frac{s}{2}\right)\right] \quad [3]$$

Where θ is the mean orientation of the line element, Δθ is the orientation contrast, x is the distance in pixels of the line element from the border (where $x = 0$), and s is the distance in pixels between the line elements. k and f are respectively the Blur and Cornsweet parameters that control the steepness of the slopes, which were 22.5 and 0.026180 pixels respectively. Equation 1 represents the mean orientation for the Blur profile. Equations 2 and 3 represent the mean orientation for the Cornsweet profile for elements spatially positioned inside (θi) and outside (θo) the border.

The Blur profile is of a Logistic curve, in which the orientation of the line elements changes gradually over space from ground to figure. The highest degree of orientation contrast is between elements in the ground region and elements in the centre region of the figure. For the Cornsweet profile that varies spatially according to a Craik-O'Brien-Cornsweet edge (Cornsweet, 1970), the degree of orientation contrast at the immediate border of the figure is the highest, which tapers off further away from the edge. The central region of the figure and the background region have the same orientation. Examples of the Block, Blur and Cornsweet stimuli are shown in Fig. 1a.

The orientation contrast between figure and ground was held constant at 90°, while the orientation of the background elements (baseline orientation) was either 0° (vertical), 45°, 90°, or 135°. The positions of the line elements had a Gaussian jitter in both x and y-directions of standard deviation (SD) 3.04 arcminutes (2 pixels). The *SD* of the Gaussian distribution of orientation jitter was 7.5°. This represented the amount of external orientation noise in the stimuli (see Fig. 1b for example of stimulus).

2.4. Procedure

Before the experimental sessions, participants were shown novel examples of the stimuli to familiarize themselves with texture images that contained a target figure. These were displayed for an unlimited time on the eye tracker monitor, and the experimenter explicitly indicated where the target figure was located by tracing the outline of the figure border (see methods below for specific instructions given to participants).

The sequence of a trial began with a fixation cross appearing at the centre of the screen for 1000 ms, followed by the stimulus for another 1000 ms. After stimulus offset, the fixation cross reappeared, and the next trial was initiated.

3. Experiment 1: Eye movements to different orientation profiles

If eye movements are driven by the most salient features in a scene (e.g. Itti & Koch, 2000; Parkhurst, Law, & Niebur, 2002), we would expect to see great variations in the saccade landing positions for different edge profiles. Experiment 1 was conducted to determine whether the landing position of the saccades would be influenced by the different edge orientation profiles – Block, Blur, and Cornsweet (see Fig. 1). These orientation profiles differed in terms of the information of orientation contrast present at the edge and central region of the figure-ground texture (see Section 2.3 for more details). Participants were asked to move their eyes rapidly to the target once the texture stimulus was presented.

Based on the assumption that eye movements are driven by salient features, we would expect that the Blur and Cornsweet profiles will have primary fixations closer to the centre and edge of the target figures respectively (as that is where maximum information regarding orientation contrast is present), while the Block profile will have primary fixations throughout both figure centre and edge. However, if saccades are driven by a representation of a whole figure (post integration of elements into segmented region) as suggested by Melcher and Kowler (1999) or perhaps a global effect (e.g. Deubel et al., 1988; Ploner et al., 2004; Findlay, 1982), we would expect no difference between the saccade landing positions of the different profiles.

3.1. Methods

10 participants (5 males) between the ages of 19 and 24 ($M = 21.6$; $SD = 1.67$) were recruited.

The target figure was a 15 × 12 element rectangular patch that spanned 5.7°×4.6° [height × width] (see Fig. 1b). This figure patch could appear at six possible locations – at eccentricities of 9.1°, 6.8°, and 4.6° to the left or right of fixation.

Instructions to participants were designed to be as neutral as possible to avoid influencing eye movements to any particular region of the figure: *"Once the textured image appears, all you have to do is move your eyes as fast as possible to the figure. Once you have moved your eyes to the figure, maintain your gaze on the figure until the textured image goes off."* i.e. they were not told to look at any specific point within the target figure. The target was always detectable by the participant as the orientation contrast was high (90°). Participants performed 1 practice block before completing 5 experimental blocks (72 trials per block).

3.2. Results

3.2.1. Analysis of eye movement data

Gaze point was calculated using the average position of the left and right eye. The Velocity Threshold Identification (I-VT) method was used to separate saccades and fixations depending on the velocity of the directional shifts of eye movements. Eye movements were classified as saccades if they had angular velocities above 30°/s, while eye movements with angular velocities below 30°/s were classified as fixations (Olsen, 2012). Multiple fixations, shorter than 75 ms and smaller than 0.5° visual angle, were merged into a single fixation. Fixations that did not meet the aforementioned criteria and were also shorter than 60 ms were discarded. The saccade before and the saccade after an excluded fixation were merged to form a new saccade. Two measures, spatial position and temporal latency, were derived from the primary fixation made by the participants.

Data were analysed using repeated measures ANOVAs for Experiments 1 – 2. For all statistical tests conducted, when the assumption of sphericity had been violated, the Greenhouse-Geisser or Huynd-Feldt correction was applied to the degrees of freedom and the p-value. The Greenhouse-Geisser correction was used when ε was less than 0.75, and the Huynd-Feldt correction when ε was more than 0.75. Furthermore, only when main effects and interactions were significant, post hoc comparisons were conducted. Bonferroni corrections (adjusted p-values) were applied for all post-hoc tests.

3.2.2. *Excluded trials*

Before the results were analysed, trials in which participants failed to make a primary fixation to the figure centre or edge were removed. The exclusion criteria used were trials in which participants made a first fixation to: 1) the opposite direction of target location, 2) the correct direction, but not reaching the target edge/centre, and 3) regions above/below the target figure. These excluded trials amounted to 18.1% of the total trials.

3.2.3. *Saccade position unaffected by different edge orientation profiles*

The saccade position was determined using the saccade amplitude:

$$Saccade\ Amplitude = 100.\frac{distance\ of\ primary\ fixation\ from\ fixation\ point}{distance\ of\ target\ centre\ from\ fixation\ point}$$

As such, 100% amplitude is when the first fixation was to the exact figure centre (for all three eccentricities). However, the percentage amplitude of the figure border differs based on the eccentricity. The edge borders are ± 25%, ± 33.3%, and ± 50% for the targets at 9.1°, 6.8°, and 4.6° eccentricity respectively. These borders are represented as the dashed lines on the graphs in Fig. 2.

Fig. 2 shows the saccadic landing positions in terms of saccadic amplitude for each profile at all three eccentricities. It appears from the graphs that the different orientation profiles do not have much of an effect on the distribution of the amplitude data i.e. the profiles are not affecting the saccade position. A few other observations can be made from the frequency histograms. First, the amplitude of the saccade position seems to be on average lower than 100% (figure centre). Second, the amplitude distribution shows that the saccade positions are typically made around 80–90%. Third, very rarely did the saccade position land at amplitudes greater than 100%, especially for targets further away from fixation. Therefore, when a primary fixation is made, the landing position is typically on a point just slightly short of the figure centre, but not falling on the figure edge either.

The percentage amplitude data was also analysed using a 2 (Left-Right: target to left or right of fixation) × 3 (Position: 9.1°, 6.8°, and 4.6°) × 3 (Profile: Block, Blur, and Cornsweet) ANOVA (See Fig. 3). Participants' mean data was used for this analysis, however we did run this analysis with median data, and the outcome was the same (as one would expect given the normal distribution of the data). A significant main effect of Left-Right was found ($F(1,9) = 14.824, p = 0.004$) which showed that mean amplitudes were lower for targets to the right ($M = 80.40\%$) compared to the left ($M = 88.56\%$). Furthermore, a main effect of Profile ($F(2,18) = 4.337, p = 0.029$) found that amplitudes were lower for the Cornsweet profile ($M = 83.06\%$) than the Block profile ($M = 85.45\%$) [$p = 0.010$]. The difference in amplitude between the Block and Cornsweet profile was 2.4%. This is in line with the graphs from Fig. 2 above that show a small difference in saccade amplitudes across the various profiles. No other Bonferroni corrected post hoc tests were significant.

Bonferroni corrected pairwise comparisons of the interaction between Left-Right and Position ($F(2,18) = 7.506$, $p = 0.004$) show that position does not influence the amplitude to targets to the right (where $p > 0.05$), but for targets to the left, amplitude is lower for targets at 9.1° eccentricity ($M = 84.60\%$) compared to targets at 6.8° eccentricity ($M = 88.90\%$) [$p = 0.042$]. Finally, an interaction between Position and Profile ($F(2.17,19.52) = 5.092$, $p = 0.015$) shows that amplitude is affected by the profiles at 4.6° target eccentricity, in which the amplitude was significantly lower to the Cornsweet profile than the Block [p

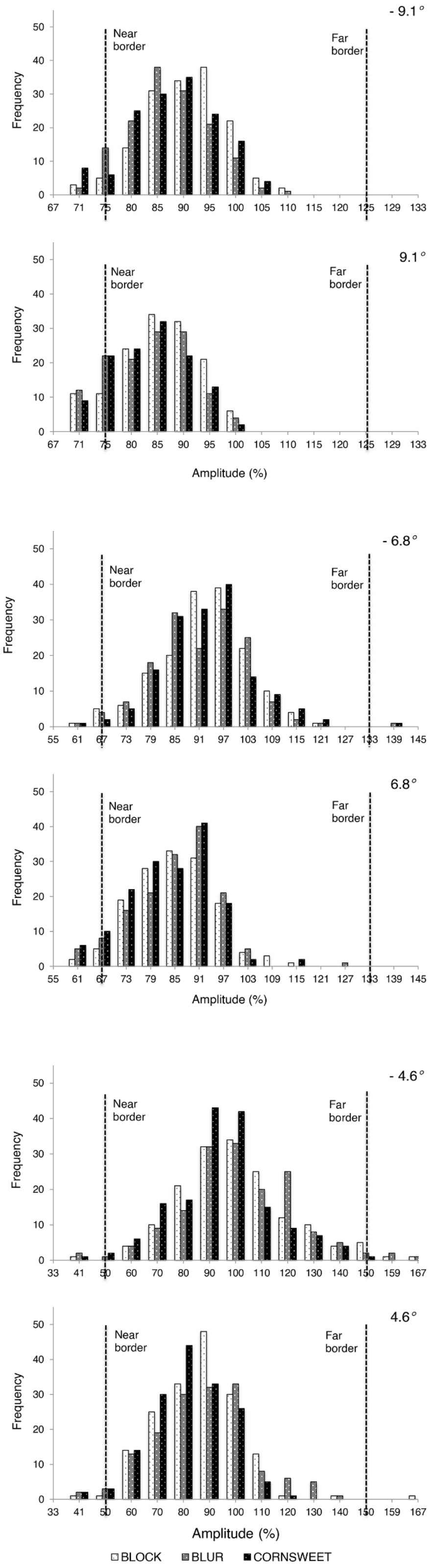

Fig. 2. Saccade amplitude data (in percentage relative to figure centre) plotted as frequency histograms, with pooled data from all 10 participants. The extremes of the x-axis scale on the graphs correspond to the edge region (2 columns away from the border). The eccentricity and direction of the target figure is indicated on the top right corner of the graph, and the dashed lines on the graph represent the border of the figure. The intervals on the x- axis represent the upper limit of the bin array e.g. 80 includes amplitude up to 80%.

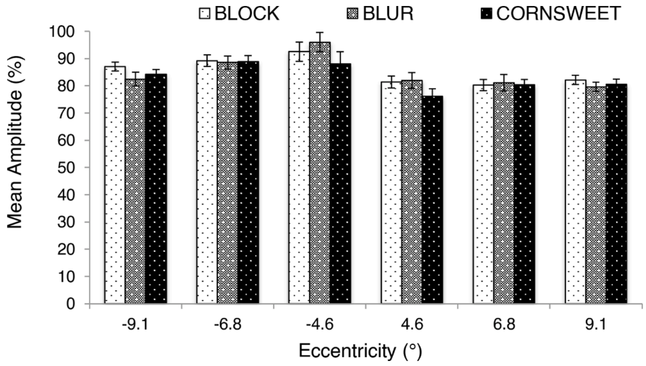

Fig. 3. Average amplitudes of saccade position in percentage relative to the centre of figure (100%). Negative (-) eccentricities represent targets to the left of fixation. Error bars represent the standard error of the mean across participants.

$= 0.008$] and Blur [$p = 0.022$] profiles ($M_{\text{Block}} = 86.95\%$; $M_{\text{Blur}} = 88.99\%$; $M_{\text{Cornsweet}} = 82.1\%$). Amplitude is not affected by the profiles at the 6.8° target eccentricity ($M_{\text{Block}} = 84.76\%$; $M_{\text{Blur}} = 84.81\%$; $M_{\text{Cornsweet}} = 84.67\%$) or the 9.1° target eccentricity ($M_{\text{Block}} = 84.63\%$; $M_{\text{Blur}} = 81.00\%$; $M_{\text{Cornsweet}} = 82.43\%$) [$p > 0.05$ for all Bonferroni corrected post hoc comparisons]. No other main effects or interactions were significant.

The focus of this analysis was to address the manner in which information from a texture target was extracted to direct eye movements. If eye movements are in fact driven by the most salient features (i.e. high orientation contrast) in a scene, saccade amplitudes to the various profiles should have demonstrated different patterns of results. Instead, the results show that saccade amplitudes were for the most part similar among the three profiles, with saccades typically directed to the centre of the target figure rather than any other regions. Thus, eye movements appear to be guided by the representation of the entire target figure rather than regions within the target with high feature discontinuity cues.

3.2.4. *Latency and precision of saccades*

For saccade latencies (see Fig. 4), a 2 (Left-Right) × 3 (Position) × 3 (Profile) repeated measures ANOVA found a main effect of Position ($F(2,18) = 9.709$, $p = 0.001$), where saccade latencies for targets at 9.1° eccentricity ($M = 304$ ms) was longer compared to targets at 4.6° ($M = 293$ ms) [$p = 0.025$] and 6.8° eccentricity ($M = 293$ ms) [$p = 0.013$]. Additionally, a main effect of Profile ($F(2,18) = 37.920$, $p < 0.001$) indicates that participants have longer saccade latencies for the Blur profile ($M = 311$ ms) compared to the Block ($M = 291$ ms) and Cornsweet profile ($M = 289$ ms) [for all Bonferroni corrected pairwise comparisons, $p < 0.001$]. No other main effects or interactions were significant.

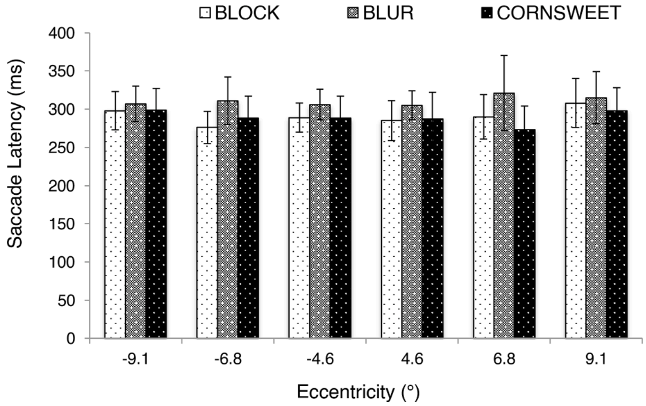

Fig. 4. Average saccade latencies as a function of target profile and eccentricity. Negative (-) eccentricities represent targets to the left of fixation. Error bars represent the standard error of the mean across participants.

These results show that the significant increase in saccadic latencies appears to be driven by the increased time needed to compute a saccade for a faraway target. Likewise, the time taken to initiate a saccade is greater for the Blur profile compared to the other profiles. We postulate that this outcome is due to the Blur profile having decreased intensity/saliency (see Experiment 3), which then means more time is required to plan a saccade.

The precision of the landing position was measured by calculating the standard deviation of the saccade amplitudes (see Fig. 5). A 3-Way ANOVA (Left-Right × Position × Profile) found a significant main effect of Position ($F(2,18) = 26.887$, $p < 0.001$) in which Bonferroni corrected pairwise comparisons reveal that the saccade position for the targets at 4.6° eccentricity was more scattered ($M = 16.5\%$) compared to targets at 9.1° ($M = 10.1\%$) [$p < 0.001$] and 6.8° eccentricity ($M = 8.0\%$) [$p = 0.002$]. Thus, the reliability of the saccadic landing position was better when the target was further away from fixation. No other comparisons were significant.

This experiment set out to investigate whether the different edge orientation profiles would influence the landing position of the saccades. If eye movements are driven by the salient properties within the target, we would expect that saccades to the Blur and Cornsweet targets would land closer to the centre and edges of the figure respectively. However, the results above show that the different orientation profiles have little effect on the saccade landing positions, which was on average ~ 84% to the target centre.

The analysis did however reveal a significant difference in saccade amplitude for the Cornsweet profile compared to the Block and Blur profiles, though only for targets at 4.6° eccentricity. A point to emphasise about this finding is that even though the amplitudes to the Cornsweet profile are lower by 4–6% compared to the Block and Blur profiles, the average saccade amplitude is still 82.1%. Therefore, saccades to the Cornsweet profile are *much* closer to the figure centre than the figure edges, which are defined at 50 and 150%.

The findings above suggest against the notion that saccades are made to salient properties within a target (as saccades to Cornsweet targets are not to either edges of the figure). However, it is conceivable that when a saccade is being planned to the Cornsweet figure, the salient properties at both edges were simultaneously extracted, thereby cancelling each other out and resulting in a saccade landing position at a midpoint between the edges i.e. the centre. This is unlikely, in our opinion, as the Cornsweet edge that is further away from fixation will impose a weaker signal when computing the saccade (a phenomenon demonstrated in this experiment where targets further away are less salient), thereby still resulting in saccades closer to the edge nearer to fixation. In fact, if a mechanism as such is operating, we should observe a similar pattern of results for the other profiles.

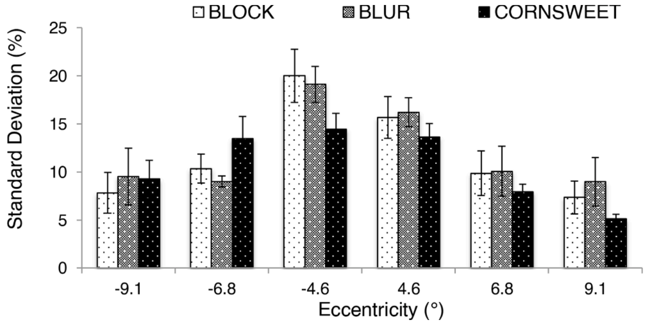

Fig. 5. Average standard deviation of the saccade position as a function of target profile and eccentricity. Negative (-) eccentricities represent targets to the left of fixation. Error bars represent the standard error of the mean across participants.

4. Experiment 2: Eye movements are to the centre of gravity of a target

From the results of Experiment 1, we posit that saccades are being made to a reference point (the centre of the target) with a certain degree of undershoot. However, the study did not inform about what exactly this reference point is. The assumption thus far has been that it is the centre of the figure i.e. the midpoint of the target width. Alternatively, there is also the geometric centre of the figure, which is the average position of all the points in the figure. We will refer to this point as the centre of gravity i.e. the centroid.

The centre and the centre of gravity of a figure may coincide with each other, especially with a symmetrically shaped object. This was the case for the rectangular shaped stimuli from Experiment 1, where both points (centre and centre of gravity) were identical to each other. In Experiment 2, the target shape was of an isosceles triangle. As a result, the centre of gravity and the centre of the figure do not coincide with each other (see Fig. 6a). This will allow us to determine whether a saccade is planned in relation to the target centre, or the target centre of gravity, or possibly something else. In the case of the former, it implies that the landing position of the saccade is calculated based on the knowledge of the two lateral edge points of the figure border, while for the latter, it implies that the saccade position is calculated based on the knowledge of the entire figure shape.

4.1. Methods

10 participants (4 males) between the ages of 21 and 28 ($M = 22.9$; $SD = 2.64$) were recruited.

The target figure was a 12 × 20 element triangular patch that spanned 4.6°×7.6° [base × height] (see Fig. 6b). In Experiment 2, only the Block profile was used. The position of the centre (midpoint) of the target figure varied at eccentricities of 6.8° and 8.4° to the left or right of a central fixation point.

The triangular shaped target could point inwards or outwards from fixation. Thus, for targets at the same eccentricity and side, both triangles will have the same centre point (half the height of the triangle), but the centre of gravity of the outwards pointing triangle will be closer to fixation, while it will be further away from fixation for the inwards pointing triangle (see Fig. 6a for a schematic representation). The distance between the centre and centre of gravity was 1.27°, while the distance between the centre of gravity of the inwards and outwards

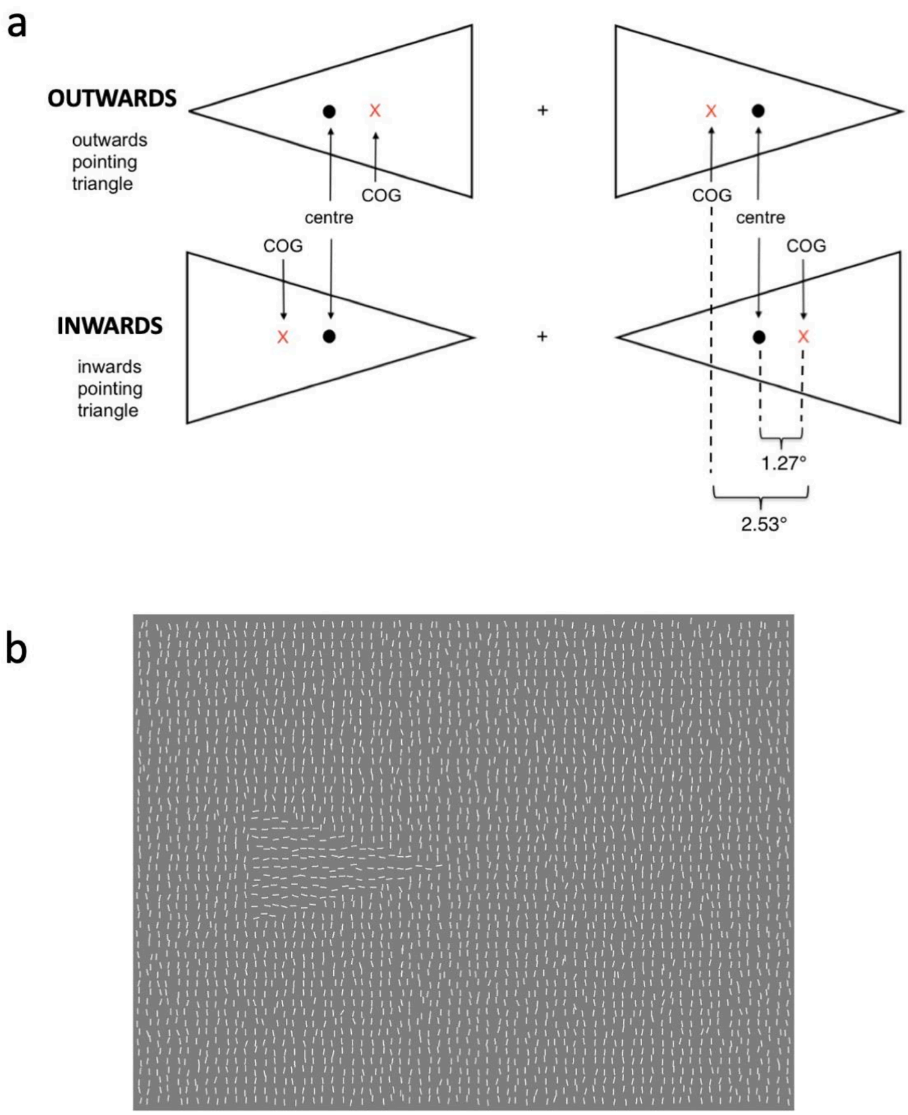

Fig. 6. A) a schematic representation of the inwards and outwards pointing triangle. as can be seen from above, the centres (circular dot) of the two triangles (outwards vs. inwards) are positioned at the same spot, assuming the eccentricities are the same. The centre of gravity (×), is closer to fixation for the outwards triangle, while it is further away for the inwards triangle. b) Example stimulus of an inwards pointing triangle.

triangle was 2.53°.

Participants performed 1 practice block before completing 4 experimental blocks (40 trials per block). The instructions to participants were the same as Experiment 1.

4.2. Results

4.2.1. Saccadic landing position to centre of gravity of target

Saccade amplitude (%) was calculated as in Experiment 1, and again, 100% refers to the point at which a primary fixation was made to the figure centre (circular dot on Fig. 6a). For the target at 6.8° eccentricity, the amplitude to the edge closest to fixation is 46%, and the edge further from fixation is 155%. These amplitudes will be the same for both the inwards and outwards pointing triangle on both sides of fixation. However, the amplitude distance to the centre of gravity of the outwards pointing triangle is 82%, while it is a 119% for the inwards pointing triangle. For the target at 8.4° eccentricity, the amplitudes to the edges are 54% and 145%, while the centre of gravity of the outwards and inwards pointing triangle are respectively 85% and 115%.

Figs. 7 and 8 show the saccade amplitudes of Experiment 2. The most apparent outcome is that the amplitudes for the inwards pointing triangle are not the same as the amplitudes for outwards pointing triangle. Since the saccade amplitude is calculated relative to the centre of the triangle (where amplitude to the centre is 100%), should participants be making a fixation to the centre, or a fixed % of the centre, the amplitudes for both the inwards and outwards pointing triangle should be the same. We do not see this pattern of results, which suggest that the saccadic landing position is not to the centre of the figure.

In fact, a 2 (Left-Right: target to left or right of fixation) × 2 (Position: 8.4°, and 6.8°) × 2 (Outwards-Inwards: triangles pointing outwards or inwards) ANOVA on the saccade amplitude data shows a significant main effect of Outwards-Inwards ($F(1,9) = 46.427, p < 0.001$), whereby outwards pointing triangles ($M = 76.2\%$) had lower amplitudes compared to inwards pointing triangles ($M = 94.7\%$) [where $p < 0.001$ for Bonferroni corrected pairwise comparison]. This is an indication that the primary fixation is to the centre of gravity rather than the centre of the figure.

A significant main effect of Position was also found ($F(1,9) = 88.709$, $p < 0.001$), whereby targets at 6.8° eccentricity ($M = 88.6\%$) had greater amplitudes than targets at 8.4° ($M = 82.3\%$) targets [where $p < 0.001$ for Bonferroni corrected pairwise comparison]. Thus, saccades to targets with high eccentricity were less accurate. Post hoc tests using Bonferroni correction was used to analyse the Position and Outwards-Inwards interaction ($F(1,9) = 14.215$, $p = 0.004$). The comparisons show that for the inwards pointing triangle, the position influences the amplitude greatly ($M6.8° = 99.23\%$; $M8.4° = 90.20\%$, $p < 0.001$). However for the outwards pointing triangle, the position only has a moderate effect on the amplitude ($M6.8° = 77.90\%$; $M8.4° = 74.40\%$, $p < 0.014$). No other main effect or interactions were significant. As with Experiment 1, participants' mean data was used for this analysis, though analysis with median data yielded the same outcome.

4.2.2. Latency and precision of saccades

The saccade latencies were analysed with a 2 (Left-Right) × 2 (Position) × 2 (Outwards-Inwards) ANOVA (see Fig. 9). The results show that saccade latency did not vary with any of the conditions. This is in contrast with Experiment 1, where we found an effect of target position on saccade latencies. We posit that this null effect has to do with the smaller target eccentricities used in this experiment.

The precision of the landing position was analysed with a 3-Way (Left-Right × Position × Outwards-Inwards) ANOVA (see Fig. 10), which shows a significant main effect of Position, whereby Bonferroni corrected pairwise comparison shows that targets at 6.8° eccentricity had saccade positions with greater variability ($M = 11.20\%$) compared targets at 8.4° eccentricity ($M = 8.43\%$). Thus, the reliability of the saccadic landing position is better when the target is further away from

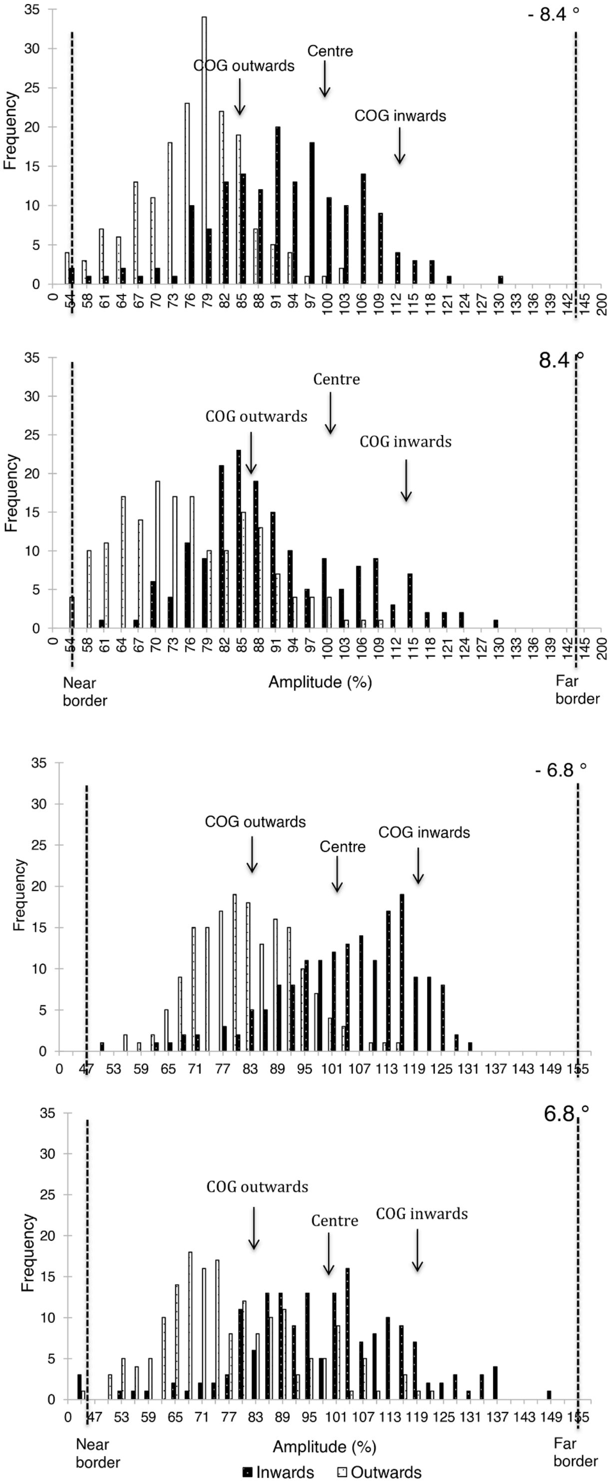

Fig. 7. Saccade amplitude data (in percentage relative to figure centre) plotted as frequency histograms, with pooled data from all 10 participants. The direction and eccentricity of the target figure is indicated on the top right corner of the graph, and the dashed lines on the graph represent the border of the figure. Outwards is the amplitude for the outwards pointing triangle, and Inwards is the amplitude for the inwards pointing triangle. The intervals on the x-axis represent the upper limit of the bin array e.g. 83 includes amplitude up to 83%. The graph also indicates where the centre of gravity, COG, (for both types of triangles) and the Centre is in amplitude. The spread seen between the two triangles is indication that the primary fixation is not to the centre (or we should see an identical pattern between the black and white bars).

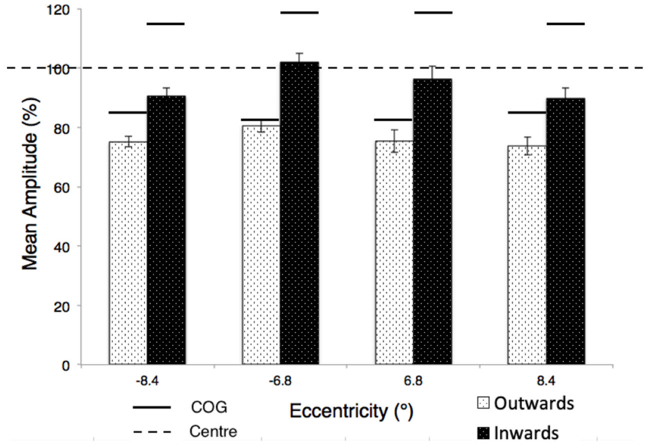

Fig. 8. Average amplitudes of primary fixation in percentage relative to centre of figure (100%). The black solid bars above each column represent the centre of gravity (COG) for the individual conditions, while the dashed line is the centre of the figure. Negative (-) eccentricities represent targets to the left of fixation. Outwards is the amplitude for the outwards pointing triangle, and Inwards is the amplitude for the inwards pointing triangle. Error bars represent the standard error of the mean across participants.

fixation (also found in Experiment 1). Furthermore, a significant main effect of Outwards-Inwards was also found, in which pairwise comparison using Bonferroni correction showed that inwards pointing triangles ($M = 10.77\%$) had fixations with greater variability compared to outwards pointing triangles ($M = 8.87\%$). This is to be expected as the inwards pointing triangle had a centre of gravity that was further away than the outwards pointing triangle, and as we have found, saccades tend to have greater variability when targets, or in this case, the landing positions, are further away. No other main effect or interactions were significant.

From Experiment 1, we concluded that saccades towards targets were apparently computed based on the whole representation of the target figure. Experiment 2 shows that this calculation is based not on the average computation of the two lateral end-points of the figure border, but instead is based on the average position of all lines within the figure.

5. Experiment 3: Matched saliency study

In Experiment 1, participants were shown texture stimuli, and had to detect the figure embedded within the texture grid. Overall, the findings show that the type of orientation profile did significantly affect the saccadic landing position, though in general, saccades were primarily being directed to the centre (or centre of gravity, as found in Experiment 2) of the target figure for all profiles. A more pronounced finding was that orientation profile did affect the saccade latency, whereby the time taken to initiate a saccade to the Blur profile is increased compared to the Block and Cornsweet profiles. These differences observed, especially with respect to the time taken to initiate an eye movement to the different profiles, suggest that the mechanisms that segregate the textures are being affected by the different profiles. However, the previous study used stimuli with orientation contrast fixed at 90°. While this allowed us to draw conclusions about eye movements to textures with high orientation contrast, it does not directly inform us about the saliency, (i.e. the quality of an object to be particularly noticeable so that it can be detected fast and effortlessly~~)~~), of the different orientation profiles. In this experiment, we sought to investigate the subjective saliency of various texture profiles to test the role texture edges play in guiding eye movements.

Two texture patterns were presented simultaneously to participants on either side of a central fixation point. Participants had to make a saccade to the embedded texture figure that was more detectable. This study will allow us to determine what values of orientation contrast will produce matched saliencies between the different profiles, which in turn will tell us which profile produces the highest levels of saliency to drive eye movements. That is, we had to use an eye movement measure, instead of a psychophysical measure, in order to show that specific profiles are best suited to drive eye movements. If orientation contrasts at both the centre and edge of a figure are required to produce the highest levels of saliency for driving eye movements, it is expected that the values of orientation contrast needed by the Blur and Cornsweet profiles to match the Block profile will be significantly higher. If orientation contrast at only the centre of the figure was sufficient to drive eye movements, we would expect that the degree of orientation contrast needed to match Block profile would be equivalent for the Blur profile, and significantly higher for the Cornsweet profile. Likewise, if eye movements are driven by the properties of orientation contrast at the edge of the figure, orientation contrast values would be similar for both the Block and Cornsweet profiles, but the Blur profile would require higher levels of orientation contrast to have equal saliency.

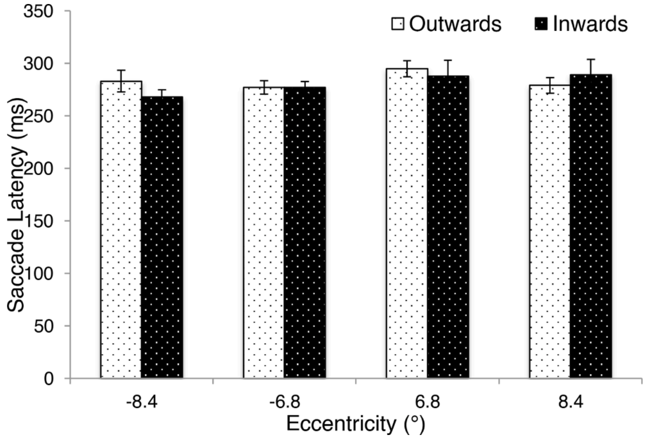

Fig. 9. Average saccade latency for the outwards (Outwards) and inwards (Inwards) pointing triangle as a function of target direction and eccentricity. Negative (-) eccentricities represent targets to the left of fixation. Error bars represent the standard error of the mean across participants.

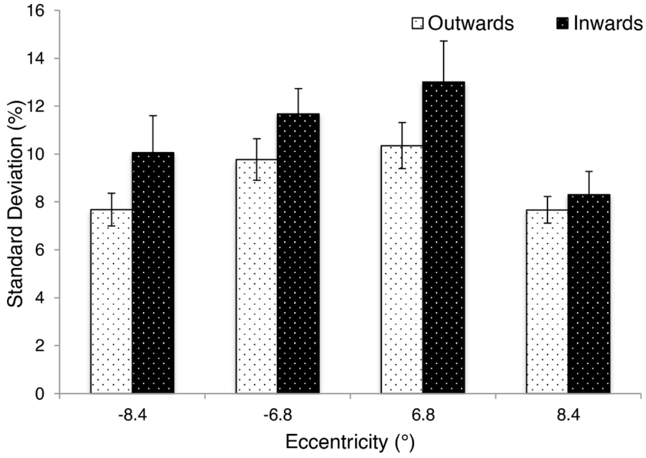

Fig. 10. Average standard deviation for the outwards (Outwards) and inwards (Inwards) pointing triangle as a function of target direction and eccentricity. Negative (-) eccentricities represent targets to the left of fixation. Error bars represent the standard error of the mean across participants.

5.1. Methods

10 participants (1 male) between the ages of 20 and 23 ($M = 21.8$; $SD = 1.03$) were recruited.

In Experiment 3, the stimuli comprised two 32 × 32 element texture grids presented on either side of a central fixation cross. Each of the texture grids had a visual angle of $12.2^\circ \times 12.2^\circ$, with the 15 × 12 element rectangular figure patch having visual angles of $5.7^\circ \times 4.6^\circ$ [height × width] or vice versa. The figure patch within the texture grid could be either the Block, Blur, or Cornsweet profile. The fixation cross in the centre spanned 1.1° in visual angle, and the eccentricity to the centre of the texture grid was 8.9°.

To match the saliency of one profile to another profile, three conditions were tested: Block vs. Blur, Block vs. Cornsweet, Cornsweet vs. Blur (see Fig. 11). To generate psychometric functions for each condition, one profile had a constant orientation contrast, while the other had orientation contrast that varied between 10° and 90°. For the varying texture, the figure was undetectable when orientation contrast was low, and extremely salient when orientation contrast was high. The psychometric plots use the orientation contrast of the varying profile on the x-axis, and the proportion of "varying profile chosen" responses on the y-axis, and thus creates a sigmoidal shape ranging from 0 to 100%. There were 5 different orientation contrast values used for the varying profile: 10°, 30°, 50°, 70°, and 90°. For the constant profile, the orientation contrast was set to 30° for the Block (Block vs. Blur & Block vs. Cornsweet condition) and 50° for the Cornsweet (Cornsweet vs. Blur condition). These were determined by piloting the study beforehand, where it was observed that these values produced the most appropriate logistic curve with physically meaningful data. Catch trials were included, with the stimuli comprising two uniform texture grids presented on either side of the fixation.

There were 750 trials in total, 150 (20%) of which were Uniform catch trials, and 200 each for the Block vs. Blur, Block vs. Cornsweet, & Cornsweet vs. Blur. All these trials were of different stimuli i.e. no stimuli were repeated. The method of constant stimuli was used. For each condition, the 200 trials are made up of equal number of trials for each value of orientation contrast (varying profile).

Participants were instructed to fixate at the cross in the middle of the screen and move their eyes to the texture grid that had a figure that was most noticeable when the stimulus appeared. For catch trials, participants were required to maintain fixation after stimulus onset. Specifically, the instructions were: *"Your task is to look at the texture in which*

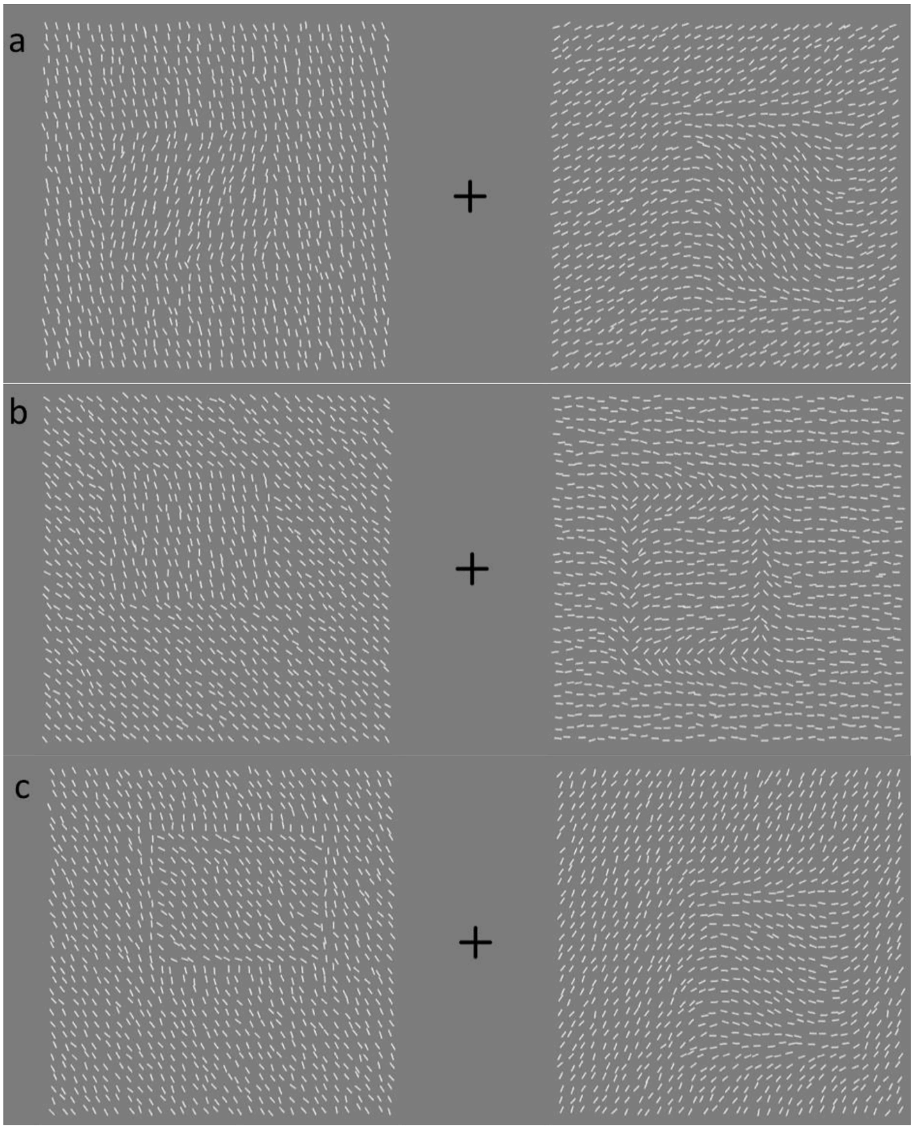

Fig. 11. Example stimuli for the three conditions. (a) Block vs. Blur: Block = 30°, Blur = 90° (b) Block vs. Cornsweet: Block = 30°, Cornsweet = 90° (c) Cornsweet vs. Blur: Cornsweet = 50°, Blur = 90°.

the embedded figure is more noticeable. Once you have moved your eyes to either one of the textures with a more noticeable figure, maintain your gaze until the image disappears. Once the image has disappeared, move your eyes to back to the fixation cross. If you find none of the textures contain a figure embedded in it, do not move your eyes, and maintain your gaze at the fixation cross.". The fixation cross was displayed for 1 s, after which the stimulus patterns were displayed for 1 s. Following that, a new trial was initiated with the presentation of a fixation cross once again.

Participants performed two blocks (40 trials each) of practice trials before completing 10 experimental blocks (75 trials per block, randomly chosen from the 4 conditions).

5.2. Results

5.2.1. Data analysis

A logistic distribution function was used to determine the value of orientation contrast of the varying profile that has equal saliency to the constant profile. For each participant, three psychometric functions were plotted (1 for each condition: Block vs. Blur, Block vs. Cornsweet, & Cornsweet vs. Blur). The y-axis of the graph was the percentage varying profile chosen while the x-axis was orientation contrast of the varying profile. Using the logistic distribution function, a least-squares curve of best fit was produced to obtain the Point of Subjective Equality (PSE), which is the orientation contrast needed by the varying profile to match the saliency of the constant profile. E.g. for the Block (constant) vs. Blur (varying) condition, the PSE value is the orientation contrast needed by the Blur profile to match the saliency of the Block at 30° orientation contrast.

5.2.2. Excluded trials

On 4.48% of trials, participants made subsequent saccades from one texture grid to the other. These trials were removed before analysis. For the remaining trials, participants were able to make a saccade in 90.7% of the figure-present trials. For the remainder 9.3% of the figure present trials, they maintained fixation at the fixation cross. These trials were not analysed as this response indicated that participants did not perceive a figure within either texture grid.

5.2.3. Eye movements driven by high saliency stimuli with orientation contrast at the edge and centre of figure

A one-sample *t*-test was used to analyse if the PSE values (see Fig. 12) were significantly different from the test value, which was the orientation contrast of the constant profile. For the Block vs. Blur condition, mean PSE value ($M = 66.53^\circ$, $S.E.M = 2.12^\circ$) was significantly higher than the orientation contrast of the Block profile of 30°, $t(9) = 17.251$, $p < 0.001$. Likewise, for the Block vs. Cornsweet condition, the PSE value ($M = 39.74^\circ$, $S.E.M = 0.57^\circ$) was greater than the 30° orientation contrast of the Block profile, $t(9) = 17.139$, $p < 0.001$. Finally, for the Cornsweet vs. Blur condition, the average PSE value ($M = 103.88^\circ$, $S.E.M = 3.23^\circ$) was significantly greater compared to the contrast of 50° for the Cornsweet profile $t(9) = 16.705$, $p < 0.001$. However, it is worth noting that an orientation contrast greater than 90° is effectively impossible, and the larger PSE value obtained merely suggests that a greater orientation contrast is required by the Blur profile to be considered equally as salient as the Cornsweet profile. A further paired-sample *t*-test indicates that a higher orientation contrast is needed by the Blur profile to match the saliency of the Cornsweet profile. The average PSE value for the Block vs. Blur condition was significantly higher than the average PSE value for the Block vs. Cornsweet condition, $t(9) = 11.329$, $p < 0.001$. That is, to match the saliency of the Block profile at 30° orientation contrast, the orientation contrast of the Cornsweet profile had to be higher at 39°, and much higher at 66° for the Blur profile. Thus, the orientation profiles show a clear hierarchy of saliency, whereby the Block profile has the highest saliency, followed by the Cornsweet profile, and finally the Blur profile.

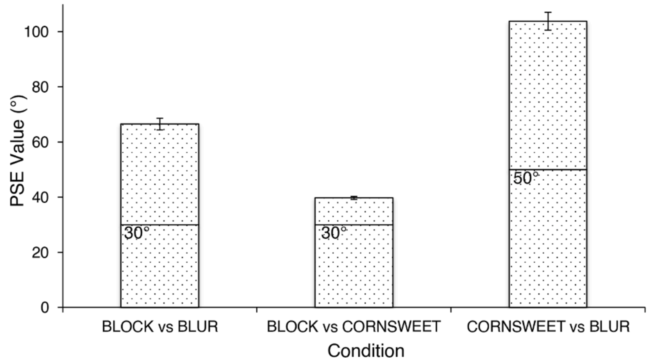

Fig. 12. The graph shows the PSE values for each condition. The PSE values represent the orientation contrast of the varying profile to have equal saliency to the constant profile (black line on the bars). The constant stimulus i.e. with fixed orientation contrast, was the Block (BLOCK vs BLUR; CORNSWEET vs BLUR) and Cornsweet profile (CORNSWEET vs BLUR). Error bars represent the standard error of the mean across participants.

6. Discussion

The aim of the experiments presented in this paper was to investigate how information from a texture target is processed in order to provide a signal for eye movement control. These experiments provide two noteworthy outcomes:

6.1. Saccades can be accurately made to spatially extended texture-defined targets

The essential feature common to Experiments 1–2 is that saccadic eye movements were to be directed to targets embedded in a background structure. In Experiment 1, we found that while edge orientation profiles did have a significant effect on the saccade landing position, this was in terms of the saccade amplitude for the Cornsweet profile being lower than the Block and Blur profiles by on average 5% (specific only to targets at 4.6° eccentricity, and none other). This observed difference, while significant, does not negate the fact that saccades to the Cornsweet profile are not sufficiently near to either figure edges, but are in fact closer to the figure centre. While further research will be required to tease out the cause of this small difference, the general picture is clear: there was little difference observed between the pattern of saccades to the Block, Blur, and Cornsweet profile. This result suggests that saccades are guided by the representation of the entire target figure, not by any particular salient location within the target.

There is a possibility that saccades to Cornsweet targets were based on **both** salient edges of the target figure, which results in the saccade averaging out in the centre due to the symmetrical target shape. While this is rather unlikely, as discussed in Section 3, we cannot at this point completely rule out the likelihood that saccade programming involved some extraction of information from both near and far edges of the Cornsweet profile. To investigate this, it would be possible to use a target similar to the Cornsweet profile (where information of orientation contrast is only available at the edge), but manipulate the far edge to be more or less salient than the near edge. If saccades are influenced by this manipulation, it would suggest that a saliency mechanism is operating with regards to saccade planning. However, if saccades are unaffected by this manipulation, it would suggest that saccades are in fact planned based on the representation of whole target figure instead of salient locations.

In Experiment 2, we used triangle-shaped target figures to address the question of how exactly saccade destinations are computed for targets embedded in a background structure. One possibility is a global processing mechanism, where saccades are planned based on the average position of the visible elements that make up the two endpoints (or edges) of the target figure (e.g. Deubel et al., 1988; Findlay, 1982; Ploner et al., 2004). Another possibility is that segmentation of target from background occurs first, and saccades are subsequently guided by this shape representation of the target figure (e.g. Melcher & Kowler, 1999).

Unlike the rectangle-shaped figures used in Experiment 1, the centre (midpoint of the target width) and centre of gravity (average position of all points in the figure) of the triangle-shaped targets do not coincide with each other. The results showed that saccades were directed to the centre of gravity, which supports the notion that saccades were programmed based on spatial pooling of information across the whole target figure, and not based on the spatial pooling of just the two endpoints of the target width. This is in accordance with the findings of Melcher and Kowler (1999) who used luminance-defined targets. However, they specifically instructed their participants to "look at the target as a whole, rather than aim the saccade to a particular place within" (p. 2933) and the targets in their study were presented in an impoverished visual environment (i.e. no background). It is abundantly clear that the natural visual environment normally constitutes complex targets in which the foreground "figure" has to first be segregated from the background structure. Our findings therefore extend theirs by claiming: 1) even when participants were not specifically told to look at the target as a whole, that is what the participants did, and 2) even when a target is embedded in a background, saccade destination is computed based on the representation of the entire shape of the texture figure by first segregating the figure from the background.

We posit that the early low-level mechanisms that segregate figure-ground textures could also be providing input to areas that guide oculomotor planning. The rationale for this stems from findings that 1) confirm the role of V1 in figure-ground texture segregation (Lamme, 1995; Lamme et al., 1999; Supèr et al., 2001; Supèr et al., 2003), and 2) show that early visual areas of the cortex – V1, V2, V3, and the middle temporal area – project to the superficial layers of the superior colliculus (Cerkevich, Lyon, Balaram, & Kaas, 2014) for integration of visual and motor signals. This proposed mechanism is further supported by findings that show neuronal activity in the V1 provides internal evidence of a stimulus that guides saccades to figure-ground texture stimuli (Supèr & Lamme, 2007; Supèr et al., 2001). In addition, previous findings have shown that stimuli that are more salient produce stronger figure-ground contextual modulations and elicit faster saccade latencies (Supèr et al., 2003), which we also find Experiment 1, further supporting the link between early mechanisms of segregation and eye movement. However, formal modelling and a comparison to psychophysical experiments with comparable stimuli will be required to confirm this (Sidhu, Allen & Keeble, 2023 In Preparation).

6.2. Effects of target saliency

In the experiments presented here, we have observed that some characteristics of eye movements are influenced by the saliency of the target. Saliency here refers to the quality of being particularly detectable. By manipulating the orientation contrast of the figure-ground texture stimuli, we can alter the detectability of a texture figure. This is evident by studies that show figures segregate more easily from the background when orientation contrast is high (e.g. Nothdurft, 1985).

The first noteworthy observation made is that texture-defined targets are more salient when information on orientation contrast is present at both figure edge and figure centre. This was shown in Experiment 3, where we found that the degree of orientation contrast needed to match the Block profile (with orientation contrast information at both the figure edge and centre) was higher by 32% for the Cornsweet profile and 121% for the Blur profile, indicating that it is the most salient orientation profile.

Second, we showed that salient texture-defined targets produced shorter saccade latencies. In Experiment 1, saccade latencies to the Blur profile were the longest compared to the Block and Cornsweet profiles. Using texture-defined targets, Supèr, Spekreijse, and Lamme (2003) showed that stronger contextual modulation (stronger neuronal response to the figure region compared to the ground region) would result in shorter saccade latencies. This is a result of a strong signal of modulation producing a rapid build-up in the motor system prior to saccade onset, which results in shorter saccade latencies (Supèr & Lamme, 2007). Thus, when a target is less salient (i.e. the Blur profile as observed from Experiment 3), the time taken to initiate the saccade is longer. A similar effect was observed by Nothdurft and Parlitz (1993), who showed that orientation-defined targets did not produce express saccades due to the signal strength being weaker than luminance-defined targets.

6.3. Conclusion

In summary, the findings from the present study add to the growing literature on the mechanisms of orientation-based texture segregation. We find that texture stimuli that have orientation contrast information at both the edge and centre of the figure (i.e. Block profile) are most salient in driving eye movements, which results in faster saccades. However, the precise form of orientation contrast – be it at the centre, edge, or both centre and edge – does not have much influence on the saccade landing position, which is typically made to the centre of gravity of the target figure with some undershoot. This supports the notion that saccade planning is guided by the representation of the entire target figure, not just by the salient locations within the target.

In comparison to studying eye movements in an impoverished environment, this study contributes to our understanding of real-world eye movements by including texture elements to the visual scene and requiring segregation of foreground from background. These findings are of particular interest as eye movements in the real world are much too complex to be fully comparable to eye movements to simple and solitary targets, and our experimental stimuli are closer to ecological reality. Additionally, investigations into orientation-based texture segregation have typically employed psychophysical or neurophysiological methods. However, as this study demonstrates, a method of investigation that uses eye movement can also inform on the mechanisms of texture segregation.

CRediT authorship contribution statement

Shumetha K. Sidhu: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Harriet A. Allen:** Writing – review & editing, Supervision. **David R.T. Keeble:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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