Visual Fixation Stability in Older Adults

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Visual fixation of a small, stationary target was measured in 12 young observers (mean age = 22 yr) and in 12 older observers (mean age = 70 yr). The two groups' fixation behavior did not differ on various dimensions of fixation stability: mean fixation area, intra-subject variability, or changes in fixation over successive test periods. Connections between these results and age-related changes in the oculomotor system are discussed. Invest Ophthalmol Vis Sci 27:1720–1725, 1986

Fixation stability, the ability to maintain an image on the fovea, is crucial for the visual extraction of spatial detail.[1,2] If the target image moves 1° from foveal center, or if random movement of the image on the fovea exceeds 2°/sec, visual acuity degrades substantially.[3,4] Either of these conditions may occur if deficiencies in oculomotor control compromise the ability to maintain target alignment within these limits.

Fixation stability has been measured in the laboratory, and the variation associated with maintaining the line of sight on the foveal center in minarc^2 is about 80.[1,5–7,‡] However, since virtually all laboratory studies have been conducted on highly trained observers, little is known about the steadiness of fixation in people who are not experienced psychophysical observers. Moreover, no studies have examined fixation stability in the elderly.

It is known, however, that many aspects of oculomotor function do change with age. For example, smooth pursuit movements slow with age,[8] and the range of voluntary eye movements becomes restricted, especially for upward gaze.[9,10] Although the velocity-amplitude profiles of saccades up to 30° displacement are normal in older adults,[11] the duration and peak velocity of saccades are reduced in older people, especially when eye movements are large.[12,13]

However, age-related deficits in dynamic oculomotor control do not necessarily imply deficits in fixation. There is evidence that different extraocular muscle (EOM) fiber types are differentially affected by the aging process. The small, slow EOM fibers are less debilitated by age than are the larger fibers.[14] Moreover, the small, slow fibers have been shown to participate to a greater extent in the tonic control of the eye than the large, fast fibers.[15]

In order to determine the extent of age-related changes in visual fixation stability, we made quantitative measurements of fixation in normal, healthy, older individuals. Because the literature on fixation stability describes fixation in only a few trained observers, it seemed unfair to compare untrained older persons with this group. Instead, we collected new control data on a group of young people who were inexperienced in psychophysical observation.

Materials and Methods

Observers

A total of 31 paid volunteers participated in the experiment. Their informed consent was obtained after explaining the nature and purpose of the experiment. For reasons described below, six of the 31 were dropped from the experiment.

The 25 observers who served in the study were 12 older adults ranging in age from 65–74 yr (mean age = 69.9 yr, SD = 3.5), and 13 young persons, whose ages ranged from 19–28 yr (mean age = 22 yr, SD = 3.14). The older observers, except one who declined to have her eyes examined, were given thorough ophthalmological exams. None exhibited any visual pathologies. Two had best-corrected distance acuities in the right eye of 20/15, seven had 20/20, and two had 20/25.§

At the time of testing, nine of the older observers denied taking medically prescribed drugs. For the three older observers who were on medication, no involvement of ocular motility was found upon examination. The young group was not given eye exams, nor were

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‡ These bivariate contour ellipse areas were transformed to correspond to a probability estimate of 68%.

§ Details of the eye exams are available on request from the first author.

visual acuities measured. Nevertheless, all reported they were in good visual health, and none indicated taking any medically prescribed drugs.

Four young and six older observers had previously participated in an eye movement experiment. Since, for each volunteer, this experience was limited to one or two recording sessions, it did not constitute the extensive practice in fixation often attained by trained laboratory personnel.

As indicated above, several volunteers from both age groups had to be dropped from the study. Eye movements from two older and two young observers could not be recorded by our instrument. One young observer could only be tested with the tracker's automatic focusing system engaged. But, because the auto-focus system increased system noise, his data were discarded rather than risk contamination. Tracking could not be maintained for the other young observer because her eyelashes interfered with the instrument's infrared light path.

Procedure

The momentary, two-dimensional positions of the right eye were measured by a Scientific Research International (SRI) Mark IV dual Purkinje-image eye tracker.[16] The recording instrument's two output channels had bandwidths of 200 Hz. These channels were low pass filtered at 50 Hz (−36 dB/octave) prior to being digitized at a 100 Hz rate and stored in computed memory.

The fixation target was a stationary luminous white square subtending six minarc on a side and displayed on a TV monitor located 2.27 m from the observer. The luminance of the target was 36.4 cd/m^2 and was clearly visible on a background luminance of 0.51 cd/m^2.

Observers viewed the target monocularly through a system of lenses that corrected for refractive errors, as neither glasses nor contact lenses could be worn during testing. The viewing system also placed the target at optical infinity. The left eye was occluded by an opaque patch. A velcro strap held the observer's head securely in a head/chin support framework.

Eye positions were sampled in trials lasting 12.8 sec each. Observers were instructed to maintain steady fixation of the target and to try to refrain from blinking or moving during recording. Data recording began a few seconds after the observer fixated the target and the eye tracker achieved tracking. A tone signalled the initiation and termination of recording. Rest periods were given after each trial, ad lib. A recording session consisted of 9–18 trials. Depending on the need for rests and the ease of recording, a session lasted 45–90 min.

Calibration and Noise Levels

Since the optical characteristics of the eyeball vary for each person, the instrument's horizontal and vertical channels were calibrated for each observer. The calibration factors were not systematically different for the old and young observers, however. The instrument's noise level was determined by tracking a stationary, artificial eye. Expressed as the standard deviation of the sampled positions of the stationary artificial eye, the eye tracker's noise level was 0.43 min of arc for the horizontal and 0.40 min of arc for the vertical channel.

Editing Eye Position Records

A continuous record of the status of the eye tracker was obtained at the same time that eye positions were being sampled. This status report contained information about the occurrence of eye blinks, interruptions in tracking, and movements of the head. Because the eye tracker has a small, but finite latency of response to conditions such as these, for a brief time just prior to and just after the detection of any of these conditions, the recording is susceptible to artifact. For example, partial closures of the eyelid, which deflects the infrared recording beam, would not be instantaneously detected by the eye tracker. Similarly, artifact associated with translational movements of the head may contaminate the eye position record before the eye tracker recognized such a condition. Thus, the response and recovery times of the eye tracker to interruptions in tracking and movements of the instrument's stage, with which it compensates for head movements, had to be estimated and removed from the eye position records.

The eye tracker's response and recovery times to these potentially noisy conditions were estimated from simulations using an artificial eye. The response and recovery times to a simulated eye blink or other tracking interruption were 170 msec prior to and 120 msec following the detection of the event, respectively. The response and recovery times to a simulated translational head movement were 400 msec before and 120 msec after detection of the movement, respectively.

We were also concerned that there might be large differences between the old and young groups with respect to interruptions in tracking and head movements. But examinations of age group differences in the frequency of tracking interruptions and head movements found them to be statistically nonsignificant.

We were also concerned that long periods of tracking interruptions or stage movements during recording would severely reduce the size of the record. Therefore, we eliminated records whose samples had been reduced by 40% or more as a consequence of the editing process.

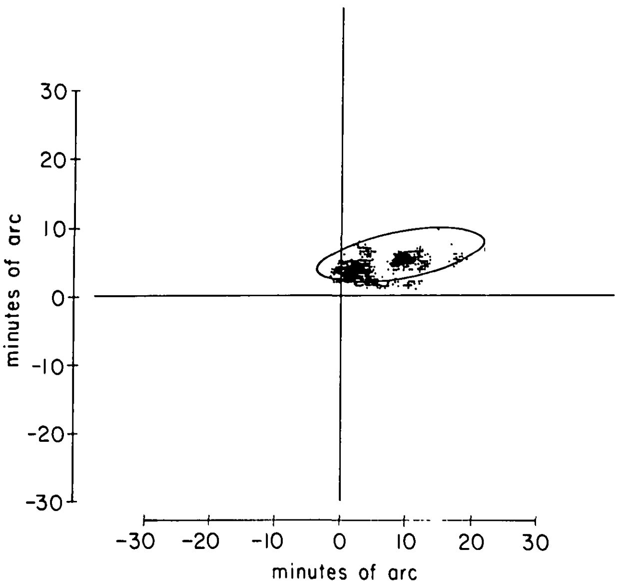

Fig. 1. A scattergram of the eye positions sampled during a single fixation trial for one observer. The contour line encloses 63.2% of the area, assuming a bivariate normal distribution. Note that the decentration of the scatter of eye positions from the center of the target (marked by the crosshairs) is due to imprecision of calibration of dc offsets.

Results

Data Analysis

Fixation stability was defined by the scatter of eye positions about their mean position. This measure was described by the two-dimensional area of the bivariate contour ellipse expressed in minutes of arc squared.[1,7] This measure assumed that the scatter of the sampled eye positions generated a bivariate normal distribution. The bivariate contour ellipse area (BA) described that region of the retinal surface within which the target's center was imaged 63.2% of the time. It is analogous

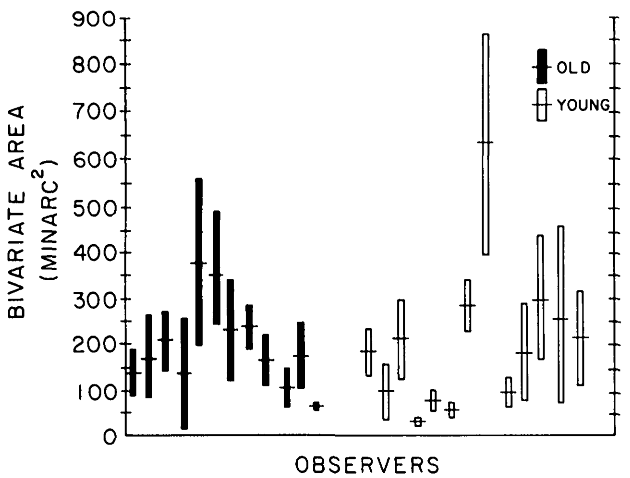

Fig. 2. Distribution of the mean bivariate contour ellipse areas (BAs) of all observers. The vertical bars extending above and below the mean values indicate ± one standard deviation.

to the univariate standard deviation of the line of sight along a single meridian.

To illustrate, a scattergram of the 1280 eye positions sampled during a single 12.8 sec trial for one observer is shown in Figure 1. This two-dimensional area approximated an ellipse with a greater dispersion of eye positions along the horizontal meridian. The contour line drawn around the scattergram encloses an area where the eye fixations were located 63.2% of the time.

Measures of Dispersions of Eye Position

For each observer, a BA was computed for each 12.8-sec fixation trial, and these BAs were averaged across all trials collected on that observer. Nine to eighteen trials were included in the average for each observer. The distribution of the mean BAs is shown in Figure 2 for old and young observers. The sequence of the BAs are arranged by the order in which the observers were tested. All observers had BAs less than 373 minarc^2, except for one young observer who had a BA almost double this value.‖

This observer's score was tested against the hypothesis that it came from the same population as the other scores in his group using Dixon's test for extreme scores.[17] His BA was found to lie outside the distribution of the other scores in the young group ($R = 0.605$, $P < .05$). In addition, this score was 4–20 times larger than BAs reported by others.[6,7] These results indicate that this score was not representative of the population of young observers, and, consequently, we excluded this observer's data from subsequent analyses.

To determine if the fixation of older observers was less steady than that of young observers, we analyzed two measures of fixation stability: 1) the bivariate contour ellipse area (BA), and 2) the standard deviation of the eye positions along the horizontal and vertical meridia. The second measure was used because, as reported earlier, horizontal and vertical eye movements may be differentially affected by aging.[9,10]

For each group, we computed the mean BA and the mean horizontal and vertical standard deviations of the scatter of eye positions. These means and their standard deviations are shown in Table 1. The mean BA of the older group was 33 minarc^2 larger than the mean BA of the young group, although this difference was not statistically significant ($t = 0.86$, df = 22, $P > .5$).

‖ When this observer was tested in a subsequent session, we found that his fixations were similarly erratic. We don't know of a cause for his unusually large scatter. However, extensive tests led us to take these measures to be accurate estimates of his fixation stability and, for unknown reasons, his stability was greatly deviant from the other members of his group.

Group differences in meridional fixation stability were examined in an analysis of variance with factors Age and Meridian. There was a significant main effect for Meridian ($F = 21.5$, df = 1, 22, $P < .001$), showing greater variability in eye fixations along the horizontal axis than along the vertical axis for both groups. The main effect of Age was not significant.

A significant interaction between Age and Meridian ($F = 5.23$, df = 1, 22, $P < .05$) indicated that the relation between horizontal and vertical dispersions differed in the old and young groups. As seen in Table 1, the older group had larger dispersions on the horizontal meridian than the young group, 8.28 minarc^2 vs 6.24 minarc^2, respectively. The relationship was reversed for the vertical meridian; the older group had smaller dispersions on the vertical meridian, 3.96 minarc^2 and 4.80 minarc^2, respectively.

We then examined the effect of age on eye fixations for each meridian separately. No differences between old and young were found for either horizontal ($F = 3.14$, df = 1, 22, $P < .10$) or vertical eye fixations ($F = 1.03$, df = 1, 22, $P > .50$).

Although old and young observers did not differ in their mean stability of fixation, this does not guarantee that observers in the two groups were necessarily equally reliable in maintaining this degree of steadiness over time. For example, older people, as a group, might still exhibit greater variability from trial-to-trial. So, we decided to compare the within-subject fixation variability of the two groups.

To accomplish this, the standard deviation of the BA was computed across all the trials for a given observer. Each observer's standard deviation is shown in Figure 2, as the vertical bars extending above and below each mean BA value. The mean standard deviation of BA's for the old group was marginally greater than that for the young group: 82.1 minarc^2 and 74.3 minarc^2, respectively. However, this difference proved to be nonsignificant ($t = 0.38$, $df = 22$, $P > .5$).

Since, under some circumstances, older people may tire more quickly than young people, we were curious to see if fixation stability deteriorated over the course of the recording session. To compare the two groups with regard to fixation stability over time, we averaged each group's BAs within trials. That is, BAs from the first trial were averaged together across all observers, BAs from the second trial were averaged together, and so on. Fifteen mean BAs—corresponding to 15 trials—were obtained for each group, and are shown in Figure 3.

Note that the BA for the first session of the young group corresponds to the third session of the old group. This is because calibrations were made on the young group at the start of their session, whereas these procedures were performed at the end of the session for

Table 1. Mean bivariate contour ellipse areas (BA) and mean standard deviations of eye fixations along the horizontal (H) and vertical (V) meridia

	BA (Minarc^2)	*H (Minarc)*	*V (Minarc)*
Old	198	8.28	3.96
	(90.4)	(3.48)	(0.84)
Young	165	6.24	4.80
	(90.2)	(1.86)	(2.58)

Standard deviations are shown in parentheses.

the old group. With the data arranged in the manner shown, the two groups can be directly compared on the amount of experience they had with fixating the target. Of particular significance in Figure 3 is the fact that the older observer's fixations did not appear to deteriorate over the course of testing.

Discussion

The overall measure of fixation stability, the bivariate area, did not change with age. Older observers were as stable in their fixations as the young observers. Moreover, the older observers were no more variable in their trial-to-trial fixations than their younger counterparts. Thirdly, the older observers maintained the same degree of stability over the course of the test session. This last finding indicates that older adults' oculomotor mechanisms controlling fixation did not show signs of fatigue over the hour or so of testing.

Old and young observers did differ, however, in the scatter of their fixations with respect to the two principal meridia. Older observers showed greater variability in their fixations along the horizontal meridian compared to the vertical meridian. The variabilities of the young observers' fixations were more equivalent along the two meridia. This result indicates that the bivariate distribution of the older observers' fixations tended to be more eccentric along the horizontal than the young observers' fixations.

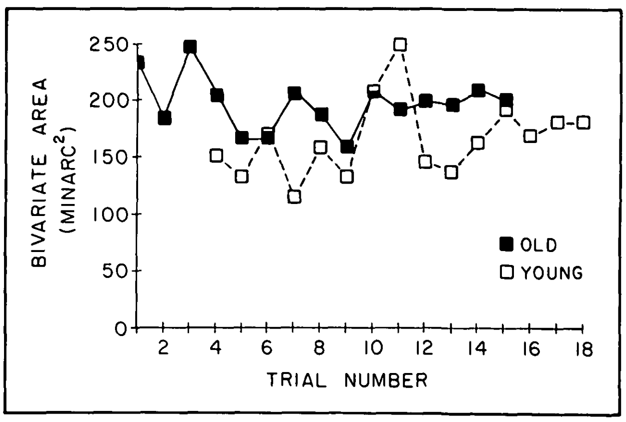

Fig. 3. Fixation stability, defined as the mean bivariate contour area, in the younger and older observers across trials.

We emphasize, however, that this effect was not large. When older and younger observers were compared on each meridian separately, there were no significant group differences in the dispersion of fixations on either meridian. This point is reinforced by noting that the standard deviations of the mean horizontal and vertical fixations (Table 1) show a large overlap between the two groups. Thus, the greater eccentricity in older adults may be more indicative of the idiosyncratic performance of a few observers, rather than a consequence of the aging process.

Fixation stability in our young observers was not as good as that reported by others.[1,5–7] Previous studies used highly trained observers, while we used observers not well experienced in psychophysical observation. To see if experience could account for the larger scatter of eye fixations in the present study, we trained two young adults to control their eye movements by providing real-time visual feedback of eye position. Over a 10-day training period, both subjects reduced the scatter of fixations by half. These trained eye fixations were comparable to other studies that used trained observers.

Steinman et al[18] have reported that fixational eye movements can be brought under voluntary control with appropriate instruction. Thus, differences in fixation area reported here and those reported elsewhere may be due to variations in the extent of training and the instructions given to the observers. This point reinforces the importance of simultaneously collecting data in samples matched for instructions and experience when group differences are of interest.

Histochemical investigations of EOM in both humans and monkeys have shown age-related variations in the degeneration rates of different fiber types.[14] Although all EOM fibers showed signs of degeneration with age, the small fibers were more resistant than other EOM fiber types. Aged, small fibers in both the peripheral and central portions of the muscle displayed only slight changes in mitochondria and sarcoplasmic spaces, with occasional pigment and leptomeric bodies. In contrast, larger cells within the EOM central core showed the greatest atrophy, including myofibrillar degeneration and changes in mitochondrial shape and content.

The small, slow EOM fibers exhibit electrophysiological properties consistent with tonic control of the eye.[15,19,20] Slow fibers have low thresholds, and are capable of maintaining sustained contraction rates necessary for tonic control of the eye. The resistance of these fibers to the effects of age, and their contribution to fixational eye movements, may, therefore, account for the high degree of fixation stability observed in the older observers.

Other aspects of the oculomotor system, which include tonic control of the eye, also appear to be preserved in old age. Miller[14] noted that the vast majority of nerves and motor end plates were intact in the aged EOM. This was true even of fibers that showed extensive degeneration. Intact innervation of EOM stands in sharp contrast to aging skeletal muscles, in which motor neuron loss is accompanied by muscle wasting.[21]

Oculomotor nuclei are also resistive to age-related cell loss. Vijayashankar and Brody[22,23] reported no decline in the number of cells in the abducens or trochlear nuclei in human specimens from birth to 87 yr of age. The brainstem tegmentum also showed normal cell count in the elderly.[24] Thus, the accumulated evidence suggests that the preservation of fixation stability in old age may be due to the resistance of the tonic oculomotor control system to the degenerative effects of age.

In contrast to fixational eye movements, both fast twitch and slow fibers are maximally recruited in saccades.[15] One would expect, then, that the effects of age-related degeneration of EOM fibers should be more readily apparent in high velocity eye movements in elderly adults. This hypothesis is supported by some researchers who have reported that maximum saccadic velocity and high velocity smooth pursuit slows down in old age.[8,12,13] On the other hand, others have reported that peak saccadic velocity is highly variable with age.[11] Future studies that focus on the relationship between EOM morphology and oculomotor performance in the elderly may help to resolve this question.

Key words: aging, vision, fixation stability, oculomotor function, extraocular muscles

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