Vision Res. Vol. 11, pp. 743–746. Pergamon Press 1971. Printed in Great Britain.

LETTER TO THE EDITORS

EXTRARETINAL CORRECTION AND MEMORY FOR TARGET POSITION[1]

(*Received* 23 *July* 1970; *in revised form* 20 *November* 1970)

RECENTLY, SKAVENSKI and STEINMAN (1970) reported a study of oculomotor control when the eye depends on what MATIN, MATIN, POLA and PEARCE (1968) have called extraretinal signals (signals that do not arise from the relative location of a target image on the retina). We concluded that there was an extraretinal signal of considerable fidelity because the eye could be kept within 2 deg arc of the target position for more than 2 min after a lighted target was turned off.

Since this work was published, MATIN, MATIN and PEARCE (1970) reported a study of horizontal eye position control during 3 sec in the dark in which they found that the eye movement pattern was nearly random in the following sense: "The pattern of correlations between eye position at a given moment in the dark interval and subsequent displacements contained statistically significant deviations from expectation based on a random walk model indicating some control of eye position by an extraretinal signal; however, these deviations were not large" (MATIN *et al.*, 1970). Furthermore, error (the distance of the line of regard from the prior target position) increased systematically after target removal. In our experiments, although eye position did not change much, it also tended to move slowly away from the prior target position throughout the dark period. This finding, coupled with the MATIN *et al.* (1970) analysis, suggested that the eye in the dark might continue to follow a nearly random process in which error accumulates very slowly for very long periods of time. This was not the case because (1) a correlational analysis of our prior data shows that many eye movements in the dark tend to be corrective and (2) a new experiment, described in this paper, shows that error stabilizes at about 3·5 deg arc over very long periods of time.

1. *Eye movements in the dark tend to be corrective*

(a) *Method.* The apparatus and experimental conditions have been described in detail before (STEINMAN, 1965; SKAVENSKI and STEINMAN, 1970). Briefly, a contact lens optical-lever technique was used to record two-dimensional eye positions of experienced *S*s (RS and AS) who attempted to keep their eyes in the position defined by a target after it had been removed from view. In the first condition, each trial began with about 10 sec of fixation with the target visible in either the primary position (perceived "straight-ahead") or 10 deg arc to the left or right of this position. The target was then switched-off and *S* tried to maintain fixation for 38 sec in total darkness. The second condition was a replication of the first except that the conjunctiva of both of RS's eyes were anesthetized with 0·5% tetracaine hydrochloride to eliminate tactile cues produced by the large scleral contact lens. The third condition was also a replication of the first, except that the target was always presented in the primary position and the orientation of *S*'s torso, relative to his head, was varied. Records were made with

[1] This research was described at the E.P.A. Meeting in Atlantic City, N.J., April 1970.

the head and body pointing in the same direction and with the body rotated to the right or left of the head as far as possible (about 45 deg arc). Data were available for all three conditions for RS and for the first and third conditions for AS. Within each condition, five trials were measured for each of the three eye and body positions (totalling 45 trials for RS and 30 trials for AS). For each of these trials, one paired horizontal and vertical eye position was measured at randomly selected times within successive 0·5 sec periods. In all, 96 paired position measures were made for each trial (20 at the beginning of the trial when the target was visible and 76 during the 38 sec in total darkness).

A correlational analysis was used to determine the degree to which eye movements tend to be corrective. A straightforward way to determine the degree of correction in two-dimensional eye position data is to: first, convert each eye position measure to an absolute fixation error (absolute distance between mean eye position when the target was visible and eye position during the sampled 0·5 sec period). Then, calculate Pearson Product–Moment correlations between the following two quantities: (1) the absolute fixation error at a 0·5 sec sample and (2) the algebraic change in the fixation error 0·5 sec later.[2] If there is no "correction" in the eye movement pattern, then algebraic changes in fixation error would not be related to the amount of fixation error 0·5 sec earlier (the expected correlation would be zero). However, in a corrective movement pattern, subsequent movements should tend to reduce fixation error, and a significant negative correlation would be expected.

(b) *Results*. Figure 1 shows correlations between absolute fixation errors and subsequent algebraic changes in the errors. Many eye movements were corrective, both when the target was visible and also in the dark. The amount of correction was less in the dark. Correlations dropped from about −0·6 when the target was visible to about −0·3 after it had been removed from view. Only AS's first 3 sec in the dark failed to show correction. RS began

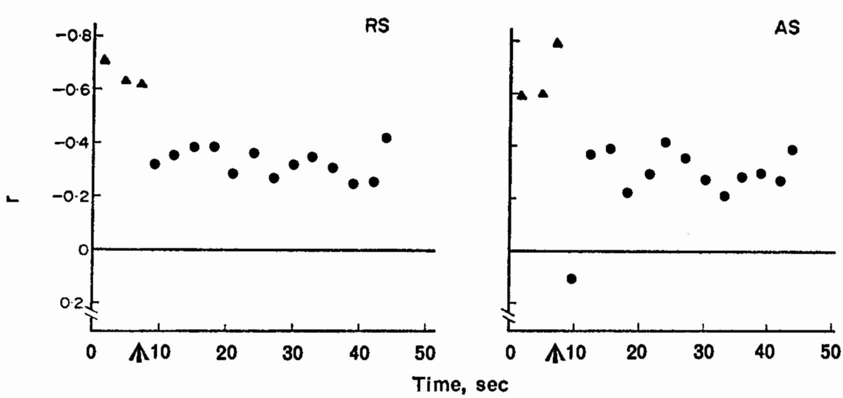

FIG. 1. Product–moment correlations (r) between absolute fixation error and subsequent algebraic change in fixation error. Subject RS is shown on the left and AS on the right. Correlations for the portions of the trials when the target was visible are plotted as triangles to the left of the arrows on the abscissa that signify the time of target disappearance. Circles to the right of the arrows show the correlations in the dark. Each data point is based on 270 pairs of fixation errors and changes in fixation errors for RS and 168 pairs for AS. With these Ns correlations of 0·14 and 0·17 are significantly different from zero ($P < 0{\cdot}01$) for RS and AS, respectively. Data points are plotted at the mid-point of 3 sec grouping intervals.

[2] The algebraic change in the fixation error was calculated by subtracting the absolute fixation error from the absolute fixation error 0·5 sec later.

to use extraretinal signals to control eye position soon after the target was removed from view.

2. *Subjects remember where the target was*

(a) *Method.* Horizontal eye positions were recorded by means of a diffuse reflection technique. In this method a photoresistor measures the amount of diffuse infrared light reflected from the limbus. With suitable calibration and linearizing procedures, horizontal positions of the eye could be measured to within 0·5 deg arc.

At the start of each trial, *S* was seated in the experimental cubicle in total darkness with his head stabilized by a tight acrylic biteboard. When *S* initiated the trial, records were made while he fixated a point target that appeared for 1 min in one of nine randomly chosen horizontal positions within a 10·5 deg arc region, centered 5 deg arc to the left of his primary position. The target was then switched-off and *S* attempted to maintain fixation of target position for 7·5 min in total darkness. The target then reappeared in the same place for 1 min. *S* then left the experimental cubicle for 15 min and was permitted normal vision. At the end of the 15 min break, *S* re-entered the experimental cubicle in darkness and attempted to return his line of regard to the position the target had appeared 15 min earlier. Eye

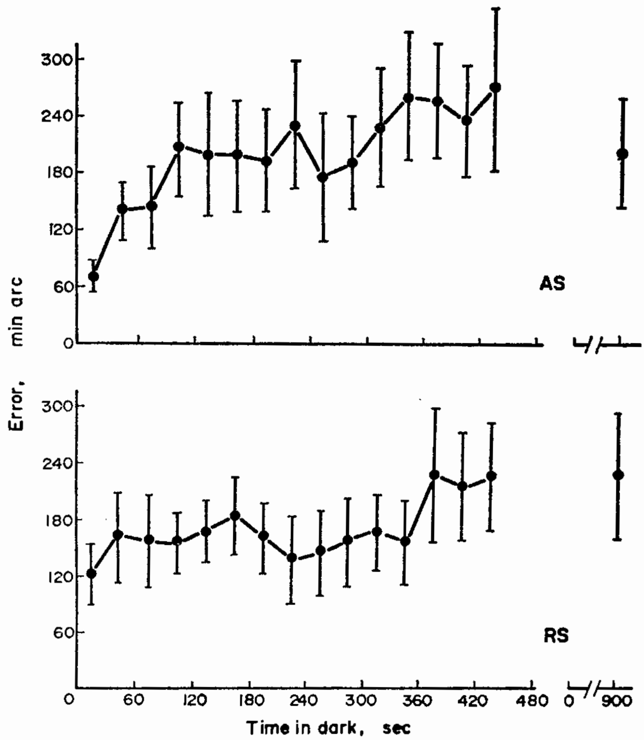

FIG. 2. Mean errors and their standard deviations on the horizontal meridian during the 7·5 min period in the dark (connected points). Each mean (based on 135 horizontal eye position measures) is plotted at the midpoint of a 30 sec sampling period. The unconnected point on the right shows the mean error when *S*s attempted to realign their lines of sight with a target seen 15 min earlier.

position was then recorded for 30 sec. Fifteen such trials were run for each subject and three horizontal eye positions were randomly sampled during each successive 10 sec period.

(b) *Results*. Figure 2 shows mean absolute error on the horizontal meridian for successive 30 sec portions of the 7·5 min period in the dark. Points plotted on the right (not connected) show mean absolute error when *S*s attempted to look in the direction the target appeared 15 min earlier. Mean absolute error, during the long period in the dark and after 15 min of normal visual activity, was less than 4 deg arc.

In summary, a correlational analysis showed that there was a corrective eye movement pattern in the absence of a visible target. Also, eye position was maintained, reasonably well, over extremely long periods of time spent in total darkness. Furthermore, *S*s, after engaging in normal visual activity, looked near the position a target appeared 15 min earlier. These findings confirm that there is a good extraretinal source of eye position information and show that such information can be stored in memory and used to control eye position when visible targets are not available.

Acknowledgements—This research is based on a portion of a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy. I am greatly indebted to Professor ROBERT M. STEINMAN for his assistance in all phases of this research and also to Professors NANCY ANDERSON, W. LARKIN, C. STERNHEIM and H. TEITELBAUM for serving on my committee. I would like to thank GENEVIEVE HADDAD, Dr. L. MATIN and Dr. S. STERNBERG for their valuable suggestions and criticisms, LUCINDA ROMBERG, R. SANSBURY and ANITA WEBER for technical assistance.

Computer time for this project was provided by National Aeronautics and Space Administration, Grant NsG-398 to the Computer Science Center of the University of Maryland.

This research was supported by a USPHS predoctoral fellowship to the author and by Grant EY-00325 from the National Eye Institute to Robert M. Steinman.

ALEXANDER A. SKAVENSKI[3]

Department of Psychology,
University of Maryland,
College Park, Maryland 20742,
U.S.A.

REFERENCES

MATIN, L., MATIN, E., POLA, J. R. and PEARCE, D. (1968). Visual perception of direction before, during and after voluntary saccades. Paper read at the Psychonomic Society Meeting in St. Louis, Missouri.

MATIN, L., MATIN, E. and PEARCE, D. (1970). Eye movements in the dark during the attempt to maintain a prior fixation position. *Vision Res.* **10,** 837–858.

SKAVENSKI, A. A. and STEINMAN, R. M. (1970). Control of eye position in the dark. *Vision Res.* **10,** 193–203.

STEINMAN, R. M. (1965). Effect of target size, luminance and color on monocular fixation. *J. opt. Soc. Am.* **55,** 1158–1165.

[3] Current mailing address: Johns Hopkins University, Department of Medicine, Traylor Building, Rm. 830, 1721 East Madison St., Baltimore, Maryland 21205, U.S.A.