Control of eye fixation by auditory feedback¹

William M. Smith
DARTMOUTH COLLEGE

Abstract

The results of an experiment with two Ss indicate that auditory information can be utilized in controlling eye fixation, particularly as normal visual control of fixation is decreased. It is concluded that the retinal component of the normal visual feedback loop is not a necessary condition for maintaining eye position.

Problem

The positions of the eyes in the head under normal circumstances are controlled by multiple sources which include light from an object in the environment, impulses from the inner ear, impulses from head, neck, and body muscles, and impulses from the extrinsic eye muscles. In addition, eye position can be under "central" control, e. g., voluntary movement of the eyes with the lids closed. From the standpoint of using the eyes to see, however, the primary control of eye fixation is dependent upon the utilization of visual information. The eye must position itself in such a way that the image of the object or point to be seen is located on the area centralis. Displacement of the image from the center of the fovea initiates a correction in position so that the displacement approaches zero. Thus, in normal fixation, position error is corrected through a negative feedback loop in which the signal is of a visual nature. The question raised in the present experiment concerned the extent to which sound could supplement and/or replace the usual visual component of eye position control. In attempting to answer this question an arrangement was devised so that as long as the eye maintained a prescribed fixation position, S heard a distinctive sound; deviation from fixation terminated the auditory signal.

Method

Eye position and movement was measured by a photoelectric method (Smith & Warter, 1960). The DC signal for eye movement provided not only a record of eye position but, in addition, was used as the trigger source for controlling the auditory signal. Through calibration, a given voltage output representing eye position was made to correspond to a particular visual direction. This output voltage was used as input to a DC comparator circuit with an adjustable voltage aperture. When the output from the eye detector reached the pre-set level of the voltage aperture, a negative low voltage was generated and sustained as long as the eye signal remained within the voltage aperture range. This negative voltage in turn was used to control the auditory signal as well as to provide a record of this stimulus. The pattern of eye movement and the on-off pattern of the auditory stimulus were recorded oscillographically. Considering the sensitivity of the photo-detector and the minimum size of the comparator voltage aperture it was

determined that the error of eye-movement measurement was approximately $\pm 10'$ of arc.

Observations were obtained from two college males under four different experimental conditions with and without auditory feedback. Both Ss made all observations with their left eyes. In Condition A, S was provided with a pin-point fixation light directly in front of him. He was instructed to maintain visual fixation on this light for the duration of the sampling period. He heard a low-frequency sound through earphones as long as he maintained fixation. In Condition B, three fixation lights were presented, each separated by 1.2° of arc. S was instructed to fixate the middle light, and when he had done so this light was extinguished. His task was to maintain his eye position for the sampling period midway between the two remaining reference lights. He received the tone whenever his eye was in this position. Condition C required S to fixate the target light, 1.2° to the left of which was a reference light. When fixation was established, the target light was extinguished and the task was to maintain fixation 1.2° to the right of the reference light in order to hear the sound. Condition D was the most demanding of all in that, after being instructed to fixate on the target light directly ahead, it was extinguished and S attempted to maintain fixation in a dark room with no visual reference points—only auditory information of eye position.² Data were recorded for each S in eight sessions. In six of the eight sessions auditory feedback was provided. In two of the sessions the four conditions noted above were run without the auditory signal. In every session two 30 sec. sampling periods were recorded for each S.

Each 30-sec. record was analyzed on the basis of (a) percentage time on target (TOT), and (b) mean deviation from target regardless of sign (MD). Data points were obtained every 100 msec. interval of each record. These measures were used to assess the effects of the four conditions of observation with and without auditory feedback, the variation in the two halves of each sampling period, and changes in performance over sessions.

Results

The conclusion that auditory information was effective to some extent in maintaining eye fixation is indicated by the data in Fig. 1. Except for the condition involving normal fixation (A), the TOT measure is larger when S received auditory feedback. The MD measure, except for Condition A, is consistently smaller when auditory feedback was available. The difference between the feedback and no-feedback conditions is significant at the .05 level for both TOT and MD (F, 11.4 and 18.0, respectively).

Fig. 1 Data of both Ss combined for percentage time on target (TOT) and mean deviation in degrees (MD) with and without auditory feedback under the four experimental conditions. The left hand ordinate is the percentage scale for TOT; the right hand ordinate is the mean deviation scale in degrees for MD.

The data of Fig. 1 indicate also the gradual loss of control of eye position with the decreasing specificity of the visual information available to S. Having a specific visual point to fixate (A) obviously provided the most control.

The variation among the four experimental conditions with feedback is significant at the .01 level for both TOT and MD (F , 52.2 and 18.3, respectively). Corresponding F values for the no-feedback condition are 27.6 and 12.5. Both are significant at the .01 level. Assessment of the differences between the various pairs of means by Duncan Multiple Range Tests (Duncan, 1955) is summarized in Table 1. The pattern of differences between the means in Table 1 shows in general that most differences at the .05 level are between either A and D or B and D. At the more stringent level of p at .01 essentially the only differences are between A and D for both measures.

Discussion

Control of fixation by the kind of auditory information used in this experiment is almost as effective in the absence of visual reference (Condition D with feedback) as that found with visual reference alone (Condition C without feedback) or with visual reference on each side of the non-visual point to be fixated (Condition B without feedback). At the very least auditory feedback is far more effective than mere proprioceptive feedback from the ocular muscles. Moreover, the near instability of eye position control in the absence of retinal feedback (Fender & Nye, 1961) is clearly avoided when auditory feedback is substituted for retinal feedback.

On the basis of these results with two Ss it would be expected that even greater control of eye fixation by

Table 1. Duncan Multiple Range Tests of the Different Pairs of Means (TOT and MD) with and without Auditory Feedback*

Condition Means				
	A	B	C	D
TOT with feedback	83	67	62	42
TOT without feedback	85	49	45	16
MD with feedback	.05	.16	.27	.46
MD without feedback	.02	.23	.36	.90

* Those means not connected by a solid line are significant at the .05 level; those means not connected by a dashed line are significant at the .01 level.

auditory feedback could be obtained by using a more informative auditory signal, for example, one which varied continuously along two parameters as both direction and amount of deviation from desired fixation varied. With such an arrangement a level of control (with extended practice) comparable to visual control of fixation would be predicted. The presence of light as such in the feedback control loop of eye fixation would not seem to be necessary condition for maintaining the eye in a particular direction of regard.

References

- DUNCAN, D. B. Multiple range and multiple F tests. *Biometrics*, 1955, 11, 1-42.
- FENDER, D. H., & NYE, P. W. An investigation of the mechanisms of eye movement control. *Kybernetik*, 1961, 1, 81-88.
- SMITH, W. M., & WARTER, P. J., JR. Eye movement and stimulus movement; new photoelectric electromechanical system for recording and measuring tracking motions of the eye. *J. Opt. Soc. Amer.*, 1960, 50, 245-250.

Notes

1. This work was supported by NSF Grant GE-1110. The author should like to acknowledge the assistance of Robert W. Reidy in the collection and analysis of data.
2. It is recognized that the method of eye-movement measurement used in this study did not detect differentially horizontal and vertical eye motion. However, the system as employed was insensitive to vertical displacement of the eye of about 2° or less.