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Saccadic suppression of displacement: Effects of illumination and background manipulation

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Abstract. In contrast to other functions which are suppressed during saccades, saccadic suppression of displacement (SSD — a decrease in sensitivity to visual displacements during saccades) has often been considered to be due to efferent processes rather than to visual masking. The aim of this study was to explicitly assess the importance of visual conditions in SSD. In two experiments, a small computer-generated target made random horizontal jumps. An infrared eye tracker was used to detect the saccade toward the new position, triggering a smaller centripetal displacement of the target. Subjects reported awareness of these intrasaccadic displacements by pressing a key. In the first experiment, the task was performed in both a well-lit environment and in darkness. In the second experiment these conditions were replicated and additional factors such as the contrast of the background and the effect of moving the target spot alone or the target plus the entire background were investigated. Unlike other forms of saccadic suppression, SSD was stronger in the dark, although subjects also had a greater bias to report detections in that condition. Other background manipulations had no effect. The effect of ambient lighting on SSD is small and subtle. Effects of other background manipulations may be overridden by the focusing of attention on a small moving target.

1 Introduction

Sensitivity to many visual events is lowered during saccades. Perhaps most strikingly, in normal conditions we have no phenomenal experience of blurring during a saccade, even though such a blur would be expected with the visual field rapidly traversing the retina. We are aware only of successive stable fixations and not of the disruptions between them. Campbell and Wurtz (1978) termed this lack of blur perception ‘saccadic omission’. Although a strong effect, it operates only in well-lit conditions: in a dimly illuminated room with only a few dim light sources, a saccade causes those lights to appear as streaks with a shape and size related to the saccade trajectory. Campbell and Wurtz conclusively demonstrated that the effect is due to visual masking: a visually rich fixation either before or after a saccade is a stimulus sufficiently strong to mask the perception of blur during that saccade. A dimly lit environment, however, does not provide sufficiently strong masking stimuli from the adjacent fixation periods, allowing saccadic blur to be perceived.

The threshold for detecting a flash is also raised during a saccade, an effect termed saccadic suppression of vision (SSV). There is evidence that SSV may also be caused predominantly by visual masking from the preceding and succeeding fixations. SSV and saccadic omission may indeed be the same phenomenon, simply assessed with a different dependent measure (Chekaluk and Llewellyn 1992). A number of researchers (Matin 1974; Chekaluk and Llewellyn 1992, 1994; Li and Matin 1997) have agreed that while visual masking is the primary contributor to SSV, there is a small extra-retinal contribution (the putative corollary discharge of the eye-movement signal). Bridgeman (1977) hypothesised that SSV was mediated by two different mechanisms, their relative contributions dependent on the stimulus conditions under which they are tested (masking in the light, extraretinal signals in the dark). It should be noted, however, that the relative strength of the suppression due to the postulated central efferent signal means that it is probably not significant in real-world situations. The debate is not yet settled, however, and three decades later, the question of the relative contribution of visual and extraretinal influences to SSV remains a subject of active investigation (Diamond et al 2000; Thiele et al 2002).

Saccadic suppression of displacement (SSD) is the concern of this study. SSD is the phenomenon by which the ability of an observer to detect the discrete visual displacement of an object is impaired when that displacement occurs during a saccade (Bridgeman et al 1975). The canonical example of the phenomenon is our inability to see the saccadic movements of our own eyes in a mirror, although we can readily perceive the saccades of another person's eyes while we are fixating upon them (Dodge 1900; Tatler and Trośianko 2002). The displacement ratio is defined as the ratio of the displacement size to the size of the saccade. Displacements which are small relative to the size of the saccade are least likely to be detected. Estimates of the displacement-ratio threshold range from 10% to 30% (Mack 1970; Bridgeman et al 1975; Bridgeman 1981; Li and Matin 1990, 1997; McConkie and Currie 1996; MacAskill et al 1999), depending on the relative timing of the saccade and the displacement.

Debate on the mechanism underlying SSD has often been hindered by a lack of distinction between this and the other forms of suppression. Beeler, as early as 1967, concluded that different neural mechanisms controlled SSV and SSD (although he did not use those terms). Perhaps the most striking evidence for this is that the decrease in sensitivity to target flashes during saccades is small (0.5 – 0.7 log units), and even then occurs only at light intensities which are already close to threshold values. The decreased sensitivity to object movements which occur during saccades (4 log units) is a much stronger effect (Macknik et al 1991). Unfortunately, in much of the literature, the term 'saccadic suppression' has been used indiscriminately to refer to any and all of what we now term saccadic omission, SSV, and SSD. There has, therefore, been a tendency to generalise experimental results from one form of suppression to all forms of suppression, or at best to draw similarities between them. For example, Li and Matin (1997) stated that "... the identity of time course of the first [extraretinal] component of SSV with that for SSD and the increased spatial uncertainty underlying both SSV and SSD provide a basis for suggesting that they are governed by the same mechanism" (page 1780). Bridgeman and Macknik (1995) recast Brooks and Fuch's (1975) work on SSV as concerning the "visual component" of SSD. The two phenomena should, however, be seen as separate. SSV is a decreased sensitivity to events which occur during a saccade, while SSD is an impairment of a comparison of the fixations before and after a saccade. A displacement itself is, of course, unlikely to be perceptible during a saccade, as motion channels are swamped at that time (Burr et al 1994). SSD is the separate phenomenon of an impairment of perception of discrete displacement between fixations, not of motion during a saccade.

The efferent component has often been seen as the most significant contributor to SSD despite its apparent weakness in SSV. This is because SSD has been implicated in the role of maintaining the perceived spatial constancy of objects despite disruptive eye movements, which is often thought to require the presence of a non-retinal signal to specify current eye position [but see Currie et al (2000) for a different account]. Using differing methods, Li and Matin (1997) claimed that 80% of SSD is due to extraretinal influences while Bridgeman and Macknik (1995) calculated its contribution to be 49%. In either case, there is still room for the manipulation of visual factors to have a significant influence on the magnitude of SSD. For example, Bridgeman and Macknik speculated that at least a partial contributor to the SSD effect may be a backward masking process whereby the current fixation masks the previous one, disrupting the ability to detect changes in target location. We have mentioned that, for SSV, performing the task in darkness minimises the influence of masking effects. In both experiments reported in this paper we measured the strength of SSD in well-lit and in dark environments, so as to investigate whether lighting conditions are as significant in SSD as they are in SSV.

The visual world not only provides a strong masking stimulus but also a frame of reference from which object locations can be determined relative to one another. Therefore, we also measured the magnitude of SSD under conditions in which the background contrast could provide various levels of assistance in specifying target location. A uniform background with no contours was compared to both an unstructured background and a strongly contoured background. We did this in order to examine whether visual spatial information could be used to aid the detection of change in a target location relative to that background.

Some researchers achieved larger displacement thresholds by displacing large images rather than small targets (Bridgeman et al 1975; McConkie and Currie 1996). We therefore also implemented a similar condition in order to assess its effects on displacement detection.

2 Method

2.1 *Subjects*

Experiment 1 involved eight experimentally naïve, neurologically normal subjects (mean age 24 years, range 17 – 43 years; six female).

Experiment 2 involved another fifteen experimentally naïve, neurologically normal subjects (mean age 23 years, range 18 – 55 years; twelve female).

All subjects had corrected or uncorrected visual acuity of 6/12 or better in each eye. All gave informed consent to take part in the study.

2.2 *Apparatus*

Eye movements were recorded with a Skalar IRIS infrared limbus tracker (Delft, The Netherlands) (Reulen et al 1988). A computer-generated stimulus (a red square target subtending 0.75 deg) was video front-projected on to a large reflective screen 1.72 m in front of the subjects who were seated with their head restrained by use of a bite bar. The resolution of the screen at the subjects' viewing position was 12.72 pixels per degree of visual angle. Target stimuli always appeared within 15 deg of the centre of the screen. The screen image subtended a horizontal angle of 50 deg and a vertical angle of 37 deg from edge to edge, although in practice the IRIS sensors occlude the upper and lower borders of the screen. The refresh rate of the video projector was 70 Hz.

Luminances were measured with a Nuclear Associates (Long Island, New York) model 07-621 precision photometer (PMLX). The red target stimulus had a luminance of 5.1 cd m^{-2}. Background image luminances are given in the following section.

A 486 PC controlled the screen display, and its keyboard was used by the subjects to give keypress responses. A second 486 PC stored the eye-movement data (sampled at 200 Hz), detected saccades in real time, and communicated this information to the other PC in order to trigger the saccade-contingent display changes.

Calibration was performed prior to each trial block, with the subject alternately fixating three point targets at 15 deg left, at centre, and at 15 deg right. Signal gain and offset and sensor position were adjusted in an iterative process until the eye-position signal corresponded to the three target values (the IRIS is linear within this range).

2.3 *Procedure*

2.3.1 *Experiment 1.* A typical experimental trial is depicted in figure 1. Subjects were instructed to follow the target with their eyes as it jumped left or right by 8, 12, 16, 20, or 24 deg. The computer detected the subject's saccade toward the new target position

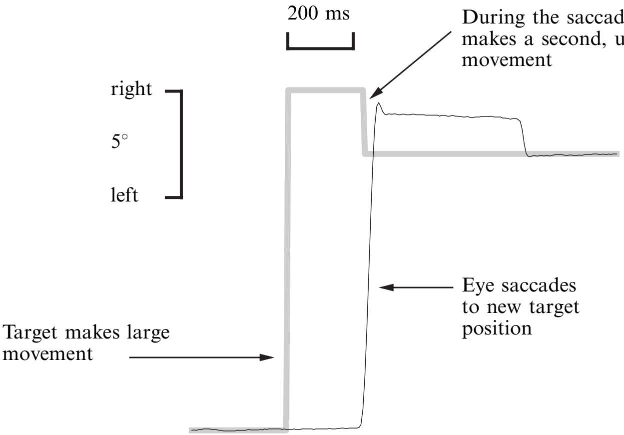

Figure 1. Representative recording of target position (grey line) and eye position (black line) in the intrasaccadic displacement paradigm (upward deflection of the trace indicates a movement to the right, downward to the left). At the beginning of the trial, the subject fixates the target. The target then shifts, and the subject makes a saccade to follow it. During this saccade, the target is displaced again and a corrective saccade brings the eye to the final target location. The subject indicates awareness of the second target displacement by a keypress.

when eye velocity exceeded 30 deg s^{-1}. On 120 trials the target was then displaced toward the centre of the screen by 1, 2, 3, or 4 deg (ie displacement ratios ranged from 0.04 to 0.50). Displacements occurred at a range of times between the initiation and the termination of the saccade. On the remaining 60 'catch' trials, no displacement occurred, allowing the false-alarm rate to be calculated. The position of the target at the end of a trial served as the start position for the following trial. Intertrial intervals were 2 s. The 180 trials were randomised and split into four 2 min blocks of 45 trials each.

Prior to data collection, subjects were shown examples of how the target could make either a single or a double step. They were instructed to press a key if they were aware that the target made a double step on a given trial and were given sufficient practice on the task to achieve proficiency.

Each person performed the experiment twice in a single session: 180 trials in both dark and light conditions (see figure 2). The order of light and dark conditions was balanced across subjects. In the dark condition, the room was completely dark during each block of trials (luminance < 0.1 cd m^{-2}), with the red stimulus being the only visible feature. Room lights were turned on in the short breaks between trial blocks to minimise dark adaptation. In the light condition, a light background (a homogeneous light blue/grey marbled texture, luminance 15.6 cd m^{-2}) was projected on the screen, leading to ambient lighting of the entire room.

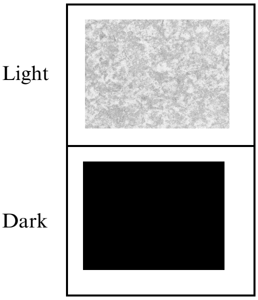

Figure 2. The two background conditions in experiment 1. Each subject performed the task under both conditions within a single session.

2.3.2 *Experiment 2.* In experiment 2 the task was the same task as in experiment 1, although it was performed in six different conditions within a session (see figure 3). All displacements were triggered as soon as possible after saccade initiation (mean 27 ms; MacAskill et al 1999) and all occurred within the duration of the saccade.

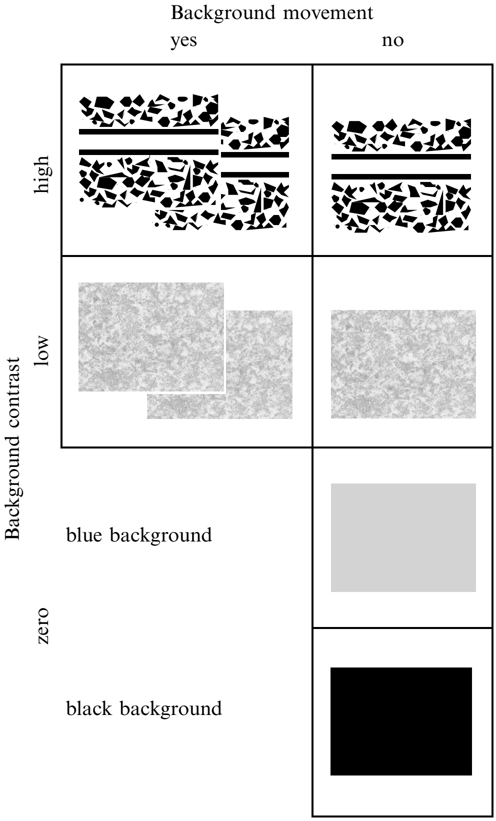

Figure 3. Experimental conditions in experiment 2. Two background types (high-contrast and low-contrast) either moved intrasaccadically with the target (left column) or remained stationary while only the target moved (right column). The remaining two backgrounds (blue and black) were uniform and contour-free (ie zero contrast), making background movement and non-movement equivalent.

There were two backgrounds of differing contrast: the low-contrast background employed in the 'light' condition of experiment 1, and a high-contrast black (luminance 0.4 cd m^{-2}) and white (luminance 23.7 cd m^{-2}) geometric pattern. The latter was modelled on that employed by Mitrani et al (1971), with the target stimuli appearing within the horizontal white area (see figure 3) so that the geometrical shapes would not provide unambiguous position references for the location of the target. Against these backgrounds, the intrasaccadic displacement could occur in two ways. First, the target could move relative to the static background, as in experiment 1. Second, the intrasaccadic displacement could consist of the entire image (ie target and background) moving by the same amount. That is, the target moved intrasaccadically relative to the observer but not relative to the background image. The background image as displayed on the screen was 640 (horizontal) by 480 (vertical) pixels. The background image held in the computer memory was wider than this, so that when the background was shifted by, say, 1 deg to the left, the leftmost 1 deg was hidden while a previously hidden 1 deg strip was exposed along the right-hand edge, so that the image content shifted across the screen but the edges of the image remained stationary.

Crossing the two types of background and the two types of displacement gave four conditions (the upper four cells of figure 3). The final two conditions comprised the black background from experiment 1 and a uniform light-blue background (luminance 2.6 cd m^{-2}), approximately equivalent in average hue to the low-contrast background.

As both of these backgrounds had no contours, target-only and target-plus-background movement conditions were equivalent, and therefore each of these backgrounds was presented in only one block.

Each condition in figure 3 was presented in a separate block of trials, with each subject tested once with each of the six blocks during a single session. The order of presentation of the conditions was balanced across subjects with the use of a Latin square. Saccade sizes were 15, 18, 21, or 24 deg. Intrasaccadic displacements were set as a ratio of the saccade size rather than the absolute sizes used in experiment 1, with displacement ratios of 5%, 7.5%, 10%, 12.5%, 15%, 20%, 25%, or 30% on a given trial. Crossing the saccade size and displacement ratio factors and adding twelve additional ‘catch’ (ie non-displacement) trials yielded 44 trials per block.

2.4 *Analysis*

The dependent variable in both experiments was a categorical (yes/no) response by the subject, indicating the perceived presence or absence of a double target displacement on a given trial. Sensitivity, d', and bias, c, measures were calculated by collapsing observations across subjects. A number of subjects had a zero false-alarm rate in some conditions. Pooling subject data allows false alarms to be ‘shared’ across subjects, thus allowing d' and c to be calculated validly in such situations. Collapsed d' is statistically biased (tending to minimise the true sensitivity) but this bias is negligible if most subjects lie close together in receiver operating characteristic (ROC) space (Macmillan and Kaplan 1985; MacMillan and Creelman 1991).

3 Results

3.1 *Experiment 1*

Sensitivity (collapsed d') was higher in the light (1.58) than in the dark (0.76) (see figure 4a). The 95% confidence interval for the difference between the two was 0.81 ± 0.41. The response criterion c was also higher in the light (1.42) than in the dark (0.72). That is, subjects were more biased to respond “yes” in the dark condition. The 95% confidence interval for the difference was 0.71 ± 0.21. Hence the difference in performance in the two conditions was due to changes in both sensitivity and response criterion. The individual subject data which were pooled to produce these measures

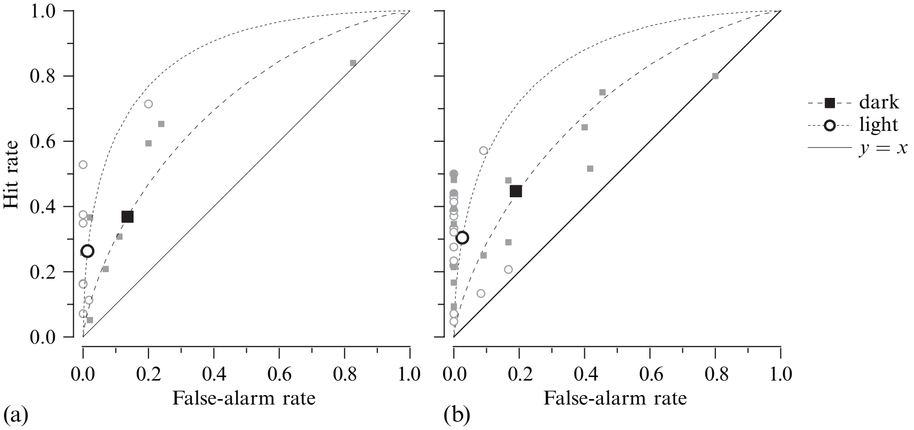

Figure 4. Hit and false-alarm rates for the light (circles) and dark (squares) conditions of (a) experiment 1 and (b) experiment 2. Black data points represent pooled values while grey data points represent individual subjects. The ROC curves were calculated from the pooled d' values. In each experiment, the pooled data point obtained in the dark condition lies on the lower ROC curve, indicating lower sensitivity. However, it is also closer to the apex of its ROC, indicating an increased bias to respond “yes”.

are also plotted in figure 4a. It can be seen that there is a range of performance across subjects.

3.2 *Experiment 2*

3.2.1 *Background effects.* Both conditions from experiment 1 were examined again in experiment 2, and the same comparison was made between them to serve as a replication. Results were strikingly similar: collapsed d' was again higher in the light (1.43) than in the dark (0.74), with a 95% confidence interval for the difference between the two of 0.69 ± 0.51. The criterion c was again higher in the light (1.23) than in the dark (0.51). The 95% confidence interval for the difference was 0.72 ± 0.25. The performance of individual subjects in ROC space is shown in figure 4b. Compared to figure 4a, there is clearer evidence that individual differences underlie the group effect of decreased sensitivity and response criterion in the dark, as there appear to be distinct sub-groups in this condition: some subjects have elevated false-alarm rates whereas others have a zero false-alarm rate and are clustered along the y axis where the results for most subjects in the light condition also lie. The decreased sensitivity to displacements in the dark appears to not be a universal effect but to be due to the performance of a sub-group of the subjects.

All results of experiment 2 are summarised in ROC space in figure 5, with the corresponding d' values given in table 1. As noted above, there was again a much higher response rate in the dark condition, paradoxically indicating lower sensitivity. The remaining five conditions in which there was some form of background illumination are closely clustered together in ROC space, indicating similar sensitivities and biases. Sensitivity and criterion values were significantly different from those in the black-background condition

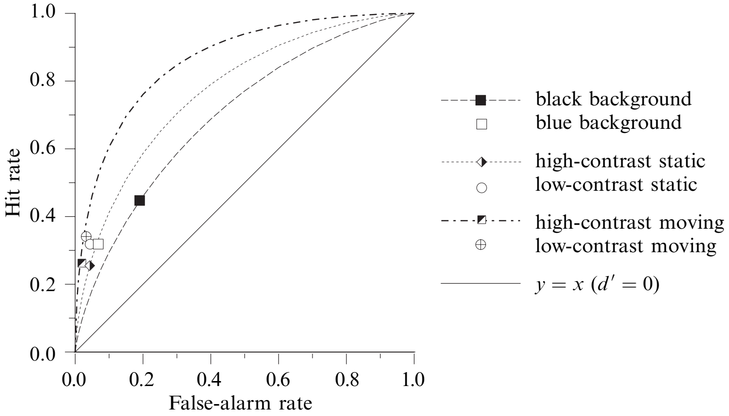

Figure 5. Data from all conditions in experiment 2. All five non-dark conditions lie close together in ROC space. Indicative ROC curves are plotted for the black-background condition ($d' = 0.74$) and for the highest and lowest d' values for the other conditions (1.55 and 1.06).

Table 1. Sensitivity values for each experimental condition in experiment 2 (pooled d' values with 95% confidence intervals). Conditions with sensitivity significantly higher than that of the black-background condition are indicated with an asterisk.

Background contrast	Background movement	
	yes	no
High	1.55 (±0.56)*	1.06 (±0.39)
Low	1.44 (±0.41)*	1.43 (±0.43)*
Zero	blue background	1.09 (±0.36)
Zero	black background	0.74 (±0.27)

in all conditions excepting the blue-background and the static high-contrast background (see table 1). Was the lowered sensitivity in the dark due to an artifact of the increased variability of bias across subjects? Pooling data from subjects with equal sensitivity but widely discrepant bias can lead to a pooled sensitivity estimate which is lower than it should be. In both experiments, however, the points with high bias do actually lie on a lower ROC curve—that is, they indicate that these subjects were genuinely less sensitive.

There was no main effect of background contrast on sensitivity (95% confidence interval of the difference = 0.18 ± 0.43) or bias (0.10 ± 0.21). Neither was there a main effect of background movement on sensitivity (0.21 ± 0.43) or bias (0.05 ± 0.22). Interaction effects cannot be assessed but were unlikely given the magnitude of the differences between data in these conditions, as presented in table 1 and figure 5.

4 Discussion

4.1 *Dark versus light conditions*

We know of only two other papers in which the effect of lighting conditions on SSD has been examined, but in both cases those observations were parenthetical to the main findings. Deubel et al (1996) measured the ability of two subjects to detect discrete displacements of a small red laser spot in complete darkness, and found performance to be essentially identical to that in an illuminated environment. Our results show that, although there is a statistically significant difference in sensitivity between the conditions, it is subtle and is strongly influenced by individual differences in performance (see figure 4), and would be difficult to demonstrate with data from only two observers. Campbell and Wurtz (1978) manipulated lighting conditions such that visual masking could not eliminate vision during eye movements. Using themselves as subjects, they were then able to perceive the reflection of their own saccades, which is normally impossible. This increase in sensitivity may seem at variance with our findings and those of Deubel et al. We contend, however, that what Campbell and Wurtz saw was the blur of their own pupils: a perception of motion rather than of discrete displacement. Dodge's (1900) observation that people cannot perceive the reflection of their own saccades is the canonical example of SSD. Unfortunately, in that phenomenon the non-perception of intrasaccadic movement is confounded with the effects of saccadic omission. Saccadic omission acts to prevent the perception of movement (and most other things) during a saccade. Subjects should still be able to detect that a discrete change in location has occurred despite failing to see the movement directly: SSD is the separate phenomenon which prevents that awareness. By removing the effects of saccadic omission, Campbell and Wurtz directly saw intrasaccadic motion, thus making the detection of displacement immaterial. In both our experiment and that of Deubel et al, dark conditions also eliminated saccadic omission. However, the targets were displaced discretely between locations, necessitating a before-and-after comparison rather than allowing the perception of motion. That is, SSD is a failure to detect differences between locations before and after a saccade, with saccadic omission responsible for hiding events during a saccade. This conclusion supports the contention put forward by Li and Matin that "the invisibility of the saccadic stimulus—due to SSV—indicates that the detection of displacement as measured in SSD is more likely to be based on a comparison of pre- and postsaccadic stimulation than on the displacement itself, although most workers have assumed the latter" (1997, page 1780).

Experiments 1 and 2 are the first experiments in which SSD has been examined under different background illumination levels with a reasonable number of subjects. The results reveal subtle effects of illumination on the magnitude of the SSD effect, with subjects showing both an increased bias to respond "yes", and a slightly decreased sensitivity, to target displacements made against a dark background.

Paradoxically, although the subjects were objectively less sensitive to displacements in darkness, their responses indicated that they believed themselves to be more sensitive.

To explain this result, we must examine the reasons for the changes in both bias and sensitivity. The change in response bias may be due to the lack of saccadic omission in dark conditions (Campbell and Wurtz 1978). Our subjects reported that they perceived red streaks during saccades and afterimages in the subsequent fixations. These were not perceived in the other background conditions as they were presumably eliminated by saccadic omission. These streaks and afterimages would make the target appear less stable and could plausibly have led to erroneous judgments of target displacement. These erroneous judgments would be distributed randomly across both displacement and non-displacement trials, resulting in the false-alarm rate and hit rate both increasing. This corresponds to a lowered response criterion; that is, an increased bias to respond "yes".

Sensitivity, as measured by d', was decreased in the dark in both experiments, leading us to believe that the differential sensitivity is a real, albeit small, effect. It may be due to the lack of visible features other than the target itself, reducing the ability to make judgments of the target location in the absence of a visual 'frame of reference'. This is consistent with the phenomenon in which observers often mislocalise targets that are flashed perisaccadically (Ross et al 1997). Mislocalisation is greater in the dark than in conditions where visual contextual information is available (Honda 1993; Lappe et al 2000), as in the dark the only target-position information available is derived from an extraretinal-eye-position signal. This signal is inaccurate and slow [it "begins about 100 ms before the saccade onset, but it develops so slowly that it cannot catch up with the movement of the eye until more than 50 ms after the end of the saccade" (Honda 1993, page 715)]. Richer and more accurate information is available from vision, which could explain why our subjects were better at detecting changed target positions in the light. There is other compelling evidence that we utilise efferent signals to localise objects when visual information is lacking. Matin et al (1982) temporarily paralysed the oculomotor muscles of volunteers with curare, thus destroying the correspondence between actual eye position and the strength of the efferent oculomotor signal. Subjects made large errors in reporting the location of targets in the dark, yet localisation was normal in a well illuminated environment which provided a visual context for the target. Matin et al concluded that extraretinal signals are not involved in visual localisation in normal viewing but are used when visual structure is lacking. Stark and Bridgeman (1983) found equivalent results, using an eye-press method that created a similar dissociation between the efferent signal and actual eye position. They concluded that while extraretinal information can be used in position perception, it is superseded by visual information in normal structured environments.

An additional explanation for the apparent lower sensitivity in the dark in this experiment is that the stimulus was shifted only toward the previous fixation point. The gain of the efference copy signal is less than unity, and therefore the point of subjective stability occurs when the stimulus shifts slightly in the direction opposite to that of the saccade (Deubel et al 1996). In this study, it may have been that we did not induce a reduction in sensitivity but rather a bias in the point of subjective stability. If the target had shifted further in the direction of the saccade, it is possible that an apparent *increase* in sensitivity would have been observed.

4.2 *Influence of background displacement and contrast*

Robinson et al (2000) examined adaptive changes in saccade amplitude in two monkeys in a variety of conditions similar to those in experiment 2, with the addition of a condition in which the target made the primary step across the background but then remained stationary while only the background was intrasaccadically displaced.

Adaptation occurred in all but this last condition. That is, displacement of the entire background was ignored in preference to the non-displacing behaviour of the small point target. Additionally, there was no difference in the degree of adaptation caused by target displacement across a stationary background and displacements when both the target and the background shifted. It appeared that the target spot drove saccadic adaptation, even though the same information could be gained from background movements. In fact, the only condition under which adaptation was elicited by background movement was one in which the target spot was extinguished for 250 or 1000 ms. It appears that subjects focus their attention exclusively on the movement of a target spot to the extent that movement of a much larger amount of visual information in the background is ignored, and that information from the background is not attended to unless there is no other information available.

The importance of the attention paid to the target spot is consistent with the concept of the 'visual attention focus', which shifts to the saccade target prior to the saccade itself (Ditterich et al 2000). A physiological basis for this attention shift has been found in neurons in the lateral intraparietal area (LIP) which have retinotopic receptive fields that shift prior to a saccade, such that a neuron encodes the same part of a scene immediately before a saccade as in the fixation following it (Duhamel et al 1992; Goldberg et al 2002). Ditterich et al manipulated the size of the visual attention focus by using either a 4.8 deg diameter ring-shaped target or a small point target. Subjects were instructed to follow the movements of the centre of each target. Consequently, a considerable amount of background lay within the attention focus when the ring target was used. It was found that the size of the attention focus was determined by the size of the saccade target. When the ring target was used, the displacement of background elements influenced the rate of adaptation whereas it did not when a small target was used. Thus the size of the visual attention focus selects how much information is able to be compared pre- and post-saccadically.

The results from these adaptation studies explain why we did not observe any influence on the degree of SSD by displacing the entire image. No difference in performance was caused by displacing the large background along with the point target because subjects paid attention exclusively to the target displacements and disregarded the concurrent displacement of the background. In the studies in which the highest displacement ratio thresholds have been found (Bridgeman et al 1975; McConkie and Currie 1996), subjects were asked to detect shifts of an entire large image. In those experiments, however, saccades were made freely across the image rather than in response to a superimposed small moving target. When an experimenter wishes to control the size and timing of saccades by asking subjects to follow a target, any threshold advantage due to the concurrent displacement of a large image will not be realised. This can be seen in figure 6, where the hit rate remains at low levels when the displacement ratio is less than or equal to 12.5%, but then rises rapidly until it begins to saturate near 30%. This shows that the oft-quoted threshold value of the displacement ratio of 30% (derived from the large-image free-saccade study of Bridgeman et al) is clearly not always appropriate for studies with saccades that follow a small target (see also MacAskill et al 1999; Currie et al 2000). (The high threshold found by Bridgeman et al may also be due to that study having measured all possible relative latencies of target and saccade, including displacements that occurred before a saccade was initiated. The strongest suppression of displacement was found about 10 ms after the eye began to move, earlier than the saccade-triggered displacements in many other experiments. By 30 ms after saccade onset, the thresholds found by Bridgeman et al were similar to those found by others.)

The small size of the attention focus when a small target is used also explains the lack of any effect due to background contrast in our experiment. The high-contrast

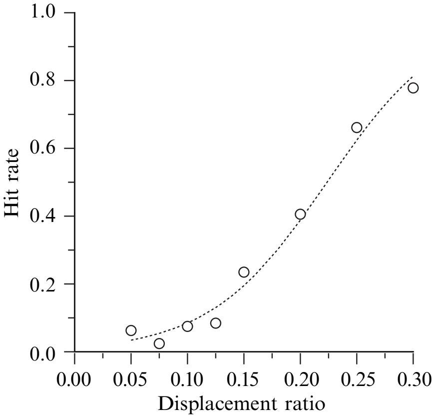

Figure 6. Hit rate as a function of displacement ratio. The data are collapsed across all subjects and all of the experimental conditions in experiment 2 except the black background, as the hit rate was inflated by the decreased response criterion in that condition. The data are fitted by logistic regression.

background provided an array of geometrical shapes that were intended to provide a visual frame of reference against which to judge target location. For clarity, however, the target appeared within a clear horizontal strip in the middle of the background (see figure 3). The geometrical shapes would thus have been outside the area of the attention focus and their influence on localisation would therefore have been minimal. Our low-contrast background also offered no improvement over the zero-contrast background. As shown by Ditterich et al (2000), even when the target is placed directly over features in the background, the visual attention focus is specific enough to disregard them. Our results are consistent with saccade target object theories (Deubel et al 1996, 1998; Currie et al 2000), in which visual stability is maintained in spite of saccades by way of processing focused on the region local to the target object of the saccade rather than by some global remapping of visual coordinates.

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