Age-group Differences in Saccadic Interference

Lawrence R. Gottlob, Mark T. Fillmore, and Ben D. Abroms

University of Kentucky

Lexington, KY 40506-0044

IN PRESS: Journal of Gerontology: Psychological Sciences
Abstract

Age-group differences were examined in a saccadic interference task, which requires that participants execute a saccade (eye movement) toward an abrupt-onset visual target presented to the right or left of fixation. On some trials, diffuse interference was imposed by bilateral (top and bottom) flashes of light presented 20 to 210 ms after target onset. When the flashes followed the cue at shorter intervals, time to execute a saccade was slowed relative to no-flash trials. This slowing was greater and sustained over a larger cue-flash interval for older participants than for the young participants. The results indicate that older adults are more susceptible to saccade disruption than are young adults, when diffuse distractors are used.

Keywords: eye movements, saccades, aging, inhibition
As we move through the world, the visual field is continually changing. We often must fixate the portion of the visual field that is most salient to our immediate goals, while resisting the “automatic” attraction of other objects. For example, while navigating a bicycle through rush-hour city traffic, a cyclist must monitor parked cars for opening doors and the oncoming lane for turning cars, while simultaneously resisting the urge to fixate shiny coin-like objects on the road. This control over eye movements (oculomotor control) is also exerted in many laboratory contexts, including visual search, location cuing, and reading. Because oculomotor control is intrinsic to the efficient execution of eye movements, and because it is closely tied to attentional control (Kramer, Hahn, Irwin, & Theeuwes, 1999), age-group differences in this ability are important to study.

Oculomotor control is often examined directly by monitoring eye movements in experimental paradigms involving instructions to fixate certain objects in the visual field while ignoring others (e. g. Reingold & Stampe, 2002). Age-group differences in this ability have been examined using the attentional capture paradigm. In Kramer, Hahn, Irwin, and Theeuwes (2000), participants first fixated a display containing six items in a circular configuration with a radius of 12.6 deg. All of the display items, except one, then changed from gray to red; participants had been instructed to execute a saccade to the single item that remained gray. On some trials, a new red (distractor) item appeared at the same time that the other items changed from gray to red. When red and gray were...
equiluminant, participants were generally unaware of the distractor, and there were no age-group differences in the percentage of trials in which saccades were initially directed toward the distractor. When the distractor was brighter than the target, and consequently participants were aware of its presence, younger adults had a decreased incidence of saccades toward the distractor (compared to equiluminant trials), whereas older adults had an increased incidence. The inference was that older adults had relative difficulty inhibiting reflexive saccades when the intrusive object occupied awareness, but that there were no age deficits when the inhibition was related to unconscious or automatic processes (see also Kramer et al., 1999).

In Kramer et al. (2000), saccade latencies were the same for no-distractor and distractor trials. If the distractor interfered with the execution of saccades, why were the latencies not different? One possible explanation is in the geometry of the task: Distractors could appear close to (19.4 deg) or far from (25.4 deg) the target, but because the possible target locations were on a circle, the spatial relationship between the distractor and the target was highly variable. This spatial relationship has been found to influence attentional capture in a complex manner, sometimes affecting saccade accuracy and sometimes affecting saccade latency. In a study examining spatial properties of attentional capture, Walker, Deubel, Schneider, and Findlay (1997) presented abrupt-onset targets at a variety of locations on the horizontal midline of a computer screen and manipulated the spatial relationship of the distractor and target. When the distractor was presented in the same vertical hemifield as the target and within
20 deg of the horizontal meridian (i.e. close to the path of a target saccade), accuracy was affected, but latency was affected only very slightly. When the distractor appeared outside the saccade-path zone, latency was primarily affected, with accuracy mostly unaffected. The differential effects were explained in terms of adding or subtracting inputs in the neural structures that control oculomotor movements. When the distractor and target are in close proximity, the final saccade path is determined by spatial averaging of inputs. When the distractor and target are in opposite hemifields or otherwise sufficiently separated, inhibitory mechanisms in the neural areas that program saccades (e.g., superior colliculus; Reingold & Stampe, 2002) cause delays in the programming of target saccades, but do not have much impact on accuracy. Thus, the failure of Kramer et al (1999; 2000) to find distractor effects in saccade latency may have been due to variations in the spatial relationship between target and distractor (although if mean latency was a weighted average of accuracy- and latency-affected trials, there should have been an effect of distractor).

In addition to spatial properties of the distractor, the timing of the distractor onset has been shown to affect the saccadic response to distractors. In Kramer et al. (1999; 2000), onsets of distractor and target were simultaneous. Reingold & Stampe (2002), in a study using young participants only, investigated the time parameters of distractor onset. Participants were required to execute saccades to targets presented 4 deg to the left or right of fixation. On some trials, the top and bottom third of the display was illuminated (flashed) briefly. The onset
asynchrony between target and flash was manipulated on an adaptive basis for each observer, such that the target-flash delay would have the maximum effect on saccade reaction time. This optimal delay, suggested by a previously-performed experiment (Reingold & Stampe, 2004), was the median saccade latency for each observer, minus 100 ms. In their Experiment 1, Reingold and Stampe (2002) manipulated the fixation point-target relationship and measured the magnitude of the flash effect in each condition: gap (fixation offset before target onset), step (fixation offset simultaneous with target onset), and overlap (fixation point remained on for the entire trial). They found that maximum saccade disruption occurred in the overlap condition, with the flash producing its strongest inhibition on saccades 60-70 ms after its onset. They explained their results in terms of disruptions in the programming of the saccade, with the effect strongest in the overlap condition because of the already-existing competition between the activations from “fixation-point neurons” and “target neurons” in the superior colliculus.

In the current study, we used the paradigm developed by Reingold and Stampe (2002) to investigate age-group differences in saccade interference. According to the findings of Walker et al. (1987), saccade latency, but not accuracy, is affected when the distractor appears outside of the saccade path to the target. Reingold & Stampe (2002), accordingly, used bilateral bars of light occupying the top and bottom thirds of the screen. This type of distractor also has the advantage of high salience, which should minimize age-related differences in visual acuity or useful field of view (although Kramer et al., 1999,
investigated this potential confound and found no evidence for it). In addition, we used the overlap condition (fixation point remaining on for entire trial), which as Reingold & Stampe (2002) found, induced the largest interference effect as measured in saccade latency. The bilateral flashes and the overlap condition would work together to produce the largest distraction effect on saccade latency; we wanted to maximize this because the previously-obtained interference effects on the order of 20 ms (Reingold & Stampe, 2002) might produce difficulties in measuring age-group effects. Unlike Reingold & Stampe (2002), who used an adaptive technique to estimate the target-flash onset that would produce the largest distractor effect, we manipulated target-flash SOA so that we could get estimates of age-group differences in both the magnitude and duration of the distractor effect.

By using bilateral distractor flashes both above and below the saccade path, our goal was to extend the work of Kramer et al. (1999, 2000) by reducing the confusability between target and distractors. Given an age-group deficit in inhibition of distractors that has been manifested in both saccade accuracy (Kramer et al., 1999, 2000) and saccade latency (Cassavaugh, Kramer, & Irwin, 2003), we predicted that the older participants would show a greater interference effect (slowing in the flash condition relative to the no-flash condition) than the young participants. In addition, the manipulation of target-flash SOA would allow us to compare, across age groups, the duration of the disruption effect. On the other hand, if age-group deficits in the ability to inhibit disruptions are only
manifested in saccade accuracy, but not saccade latency (Kramer et al., 1999, 2000), then we would not find age-group effects in the current paradigm.

Method

Participants. Twenty one older adults (M age = 70.6 yrs; range 65 - 78 yrs) and 19 young adults (M age = 20.8 yrs; range = 18 - 25 yrs), recruited from the community, participated. The older adults were members of the Sanders-Brown subject registry, and the young adults were university students. Participants were paid $10 for the session. Participants passed a color-blindness test, and minimum visual acuity, measured at four feet, was 4/8 (equivalent to 20/40). All participants had a minimum of 12 years of education. A computerized version of the Mill-Hill vocabulary test was administered; mean scores were 16.6 (se = 0.94) and 13.4 (se = 0.59) for older and younger participants respectively, F (1, 38) = 7.01, p < .05. A computerized version of the digit-symbol test was also administered as a test of visual processing speed; mean RTs were 1443 ms (se = 47) and 993 ms (se = 51) for older and younger participants respectively, F (1, 38) = 37.7, p < .001.

Apparatus. The stimulus displays were controlled by a Pentium 4 computer, connected to a 19” monitor running at 100 Hz, at a screen resolution of 800 x 600 pixels. Stimulus displays were programmed in EPrime, which also started and stopped eye position recording. The eyetracker was an ASL model 504 (Applied Science Laboratories; Bedford, MA), connected to an eye-position camera sampling at 60 Hz. The ASL system measures eye position with precision of
approximately +/- 1 deg. A chin- and head-rest fixed eye position and maintained an eye-to-screen distance of 76 cm. The room had dim natural lighting.

**Stimuli and procedure.** The background of the monitor was gray with a brightness of 3 cd/m², and stimuli were white with a brightness of 69 cd/m². All stimulus parameters were randomly determined within blocks. The fixation point (+) was presented at the center of the screen and remained on the screen throughout each block (Figure 1). Each trial began with the fixation point presented alone for 500 or 900 ms (randomly chosen); participants were to fixate this. The target (1 sec) was then presented at one of four possible locations, 3.125 deg (close) or 6.25 deg (far) to the left or right of fixation. Participants were instructed to execute a saccade as rapidly as possible to the target location. On half the trials, white bars with a duration of 30 ms were presented, filling the top and bottom thirds of the computer screen. Onset of the bars (target-flash SOA) was 20, 60, 110, 160, or 210 ms after onset of the target. There were 40 trials per block, for a total of 4 blocks. (Only the last 3 blocks were analyzed.)

Trials were presented in a single session. The eyetracker operator was present in the room and monitored the observer's eye position on a separate screen with the display superimposed. The operator would remind the observer of the task requirements if he saw that the observer was failing to follow instructions (e.g. failure to fixate the fixation point, failure to execute a saccade to the target). Eye movements were measured with ASL Eyewin software, which recorded a 60-HZ stream of x and y values, along with pupil diameter. Fixations were defined according to the defaults provided by the eye-recording software: A
fixation was recorded if six sequential gaze samples (16.7 ms each) had a standard deviation of no more than one-half degree in the x- and y-axes. A fixation was ended if three sequential gaze samples were more than one degree from the fixation position. Saccade latency was measured as the time elapsed between target onset and the end of the central-point fixation. Saccade time was measured as the time elapsed between the end of the central-point fixation and the beginning of the target fixation.

Results

A repeated–measures design using the generalized linear mixed model, as implemented in PROC MIXED (Littell, Milliken, Stroup, & Wolfinger, 1996), was employed. The advantage of PROC MIXED over a standard repeated-measures ANOVA is that in PROC MIXED, the unit of observation is the individual trial, whereas in ANOVA, the unit is a participant’s cell mean. Therefore, PROC MIXED takes into account intra- as well as inter-observer variability. In these results, least-square means are presented, with standard errors in parentheses. Because PROC MIXED does not compute sums-of-squares, effect sizes (only for the most important two-group or two-level comparisons) were computed as Cohen’s $d$ (Rosenthal & DiMatteo, 2002). All multiple comparisons were adjusted using the Sidak correction. Repeated-measures analyses were performed on saccade latency and landing accuracy (x-axis distance between target fixation and target location), with age group, flash presence, and fixation-target distance as fixed-effect factors. In addition, latency was measured as a function of flash SOA for flash-present trials only (this factor was irrelevant to flash-absent trials).
Saccade latency, as stated above, was measured as the difference between target onset and the end of the central fixation. Latencies greater than one second were excluded (less than 2% of trials). There was a main effect of age group, $F(1, 38) = 4.86, d = 1.03, p < .05$, with mean latencies of 213 ms (se = 14) and 256 ms (se = 13) for young and older participants respectively. There was also a main effect of flash presence, $F(1, 38) = 23.93, d = 1.10, p < .001$, with mean latencies of 218 ms (se = 10) and 251 ms (se = 10) for flash-absent and flash-present trials. There were no effects of target distance.

Main effects of age group and flash presence were both qualified by the presence of an Age Group x Flash Presence interaction $F(1, 38) = 12.33, p < .001$ (Table 1). Examining simple effects of age group, for flash-absent trials, there was no effect of age group, $F(1, 38) = .04, d = 0.06, p > .05$, whereas for flash-present trials, young adults were significantly faster than older adults, $F(1, 38) = 8.72, d = 0.93, p < .01$. Examining simple effects of flash presence, there was no difference for young participants, $F(1, 18) = 1.67, d = 0.41, p > .05$, but there was an effect of flash presence for older participants, $F(1,20) = 17.80, d = 1.34, p < .001$. Thus, the Age Group x Flash Presence interaction was carried primarily by the older adults’ increased latency in the flash-present condition. The interaction was not removed by log transformation, indicating that these age-group effects could not be explained by generalized slowing (Cerella, 1990).

Saccade latency for flash-present trials as a function of flash SOA, along with saccade latency on flash-absent trials (a control condition), is presented in Figure 2. For flash-present trials only, there was a main effect of flash SOA, $F(4, 151) =$
4.77, \( p < .01 \), but there was no Age Group x SOA interaction, \( F(2, 151) = 1.30, p > .05 \). In order to investigate the duration of the flash effect within each age group, we conducted pre-planned comparisons between flash-present latency at each SOA, and latency in the control (flash-absent) condition. Because we were performing multiple comparisons between flash-present latencies and control latencies, \( p \)-values were corrected by Bonferroni. For young participants, the first flash SOA produced an effect of flash presence, \( F(1, 18) = 12.75, p < .05 \), but the other four did not, \( F(1, 18) = 1.41, 0.44, 0.02, \) and \( 0.11, p > .05 \). For older participants, the first three flash SOAs produced effects of flash presence, \( F(1, 20) = 12.09, 17.26, \) and \( 9.09, p < .05 \). The last two flash SOAs produced no effect of flash presence, \( F(1, 20) = 4.56 \) and \( 3.01, p > .05 \).

We wanted to investigate whether the magnitude of the flash presence effect (flash-present minus flash-absent latency) was related to speed of executing the saccade, i.e. whether participants who were slow to execute a saccade would have more saccade interference. Correlations at each SOA, between the magnitude of the flash-presence effect and flash-absent latency, were examined separately by age group. For young participants, there was a correlation at SOA = 20, \( r = .51, p < .05 \), and for older participants, there was also a correlation at SOA = 20, \( r = .75, p < .001 \), but there were no other significant correlations. We also checked for significant correlations between Digit Symbol response time and magnitude of the flash-presence effect (within age groups), but they were not present.
Saccade landing accuracy was measured as the absolute value of the horizontal distance between the target and the target fixation. Precision of measurement for fixation position, as noted above, was +/- 1 deg. There was a main effect of flash presence, $F(1, 38) = 5.74, d = 0.76, p < .05$, with deviations of 1.24 deg (se = 0.09) and 1.32 deg (se = 0.09) for flash-absent and flash-present trials respectively. There was no main effect of age group; mean deviations were 1.17 deg (se = 0.12), and 1.38 deg (se = 0.12), for young and older participants respectively, $F (1, 38) = 1.50, d = 0.39, p > .05$. In addition, there was no Age Group x Flash Presence interaction for landing accuracy, $F (1,38) = 0.74, p > .05$. Pairwise comparisons of landing accuracy between control (flash-absent) and flash-present trials at each SOA were examined within each age group, as was done for saccade latency. None of the pairwise comparisons were significant ($p < .05$ with a Bonferroni correction).

The variability in saccade landing accuracy was also examined. There was no main effect of flash presence and no effects involving age group; the standard deviation of landing accuracy was 0.90 deg (se = 0.07) for young participants and 1.00 deg (se = 0.07) for older participants, $F (1,38) = 0.90, d = 0.30, p > .05$. Pairwise comparisons of landing accuracy variability between control (flash-absent) and flash-present trials at each SOA were examined within each age group. None of the pairwise comparisons were significant ($p < .05$ with a Bonferroni correction).

Saccade transit time was measured as the end of the central fixation to the beginning of the fixation on the target. There was a main effect of flash presence,
F (1, 38) = 17.67, $d = 0.94, p < .001$, with flash-absent trials (M = 84 ms, se = 8) faster than flash-present trials (M = 94 ms, se = 6). Analysis within each age group yielded flash presence effects (flash-present time minus flash-absent time) for young participants of 8.6 ms, F(1, 18) = 5.32, $d = 0.93, p < .05$, and for older participants of 12.7 ms, F(1, 20) = 13.44, $d = 1.16, p < .001$. Mean saccade transit times were 95 ms (se = 8), and 84 ms (se = 8), for young and older participants respectively, which did not differ significantly, F (1, 38) = 0.86, $d = 0.30, p > .05$.

Discussion

In this study, we investigated the magnitude and time course of interference in initiating and executing saccades, as a function of age group. Age-group differences were found in saccade latency, as manifested in an Age Group x Flash Presence interaction. The two decompositions of this interaction are each meaningful: (1) There was an age-group difference in magnitude of the interference effect (flash-present – flash-absent latency) in that young participants had a non-significant 10 ms interference effect, whereas older participants had a 60 ms interference effect. (2) In the flash-absent (baseline condition), there was no age-group difference in saccade latency (a non-significant 15 ms), but in the flash-present condition, older participants were 65 ms slower than young participants. Although there was no Age Group x SOA interaction for flash-present trials, pre-planned analyses indicated that for the young participants, the flash interfered with the execution of saccades when it was presented within 20 ms (inclusive) of target onset, whereas for the older
participants, this interference was sustained until at least 110 ms after target onset. The main findings, therefore, were that there were no age differences in the baseline condition, and that the older participants showed saccade interference over a longer target-flash interval than the young participants. There was some evidence that the age-group differences in interference were related to processing speed: Within each age group, control (flash-absent) saccade latency was correlated with the magnitude of interference, but only at the first flash SOA.

The current results for saccade latency can be compared to those from the analogous condition in Reingold and Stampe (2002). Their (young) participants had latencies of 209 ms and 231 ms in the flash-absent and flash-present conditions respectively, whereas our young participants had latencies of 208 and 218 ms. We cannot precisely account for the different flash-present latencies in the two experiments; differences in subject or stimulus variables could have been responsible.

Although we found an age group difference in flash-present saccade latency, other measures were equivalent across age groups. Saccade transit times did not differ across age groups, indicating no declines in the motor components of the saccade. Saccade accuracy (distance between the target fixation and the target) was equivalent across age groups, although there was a small effect of the flash. Minimal effects on accuracy would be consistent with the assertions of Walker et al. (1977) that distractors not on the saccade path would primarily affect latency and not accuracy. There were other factors that would also tend to minimize accuracy effects: the distractors did not resemble the target (although
they were higher in overall luminance), and their “center of mass” was the midline of the screen. The present results can be contrasted with those of Kramer et al. (2000), whose age-group decrement was manifested in saccade accuracy (but see Cassavaugh et al., 2003). In their paradigm, the distractor resembled the target in shape (but differed in color); older participants were lower in saccade accuracy than the young participants only when the distractor was higher in luminance than the target. Therefore, the older participants in Kramer et al. (2000) may have had reduced saccade accuracy because of confusability between the target and distractor. In the present experiment, the age-group equivalences in saccade transit times and accuracy would be evidence against a purely sensory explanation for the older participants’ saccade interference; i. e. that the flashes interfered with the ability of the older participants (but not the young participants) to see the target. The age-group difference in interference was manifested in a delay in initiating the target saccade, but once the saccade was executed, the age groups were equivalent in speed and accuracy of the saccade.

The age-group difference in interference that we found may have been mitigated by a few factors. Age-related restrictions in useful field of view (UFOV; Sekuler & Ball, 1986; Scialfa, Thomas, & Joffe, 1994) would predict less visual processing of parafoveal regions in the older adults, which would tend to reduce the magnitude of age-group differences in saccadic interference. Furthermore, the flashes were never presented in parts of the visual field in which saccade targets also appeared, in contrast to Kramer et al’s (1999, 2000) paradigm.
Therefore, the flash interference we found was not due to mistaking the flashes for targets, nor to obligatory processing of the parts of the visual fields in which the distractors appeared. On the other hand, the diffuse nature of the flashes may have made their inhibition difficult.

Reingold and Stampe (2002) proposed a mechanism for the flash interference effect, which they located in the superior colliculus, the part of the midbrain involved in programming eye movements. They speculated that the flashes caused disruption of saccade targeting in the superior colliculus neurons that program saccades. If that mechanism were operating in the current experiment, then it could be said that the young participants were able to inhibit the disruptive effect of the flash, whereas the older adults were deficient in inhibition. It is not likely that the effects could be explained solely by higher target-saccade activation in the younger adults, because their saccade latency, saccade accuracy, and saccade transit time were all comparable to those of the older adults in the baseline (flash absent) condition. This interpretation of age differences in terms of an inhibition deficit is similar to that of Kramer et al. (1999, 2000), who posited that the ability to resist oculomotor capture by irrelevant objects in the display was a form of inhibition.

An alternative explanation to an inhibition deficit would be an age-related deficit involving lower-level (sensory) types of interference. The most plausible sensory explanation for the increase in flash-present saccade latency would be that the flashes produced glare that “bled” into the central part of the visual field, reducing the salience of target onset. One way to check for effects of this glare
would be to look for other effects beside saccade latency that would be consistent with reduced target salience in flash-present trials; these would include landing accuracy and variability in landing accuracy. We did not find evidence, however, of age-group differences in either of those measures, which is inconsistent with the idea that the target onset was less salient for the older adults in the flash-present condition. In addition, within each age group, there were no effects of the flash (flash-present vs. control) at any SOA, for landing accuracy or variability in landing accuracy. Therefore, while sensory factors underlying age-group differences in flash-present saccade latency cannot be conclusively ruled out, we did not find any supporting evidence that the flashes produced glare that reduced the salience of target onset.

In summary, we found an age-group deficit in the ability to inhibit distraction in the execution of saccades toward a target. The deficit was manifested in an interference effect when distractors were presented prior to a target saccade. For the young participants, the interference effect was present when the distractors appeared 20 ms after target onset; for the older participants, interference was present when the distractor occurred 20, 60, and 110 ms after target onset (although there was no Age Group x SOA interaction for flash-present trials). The distractors were highly visible, but they occurred in parts of the visual field that never contained saccade targets. Therefore, the interference they caused was probably from diffuse activation in the neural centers that control eye movements. It may be that diffuse interference is especially difficult to inhibit if the visual system is compromised by age-related changes.
References


Figure Captions

Figure 1. Schematic of trial events. The target was an abrupt-onset square presented to the left or right of fixation, at one of two distances from the fixation point. The flash was presented on 50% of the trials with a variable target-flash onset asynchrony. Participants were instructed to execute a saccade to the target location as fast as possible.

Figure 2. Saccade latency for flash-absent (control) trials and for flash-present trials as a function of target-flash interval, for older and young participants. Error bars indicate one standard error.
Table 1. Mean saccade latencies (in ms) for flash-absent (control) and flash-present trials, by age group. (Standard errors in parentheses.)

<table>
<thead>
<tr>
<th></th>
<th>Flash-absent</th>
<th>Flash-present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>208 (15)</td>
<td>218 (15)</td>
</tr>
<tr>
<td>Older</td>
<td>223 (14)</td>
<td>284 (14)</td>
</tr>
</tbody>
</table>
Fig. 1
Fig. 2
Author Note

This research was supported by National Institute on Aging grant RO1 AG20860 to the first author.

The authors are grateful for the helpful comments of Richard Abrams on a previous version of this manuscript.

Correspondence concerning this article should be addressed to Lawrence R. Gottlob, 201 Kastle Hall, Lexington, Kentucky, 40506-0044. Email: gottlob@uky.edu.