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Age-group Differences in Inhibiting an Oculomotor Response

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ABSTRACT

Age-group differences were examined in the delayed oculomotor response task, which requires that observers delay the execution of a saccade (eye movement) toward an abrupt-onset visual cue. This task differs from antisaccade and attentional capture in that inhibition causes saccades to be postponed, not redirected. Older adults executed more premature saccades than young adults, but there were no age-group differences in latency or accuracy of saccades executed at the proper time. The results suggest that older adults are less capable of inhibiting a prepotent saccadic response, but that other aspects of visual working memory related to the task are preserved.

Age-group deficits in attentional inhibition (Hasher & Zacks, 1988) have been used to explain age-related cognitive changes in many tasks, including negative priming (Hasher et al., 1991) and reading for meaning (Connelly et al., 1991). Many other studies, however, have reported age-related preservations of attentional inhibition (e.g. Hartley & Kieley, 1995; Kramer et al., 1994). Although deficits in inhibition do not explain all age-related cognitive changes, they do appear in a large variety of tasks (Zacks & Hasher, 1997).

One area in which age-related failures of inhibition have been found is in the control of eye movements (saccades). Saccades are often highly automatized and prepotent, such that their inhibition is difficult. For instance, when an abrupt-onset object is presented in the visual field, observers have a strong tendency to execute a saccade in order to fixate (foveate) the object. In the *prosaccade* task, the new object is fixated; in the *antisaccade* task, a new object is presented in the visual field, but observers are required to execute a saccade to the opposite hemifield from this object. The antisaccade task requires control over several processes: inhibiting a reflexive

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response, shifting attention away from a target, and executing a saccade to an unmarked location (Olincy et al., 1997; Bojko et al., 2004). Generally, latencies and errors are compared between conditions in which prosaccades and antisaccades are required. In general, saccade latency is higher for antisaccades than for prosaccades, and a high incidence of saccade errors (executing a prosaccade) is observed in the antisaccade condition.

Antisaccade performance has been examined in several aging studies, mostly in order to investigate inhibitory processes. Olincy et al. (1997) used an antisaccade task to study eye movements in a continuous age range between 19 and 79 years. They found age-related increases in both antisaccade latency and errors. Butler et al. (1999) also found an age-group increase in antisaccade errors, as did Nieuwenhuis et al. (2000), Bojko et al. (2004), and Crawford et al. (2005). Age-group effects on antisaccade latency, however, were not found in all of these studies.

The antisaccade task measures the ability to inhibit one saccade and substitute another. In contrast, studies on *attentional capture* measure the ability to inhibit disruptions to a saccade. Age-group differences in attentional capture have been examined in a couple of recent studies by Kramer and colleagues. In Kramer et al. (2000), observers first fixated a display containing several items. All of the display items, except one, then changed from gray to red, and observers were 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, observers 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 observers were aware of its presence, younger adults had a decreased incidence of saccades toward the distractor, 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 the antisaccade task, as stated above, a prosaccade is inhibited and an antisaccade is executed instead. In the attentional capture task, disruptions are inhibited and a target saccade is executed. Inhibition is involved in both cases, but both tasks require an execution of a saccade at the same time the inhibition is measured. Thus, in neither case is the ability to inhibit a saccade measured in isolation. A more direct test of saccadic inhibition is the delayed oculomotor response (DOR) task (Ross et al., 1994; Ross et al., 2000). In the DOR task, observers fixate a stimulus. A peripheral cue is presented briefly, and observers are instructed to execute a saccade to the cued location, but only *after* the fixation point is extinguished. Various groups have been tested with this task, in order to determine whether they have more difficulty withholding saccadic responses during the time the fixation point is present on the screen (a measure of response inhibition), and whether they can accurately execute a proper saccade to the cued location even though the cue is no longer present (a measure of visual working memory). Previous findings have indicated that ADHD children (Ross et al., 1994) and ADHD adults (Ross et al., 2000) have an increased rate of premature saccades compared to controls, but similar accuracy of proper saccades, indicating a simple failure of inhibition. On the other hand, schizophrenic adults show both a higher rate of premature saccades and decreased saccade accuracy, indicating a more diffuse deficit in visual working memory (Ross et al., 2000). Recently, the DOR was examined in an alcohol context (Abroms et al., 2006). It was found that a moderate blood-alcohol concentration of 67 mg/dl resulted in an increased incidence of premature saccades; however, it did not affect saccade RT or accuracy. Thus, inhibition of a voluntary response was affected at a dose which spared other saccade-related functions.

In the present study, the DOR was used, in order to examine directly age-group differences in the ability to suppress (postpone) saccades. Both antisaccade and attentional capture tasks, as stated above, have been used to measure age-group differences in inhibition, but both tasks also involve executing a saccade at the same time the inhibition is to be exerted. If there are age-group decrements in the ability to postpone a saccade, then the DOR should produce a greater proportion of premature saccades in the older adults. In addition, this paradigm would allow us to examine the ability of young and older adults to execute a saccade to a cued but now-empty location, which would be a measure of visual working memory.

METHOD

Observers

Twenty-one older adults (mean age = 70.6 years; range 65–78 years) and 19 young adults (mean age = 20.8 years; range = 18–25 years), recruited from the community, participated. The older adults were members of the Sanders–Brown subject registry, and the young adults were university students. Observers were paid $10 for the session. All observers passed a phone screening for visual pathology (cataracts, retinal degeneration, etc.), general health, and drug and alcohol use. Observers passed a color-blindness test, and minimum visual acuity, measured at 4 ft, was 4/8 (equivalent to 20/40). Approximately 20% of the older observers were excluded from the study due to visual problems apparent at the beginning of the test session. All observers 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, $F(1, 38) = 7.01$, $p < 0.05$. A computerized version of the digit-symbol test was also administered; mean RTs were 1443 ms (SE = 47) and 993 ms (SE = 51) for older and younger participants respectively, $F(1, 38) = 37.7$, $p < 0.001$.

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 × 600 pixels. The background brightness of the monitor was 3 cd/m^2, and stimuli were white with a brightness of 69 cd/m^2. 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°. 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

All stimuli were located on a horizontal line in the center of the screen. There were five possible locations for the fixation points and targets, spaced at 2° with the center location in the middle of the screen. Each trial started with a "+" sign fixation cue at one of the five locations, presented for 2500 (±50) ms. Next, a 0.5° square cue (110 ms) was presented at one of the other four locations (selected at random). Observers were instructed not to move their eyes at this time. After cue offset, the fixation point remained on the screen for another 800, 1000, or 1200 ms (selected at random); observers were still required to maintain fixation on the fixation point. Then the fixation point disappeared and the screen remained blank for 1000 ms, during which time observers were to fixate the cued location (although the cue was not present on the screen any more). Following the blank interval, a new fixation point appeared at the formerly cued location. Observers were then required to fixate this new fixation point, whereupon a new trial would begin. There were 30 trials per block, for a total of four blocks. (Only the last three blocks were analyzed.)

Procedure

Each observer completed a single session of the eye-tracking experiment. 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, premature saccades to the cued location, etc.). 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 had a standard deviation of no more than 0.5° in the *x*- and *y*-axes. A fixation was ended if three sequential gaze samples were more than one degree from the fixation position. A saccade was labeled *premature* if a fixation was ended and a new one established before the fixation point disappeared from the screen, and if it landed more than half the distance to the cued location. *Proper* saccades were those executed after the fixation point disappeared, but before the fixation reappeared at the formerly cued location. *Corrective* saccades were those executed after the fixation point appeared (which started the next trial), in order to foveate the fixation point.

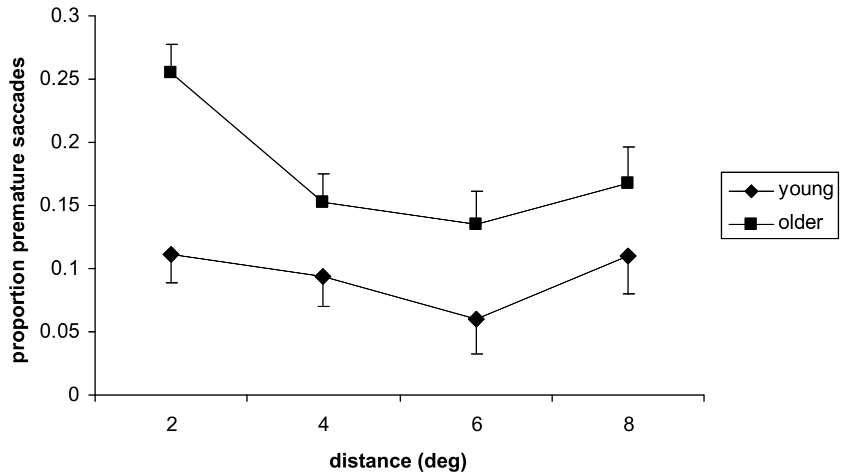
RESULTS

A repeated-measures design using the generalized linear mixed model, as implemented in Proc Mixed (Littell et al., 1996), was employed. The models implemented in Proc Mixed are evaluated using likelihood functions instead of sums-of-squares as in ANOVA. In Proc Mixed, generalized F ratios are calculated using (restricted) maximum likelihood estimates of variance components and generalized least-squares estimates of treatment differences (Littell et al., 1996). In these results, least-square means are presented, with standard errors in parentheses. All multiple comparisons were adjusted using the Sidak correction (SAS Institute, 1989). Repeated-measures analyses were performed on the various types of saccades, with age group, cue delay, and fixation-cue distance as factors.

For numbers of trials with premature saccades (expressed here as proportions), there was an age group × distance interaction, $F(3, 114) = 3.80$, $p < 0.05$ (see Figure 1). For young observers, there was no effect of distance, $F(3, 54) = 2.33$, $p > 0.05$. For older observers, there was an effect of distance, $F(3, 60) = 11.01$, $p < 0.001$, with distance 1 significantly higher than distances 2–4, but with no other pairwise differences. There was a main effect of age group, $F(1, 38) = 8.64$, $p < 0.01$, with young observers (M = 0.09, SE = 02) lower in premature saccades than older observers (M = 0.18, SE = 0.02). There were no effects involving cue delay.

Late saccades comprised about 2% of trials; there were no age group effects involving this variable. On trials with proper saccades, saccade latency was the time elapsed between offset of the fixation point and initiation of the saccade. There were no effects involving latency; mean latencies were 347 ms (SE = 11) and 317 ms (SE = 11) for young and older observers, respectively. Saccade accuracy was defined as the horizontal deviation between landing spot of the saccade and the cue location (although the cue was not on the screen during execution of the saccade). There were no age group effects for saccade accuracy.

FIGURE 1. Premature saccades as a function of distance from fixation point to the cue, for older and young observers. Error bars indicate one standard error.



Corrective saccades were defined as follow-up saccades that were executed after the fixation point for the next trial appeared on the screen. There was a main effect of age group, $F(1, 38) = 7.12$, $p < 0.05$, with young adults ($M = 0.67$, $SE = 0.03$) executing a higher number of corrective saccades per trial than older adults ($M = 0.56$, $SE = 0.03$). There was also a main effect of distance, $F(3, 114) = 4.95$, $p < 0.01$, with means of 0.61, 0.63, 0.66, and 0.56 ($SE = 0.03$) for distances 1–4. The only significant pairwise differences were those between distances 2 and 4, and 3 and 4.

DISCUSSION

The older adults in the current study showed a higher rate of premature saccades (saccades executed while the fixation point was present) than the young adults, which indicated an age-related deficit in the ability to inhibit saccades to abrupt-onset targets. Premature saccade rate for the young adults was constant with cue-fixation distance, but for the older adults, a cue appearing next to the fixation point provoked more premature saccades than cues appearing further from the fixation point. The older adults were less able to inhibit saccades to more proximal and thus presumably more salient cues, consistent with the findings of Kramer et al. (2000).

For the other measures, there were no age-group effects (except for a higher rate of corrective saccades for young than for older adults), which implies that many functions of visual working memory in this task were preserved in the older adults. The lack of an age-group effect in saccade latency indicated that a saccade, once prepared, was executed with equal speed across age groups. This result, however, could have been a by-product of the higher rate of premature saccades on the part of the older adults; a greater propensity to execute a premature saccade could result in faster proper saccades. An age-group effect was also not found in saccade accuracy; apparently the older adults were not impaired in their ability to store the location of an intended saccade, and to execute the saccade to the desired location.

The current results confirm that previous findings of age-related increases in antisaccade errors (e.g., Butler et al., 1999; Nieuwenhuis et al., 2000; Olincy et al, 1997) were at least partially due to age-group decrements in the ability to withhold reflexive saccades to the cues. The present study tested this ability in relative isolation, without the additional components that would be involved in executing a saccade to the opposite hemifield. The DOR, however, does require observers to store a location for a delayed saccade, and it is possible that the resultant additional load or confusion (don't execute saccade now; execute saccade later) is correlated with failures to withhold saccades. Support for this load/confusion hypothesis is provided by Crawford et al. (2005), who tested AD patients along with older and young normal controls on a battery of saccadic tasks. In a *no-go* task where the only requirement was to maintain fixation without executing a saccade, Crawford et al. found no age-group effect among normal controls (possibly, however, due to insufficient power). (For AD patients, they did observe a higher rate of no-go errors, but there could have been many factors present, including severe memory problems, vigilance, eye tremors, etc.) In contrast, in a *go/no-go* task which required observers to ignore a cue presented to one hemifield but execute a saccade toward a cue presented in the other hemifield, older controls were higher in errors than young controls. One factor that may have contributed to the different results is that in the no-go condition, it would be beneficial to completely ignore the periphery of the visual field, whereas in the go/no-go condition, peripheral information must be processed. It is also possible that the salient difference between the two conditions was that of simple versus compound instructions; i.e. "maintain fixation" versus "maintain fixation if cue is on the left but execute saccade if cue is on the right".

Inhibition in the present task, therefore, may be conflated with memory requirements of maintaining a compound instructional set (inhibit the saccade, but execute it after the fixation point disappears). It may have been that the older observers executed premature saccades simply because they temporarily dropped the instruction to delay the saccade. We did not, however, find evidence of any general deficits in maintaining saccade instructions, such as saccade latency and number of late saccades. Regardless of the precise mechanisms underlying inhibition, from the current results it appears that older observers experience more failures of the instruction to delay a saccade. The other functions subserving delayed saccades, however, are preserved in older adults.

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