

VOLUNTARY SELECTION OF THE TARGET FOR SMOOTH EYE MOVEMENT IN THE PRESENCE OF SUPERIMPOSED, FULL-FIELD STATIONARY AND MOVING STIMULI

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Abstract—Prior work has shown that smooth eye movements in the presence of both stationary and moving stimuli are determined, at least in part, by the voluntary selection of either the stationary or the moving stimulus as the target for smooth eye movements. The effectiveness of voluntary selection in eliminating the influence of the stimuli not selected (i.e. backgrounds) on smooth eye movement is not known because prior studies used targets and backgrounds with different physical characteristics. Thus, effects of voluntary selection were confounded with the relative strength of target and background as stimuli for smooth eye movements. We measured eye movements (resolution 1') of two highly-experienced eye movement subjects with a target and background with the same physical characteristics: two, identical, full-field, superimposed patterns of randomly-positioned dots (1 dot/deg² or 8 dots/deg²). One field was stationary and the other moved at 70.2 minarc/sec. The effect of the moving background on smooth eye movements when the stationary field was the target, and the effect of the stationary background on smooth eye movements when the moving field was the target was negligible (0-4% for one subject; 0-2% for the other). The influence of the background on smooth eye movements was affected by a six-fold reduction in the intensity of either the target or background, but effects of such intensity changes were small and different for each subject. Taken together, these results show that the effectiveness of voluntary selection in eliminating the influence of background stimuli on smooth eye movements can be virtually complete. Any observed influence of the background—however small—can be attributed to voluntary factors (e.g. subjects' failure to apply sufficient effort or attention) rather than to the operation of an involuntary mechanism that automatically integrates velocity information from target and background. The attention and effort required to ensure that voluntary selection is perfect may impair the accuracy of psychophysical judgments made about the background.

Eye movements Smooth pursuit Attention

INTRODUCTION

Evidence has accumulated since Mach (1906/1959) showing that smooth eye movements made in the presence of both stationary and moving stimuli are determined, at least in part, by the observer's selection of either the stationary or the moving stimulus as the target for smooth eye movements. For example, a number of investigators have shown that the instruction to pay attention to a small stationary target (Mach, 1906/1959; Dodge and Fox, 1928; Fischer and Kornmuller, 1930; Stark, 1971; Murphy *et al.*, 1975; Tamminga, 1983), or to a stabilized, central scotoma (Cheng and Outerbridge, 1975; Dubois and Collewijn, 1979) superimposed on a large pattern of moving stripes, leads to inhibition of smooth pursuit of the background stripes. The role of voluntary selection is not, however, limited to inhibition of smooth pursuit by the selection of a stationary target. Voluntary selection is also effective in initiating smooth pursuit of a moving target. For

example, some of the studies cited above reported that smooth pursuit of the background stripes was initiated by the voluntary decision to track the stripes (Murphy *et al.*, 1975) or, in the case of studies employing the stabilized, central scotoma, by the instruction to ignore the scotoma and pay attention to the stripes (Cheng and Outerbridge, 1975; Dubois and Collewijn, 1979). Other studies have demonstrated the role of voluntary selection in initiating smooth pursuit by showing that subjects can voluntarily elect to track either one of two moving targets (Ter Braak, 1936; Collewijn *et al.*, 1982) or voluntarily elect to track a point moving across a stationary background (Collewijn and Tamminga, 1984; Tamminga, 1983).

These studies show that smooth eye movements are not determined solely by involuntary, automatic processing of all available stimulus motions. Rather, the contribution of some stimulus motions to smooth eye movements can be reduced by voluntary selection of the target. The extent to which voluntary selection

can be effective in reducing the influence of background stimuli on smooth eye movements when subjects perform at capacity levels has not yet been determined.

Determining the effectiveness of voluntary selection is important because of its implications for interpreting characteristics of smooth eye movements made in the presence of stationary and moving stimuli. Suppose, for example, that voluntary selection is found to be completely effective in eliminating the influence of background stimuli provided that subjects do their best to maintain the line of sight on the target and ignore the background. This result means that observed instances in which the background is found to influence smooth eye movement (e.g. Stark, 1971; Cheng and Outerbridge, 1975; Dubois and Collewijn, 1979; Tamminga and Collewijn, 1981; Tamminga, 1983; Collewijn and Tamminga, 1984) may be accounted for by decisions on the part of the subject. For example, an influence of a background stimulus could result from the decision to pay some attention to the background rather than attend exclusively to the target. Suppose, on the other hand, that voluntary selection is found to be at best only partially effective in eliminating influence of background stimuli on smooth eye movement. This result means that observed instances in which the background is found to influence smooth eye movements are due, at least in part, to the involuntary operation of some, as yet unspecified, neural mechanism that integrates different patterns of image motions occurring at different locations across the retina. Thus, understanding the capacity of voluntary selection to eliminate the influence of background stimuli on smooth eye movements is essential to avoid confusing effects of voluntary decisions on the part of the subjects with effects of involuntary neural mechanisms on smooth eye movements.

Prior studies are inadequate to determine whether voluntary selection is completely effective in eliminating the influence of background stimuli on smooth eye movements. There are two problems with the prior studies. First, some prior studies did not report quantitative analyses of eye velocity, but instead reported only that the decision to fixate either the stationary or moving stimulus affected smooth eye movements (Mach, 1906/1959; Dodge and Fox, 1928; Fischer and Kornmuller, 1930; Ter Braak, 1957). Second, the studies that did report quantitative analyses of eye velocity reached conflicting conclusions. Some reported that the influence of background stimuli on smooth eye movements could be almost completely eliminated (Murphy *et al.*, 1975). Others reported that the influence of background stimuli could be at best only partially eliminated (Stark, 1971; Cheng and Outerbridge, 1975; Dubois and Collewijn, 1979). Still others reported that the influence of the background stimuli depended on the task. Tamminga (1983) provides an example of the last case. He found that a moving background had no

effect on smooth eye movements with a stationary point. But, a stationary background impaired smooth pursuit of a moving point.

One likely reason for the different conclusions drawn by these prior studies is that all used target and background stimuli which differed in physical characteristics, such as size, luminance, and retinal location. This means that the effectiveness of voluntary selection was confounded with the relative strength of the target and the background as stimuli for smooth eye movements. Thus, studies reporting highly effective selection may have employed strong targets and weak backgrounds, while studies reporting partially effective selection may have employed weak targets and strong backgrounds.

The experiment reported in this paper examined the effectiveness of voluntary selection unconfounded by the relative strength of the target and background as stimuli for smooth eye movements. This was done by using a target and background stimulus with identical physical characteristics. The stimuli were two, full-field, superimposed patterns of randomly-positioned dots. One of the patterns was stationary, and the other moving. These patterns were identical in that the size, density, and luminance of the dots in each pattern were the same, and in that each pattern filled the visual field at all times, regardless of the subjects' eye movements. Thus, any observed influence of the background stimulus on smooth eye movements could only be due to failure of voluntary selection to be completely effective in determining the target.

Influence of the background stimulus could, of course, be caused by failure of subjects to perform at capacity levels. This possibility was minimized by using experienced eye movement subjects who were carefully instructed about the task.

We found that when the target and background stimuli were physically identical, the ability to voluntarily select the target for smooth eye movements and eliminate influence of the background could be perfect. Changing the luminance of the target relative to the background diminished this ability somewhat. The implications of these results for understanding the effects of voluntary selection and attention on smooth eye movements will be discussed.

METHODS

Eye movement recording

Horizontal eye movements were measured with an induction coil mounted in a scleral silicone annulus, worn in an a.c. magnetic field (Collewijn *et al.*, 1975). Motion of only the left eye was recorded while the right eye was covered by a patch. The head was stabilized by chin, forehead, and temple supports. Eye movements were stored digitally at 333 Hz by a DEC PDP 11/10 computer. Eye movements as small as 1 min arc could be resolved. Calibration factors for each subject were determined behaviorally by asking

them to fixate a point target which was moved in calibrated steps.

Stimuli

The stimuli were two superimposed fields of randomly-positioned dots, rear-projected on a translucent screen located in an otherwise dark room. The size of the visible portion of the random-dot fields (76 deg horizontally by 87 deg vertically) was limited by the field coils of the eye movement recording system which appeared as vague shadows at the edges of the subject's field of view. No other objects were visible to the subject.

Each dot was actually a small rectangle (7.1 min arc horizontally by 9.5 min arc vertically) with a luminance of 8.9 cd/m². The density of the dots in each field was 1/deg², which means that about 1.4 dots/field were imaged within the 80 min arc floor of the fovea (Polyak, 1941). Both the luminance and the density of the dots were changed in subsequent experiments to be described later.

Either one of the random-dot fields, or both fields superimposed, were presented on any trial. One of the fields always remained stationary. The other field was moved to the left at a constant velocity of 70.2 min arc/sec by means of servo-controlled mirrors mounted in the light pathway. This velocity was chosen for two reasons. First, it is an effective stimulus for smooth pursuit (e.g. Puckett and Steinman, 1969; Dubois and Collewijn, 1979). Second, the velocity was low enough so that the smeared image of the dots on the retina would not impair their visual resolution even when the line of sight was maintained on the stationary field in the presence of the moving background, or on the moving field in the presence of the stationary background (Westheimer and McKee, 1975; Murphy, 1978).

Conditions

Four conditions were tested, differing according to the stimulus and according to the instruction. The conditions were:

(1) *Stationary/Stay*. Only the stationary random dot field was presented. The subject was instructed to use smooth eye movements to maintain the line of sight on the random-dot field. In this condition, as in the others, described below, the subject was free to choose whether to maintain the line of sight on a single dot, or on a group of dots.

(2) *Moving/Track*. Only the moving random dot field was presented. The subject was instructed to use smooth eye movements to track the motion of the field.

(3) *Both/Stay*. Both the stationary and the moving random dot fields were presented. The subject was instructed to use smooth eye movements to maintain the line of sight on the stationary field in an attempt to mimic performance in trials when only the stationary field was presented.

(4) *Both/Track*. Both the stationary and the mov-

ing random dot fields were presented. The subject was instructed to use smooth eye movements to track the moving field in an attempt to mimic performance in trials when only the moving field was presented.

Trials were run in blocks of 20. Each block consisted of four 5-trial sequences, one sequence for each of the 4 conditions described above. Within each block of 20 trials the order of running the conditions was constrained only in that the two conditions in which one field was presented were always run before the two conditions in which both fields were presented. This order was used to aid the subject, during trials in which both fields were presented, in following the instruction to mimic performance when only one field was presented. The relative order of the conditions using one random dot field and the relative order of the conditions using both random dot fields was varied from block to block so that all possible orders were used during a single session.

Procedure

The stimulus to be used on that trial was presented before the trial began. Trials, which lasted 3 sec, were started by the subject who pressed a button when ready. Data acquisition began immediately after the button press.

Subjects

Subjects were H. Collewijn (H.C.) and R. Steinman (R.S.), both highly experienced in eye movement experiments. H.C. is myopic and wore his usual spectacles during the recording sessions. R.S. did not require spectacle correction.

Trials

A total of 400 trials were run for H.C. and 240 for R.S. in two recording sessions.

Data analysis

Eye movement data were analyzed by computer programs which computed average eye velocity for 21 msec intervals during the 3 sec trials by means of a "sliding-window" technique. This technique computed eye velocity of overlapping 21 msec intervals whose onsets were separated by 3 msec. Intervals containing saccades were removed from the analyses. These saccades were detected by means of a computer algorithm employing velocity, acceleration and duration criteria. Details of the algorithm are described in Tamminga (1983). Inspection of analog eye movement records, in which flags marked the saccades detected by the computer algorithm, confirmed that the algorithm accurately detected the saccades.

The number of saccade free 21 msec velocity samples/trial ranged between 887 and 1019 for R.S. and between 913 and 1020 for H.C. These samples were used to compute the mean 21 msec eye velocity for each trial. The results to be described were based on averages of these trial means.

RESULTS

The presence of a moving background had little effect on smooth eye movements with the stationary target

The difference between mean 21 msec eye velocity with and without the moving background was only 1.3 minarc/sec for R.S. and 1.6 minarc/sec for H.C. These differences were 1.3 and 2.3%, respectively, of the velocity of the background. These results are illustrated by the representative records in Figs 1 and 2 and summarized by the mean 21 msec eye velocities shown in Fig. 3.

The observed small effect of the background on mean eye velocity was due to an effect of the moving background on the direction of smooth eye movements. The moving background increased (from 0.08

to 0.35) the proportion of trials in which H.C.'s smooth eye movements were in the direction of background motion (i.e. leftward) and increased (from 0.27 to 0.52) the proportion of trials in which R.S.'s smooth eye movements were opposite to the direction of background motion (i.e. rightward). However, the background had little effect on the velocity of smooth eye movements in these directions. The velocity of H.C.'s leftward smooth eye movements increased by only 0.4 minarc/sec, and the velocity of R.S.'s rightward smooth eye movements increased by only 0.7 minarc/sec in the presence of background motion. These increases were less than 1% of the velocity of the background. Eye velocity in the remaining trials in which R.S. drifted leftward and H.C. rightward, decreased in the presence of the

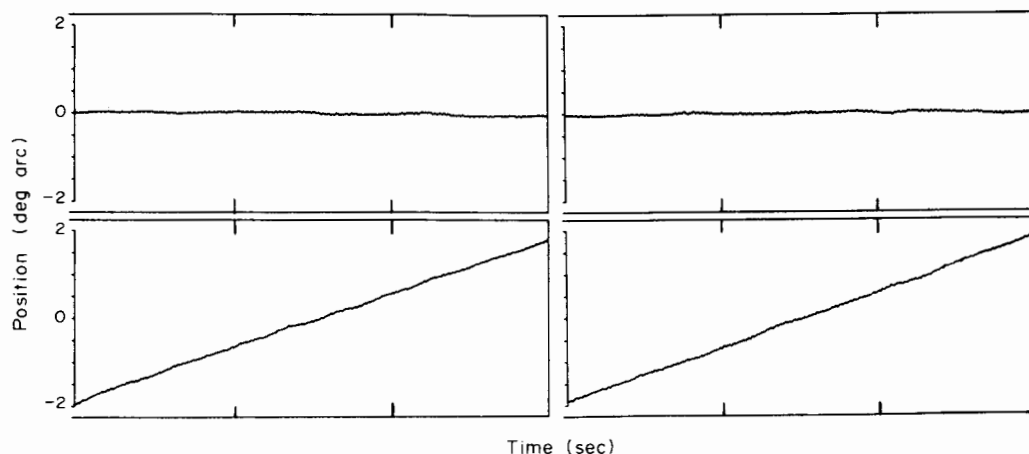


Fig. 1. Representative records of horizontal eye movements for subject R.S. under instructions to maintain the line of sight on the 1 dot/deg² stationary (top 2 graphs) or moving (bottom 2 graphs) target field in the presence of the stationary field alone (top left), the moving field alone (bottom left), or both the stationary and moving fields (2 righthand graphs). Tic marks on the X-axis separate 1 sec intervals. Upward deflections of the eye trace indicate movements to the left.

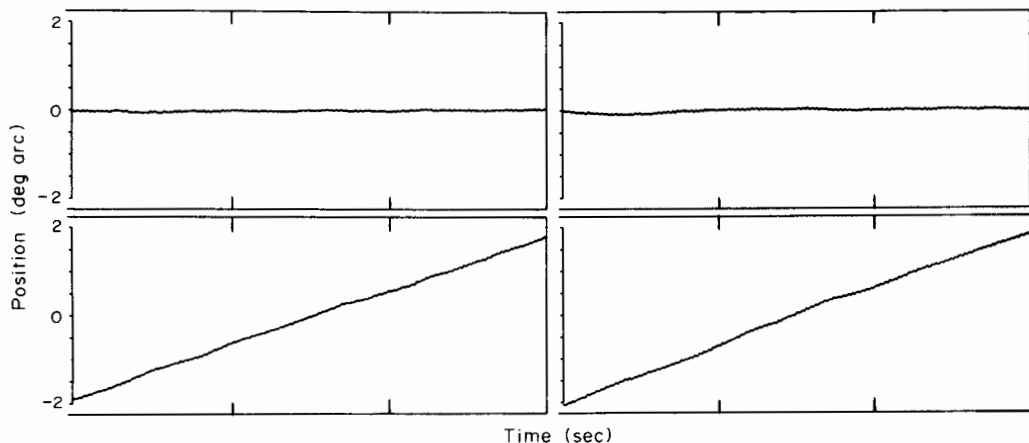


Fig. 2. Representative records of horizontal eye movements for subject H.C. under instructions to maintain the line of sight on the 1 dot/deg² stationary (top 2 graphs) or moving (bottom 2 graphs) target field in the presence of the stationary field alone (top left), the moving field alone (bottom left), or both the stationary and moving fields (2 righthand graphs). Tic marks on the X-axis separate 1 sec intervals. Upward deflections of the eye trace indicates movements to the left.

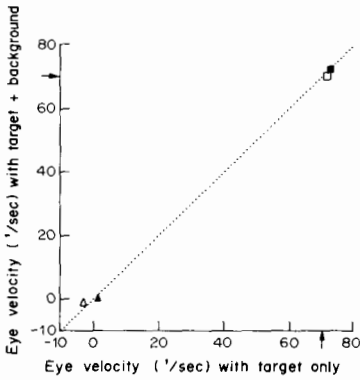


Fig. 3. Mean 21 msec eye velocities for subjects H.C. (open symbols) and R.S. (solid symbols) under the instruction to maintain the line of sight on the 1 dot/deg² target field presented either alone (abscissa) or with the superimposed background field (ordinate). Triangles show eye velocity when the stationary field was the target, squares where the moving field was the target. Each mean velocity is based on 40 trials for H.C. and 30 for R.S. Standard errors are smaller than the plotting symbols. Negative values on the axes indicate rightward velocities. The arrow indicates the velocity of the moving field. Velocities falling on the dotted diagonal line indicate no effect of the background. Velocities falling above the line, when the stationary field was the target, indicate smooth eye movements in the direction of the moving background. Velocities below the line, when the moving field was the target, indicate smooth eye movements slowed by the stationary background.

background for both subjects. As was the case for the increases in velocity described above, the magnitude of these decreases was less than 1% of the velocity of the background.

The presence of background motion did not cause the subjects to make saccades. H.C. made only 1.2 saccades/3-sec trial with no background motion and 1.3 saccades/trial with background motion. R.S. made 0.4 saccades/trial with no background motion and 0.3 saccades/trial with background motion.

The results described above show that background motion had almost no effect on eye movements. In contrast to this result, background motion had the following striking effect on perception: The stationary field of dots was never seen as stationary when the two fields were superimposed. Rather, it always appeared to be moving to the right at about the same speed as the leftward moving background. The perception of this induced rightward motion may have been responsible for the small rightward shift in R.S.'s smooth eye movements described above. Even if this were the case, however, the shift in R.S.'s smooth eye movements does not argue for a strong influence of perceived induced motion on eye movements for two reasons. First, the mean velocity of R.S.'s smooth eye movements in the direction of the perceived motion was slow (2.0 minarc/sec) and, as was described above, almost the same as his mean eye velocity when the stationary field was seen by itself. Second, H.C. did not show any influence of the

rightward perceived motion. His smooth eye movements shifted to the left.

The presence of the stationary background had little effect on smooth eye movements with the moving target

With no stationary background, both subjects' average smooth pursuit velocity was slightly faster than the velocity of the moving field. Finding that the average velocity of smooth pursuit can be slightly faster than the velocity of the target with moderately slow, predictable target motion has been reported before (Kowler *et al.*, 1978; Kowler and Steinman, 1979; Collewijn and Tammenga, 1984; Martins *et al.*, 1985). The new finding is that the stationary background did not impair this pursuit. The largest effect of the stationary background was a 1.5 minarc/sec reduction in average eye velocity for H.C. This reduction was only 2.1% of the velocity of the moving field. These results are illustrated in Figs 1 and 2 and summarized in Fig. 3.

The finding that the stationary background had little effect on average smooth pursuit velocity was not due to averaging of trials in which the stationary background strongly inhibited smooth pursuit with trials in which the stationary background strongly facilitated smooth pursuit. To show that such strong inhibition and strong facilitation did not occur, we computed mean eye velocity separately for trials in which the mean eye velocity of the trial was slower than, and faster than, the velocity of the target. The largest effect of the stationary background was a 2.0 minarc/sec reduction in H.C.'s mean eye velocity for trials in which he tracked slower than the moving field. This reduction was less than 3% of the velocity of the moving field.

Saccade rates were increased by the stationary background, but as was the case for smooth eye movements with the stationary target, saccades were relatively infrequent even in the presence of the background. The background increased H.C.'s saccade rate from 1.3 to 1.8 saccades/trial and R.S.'s saccade rate from 0.4 to 0.9 saccades/trial.

In summary, background stimuli have almost no effect on eye movements. Subjects demonstrated almost perfect capacity to select which of two superimposed, identical fields of random dots was to be the target for smooth eye movements. The next experiment demonstrated this capacity when the task was made more difficult by increasing the density of the dots in each field.

The ability to maintain the line of sight on the target field was not impaired by increasing the density of the dots

It was possible that the subjects' success at avoiding influence of the background field on smooth eye movements, demonstrated in the previous experiment, was due in part to their selection of a dot, or group of dots, from the target field that remained superimposed on a relatively sparse section of the

background field during the trials. This possibility was ruled out in the present experiment by increasing the density of dots in each field to 8 dots/deg². At this density, about 11.2 dots from each field were contained within the 80 minarc diameter foveal floor. Thus, with these fields, unlike the fields used in the previous experiment, selection of dots from the target field in a region relatively free of dots from the background field was impossible. Instead, dots from the target field were continually colliding with dots from the background field during each trial. All other aspects of stimuli and procedures were the same as in the previous experiment.

R.S.'s performance with the dense field was about the same as his performance with the sparse fields in the previous experiment. That is, when the target was the stationary field, the moving background increased (from 0.3 to 0.8) the proportion of trials in which smooth eye movements were opposite to the direction of the background motion and increased slightly (by 1.8 minarc/sec) the average velocity of the eye in these trials. When the target was the moving field, the stationary background reduced the average velocity of his eye slightly (2.5 minarc/sec, or, 3.6% of the velocity of the moving field).

H.C.'s performance was better with the dense field than it was in the previous experiment with the sparse field in that with the dense field he showed no effect of the background on smooth eye movements. The proportion of smooth eye movements in either direction was not changed by the presence of either the stationary or the moving background. Mean eye velocity in either direction changed by only 0.5 minarc/sec in the presence of a background. Eye velocity averaged over trials for H.C. and R.S. are shown in Fig. 4.

Saccades were generally less frequent in the presence of the background. H.C.'s saccade rate decreased from 1.2 to 0.9 saccades/trial with the moving background, and from 1.5 to 1.2 saccades/trial with the stationary background. R.S.'s saccade rates were 0.2 saccades/trial both with and without the moving background, and decreased from 0.4 to 0 saccades/trial with the stationary background.

These results show that the ability to select the target for smooth eye movements is almost perfect even when the difficulty of the selection is increased by increasing the density of dots in both target and background fields. The next experiment shows that the ability to select the target can be demonstrated when the task is made still more difficult by decreasing the intensity of the target.

The ability to maintain the line of sight on the target was slightly impaired by decreasing the intensity of the target relative to the background

To examine the effect of intensity on the ability to maintain the line of sight on the selected target, the luminance of one field was reduced to 1.5 cd/m² while the luminance of the other field remained at the value

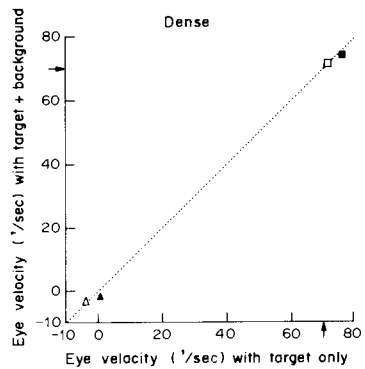


Fig. 4. Mean 21 msec eye velocities for subjects H.C. (open symbols) and R.S. (solid symbols) under the instruction to maintain the line of sight in the 8 dot/deg² target field presented either alone (abscissa) or with the superimposed background field (ordinate). Triangles show eye velocity when the stationary field was the target, squares where the moving field was the target. Each mean velocity is based on 20 trials for H.C. and 10 for R.S. Standard errors are smaller than the plotting symbols. Negative values on the axes indicate rightward velocities. The arrow indicates the velocity of the moving field. Velocities falling on the dotted diagonal line indicate no effect of the background. Velocities falling above the line, when the stationary field was the target, indicate smooth eye movements in the direction of the moving background. Velocities below the line, when the moving field was the target, indicate smooth eye movements slowed by the stationary background.

used in the previous experiment (8.9 cd/m²). The reduced luminance value of 1.5 cd/m² was chosen by asking subjects to adjust the intensity of one field until its dots could just barely be detected among the dots of the other, more intense, field.

Only the dense (8 dots/deg²) pattern of dots was used. All other aspects of the stimuli and procedures were the same as in the previous experiment.

Decreasing the intensity of the stationary field had little effect on smooth eye movements when the stationary field was presented alone. Differences between mean eye velocity with the dim stationary field (see Fig. 5) and mean eye velocity with the more intense stationary field used in the prior experiment (see Fig. 4) were less than 2 minarc/sec for each subject. Similarly, decreasing the intensity of the moving field had little effect on smooth pursuit when the moving field was presented alone. Differences between mean smooth pursuit velocity with the dim moving field (see Fig. 5) and mean smooth pursuit velocities with the more intense moving field (see Fig. 4) were less than 3 minarc/sec. These results confirm prior findings (Steinman, 1965; Winterson and Steinman, 1978) that luminance does not affect smooth eye movements when one stimulus, either stationary or moving, is presented alone.

The ability to maintain the line of sight on the target when both fields were presented simultaneously was only slightly impaired by reducing the intensity of the target. When the target was the dim stationary field, R.S.'s mean eye velocity increased by

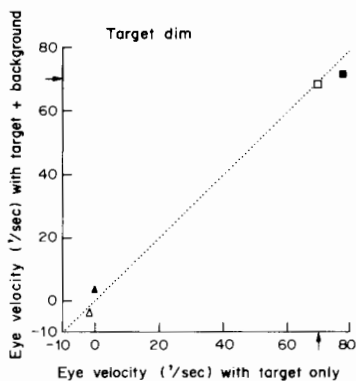


Fig. 5. Mean 21 msec eye velocities for subjects H.C. (open symbols) and R.S. (solid symbols) under the instruction to maintain the line of sight on the 8 dot/deg² dim target field presented either alone (abscissa) or with the superimposed background field (ordinate). Triangles show eye velocity when the stationary field was the target, squares where the moving field was the target. Each mean velocity is based on 20 trials for H.C. and 10 for R.S. Standard errors are smaller than the plotting symbols. Negative values on the axes indicate rightward velocities. The arrow indicates the velocity of the moving field. Velocities falling on the dotted diagonal line indicate no effect of the background. Velocities falling above the line, when the stationary field was the target, indicate smooth eye movements in the direction of the moving background. Velocities below the line when the moving field was the target, indicate smooth eye movements slowed by the stationary background.

3.7 minarc/sec in the direction of background motion (see Fig. 5). This effect of background motion was larger and in a different direction than the effect found in the previous experiments when the intensity of target and background were equal (Figs 1 and 2). Nevertheless, the effect of the moving background was small when the stationary target was dim. R.S.'s 3.7 minarc/sec increase in mean eye velocity in the direction of background motion is only 5.3% of the velocity of the moving background. Analogous results were observed when the target was the dim moving field. R.S.'s mean smooth pursuit velocity in the presence of the stationary background decreased by 5.7 minarc/sec from his mean smooth pursuit velocity when no stationary background was present. This decrease in mean smooth pursuit velocity, although twice as large as the decrease observed in the previous experiment when the intensity of the target and background were equal, is only 8% of the velocity of the moving field.

The influence of background stimuli on H.C.'s smooth eye movements with the dim target was less than the influence observed for R.S., although H.C. did not demonstrate the complete independence from the background that he showed in the previous experiment when the intensities of the target and background were equal. H.C.'s mean eye velocity when maintaining the line of sight on the dim stationary target was increased, and his mean eye velocity when tracking the dim moving target was decreased,

by the presence of the intense moving background. But the largest effect of the moving background was a 2.5 minarc/sec increase in the mean eye velocity in the direction of the background motion. This increase is only 3.6% of the velocity of the moving field. These results are summarized in Fig. 5.

When the intensity of the background field was reduced, R.S. showed no effect of the background on smooth eye movements. His mean eye velocities, shown in Fig. 6, were the same with and without the background. H.C. performed differently in that the effects of the dim background on his smooth eye movements (see Fig. 6) were similar to the small effects of the background on smooth eye movements with the dim target (Fig. 5). In neither case did he show the complete independence from the background that he showed when the intensity of target and background were equal (see Fig. 3).

Saccades were infrequent and not affected by the presence of the background, regardless of whether target or the background were dim. H.C.'s saccade rate decreased from 2.7 to 0.9 saccades/trial, and R.S.'s remained at 0.3 saccades/trial in the presence of background motion when the stationary target was dim. H.C.'s saccade rate decreased from 2.1 to 1.4 and R.S.'s from 0.8 to 0.4 saccades/trial in the presence of the stationary background when the moving target was dim. H.C.'s saccade rate decreased from 1.9 to 1.3 and R.S.'s increased from 0.3 to 0.7 saccades/trial in the presence of the dim, moving

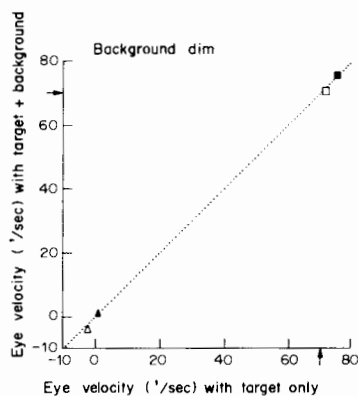


Fig. 6. Mean 21 msec eye velocities for subjects H.C. (open symbols) and R.S. (solid symbols) under the instruction to maintain the line of sight on the 8 dot/deg² target field presented either alone (abscissa) or with the superimposed dim background field (ordinate). Triangles show eye velocity when the stationary field was the target, squares when the moving field was the target. Each mean velocity is based on 20 trials for H.C. and 10 for R.S. Standard errors are smaller than the plotting symbols. Negative values on the axes indicate rightward velocities. The arrow indicates the velocity of the moving field. Velocities falling on the dotted diagonal line indicate no effect of the background. Velocities falling above the line, when the stationary field was the target, indicate smooth eye movements in the direction of the moving background. Velocities below the line, when the moving field was the target, indicate smooth eye movements slowed by the stationary background.

background. H.C.'s saccade rate decreased from 2.5 to 1.1 and R.S.'s remained at 0.7 saccades/sec in the presence of the dim, stationary background.

In summary, decreasing the intensity of one of the fields slightly impaired the ability to eliminate the influence of the background on eye movements. Nevertheless, the largest influence of the background, observed for R.S. with the dim target, was small—about 4–8% of the velocity of the moving field. These results show that the ability to select either the moving or the stationary field as the target for smooth eye movements obtains even when the target field is barely perceptible among the elements of the background field.

DISCUSSION

Our results show that voluntary selection can be completely effective in determining which of two, full-field, physically identical, superimposed patterns of random dots—one stationary and the other moving—is to be the target for smooth eye movement. No influence of the background pattern on smooth eye movements was observed in one case (H.C., dense patterns, equal luminance) and negligible influence of the background (1–4%) was observed in all other cases when the target and background were physically identical. These results show that the smooth oculomotor subsystem does not automatically and involuntarily combine information originating from different stimuli in the visual field.

Previously observed instances of influence of a background on smooth eye movements (e.g. Stark, 1971; Cheng and Outerbridge, 1975; Doubois and Collewijn, 1979; Tamminga and Collewijn, 1981), even when such influence was small (Murphy *et al.*, 1975; Tamminga, 1983; Collewijn and Tamminga, 1984), may have been due to failure of subjects to apply sufficient effort or attention to the selection of the target. The suggestion that voluntary processes were responsible for instances in which effects of background stimuli on smooth eye movement were observed is supported by our finding that changing the luminance of one of the fields affected each subject's performance differently. The influence of the background stimulus on H.C.'s smooth eye movements was increased slightly when the luminance of the fields differed, regardless of which field was more intense. But, in contrast to H.C.'s performance, the influence of the background on R.S.'s smooth eye movements depended on which field was more intense. Dimming the target field increased the influence of the background, whereas dimming the background removed all influence of the background. Such idiosyncrasies would not be expected of involuntary mechanisms that analyze target velocity. Such mechanisms would be influenced by stimulus characteristics such as luminance in the same way in all individuals. Idiosyncrasies would, on the other hand, be expected from processes that relied on

subjects' decisions, strategies, or effort in performing the task.

Attributing the effects of background stimuli to the operation of voluntary processes does not show how such processes operate to determine the relative influence of target and background on smooth eye movement. Our results, however, do have implications for one characteristic of voluntary selection, namely, the kind of information used by the smooth oculomotor subsystem to distinguish the target from the background.

Previous investigators have suggested that target and background are distinguished according to location (e.g. Collewijn *et al.*, 1982; Tamminga, 1983). Our results, however, cannot be accounted for by selection of location because the target and background fields we used were not in distinct locations, but rather, overlapped all across the visual field. Even the selection of a single dot as the target would not be sufficient to isolate one location as the target because with our dense patterns, dots from the background field were continually passing across the dots from the target field. Thus, voluntary selection of a location would not provide sufficient information to the smooth oculomotor subsystem to enable it to distinguish target from background as completely as we had observed.

Our results also rule out the possibility that the smooth oculomotor subsystem distinguishes target from background according to the perceived motion of the target. This possibility can be ruled out because the perceived induced motion of the stationary field was not reflected in the subjects' eye movements when the stationary field was the target. If perceived motion were used, then the eye would have moved rightward. Instead, we found that it remained nearly stationary.

The only remaining information which could allow the smooth oculomotor subsystem to successfully distinguish target from background is the perception of a target as a distinct perceptual configuration. In other words, subjects can voluntarily select which configuration is to be the target for smooth eye movements. But, subjects do not need to select either where the target is located, nor where it is moving. This conclusion implies that information about the configuration of a target is provided to the smooth oculomotor subsystem by means of voluntary processes, whereas information about the location or motion of a target is processed independently by the smooth oculomotor subsystem by means of mechanisms not susceptible to voluntary control.

Implications for attention and psychophysical performance

The instruction to selectively attend a region in space can increase the probability of correctly identifying a target from that region in psychophysical tasks (Shaw and Shaw, 1977; Sperling and Melchner, 1978; Shaw, 1982; Sperling, 1983). Does the decision

to select a stimulus as the target for smooth eye movements have the same consequence for psychophysical performance as the decision to selectively attend a region in space?

Determining how the decision to select a stimulus as the target for smooth eye movements affects psychophysical performance is important because many psychophysical experiments require subjects to maintain the line of sight on one stimulus while simultaneously making judgments about other stimuli. Our results show that the subjects can successfully keep the line of sight on the designated target. But the consequences of their success for psychophysical judgments made about the background are not known.

There are hints that such consequences may be severe. Murphy (1978) noticed that subjects could not smoothly pursue a point moving over a stationary background grating while simultaneously judging the contrast of the background. Any attempt to attend to the background in order to make the judgment caused the pursuit to stop. Murphy (1978) did not systematically study this condition because he was interested in measuring contrast sensitivity under conditions where retinal image velocity was known. Thus, he restricted his investigations to the situations in which subjects could make the judgments while simultaneously following the eye movement instructions. He found two: subjects could make judgments about a moving background grating while either simultaneously maintaining the line of sight on a superimposed stationary point, or while simultaneously tracking a superimposed point moving at the same velocity.

Systematic determination of the effects of the selection of a stimulus as the target for smooth eye movements on the ability to make psychophysical judgements about the target or the background will require experiments in which oculomotor performance and psychophysical performance are measured simultaneously. Our results provide the basis for interpreting the results from such experiments. Now that we know that the ability to prevent influence of background stimulus on smooth eye movements is virtually perfect when no concurrent psychophysical task is provided, then any impairment of this ability can be attributed to attention to the psychophysical task, and not to the operation of an involuntary oculomotor mechanism that integrates information from target and background.

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