Voluntary Control of Microsaccades during Maintained Monocular Fixation

Abstract. *A contact-lens technique was used to record eye movements made by two subjects instructed either to "fixate" stationary white-light targets or to "hold" their eyes in position in the presence of the same targets. A marked reduction in saccade rate, frequently reaching zero throughout 9.8-second trials, was observed under the "hold" instruction.*

Microsaccades (very small, high-velocity eye movements) occur once or twice each second while subjects maintain fixation of a stationary target. These movements are commonly described as "involuntary" because they are observed after experienced subjects have been instructed to "fixate." The instruction to "fixate" has been considered to be equivalent to an instruction to hold the eye *still* once the image of a fixation target has been brought to some preferred position on the retina (*1*).

Microsaccades may serve an important visual function. Cornsweet, for example, showed that they return the retinal image of the fixation target object to some "optimal locus" from which it has drifted during intersaccadic intervals (*2*). This "optimal locus" is assumed to be the center of best vision. It seems possible, then, that microsaccades are executed in order to produce the best visual detail in the target image; and, therefore, the conventional instruction, "fixate," may, in fact, be different from an explicit instruction to "hold" one's eye still in the presence of a visible fixation target. If a subject chooses to ignore detail in the fixation target under "hold" instructions, microsaccades should be eliminated or reduced appreciably.

Eye movements under "fixate" and "hold" instructions were recorded by a contact-lens technique incorporating features which permit simultaneous and independent recording of rotations about the horizontal and vertical axes in Listing's plane, uncontaminated by torsions of the eye or translations of the head. The recording and fixation systems have been described in detail elsewhere (*3*).

Two experienced subjects participated in the experiments: R.S., one of us; and A.S., a graduate student at the University of Maryland. Both subjects were emmetropic and had acuities of 20:20 with the contact lenses in place.

In the first experiment subjects were instructed either to "fixate" or "hold" their eyes in position throughout 9.8-second recording trials in the presence of a round homogeneous disk of white light (5.4 or 31.2 minutes of arc) whose luminance was 1.0 mlam. Trials under each instruction with each target size were alternated. The experimenter presented a target of the appropriate size before each trial. The subject began recording when he felt that he had complied with the instruction given.

The results of this experiment were striking. Both subjects made very few saccades under "hold" instructions. Table 1 gives mean saccade rates under the four conditions (*4*). R.S. reduced his saccade rate with the small target under "hold" instructions to one-fourth the rate observed under "fixate" instructions. A reduction of one-third was obtained with the larger target. Similarly, A.S. reduced his saccade rates markedly with both targets under the "hold" instruction. R.S. made no saccades whatsoever on 22 percent of his "hold" trials. A.S. also succeeded in totally inhibiting saccades occasionally, although such trials were less frequent (6 percent) (*5*).

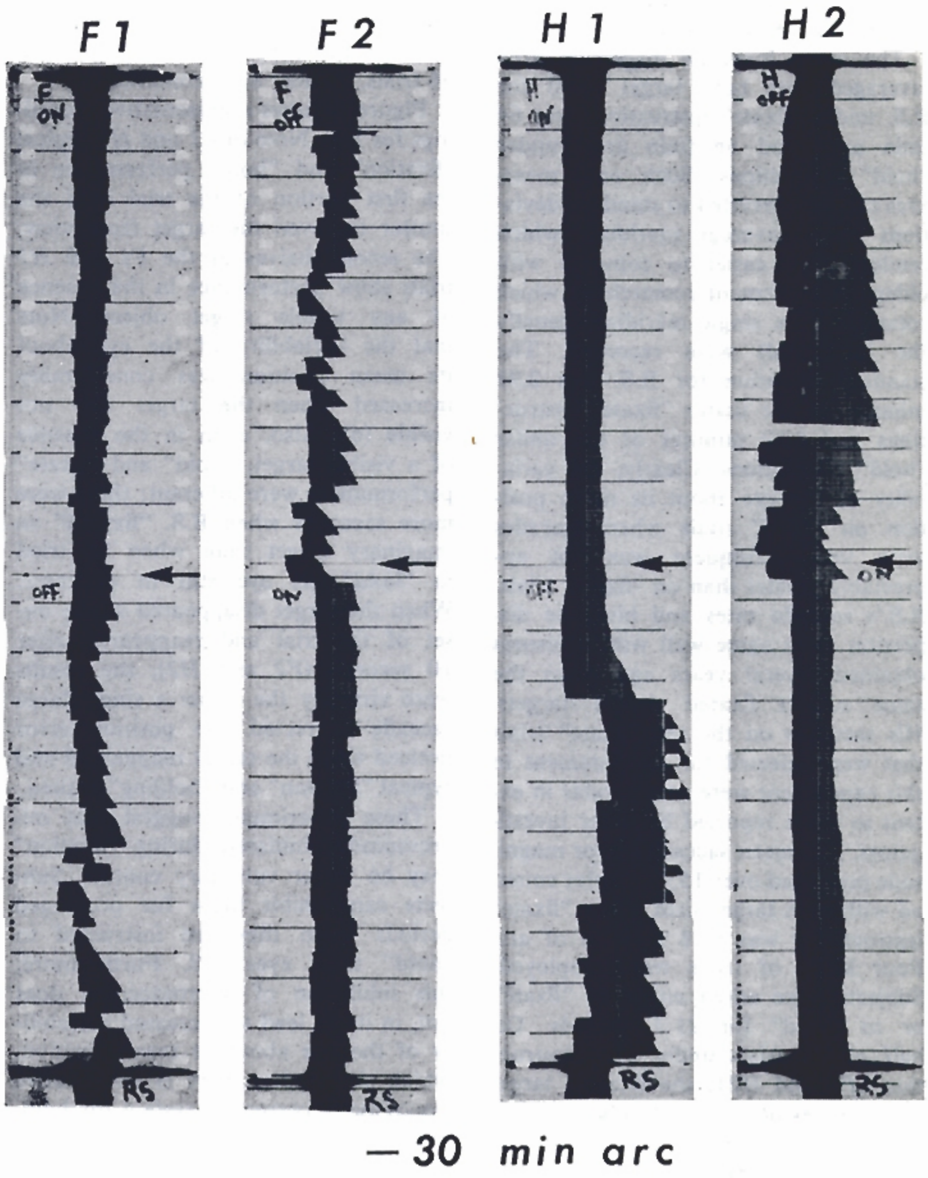

Fig. 1. Representative eye-movement recordings for subject R.S. when asked to either "fixate" or "hold" his eye for 21.3 seconds. The arrows point to a faint dark stripe on the film, signifying when a shutter either removed the target from view (*F1* and *H1*) until the end of the trial or allowed the target to come into view after 10 seconds (*F2* and *H2*). A 1-second time base is recorded as repetitive dark stripes across the film, and the recording trace was interrupted every 0.1 second (faint white lines). The position of the left edge of the trace is proportional to the position of the eye on the horizontal meridian, and the width of the trace is proportional to the position of the eye on the vertical meridian. The interruption in the recording trace in the 8th second of *H2* occurred when the wedge of light drifted below the recording slit.

In view of Cornsweet's results noted above, it is of interest to compare the stability of fixation on trials when saccades were very infrequent with trials when they occurred often. If saccades are largely responsible for maintaining the eye in a preferred position, the variability of eye position should be greater on trials when saccades are very infrequent. Five trials with R.S. under each instruction with each target size were chosen for this analysis. The median saccade-rate trial and the two trials just above and below the median-rate trial were selected from each condition and were used to estimate the bivariate dispersion of the eye about its mean position.

The mean bivariate dispersion area (averaged over both target sizes) for R.S. under "fixate" instructions was 64 (min arc)^2 and 66 (min arc)^2 under "hold" instructions. Such area measures can be converted to standard deviations on an average meridian, which renders them easier to compare with older eye-movement research in which rotations on a single meridian (usually the horizontal) were recorded. The standard deviation for R.S. was 2.98 minutes of arc under "fixate" instructions and 3.02 minutes of arc under "hold" instructions. Clearly, the variability of the eye about its mean position on "hold" trials when saccades were very infrequent was not appreciably greater than on "fixate" trials. R.S.'s saccade rates and bivariate dispersion areas agree well with measures obtained several years ago when the same subject fixated similar targets. His saccades on the ten "fixate" trials that were selected for measurement in this experiment were very similar in extent to those reported by other investigators. The mean saccade vector magnitude (averaged over 155 saccades counted with both target sizes under "fixate" instructions) was 8.18 minutes of arc. Four kinds of trials were employed. Subjects were asked either to "fixate" or to "hold" for 21.3 seconds. On half of the trials under each instruction (*F2* and *H2*), the fixation target (5.4 minutes of arc at 1.0 mlam) visible during intertrial intervals was obscured by a shutter when the subject began recording. After 10 seconds the shutter opened and the target was visible for the remainder of the trial. On the other half of the trials (*F1* and *H1*) the target remained visible only for the first 10 seconds; the shutter then closed for the remainder of the trial. Both subjects served in this experiment; each recorded 36 trials, 9 under each condition.

Table 1. Mean number of saccades per second (Rate) of subjects R.S. and A.S. viewing small (5.4 minutes of arc) and large (31.2 minutes of arc) targets under "fixate" and "hold" instructions. The standard deviations (S.D.) and number (N) of recording trials are given for each condition.

Instruction	Target	Rate	S.D.	N
	Subject: R.S.			
Fixate	Small	2.01	0.49	22
Fixate	Large	1.47	.70	25
Hold	Small	0.45	.50	20
Hold	Large	.50	.48	23
	Subject: A.S.			
Fixate	Small	1.40	0.34	48
Fixate	Large	0.86	.39	47
Hold	Small	.57	.26	49
Hold	Large	.33	.19	46

Figure 1 shows representative recordings for R.S. Note in *F1* and *H1* typical "fixation" and "hold" performance in the first portion of the trial until the shutter removed the target from view. The second halves of the *F1* and *H1* trials show performance in the absence of any visible target object. Note that the variability of the eye about its mean position was considerably increased when the target was not visible (*6*). Also, even in the absence of a visible target, "hold" and "fixate" performances were different: there were more saccades when R.S. "fixated" an imaginary target than when he tried to "hold" his eye still in darkness. When the target disappeared at the onset of the trial and reappeared after 10 seconds (*F2* and *H2*), the results were virtually the same: a single large saccade corrected the position error noticed when the target reappeared and typical "fixation" and "holding" ensued.

These experiments suggest that microsaccades initiated during "fixation" may be under voluntary control. Subjects can inhibit them for prolonged periods when they are instructed to "hold" their eyes still. Furthermore, this inhibition of microsaccades does not, in itself, lead to increased variability of the eye about its mean position, which shows that there is an effective low-velocity corrective system for holding the eye in position on all meridians. Nachmias had previously shown that when a subject attempts to maintain fixation both saccades and drifts can contribute to position control of his eye. In his work, however, saccadic correction was most prominent; corrective drifts were observed on only a few meridians where saccadic correction was not effective (*7*). In the present experiments drift correction frequently takes over completely under "hold" instructions.

It is not known, at present, whether each microsaccade that is executed under "fixation" instructions is a voluntary act. We prefer at this time to assume that there is a microsaccadic system that is called into play when "fixation" is attempted. This assumption, however, is based exclusively on the very small size of these saccadic movements, and further experiments will be necessary to determine whether it is a system, rather than individual saccades, that is being called forth by an effort of the will.

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References and Notes

1. See M. Alpern, in *The Eye*, H. Davson, Ed. (Academic Press, New York, 1962), vol. 3, for a comprehensive presentation of methodology and findings in research on eye movement.
2. T. N. Cornsweet, *J. Opt. Soc. Am.* **46**, 987 (1956).
3. R. M. Steinman, *ibid.* **55**, 1158 (1965). See also J. Nachmias [*ibid.* **49**, 901 (1959)] for the theory underlying the recording of two-dimensional motions of the eye with an apparatus similar to that employed in the present experiments, and L. Matin [*ibid.* **54**, 1008 (1964)] for an analysis of various systems for measuring eye position.
4. Three judges counted saccades. Agreement among judges was almost perfect. In those very rare instances where there was a disagreement, the count that went contrary to our hypothesis was accepted, that is, the lower value on "fixate" trials and the higher value on "hold" trials.
5. The differences in saccade rates were so large relative to the standard deviations that we felt formal statistical treatment was not necessary. The fact that saccade rates are lower with larger targets under fixation instructions has been reported previously (see Steinman *3*).
6. The increased variability in eye position found when a target is removed from view has been reported previously (see *2*, *3*, and *7*).
7. J. Nachmias, *J. Opt. Soc. Am.* **51**, 761 (1961). See also reference *3* for a related paper by Nachmias.
8. We thank A. Skavenski for serving as a subject, Ellen Mindlin for carefully measuring the film, and Elizabeth Kocher for insisting that we collect data on what seemed an unlikely problem. Supported by NIH grant NB-06361-01 to R.M.S. and a NIH predoctoral fellowship to R.J.C.

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