Eye Movement–Retina Delayed Feedback

Abstract. *Time delays between ocular movement and retinal input have been studied by yoking a visual target to eye movement by experimental programming methods and a laboratory real-time computer system. The subject's task was to manipulate this eye movement–yoked target cursor to perform either compensatory or pursuit eye tracking. The computer thereafter was programmed to store input eye-movement signals and read them out after a delay interval to control the yoked visual target cursor controlled by the eye movements. Delay time constants of 0.1 second significantly affected tracking. Eye movement–retinal feedback delays appeared to have an even more marked effect on positive pursuit eye tracking.*

This investigation measured the effects of delay of the retinal feedback of ocular movements; this feedback was controlled by yoking visual targets to the transduced electrical-analog signals of eye motion by means of a hybrid computer system. The problem has been an open one since it was disclosed that transmission lags in tracking systems impaired visual-manual behavior (*1*), and since Craik (*2*) defined visual perception and motion as a closed-loop feedback process. Its solution, however, has depended on developing a real-time, hybrid computer system which may be used to yoke visual targets compliantly to eye movements and to introduce variable feedback delays into the oculomotor-retinal interaction. The theoretical question is whether the eye movement–retinal mechanism functions as a sampled-data system governed by its input signals (*3*) or as a movement-governed system that is dependent on real-time compliance between ocular motion and retinal processes. The experiments measured the retinal delay functions of both compensatory, or reversed, and pursuit eye-movement tracking.

The subject's eye had to move in a direction opposite that normally needed to bring the retinal image to a central focus (Fig. 1). A photoelectronic eye-movement transducer and a real-time analog-digital-analog computer were set up to transduce a subject's eye position in viewing an oscilloscope target, (i) to convert the electrical analog of sensed eye position to digital form, (ii) to program feedback delays into this digitized signal, and (iii) to reconvert the programmed delayed signal back to analog form to actuate the oscilloscope feedback display which the subject viewed. One eye was occluded and the other eye, fitted with the transducer, viewed the target.

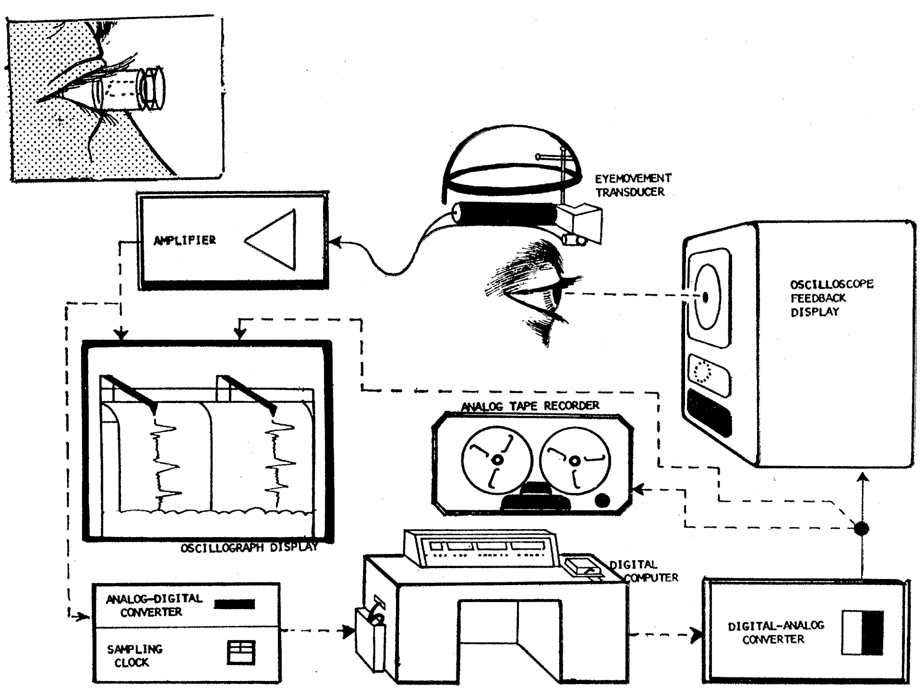

Fig. 1. Components of a hybrid analog-digital-analog computer system for calibrating transduced eye motion in relation to an oscilloscope target and for yoking the scope target to eye movement. Inset: Optical method of reversing the retinal feedback of eye movement which uses a miniature dove prism attached to a scleral contact lens.

The oscilloscope target was yoked to the subject's eye movements in a reciprocal dynamic relation with computer techniques that calibrated the relations between eye position and target position and automated all of the experimental operations on single subjects. The subject's head was fixed, and the movements of one eye were transduced by photoelectronic sensors mounted in a viewing device. At first, the subject was required to fixate five successive target positions on the oscilloscope which were controlled by the computer system. During successive fixations, the computer compared the respective eye positions and target positions and established a calibration of the proportionality of voltage values of ocular movements and target position. This calibration was automated and performed at the beginning of each 1-minute trial throughout the experiments. When the calibration was completed successfully, a computer program automatically locked the output control of the oscilloscope target to eye motions, so that horizontal ocular motions thereafter caused the target to move in a compensatory way back and forth across the oscilloscope face. The computer also was programmed to continuously compare eye position with target position and, thus, to measure relative tracking error of the eye when the target was moved in a sinusoidal course.

The subject's task was to keep the oscilloscope target centered on a zero mark of the display, while a computer program caused this spot to vary in a regular, smooth sinusoidal pattern from this center position. Inasmuch as the target was yoked to the eye movements in a reversed or compensatory feedback loop, the subject had to move his eyes in a direction opposite that of target action in order to bring the spot back to a center position. A frequency-modulated, magnetic-tape record was made of the subject's eye movements and eye-tracking errors. This record was later processed by computer methods to measure the relative tracking error in keeping the target centered on the oscilloscope face.

In the second experiment, the subject's eye movements were yoked to a light which moved as his eye pursued or followed a second light target. Methods of experimental calibration and automated, feedback-control programming similar to those described above were used, except that the yoke established between ocular motion and target movement was positive, so that when the subject moved his eyes the light spot moved in the same direction. The eye movements actuated a light galvanometer which projected a target spot (diameter 2.5 cm) on a cylindrical screen. A second light galvanometer, actuated by a signal generator, projected a second target spot on the screen. This spot moved in a sinusoidal pattern back and forth across the screen. The subject's task was to keep his yoked target cursor matched in movement to the generated motion of the target. A precision frequency-modulated tape recorder registered the voltage of both the target signal generator and the subject's eye movements. This record was processed later by computer methods to measure the relative eye-tracking error of the subject. This measure was comparable to the error measure of the compensatory tracking experiment in that it involved direct comparison of eye position and target position.

In both experiments, the computer was used to vary the feedback delay interval between ocular motion and retinal input. The variable feedback delay was produced by "writing-in" and "reading-out" eye-movement signals at differentially spaced points in the memory cycle. In the compensatory tracking experiment, retinal feedback delays of 0, 0.1, and 0.2 second were used, and in the positive feedback experiment delays of 0, 0.2, and 0.4 second were used.

The two functions relating relative error in eye-movement tracking to delay magnitude (Fig. 2) indicate that the effects of the feedback delays were quite similar in the two types of interaction between eye movement and retina, and that delays of 0.1 to 0.2 second had a marked effect on vision and eye-movement control. In the study of compensatory tracking, nine subjects were used. After practice and instruction they experienced 50 trials at each of the delay conditions. Stable calibrations were obtained with six of these subjects whose records were used to obtain the data on delayed compensatory ocular feedback (Fig. 2). Using the number of trial measures of error in each delay condition, F tests were computed. The three means were significantly different at the 1 percent level. The significant mean found when the delay interval was 0.1 second represents a real-time magnitude of ocular control of retinal input that is half the value of the optimum constant of visual

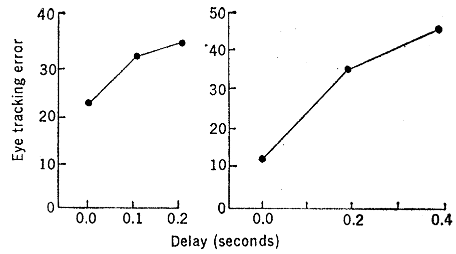

Fig. 2. Feedback delay functions of relative tracking error in compensatory (reversed) and direct positive control of visual targets by eye movements. (Left) Compensatory feedback control. (Right) Positive (pursuit) feedback control. A relative voltage measure of tracking error was used which was approximately equal in the two tracking tasks.

reaction assumed in sampled-data models of eye motion (*3*). The results thus negate the idea that there is an optimum feedback time-sampling function for vision above a value of 0.1 second and indicate that vision and ocular motions are governed directly and continuously as a movement-controlled sensory process.

After practice and instruction in pursuit tracking, six subjects experienced six trials of 25 seconds each at each delay condition. The significance of the differences between means at each delay condition was determined by the analysis of variance and the Newman-Keuls (*4*) range tests. The three means for delayed pursuit movements (11.92, 34.64, and 45.36 for delays of 0, 0.2, and 0.4 second, respectively) were all significantly different from one another.

The visual experiences in performing in the two tasks were strikingly different. Visual perception in the pursuit tracking was undistorted in an optical sense and not painful. Inasmuch as the retinal action of eye movements in the compensatory task was reversed from that of normal vision, vision in this task was highly unstable, blurred for the most part, and painful. Because the eye, in trying to fixate the target in a particular point, always caused the spot to move in an opposite direction, unstable vision resulted which the subject eventually was able to control to only a limited extent. Throughout all trials, including those with zero delay, ocular activity consisted of saccadic movements which varied in magnitude in relation to the size of the feedback delay.

The results of the compensatory tracking experiment relate to the effects of inversion of the retinal image. From this study of reversed compensatory tracking it was possible to assess the effects of practice with reversed vision on accuracy of tracking, by comparing tracking error in 3 days of practice involving 50 1-minute trials of attempted adaptation. There was no significant improvement in tracking accuracy in these trials. One of our most accurate trackers regarded the last trials of this training as next to intolerable. The ocular system showed no significant evidence of being able to adapt to this artificially reversed feedback.

The results of this experiment on compensatory, reversed eye tracking confirm and add to observations made on subjects wearing a miniature dove prism that was attached to a scleral contact lens and that reversed the feedback of horizontal eye movements (inset, Fig. 1). This contact-lens prism reversed the visual field of eye motions and also caused very painful, unstable, blurred vision, which we have defined as "skittered vision." The results do not support claims that complete adaptations can be made to reversed vision through learning. It may be possible to adapt hand, arm, head, and body motions to reversed vision, but not eye movements themselves. Statements that adaptation to reversed vision can be learned have been based on a misconception that reversal of the visual effects of body and head movements is equivalent in every way to reversal of interaction between eye movement and retina. When the retinal feedback of eye movements is dynamically reversed, as it was in these studies, it is impossible for the eye to fixate images effectively, or in the case of the yoked, reversed target, to bring a displaced image of the target to fixation onto the fovea. These findings extend observations on the effects of compensatory reversed vision on eye movements (*5*).

Significant effects of feedback delay were found at 0.1 second in the compensatory eye-tracking task and at 0.2 second in the pursuit task. These effects appeared to be more severe than those found with feedback delay of manual-visual tracking, inasmuch as subjects seem to be able to correct to some extent a 0.2 second delay with hand tracking (*1*). The observed effects of the retinal delay on vision were insidious. Except for the fact that vision was persistently ineffective and inaccurate, the subject sensed no unusual visual or painful effects that could be attributed to the delay. Time-distorted retinal input was experienced, not as a timing defect, but as space-displaced vision which could not be controlled.

In the compensatory tracking task, the visual delay produced disturbances other than those caused by the reversal of vision. To what extent are common defects of vision the result of disturbed oculomotor, accommodative, and convergence feedback timing, and to what extent are they purely optical defects? Inasmuch as there are many possibilities for delay in learning and positioning the retinal image through different stages of dynamic ocular movements, the production of visual defects by delayed retinal feedback is a possibility. Precise feedback timing may be an imperative of effective seeing that is on a par with optical factors. Real-time computers and electronic-optical methods may become essential to analysis of normal and disturbed vision in the future.

Our findings on delayed eye movement–retinal feedback add to the observations on reversed ocular feedback in challenging the validity of the Helmholtzian doctrine of learned space perception. In this view, time factors are recognized only as a condition of temporal contiguity in visual-tactual learning which serves to create the perception of space. Ocular-retinal timing in dynamic positioning of the retinal image is fundamental to control of visual direction and the accurate perception of such direction. The control and sensing of visual direction are directly determined by the built-in dynamic feedback relations between direction-specific pursuit and saccadic movements and positioning of the retinal image. When these feedback relations are altered by either spatial displacement or delay, control of vision is reduced to unstable saccadic movements. The results thus give a human behavioral meaning to past neurophysiological findings that visual nerve cells of the retina, midbrain, and cortex of animals and men are direction specific (6) and that such directional specificity is involved in directional control and specificity of ocular and head movements (7).

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Marijuana Use Among Urban Adults

Abstract. *A relatively high proportion of young adults in San Francisco have used marijuana one or more times. The proportion in this age group who have used marijuana is as great among nonstudents as among students.*

Systematic research on the use of marijuana has been conducted almost exclusively among student populations. The present analysis is an attempt to determine the generality of marijuana use among older persons and among young adults who are not necessarily students. It is also designed to identify other demographic and psychological variables that are associated with the use of marijuana. This research was part of a study designed primarily to examine the acquisition and use of psychotherapeutic drugs, including tranquilizers, stimulants, sedatives, and hypnotics.

The study was conducted among adults in San Francisco during 1967–1968. Personal interviews were held with 1104 men and women, all 18 years of age or older. In order to obtain a representative cross section of San Francisco's population, strict probability sampling was employed. The personal interview that formed the basis of this survey lasted an average of 1.4 hours. The interviewer began by asking some general questions about physical and mental health and about ways in which respondents had handled various problems. The interview then proceeded gradually to more sensitive questions about use of psychotherapeutic drugs. At the end of the interview, respondents were asked if they had ever tried any other mood-changing drugs, including marijuana and LSD. No detailed information was collected on the history, duration, or frequency of respondents' experience with psychedelic drugs. The sole question at issue, then, was whether or not the respondent had "ever used" marijuana or LSD.

Although some respondents may have withheld information, interviewers reported that most respondents appeared very candid about their use of all drugs, including the psychedelics. This judgment is supported by the fact that the proportion of people in our sample who report ever having used marijuana or LSD is much higher than we had expected; in fact, the proportion of our young San Francisco adults claiming some experience with psychedelic drugs is at least as high as the proportion of college students reporting such experience in other studies made at the same time.

Of San Francisco's adults aged 18 and over, 13 percent report having used marijuana one or more times, and 3 percent have taken LSD (*1*). About twice as many men (18 percent) as women (9 percent) have used marijuana, and the same pattern for men and women applies to LSD at much lower percentages.

Young men or women are much more likely to have used these drugs than are older men or women. Practically no one 30 years or older reports ever having used LSD. One-half of the 18- to 24-year-old men and one-third of the women of this age have used marijuana. When the age group is expanded to include those up to 34 years old, more than one-third of the men and about one-fourth of the women report having used marijuana. Among men aged 35 and over, 9 percent have used marijuana; among women in the same age group the figure is only 1 percent.

White women under 35 are twice as likely as Negro women of that age group to have tried marijuana. However, the proportions for white and Negro males of that age group are quite similar. (Slightly more than one-third report having used marijuana at least once.) Beyond age 34, relatively more Negro males than white males (18 and 8 percent, respectively) report having used marijuana at some time. This pattern undoubtedly reflects the growing acceptance by the young white middle class of a drug formerly associated with lower social classes and minority groups.

When we confine our examination to persons of college age (18 to 24 years old), we find that in general the proportion of students who report using marijuana does not differ markedly from the corresponding proportion among nonstudents. But the pattern varies by sex. Thus, in our sample,