EFFECT OF FLICKER ON OCULOMOTOR PERFORMANCE†

GENEVIEVE M. HADDAD and BARBARA J. WINTERSON

THIS work began as an investigation of the effect of flicker on saccades. Prior work on this problem is confined to a paper by West and Boyce (1967) who reported that slowly flickering lights have an entrainment effect on the saccadic pattern. We found that flicker did not elicit saccades when subjects were told not to make them. However, flicker did have a surprising and powerful effect on slow control (drift correction).

METHOD

Three subjects participated in these experiments—two through the whole series (the authors, one a highly experienced contact lens subject and the other participating in her first eye movement experiment), and a third experienced subject who confirmed the basic results. The subject, head supported on a biteboard, looked with the right eye at a 17° circular field in Maxwellian view. The source was a green LED (λ_{max} 540 nm $\pm$ 2) whose average luminance was 22 mL. The subject was instructed to suppress saccades and use slow control to maintain the line of sight for 5 sec on a 16′ diam black disk located at the center of the 17° field. When the subject began each trial, the field, which had been steadily illuminated, began to flicker at one of several frequencies (0.5, 1, 2, 5, or 10 Hz). In most experiments a square-wave of 100% modulation was used. Eye movements were recorded by means of an electronic contact lens optical lever whose position sensitivity was about 10″ (Haddad and Steinman, 1973).

RESULTS

Saccade rate dropped as flicker frequency increased, but the highest rate (at 0.5 Hz) was only 0.3 saccade/sec. When the target flickered at 2 Hz, where the greatest entrainment was found by West and Boyce, saccade rate was only 0.2 saccade/sec—one-tenth of the saccade rate observed during normal fixation of a steadily illuminated field. The failure to find an entrainment effect of flicker on saccades was not confined to 5-sec trials. All three subjects were able to suppress saccades (saccade rates <0.2/sec) throughout 75-sec trials in the presence of a field flickering at 2 Hz. They were also able to execute a variety of specified temporal patterns of saccades in the presence of steady or slowly flickering fields. These results suggest that entrainment effects of flicker arise from voluntary cognitive decisions on the part of the subject rather than

†This research was supported by Grant No. 00325 from the National Eye Institute to R. M. Steinman.

from influences of the stimulus on the oculomotor machinery. The slow control subsystem, however, is not ordinarily under voluntary control and flickering lights affect its activity profoundly. They cause the eye to drift from the target position and oscillate as it drifts. These effects are illustrated for each of the subjects in Fig. 1.

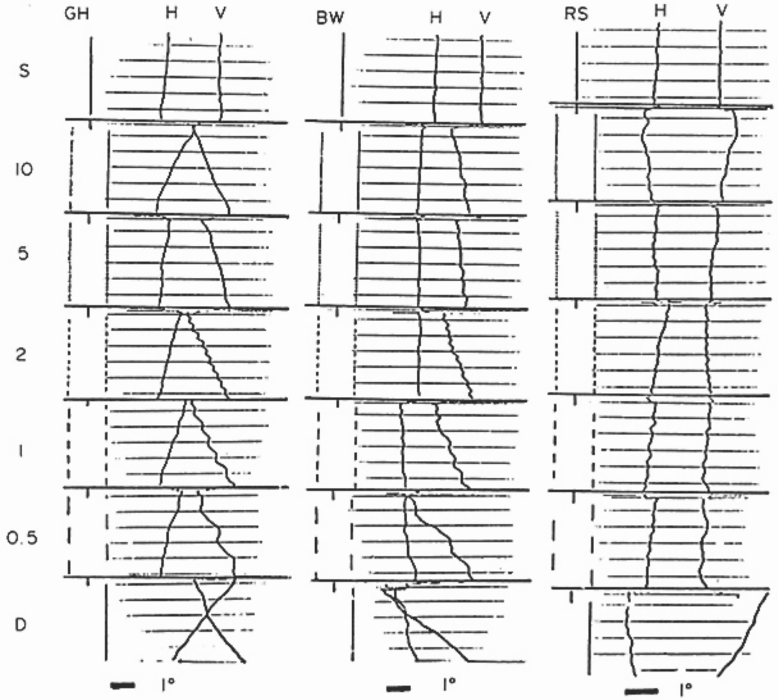

FIG. 1. The effect of a 100% modulation square-wave flicker on the slow control of three subjects (GH, BW, RS). Each of the seven records shown for each subject begins towards the bottom of the figure. The repetitive horizontal lines are a 1 sec time marker and the scale bar beneath each set of records indicates the size of 1° rotations on both the horizontal (*H*) and vertical (*V*) meridians. The bottom records show slow control in the dark (*D*), indicated by the stimulus trace on the left side of each record that is towards the right. Subject GH drifted rapidly up and to the right (the vertical and horizontal traces crossed after 3 sec). Subject BW drifted up and to the left (the eye traces also crossed after 3 sec). RS drifted slowly to the left and rapidly down. The top records show effective slow control when the field was steadily (*S*) illuminated and the intermediate records show what happened when the field flickered at one of five frequencies (0.5, 1, 2, 5, and 10 Hz). The stimulus marker to the left of the eye traces means that the light was completely off when the marker was to the right and fully on when the marker was to the left.

The top records show slow control in the presence of a steadily lighted field where small irregular drifts tend to keep the eye in place very well (S.D. < 3′). The bottom record shows that slow control is lost in the dark and the eye rapidly drifts from its starting position. The intermediate records show oscillations of the eye synchronized with the flicker and also a progressive drift away from the target position. The peak to peak amplitudes of these oscillations are appreciable and inversely related to flicker frequency (ranging from 6′ at 5 Hz to 20′ at 0.5 Hz). The oscillations of the eye follow the flicker with a mean latency of 130 ms (S.D. = 40) for the frequencies where latency could be measured directly from our oscillographic records (0.5, 1, and 2 Hz).† At

† Computer analysis of magnetic tape records is in progress.

10 Hz oscillations are not visible in the eye traces but the progressive uncompensated drift remains.† Two of the subjects (*GH* and *BW*) show these effects on the vertical meridian. *RS* showed the effects on both meridians. These effects are easily obtained as is illustrated in Fig. 2.

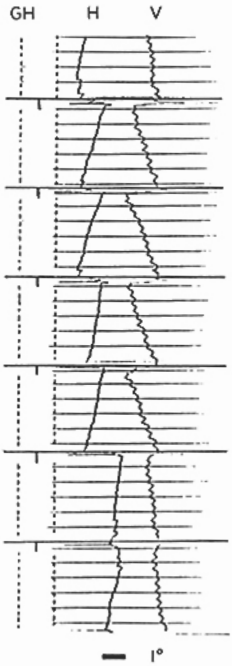

FIG. 2. Seven representative 5 sec consecutive trials of subject GH using slow control to maintain her line of sight at the center of a field that flickered at 2 Hz (100% modulation square-wave). The drift oscillations caused by the flickering light are prominent on the vertical (*V*) meridian and uncompensated drifts are seen on both meridians. Saccades (always confined to the horizontal meridian) were infrequent (0.2 saccades/sec). They were not entrained by the stimulus. The time base, eye-position scale, and stimulus marker are explained in Fig. 1.

These results are not limited to lights moderately high in the photopic range. The basic experiment was repeated 2 log units down (at 0.2 mL) where the peak to peak amplitude of the slow oscillations was found to be the same but the uncompensated drift was considerably reduced. These effects also do not require large flickering fields and do not arise exclusively from either the fovea or the periphery. The experiment was repeated with a foveal disk (4° diam) and also with a peripheral annulus (ID = 7°, OD = 17°). In both cases the oscillations and uncompensated drift remained. The oscillations were about twice as large with the peripheral annulus as with the foveal disk but in both regions their frequency depended completely on the frequency of the flickering field. These effects are also not limited to square-wave stimulation. Both sine and triangle flicker caused the eye to oscillate.

† Several trials were run at 20 and 50 Hz. The oculomotor response at 20 Hz is similar to that at 10 Hz, but at 50 Hz, where the stimulus is just below CFF, slow control returns and there is a suggestion that the stability of the eye is better than it is with a steady light.

Are these effects surprising? At first we thought not. Such results might be expected if the eye drifts in the dark and stabilizes when the light comes on. Oscillations, as well as a progressive drift, would be a natural by-product of alternating uncompensated drifts made in the dark with periods of slow control activated when the field reappears. Both effects could be caused by the periodic removal of the signal for slow control. But the next experiment showed that this was not correct.

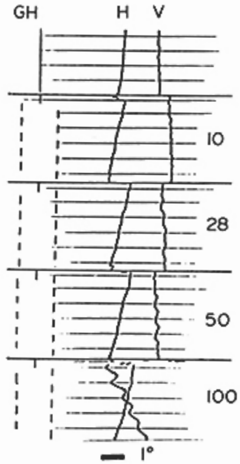

FIG. 3. The effect of modulation depth on oscillations and uncompensated drifts while viewing a 1 Hz square wave flickering field. The percentage of modulation is shown on the right of each record, and the top record shows slow control with a steadily lighted field of the same average luminance. The time base, eye-position scale, and stimulus marker are explained in Fig. 1.

Subjects were provided with a clearly visible non-flickering light that was used throughout the trial to maintain the line of sight at the center of the flickering field. The progressive drift was reduced but the oscillations remained. However, we found that decreasing modulation depth reduced the oscillations. This is illustrated for one subject in Fig. 3 where oscillations are evident at 50%, suggested at 28%, but gone when the modulation was reduced to 10%.

To insure that these effects were oculomotor a number of control experiments were performed. We checked that there was no stimulus artifact by reflecting the stimulus from a mirror attached to the biteboard holder and found no leakage of the stimulus light into the infrared recording system. We taped the lids so that they could not touch the contact lens, repeated the experiment, and found that the oscillations and progressive drift were unaffected. We paralyzed the iris and the lens with a cycloplegic drug and obtained the same result.

SUMMARY

Flickering lights do not force saccades. The entrainment effect found by West and Boyce (1967) was probably due to the fact that subjects, instructed to "fixate", voluntarily correct fixation errors that are produced by uncompensated drifts in the dark and

noticed when the target reappears. Our subjects were instructed to suppress saccades and ignore fixation errors. They were able to do so. Suppression of saccades revealed that flickering lights have a driving effect on slow control. They cause the eye to drift away from target position and oscillate as it drifts.

The underlying mechanism and functional significance of these effects are not known. They might be caused by cross-talk between neural elements in the lower brain where afferent signals, which provide input for accommodation of the lens and iris or for blinking, leak into neural centers used for slow oculomotor control.

ACKNOWLEDGMENTS

We thank R. M. Steinman for allowing us the use of his laboratory, for serving as the third subject in our basic experiments, and for valuable suggestions and observations. We also appreciate the technical assistance of K. Larson, E. Kowler, I. Nicholson and L. Watkins.

REFERENCES

Haddad, G. M. and Steinman, R. M. (1973) The smallest voluntary saccade: Implications for fixation. *Vision Res.* **13,** 1075–1086.

West, D. C. and Boyce, P. R. (1967) The effect of flicker on eye movements. *Vision Res.* **8,** 171–191.