The effect of imposed fixational eye movements on binocular rivalry

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Simulated microsaccadic eye movements were superimposed on a retinally stabilized image. Their effect on binocular rivalry was examined. The relative dominance of the stabilized image was measured for different values of saccadic repetition rate and amplitude. It was found that the optimal values for these parameters are those which are observed in naturally occurring microsaccades.

Binocular rivalry occurs when corresponding areas of the two retinas are presented with greatly dissimilar stimuli. If the two stimuli are of comparable intensity and spatial frequency, and if the subject has normal binocular vision, he will report alternating periods during which only one of the two stimuli is visible.

In a recent study (Sabrin & Kertesz, 1980), we measured microsaccadic eye movements during rivalry and analyzed them in terms of Levelt's (1965, 1967) suggestion that microsaccades serve as "spikes of information" whose accumulation causes the suppressed stimulus to become dominant. Our major findings were that: (1) the repetition rate of microsaccades increases during rivalry; (2) depending on the eye being suppressed, the microsaccade rate is highest at the beginning of a suppression interval and declines as the interval progresses; and (3) the declining microsaccadic rate may also be observed when one stimulus is physically removed from the subject's view under nonrivalrous viewing conditions.

In the current experiments, we examined whether the repetition rate and amplitude of microsaccades were of importance in determining the relative strength of a stimulus presented during rivalry. We also studied the relative effectiveness of fixational eye-movement parameters in restoring a suppressed image to dominance. This was accomplished by negating the effects of the subject's naturally occurring microsaccades by stabilizing one of the retinal images and then superimposing on it artificial stimulus movements that were designed to mimic microsaccades of a particular type.

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GENERAL METHOD

Three experienced subjects participated in the study; two of them were naive as to the purpose of the experiments. All subjects were able to perceive depth in random-dot stereograms and all had a normal fusional range. All phorias and spherical corrections were compensated during the experiments. Each subject was tested to assure that presentations of rivalrous stimuli led to sudden and complete alternations without intermediate percepts or overwhelming dominance by one eye.

The stimuli, shown in Figure 1, were: dichoptically presented in a mirror stereoscope, displayed on oscilloscopes, and generated by an LSI-11 computer. Binocular alignment of the stimulus was facilitated by fixational rings that were located on the periphery of the patterns (Figure 1). The subject sat in a dark room. He was instructed to fixate the center of the patterns and to observe the rivalry that occurred between the central circles. He was told to decide whether the light or the dark circle was dominant at any instant. He was to depress a button when the light circle was dominant and release it when the dark stimulus center was dominant. The subject was instructed to give as accurate an account of the state of rivalry as possible. This meant that, in case of an error, he was to continue to report his percept and was not to compensate for one false report by making another. If the subject reported that he had made a mistake in a given run, that run was discarded. We had to discard only one run during all of the experiments.

Eye movements were monitored by a double Purkinje image eyetracker, which provided a continuous record of horizontal and vertical eye positions. A detailed description of the eyetracker is given in Crane and Steele (1978). The resolution of the system was evaluated by using an artificial eye, and was found to be 1 min

Figure 1. Monocular images of the dichoptically presented visual stimuli that were used to induce binocular rivalry. The innermost circles subtend 1 deg; the outer annuli subtend 3 and 5 deg, respectively; the entire pattern subtends 14 deg of arc.

of arc for both horizontal and vertical movements. The baseline drift for the eyetrackers over a period of 10 min was also within 1 min of arc. Retinal image stabilization was achieved by feeding the output signals of the eyetracker to the stimulus display control circuit (Kelly, 1975). Simulation of fixational eye movements was accomplished by the addition of computer-generated signals to the voltages controlling the horizontal and vertical stimulus positions on the oscilloscope. The simulated microsaccades were programmed as sudden changes in stimulus position that were followed, after 50 msec, by a sudden return to the original position.

In each experimental run, microsaccades of a particular amplitude, orientation, and repetition rate were simulated only on the oscilloscope screen viewed by the eye whose retinal image had been stabilized. The occurrence of simulated microsaccades was determined by the Poisson distribution, that is, the time interval between successive movements was exponentially distributed. The mean time between successive movements was determined for each run, and a temporal sequence of movements was then generated by the computer. Each run was 1 min long, and was replicated six times.

EXPERIMENT 1

The purpose of this experiment was to measure the effect of microsaccadic repetition rate on stimulus dominance. If microsaccades serve as "spikes of information" that cause a change of rivalry phase to occur, as suggested by Levelt (1967), then a monocular increase in microsaccadic stimulation would be expected to yield an increased dominance of the affected eye.

Method

The mean number of microsaccades occurring within 1 sec was varied between 0 and 6.0, which covered the complete range of normally occurring microsaccades reported by Ditchburn and Foley-Fisher (1967). The movements used in this experiment were horizontal and were 8.25 min of arc in amplitude.

Results

The results are shown in Figure 2. For subjects H.W.S. and J.J.B., the proportion of left-eye dominance increased with repetition rate, but the curve

Figure 2. The results of Experiment 1. Bars represent 95% confidence intervals. Horizontal marks at the lower right represent the left-eye-dominance percentages during stabilization of the left retinal image without simulated microsaccades. Marks at the upper right represent levels obtained during normal viewing.

saturates at a value close to that of the repetition rate of naturally occurring microsaccades. Subject W.M.K. exhibited the same increase at the lower rates but also showed a substantial decline in left-eye dominance as the repetition rate surpassed an optimal value.

For all three subjects, the peaks in left-eye dominance occurred at values below the dominance percentages observed during rivalry between unstabilized images (normal viewing conditions). This implies that oculomotor factors other than microsaccadic repetition rate contribute to the relative strength of a rivalrous stimulus. The incomplete recovery may also be partly attributable to the differences between naturally occurring microsaccades and the simulated ones, for example, differences in the distributions of repetition rates, or the use of sudden image translations rather than more gradual motion, or the lack of efference copy.

The saturation effect observed with two subjects and the declining dominance at high frequencies seen with the third imply that the rivalry mechanism to which the microsaccades contribute must be more complex than that proposed by Levelt (1965), and that it may be overly simplistic to treat microsaccades as all or no "spikes" and view them as just statistical events.

EXPERIMENT 2

Method

In this experiment, the procedure was identical to that of Experiment 1, except that the average repetition rate of the movements was kept constant at 2/sec, and their amplitude was varied between 2.76 and 16.56 min of arc.

Results

The results appear in Figure 3. Subjects H.W.S. and W.M.K. exhibited responses similar to those seen in the first experiment—a saturation response for H.W.S. and a peaked response for W.M.K. The response of J.J.B., who had a saturation response in Experiment 1, exhibited a peak in this experiment when the movement amplitudes were 11.0 min of arc. For all three subjects, a reduced effect was observed at higher amplitudes. The reason for this may be that the movements themselves became noticeable to the subject, and instead of having the subliminal effect of normal microsaccades, they "disturbed" the percept of the pattern, thus reducing its visibility.

The fact that the amplitudes of subliminal events such as microsaccades can have a strong effect on the strength of a rivalrous stimulus implies, once again, that these movements are more complex than mere statistical events.

DISCUSSION

Increasing the repetition rate or amplitude of the simulated microsaccades up to naturally occurring

Figure 3. The results of Experiment 2. Bars represent 95% confidence intervals.

rates increased the percentage of dominance of the affected eye during rivalry. At higher levels, further increases were accompanied by either no change or a decline in dominance. This implies that the rivalry mechanism and the oculomotor system are well matched, in that the parameters most closely associated with natural eye movements were most effective in increasing the visibility of the stimulus.

It was found that rivalry continued to occur in the presence of monocular image stabilization, so fixational eye movements are apparently not a necessary component of the rivalry process. This is in agreement with results obtained during rivalry between stabilized afterimages (Blake, Fox, & McIntyre, 1971; Wade, 1973, 1975, 1977). Even though the introduction of simulated microsaccades was insufficient to restore image dominance to unstabilized levels, they nevertheless may play an important role in maintaining the visibility of a stimulus. While this role is of a general nature, that is, not specific to binocular rivalry, the visibility and strength contributed to an image by fixational eye movements affect the temporal characteristics of the rivalry process. It was noted, during these experiments, that when the dominance percentage of the stabilized eye was increased by the simulated eye movements, the increase was always realized as a decrease in the average suppression interval for that eye. In other words, an increased stimulus strength decreased the interval length during which the eye was suppressed, but did not increase the length of the interval during which the eye was dominant. This finding is in agreement with Levelt's (1965) data, as well as with the work

of others (Blake, 1977; Blake & Camissa, 1979; Fox & Rasche, 1969) who support a model based on partial independence between the monocular channels.

Ciuffreda, Kenyon, and Stark (1979) observed that amblyopic subjects exhibit larger fixational drift movements and fewer than normal microsaccades. It would be interesting to conduct experiments similar to the ones described in this paper on amblyopic subjects, to determine if their binocular function could be improved by using simulated eye movements. Such experiments might help to determine the role that oculomotor dysfunction plays in amblyopia.

In summary, while rivalry can take place in the absence of fixational eye movements, these movements do play an important role and are most effective at normally occurring amplitudes and repetition rates.

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