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BRIEF REPORT

Age Differences in Saccadic Averaging

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Younger and older adults were asked to saccade to an orientation-defined target that was presented alone, with a more central distractor, or with a more peripheral distractor. Both age groups exhibited saccadic averaging that was more pronounced in the central distractor condition, wherein older adults had the larger effect. These results are relevant to questions of oculomotor control and also have implications for the study of age differences in other visually guided behaviors.

Voluntary saccadic eye movements executed to a visual target are often influenced by a proximal nontarget. Typically, the primary (i.e., first) saccade falls somewhere between target and nontarget items (Coren & Hoenig, 1972; Deubel, Findlay, Jacobs, & Brogan, 1988; Findlay, 1982; Findlay, Brogan, & Wenban-Smith, 1993; Findlay & Kapoula, 1992; He & Kowler, 1989; Ottes, van Gisbergen, & Eggermont, 1985; Vitu, 1991). This error in the amplitude of the primary saccade has been termed *saccadic averaging,* the *global effect,* and less frequently, the *center of gravity effect.*

There are several visual variables that influence the magnitude of saccadic averaging, including target–distractor separation (Findlay, 1982), relative distractor size (Findlay, 1982), spatial frequency (Findlay et al., 1993), eccentricity (Findlay, 1982), and luminance (Deubel, Wolf, & Hauske, 1984). Saccadic averaging may represent spatial pooling of low-resolution oculomotor neurons in the superior colliculus (Findlay et al., 1993; Ottes et al., 1985), but central mechanisms play a role as well (Findlay & Kapoula, 1992; He & Kowler, 1989; Ottes et al., 1985). Although saccadic averaging is studied most often in simple tasks involving impoverished displays, the same phenomenon influences performance in relatively complex tasks, including reading (Vitu, 1991). Thus, age differences in saccadic averaging may well add oculomotor overhead to cognitively demanding tasks such as text processing, wayfinding, visual inspection, and search.

Researchers know relatively little about the properties of saccadic eye movements made by older adults. Saccadic latencies to isolated luminance targets increase with age (Huaman & Sharpe, 1993; Whitaker, Shoptaugh, & Haywood, 1986), and there may be an age-related decline in peak saccadic velocity and accuracy (Huaman & Sharpe, 1993). Relative to the young, older adults make more saccades when searching for an eccentric target (Scialfa & Joffe, 1997; Scialfa, Thomas, & Joffe, 1994) and when searching for a conjunction search target embedded in larger numbers of distractors (Scialfa, Joffe, & Jenkins, 1997). In addition, Scialfa and Joffe (1997) reported that older adults had longer average fixation durations than their younger counterparts, which may be a result of longer saccadic onset latencies.

Age-related increases in saccadic averaging could be expected because declines in peripheral acuity (Collins, Brown, & Bowman, 1989), contrast sensitivity (Crassini, Brown, & Bowman, 1988), and luminance sensitivity (Johnson, Adams, Twelker, & Quigg, 1988) make it more difficult to discriminate target and nontarget items. On the other hand, it is possible that age differences in saccadic averaging are influenced by the location of the distractor because age reductions in peripheral visual function, including the *useful field of view* (Cerella, 1985; Scialfa, Kline, & Lyman, 1987; Scialfa, Thomas, & Joffe, 1994; Sekuler & Ball, 1986), insulate the older adult from the effects of a nontarget item presented at a more eccentric location than the target.

In our study, a substantive replication of Deubel et al.'s (1988) second experiment, we compared the saccadic onset latency and accuracy of younger and older observers who were instructed to make a saccade to a peripheral, oriented-line target presented against a uniform, unstructured background. This target was presented in isolation, together with a more centrally located distractor, or with a more peripheral distractor. We hypothesized that older adults would show greater saccadic averaging, but we allowed for the possibility that age-related declines in peripheral function would produce smaller age differences in the peripheral distractor condition.

Method

Participants

Eighteen young adults (mean age = 24 years, range = 18–41 years) and 18 old adults (mean age = 63 years, range = 52–73 years) were paid $10 Canadian to be observers in this study. All participants reported that they were in good general and visual health. On average, younger people had 15.44 years of schooling (range = 12–21 years), and the older group had completed 15.75 years of schooling (range = 10–30 years). These age differences in education were nonsignificant (p = .823).

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Best optical corrections for the 45-cm test distance were provided for everyone. Mean Snellen decimal acuity levels were .70 (range = .60–1.05) for younger adults and 1.02 (range = .60–1.81) for older adults. The age differences in acuity significantly favored the young, $F(1, 33) = 13.06$, $p = .001$, but every observer could read print on the cathode ray tube (CRT) that was much smaller than the stimuli used in the experimental task.

Apparatus and Stimuli

Data were collected by using the Eyegaze Development System from LC Technologies, Inc. (Fairfax, VA; Cleveland & Cleveland, 1992). Details are given in Scialfa et al. (1994).

The CRT on which displays were presented was 24.8 cm (28.86°) wide and 19.8 cm (23.75°) high. The active area of the CRT was divided into 1,024 equally sized cells, which could contain a fixation stimulus (+) or line segments that were .38 cm (0.48°) long and 0.05 cm (0.06°) wide. All elements were centered in the cells of the matrix.

All displays contained a target that was a single column of 19 line segments oriented at 45° to the left of vertical. When present, distractors were 4 × 13 matrices of line segments, also oriented 45° to the left of vertical.

There were three types of displays used in this experiment. In the target alone condition, only the target was presented, centered 14.8 cm (18.2°) from fixation. In the central distractor condition, the distractor was centered 4.25 cm (5.4°) nearer to fixation than the target. In the peripheral distractor condition, the distractor was centered 4.25 cm (5.4°) further from fixation than the target. On 50% of the trials, the fixation point was presented 2 cm (2.5°) from the right edge of the CRT, and on the remaining trials it was presented an equal distance from the left edge of the CRT. Background luminance was 66 cd/m^2 and line segments had a luminance of 7 cd/m^2, yielding a Michelson contrast of 81%.

Procedure

Each participant was tested in a single 60-min time period. We obtained informed consent from everyone, gave them their best optical correction, and determined their acuity at test distance.

The experiment proper consisted of 96 trials, divided into 8 blocks of 12 trials each. Each trial started with the appearance of the fixation stimulus. When observers were satisfied that they had fixated this stimulus, they pressed the space bar on the keyboard to initiate the trial. The eye movement monitor was used to ensure the observer foveated the fixation stimulus for at least 330 ms, and after a randomly varying delay of either 600, 1,000, or 1,500 ms, the saccade display was presented. Observers were told to move their eyes to the target as quickly and accurately as possible and to maintain fixation there. After a delay of 3 s, the display disappeared and the fixation stimulus was presented again, marking the beginning of the next trial.

In total, there were 32 trials each in the target alone, central distractor, and peripheral distractor conditions, randomly ordered within blocks. Even-numbered trials began with the fixation stimulus on the left side of the CRT, and odd-numbered trials began with the fixation stimulus on the right side. Calibration of the eye movement system took place before each block of trials; this also afforded observers a brief rest.

Results

Data were retained only if the primary saccade onset latency was greater than 120 ms, the landing position of the first saccade was within 9.8° of the target, and there were at least 9 acceptable trials per condition. Application of these criteria resulted in the loss of data from 1 younger observer.

Primary Saccade Latencies

Table 1 shows the mean latency of the primary saccade as a function of age group and display condition. Older adults were slower on average, and saccadic latencies were somewhat shorter on trials containing a distractor than on trials containing only a target. An Age × Display Condition (2 × 3) analysis of variance (ANOVA) revealed significant effects of age, $F(1, 34) = 8.50$, $p = .006$, and display condition, $F(2, 68) = 33.36$, $p < .001$, but the Age × Display Condition interaction was nonsignificant ($p = .580$).

Table 1
Mean Primary Saccade Latencies (in Milliseconds) as a Function of Age and Display Condition

	Display condition					
	Target alone		Central distractor		Peripheral distractor	
Age group	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young	344	55	307	48	320	49
Old	397	63	351	52	371	55

Primary Saccade Amplitudes

Figure 1 displays histograms of the amplitude of the primary saccade, expressed as a percentage of target amplitude, for each age group and display condition. Both younger and older adults were very accurate in the target alone condition. The mean values of 97% (older adults) and 96% (younger adults) compare favorably with Deubel et al.'s (1988) average of 96% for 5 unpracticed observers. Saccadic averaging was exhibited by both age groups in the central distractor and peripheral distractor conditions but was more pronounced in the former. It appears, as well, that older adults exhibited greater saccadic averaging, although this is more obvious in the central distractor condition.

An Age × Distractor Condition (2 × 3) ANOVA was consistent with these trends. There was not a main effect of age ($p = .258$), but there was a main effect of distractor condition, $F(2, 68) = 114.21$, $p < .001$, and an Age × Distractor Condition interaction, $F(2, 68) = 3.74$, $p = .049$. Follow-up analyses revealed an age effect in the central distractor condition ($p = .035$), which did not approach significance in either the target alone condition ($p = .613$) or the peripheral distractor condition ($p = .487$).[1]

Discussion

For both younger and older adults in the target alone condition, primary saccades fell short of the target's center by less than 3%

[1] In a separate experiment with independent groups of 10 younger adults (mean age = 22 years) and 10 older adults (mean age = 62 years), we examined saccadic averaging when targets and distractors identical to those reported here were presented in textured backgrounds composed of lines oriented at 135° (see Experiment 3 of Deubel et al., 1988). We had to remove 1 younger and 5 older people from the study. Older observers were often unable to extract the peripheral target from its background. Instead, they made saccades to the center of the screen, imaging the target more centrally, and then made a smaller amplitude saccade to the target. These findings bear replication and further study to see, for example, if older adults' difficulty was related to the spatial frequency of the displays. At a minimum, researchers who are interested in conducting aging studies that examine saccadic averaging in textured scenes might want to consider the difficulties we encountered before collecting large amounts of problematic data.

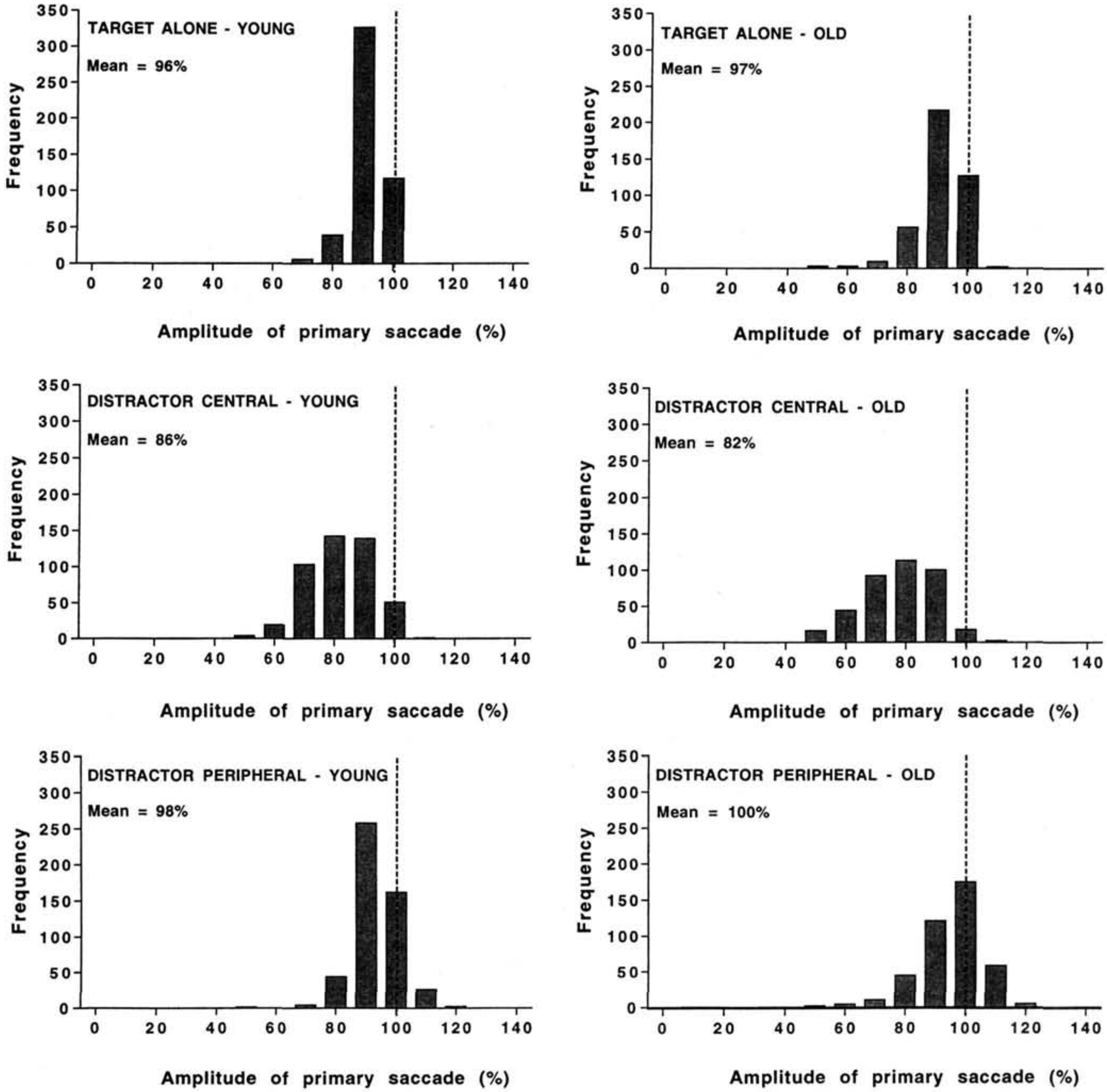

Figure 1. Distributions of primary saccade amplitudes, expressed as percentages of target amplitudes. Left panels depict data for younger adults; right panels, for older adults; upper panels, for target alone; center panels, for central distractor; and lower panels, for peripheral distractor. The vertical lines at 100% indicate target position.

on average. When the target was accompanied by a more central distractor, however, the amplitude of the primary saccade fell short of the target, and this saccadic averaging was more pronounced in the elderly. A peripheral distractor was associated with less saccadic averaging generally, which was no greater in older than younger adults.

Why were saccadic onset latencies similarly diminished in the central distractor and peripheral distractor conditions, whereas saccadic averaging occurred primarily in the former? One possibility is that in both conditions the contrast gradient (Nothdurft, 1993) associated with the distractor increases the signal that is used to initiate the saccade but that in the peripheral distractor condition the more eccentric regions of the distractor are given less weight in computing saccade amplitude. This hypothesis is consistent with data indicating that the information used to determine *when* a saccade is initiated differs from the information used to determine *where* the saccade terminates (Becker & Jürgens, 1979; Findlay, 1982). This dissociation of the temporal and spatial parameters of saccades might also help to explain why age differences in saccadic onset latencies do not interact with the display characteristics, whereas older adults exhibit more saccadic averaging in the central distractor condition. The boundaries of the distractor may be sufficiently salient to reduce the onset latencies in older adults in both the central and peripheral distractor conditions, but the location information may be sufficiently weak on peripheral distractor trials that saccade amplitude is less affected.

It is often reported that there is an inverse relation between saccadic onset latency and the magnitude of the global effect, and in fact, saccadic averaging can be reduced or eliminated when observers are instructed to delay their initial saccades (Ottes et al., 1985). These observations allow for the possibility that individual differences in the data might, in part, reflect this dependency. In addition, older adults' primary saccade latencies were longer than those of the younger adults. They might display even greater saccadic averaging than their younger counterparts on trials associated with the same onset latencies.

The relation between onset latency and amplitude was examined in two ways. First, we determined the sample correlations between primary saccade latency and deviation between target and saccade amplitude. These correlations were .15 in the target alone condition, −.08 in the central distractor condition, and .26 in the peripheral distractor condition. None of these correlations was significant, and in the central distractor condition, longer latencies were associated with greater saccadic errors.

It might be argued that faster saccades produce greater saccadic averaging within individuals. Allowing for this possibility, we determined the correlation between saccadic latencies and errors separately for each person in each display condition. The average correlations were .20, .39, and .03 in the target alone, central distractor, and peripheral distractor conditions, respectively. Of the 111 correlations generated, only 35 were significantly different from zero, and of these, 4 were not in the predicted direction. Thus, there is little evidence in our data that faster saccades are associated with greater saccadic averaging.

Given that we found no relation between onset latency and accuracy, it is unlikely that the pattern of age differences obtained would change materially for those trials on which younger and older people responded with the same onset latency. To this end, we examined the data for trials resulting in onset latencies between 250 ms and 350 ms. Individual means were not particularly stable because there were several older individuals who had few trials in this range, but a cursory examination of the means is consistent with the overall results. Relative to the younger adults, older adults exhibited more averaging in the central distractor condition than in the peripheral distractor condition.

Several thousand times each day people use saccades to move their eyes from one part of the visual world to another. So successful are they in executing these eye movements that it would be easy to assume they are carried out with negligible error. Saccades to isolated targets are very accurate (Becker, 1989), but even in this situation, some error is the norm. In the more common case in which the saccade target is close to another object, the eyes will land at some point between them. This saccadic averaging is generally followed by a smaller-amplitude, corrective saccade that images the attended object on the fovea. These corrective saccades add many milliseconds to the task of visually acquiring the object of attention.

In this study we have demonstrated that older adults exhibit greater saccadic averaging than younger adults when a nontarget is positioned between fixation and the saccade target. This greater saccadic averaging may be a reflection of diminished sensitivity in the older observers' visual periphery. If older adults are unable to differentiate target and distractor, they would have greater difficulty calculating the appropriate saccade amplitude. This hypothesis is consistent with the view that saccadic averaging reflects collicular oculomotor neurons that have large receptive fields (Lee, Rohrer, & Sparks, 1988; Ottes et al., 1985).

The greater saccadic averaging seen among older adults may interfere with their ability to efficiently execute voluntary saccades. Saccadic averaging necessitates corrective saccades and refixations in visual search (Findlay & Kapoula, 1992) and in reading (Vitu, 1991). Any greater global effect in older adults would add time to task performance that may increase in proportion to the necessity of engaging in overt search. Thus, age differences in difficult feature search (Scialfa, Joffe, & Esau, 1998; Scialfa et al., 1994) and conjunction search reaction times (Plude & Doussard-Roosevelt, 1989; Scialfa & Joffe, 1997; Scialfa et al., 1997) may reflect this oculomotor component.

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