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Suppression of reflexive saccades in younger and older adults: Age comparisons on an antisaccade task

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Inhibitory control of prepotent responses has been examined by using the antisaccade task, during which a reflexive saccade toward a peripheral onset must be suppressed before an eye movement in the opposite direction from the onset can be executed. In the present experiments, we sought to determine whether older and younger adults would perform similarly on this task. Older adults had a harder time suppressing their reflexive responses, as measured by an increase in the proportion of saccade direction errors. Despite an age-related decline in saccade direction accuracy, the increase in saccade latency associated with the antisaccade condition was the same for both younger and older adults. These results support the view that the effectiveness of inhibitory control declines with age (Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999).

Our eyes make three to four saccades every second (Henderson & Hollingworth, 1999; Rayner, 1978). These ballistic eye movements allow us to foveate stimuli in our environment for more detailed visual processing. Studies of the control of saccades under different processing conditions, such as during reading and scene perception, have provided valuable information about cognitive processes (see Rayner, 1992). Saccades to visual targets can be initiated either reflexively or intentionally (i.e., voluntarily; see, e.g., Findlay, 1981; Klein, 1978). Reflexive saccades are fast and made in response to abrupt visual onsets, whereas intentional saccades are slower and their goals may be specified by memory, expectancy, instruction, or visual stimulation (Pierrot-Deseilligny, Rivaud, Gaymard, Muri, & Vermersch, 1995). One way of describing these two types of saccades is in terms of programming their distance and direction. When intentional processing provides these parameters, they are calculated in succession, but when the parameters are specified for reflexive saccades, they are calculated simultaneously (Abrams & Jonides, 1988). After the parameters of a saccade have been generated, the execution of the saccade is not obligatory. Intentional saccades may be withheld or delayed until the appropriate time. Even the execution of reflexive saccade programs can be stopped by instructions to maintain fixation or can be overridden by commands to look to a different location.

Hallet (1978; Hallet & Adams, 1980) used an antisaccade task to study the interplay between the mechanisms responsible for intentional and reflexive saccade programming and execution. In the antisaccade task, a peripheral stimulus abruptly appears while the participant is fixating centrally. The participants are instructed to suppress the reflexive response toward the onset stimulus and to make an intentional saccade an equal distance in the opposite direction. Performance in this condition is compared with a control, prosaccade condition, in which the instructions are to look toward the onset. Antisaccades take longer to initiate than prosaccades. In addition, saccade direction errors are more common in the antisaccade condition; incorrect saccades toward an onset are more likely than incorrect saccades away from an onset.

Guitton, Büchtel, and Douglas (1982, 1985) suggested that performing antisaccades is difficult because the reflexive response must first be suppressed. They found that patients with frontal lobe damage, but not those with temporal lobe damage, had more difficulty stopping reflexive responses to peripheral onsets than control subjects did. The antisaccade task has since evolved as a measure of the ability to suppress a prepotent response. Patients with Huntington's disease (Lasker, Zee, Hain, Folstein, & Singer, 1987), individuals with severe Parkinsonian symptoms (Kitagawa, Fukushima, & Tashiro, 1994), schizophrenics (J. Fukushima, K. Fukushima, Miyasaka, & Yamashita, 1994), and individuals with obsessive-compulsive disorder (Tien, Pearlson, Machlin, Bylsma, & Hoehn-Saric, 1992) make more saccade direction errors in the antisaccade condition than do nonpatient populations. The incidence of saccade direction errors in the antisaccade condition also increases in healthy young adults when they are under a concurrent working memory load,

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as compared with a single-task condition (Roberts, Hager, & Heron, 1994).

Hasher and Zacks (1988; Hasher et al., 1999) proposed that declines in the effectiveness of inhibitory mechanisms account for aging-related changes in performance on memory and language tasks and on tasks requiring the inhibitory control of prepotent responses. These claims have received a great deal of empirical support (for reviews, see Hasher et al., 1999; Stoltzfus, Hasher, & Zacks, 1996) but have recently been called into question—in part, because of failure to observe age-related declines in inhibitory control in some circumstances, such as on location-based negative priming tasks (Burke, 1997; McDowd, 1997; but see Zacks & Hasher, 1997). If older adults have more difficulty than younger adults in suppressing their prepotent eye movements (reflexive saccades) on an antisaccade task, it would indicate that the inhibitory mechanism responsible for preventing these eye movements is impaired in older adults and would provide converging evidence supporting the inhibitory deficit hypothesis.

Evidence that prepotent responses are more difficult for older adults to withhold comes from work with the stop signal paradigm (Liu & Balota, 1995; May & Hasher, 1998). In this paradigm, participants perform a primary task and occasionally a stop signal is presented, indicating to the participant to withhold the primary task response. However, that older adults are less able than younger adults to stop no-longer-correct responses does not necessarily mean that the inhibitory control of reflexive saccades will be affected by age. Other research has shown that manual responses and reflexive saccades are affected in different ways by another manipulation of attentional control, attentional precuing (Reuter-Lorenz & Fendrich, 1992). In addition, it has been demonstrated that the inhibition of active fixation, a factor that can affect eye movement latencies (see, e.g., Munoz & Wurtz, 1992), does not decline with age (Pratt, Abrams, & Chasteen, 1997). Inhibitory control of reflexive saccades might be another case in which eye movements differ from manual responses.

There is as yet only preliminary support for the prediction that older adults will have more difficulty suppressing reflexive saccades on an antisaccades task. First, Faust and Balota (1997) compared young and older adults on an attention task that required participants to maintain fixation while an onset stimulus was flashed in the periphery. Although no attentional differences were found between the age groups, older adults had greater difficulty suppressing their reflexive eye movements toward the onset stimulus. The second supportive finding comes from the J. Fukushima et al. (1994) study of schizophrenics that had two groups of normal controls with mean ages of 57.3 and 31.1 years. Although comparing the performance of older and younger adults was not a focus of the study, it was reported that the older controls made saccade direction errors on 14.9% of the trials in the antisaccade condition, whereas the younger controls made errors on only 3.9% of the trials. Previous research has indicated that older adults can direct saccades to a specific target as well as can young adults (Moschner & Baloh, 1994); therefore, the increase in saccade direction errors is probably due to a deficit in the ability of older adults to suppress a response to the onset in the antisaccade condition. Unfortunately, J. Fukushima et al. (1994) used different procedures in the antisaccade and prosaccade conditions, hindering comparisons of latency and accuracy differences between the two tasks. The study most relevant to our own was done by Olincy, Ross, Youngd, and Freedman (1997). They compared young and older adults on an antisaccade task and showed that older adults made more saccade direction errors and were slowed to a greater extent in the antisaccade condition than were young adults, but as with the J. Fukushima et al. (1994) study, their conclusions are limited by procedural differences between the prosaccade and the antisaccade conditions.

In the following experiments, we compared the performances of younger and older adults on an antisaccade task. Three dependent measures were examined: the direction accuracy of the first saccade and the latency and distance of the first saccade when it was made in the correct direction. Previous research has shown that more saccade direction errors are made in the antisaccade than in the prosaccade condition and that antisaccades are initiated more slowly than prosaccades and more often undershoot the target (Hallet, 1978). We expected both age groups to show the basic results, along with slower saccade latencies for older than for younger adults (see, e.g., Carter, Obler, Woodward, & Albert, 1983; Moschner & Baloh, 1994).

More important, we also hypothesized that older adults would have more difficulty than younger adults in suppressing reflexive saccades toward the onset in the antisaccade condition and predicted that the difference between saccade direction accuracy rates in the antisaccade and prosaccade conditions would be greater for the older adults. It was less clear whether the latency and distance of the antisaccades would also be affected by a reduced ability to suppress the response to the onset. Saccade distances are often not reported in the antisaccade literature, and although many studies have found prolonged antisaccade latencies in populations that demonstrate a reduced ability to suppress reflexive saccades (e.g., J. Fukushima et al., 1994; Kitagawa et al., 1994; Lasker et al., 1987; Roberts et al., 1994), others have not (Tien et al., 1992).[1] In addition, prolonged antisaccade latencies are often attributed to an additional deficit in generating saccades to a location with no visual marker (J. Fukushima, K. Fukushima, Morita, & Yamashita, 1990; Guitton et al., 1985). If an impairment in the ability to suppress reflexive saccades interferes with antisaccade programming, then to the extent that older adults have difficulty suppressing their

Table 1
Characteristics of Participants in Both Experiments

	Age (years)		Education Level (years)				Shipley Vocab			
Participant	*M*	Range	*M*	Range	*t*	*df*	*M*	Range	*t*	*df*
			Experiment 1							
Younger adults	19.4	18–22	13.1	12–15			29.2	20–33		
Older adults*	70.6	65–78	16.3	12–20			36.2	30–39		
					3.7	30†			6.1	30†
			Experiment 2							
Younger adults	19.8	17–23	14.0	12–16			30.2	24–35		
Older adults	70.8	65–80	15.1	12–18			34.8	26–40		
					1.6	30‡			3.3	27†

Note—$n = 16$ for all groups. Shipley, Shipley Institute of Living Scale (Shipley, 1940); Vocab, vocabulary test. *Nine older participants ($M_{Age} = 71.8$; $M_{Educ} = 13.9$; $M_{Voc} = 33.1$) were excluded because they were unable to perform the target task. †Age difference is significant at $p < .05$. ‡Age difference is nearly significant at $p < .1$.

reflexive saccades, they will also demonstrate an exaggeration of the effects of the antisaccade condition on saccade initiation latency and distance.

EXPERIMENT 1

Older and younger adults' eye movements were recorded as they performed an antisaccade task. In this task, the participants fixated a central cross and moved their eyes after a peripheral onset occurred. The direction of the correct saccade was determined by the instructions in that condition. Following the onset, an arrow appeared for a short time at the location the participant had been told to look toward. The participants indicated the pointing direction of the arrow by pressing a button. The arrow identification task was included to provide motivation for the participants to move their eyes as quickly as possible.[2]

Method

Participants. Sixteen Michigan State University undergraduates received partial course credit for their participation. Twenty-five community-dwelling, healthy, older adults from the Lansing, Michigan, area were paid for their participation. Nine older adults were excluded from the study because they failed to detect the target arrow during the practice session and became frustrated with the task. The implications of this selection process will be discussed later. Table 1 contains the mean and range for the age, education level, and Shipley Institute of Living Scale–Vocabulary Test score (Shipley, 1940) of each group.

Apparatus and Stimuli. Eye movements were recorded with an ISCAN RK-416 high-speed eyetracker that uses an infrared video-based system to compute and track the center of the pupil in the right eye. Signals were generated by the eyetracker at a frequency of 120 Hz, allowing saccade latencies to be calculated with a temporal resolution of 8.33 msec. The spatial resolution of the apparatus was 0.2° of visual angle. Stimuli were displayed at a resolution of 800 × 600 pixels on a Multisync XE15 monitor controlled by a 486 PC-compatible computer. A chin and forehead rest was used to stabilize the participant's head. The fixation display contained a white cross in the center of a black screen, flanked by two white boxes to the left and right. The fixation cross and boxes subtended 0.9° and 1.3°, respectively, and were separated by 8.5° at a viewing distance of 40 cm. The target arrow appeared inside a box and subtended 1.1°. The onset was a change from black to white at the center of one of the boxes.

Procedure. Each participant responded to 10 practice and 60 experimental trials in each of the antisaccade and prosaccade conditions. The conditions were blocked, and their order of presentation was counterbalanced between subjects. Fifteen trials of each onset location (left or right of fixation) by arrow direction (left or right pointing) combination were presented in a random order in each experimental block. Before performing each condition, the participant read the instructions and reviewed them with the experimenter. The participants were instructed to look at the center cross until the center of one of the squares changed from black to white. In the prosaccade condition, the instructions were to look toward the onset;

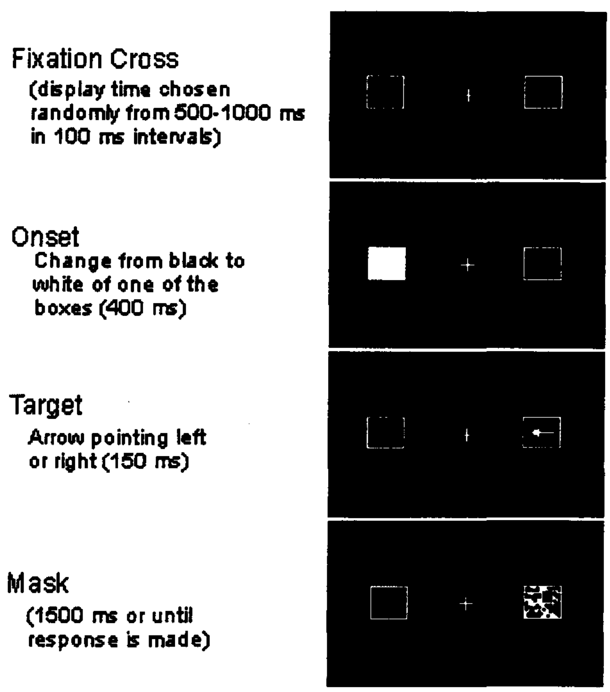

Figure 1. Schematic illustration of visual displays seen by a participant during an antisaccade condition trial. In the prosaccade condition, the onset, target, and mask were presented in the same box.

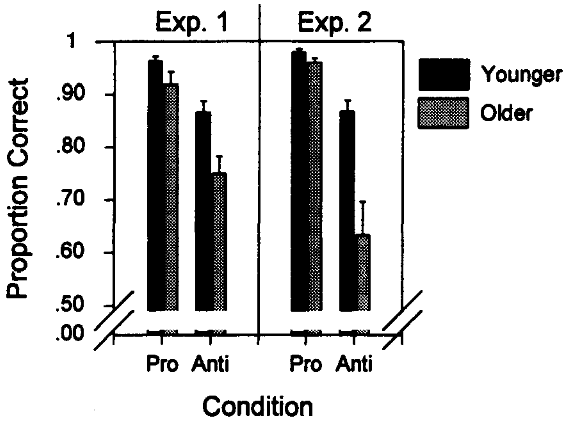

Figure 2. Mean accuracy of the direction of the initial saccade by condition and age group. The error bars are standard errors. Exp, experiment; Pro, prosaccade condition; Anti, antisaccade condition.

in the antisaccade condition, they were to look toward the box opposite from the onset. Figure 1 illustrates the sequence of visual displays seen after the experimenter initiated a trial. The fixation screen was displayed for 500–1,000 msec. The exact duration was chosen randomly by the computer in 100-msec increments. Next, the onset appeared for 400 msec in either the right or the left square. The onset was immediately followed by the target arrow. The arrow appeared in the box where the onset occurred in the prosaccade condition or in the box opposite from the onset in the antisaccade condition. After 150 msec, the arrow was replaced by a pattern mask. The trial ended when a buttonpress was recorded or after an additional 1,500 msec. The participants pressed the corresponding right or left button to indicate the direction in which the arrow had been pointing. After a 4-sec delay, during which the fixation display was presented, the calibration of the eye movement monitor was checked. If the calibration was misaligned with the participant's eye position by more than about 0.5° of visual angle, the eye movement monitor was recalibrated.

Results

The initial saccade following the presentation of the onset was determined by looking for three consecutive eye movement samples that moved in a single direction horizontally, of which the last two samples had durations of 8 msec (a minimum sample value). Saccade latencies were calculated from the presentation of the onset until the beginning of the first 8-msec sample in this group. The accuracy of the apparatus allowed for the detection of eye movements greater than 0.4° of visual angle. If the first saccade was made toward the correct box, the saccade was considered correct; if it was made toward the incorrect box, it was considered incorrect. We did not analyze trials in which (1) the participant was not looking at the fixation cross when the peripheral onset occurred, (2) the latency of the initial saccade was less than 100 msec,[3] (3) no saccade was made during the trial, or (4) a buttonpress was made before the initial saccade ended. Application of these criteria eliminated 10.6% of the young adults' data and 8.8% of the older adults' data. For each trial, the direction accuracy, latency, and distance of the initial saccade were calculated from the eye movement data. A correct saccade was one made in the correct direction, as defined by the instructions for that condition.

Each dependent measure—saccade direction accuracy, latency, and distance—was submitted to a 2 (age group) × 2 (condition order) × 2 (condition) mixed analysis of variance (ANOVA), with age group and condition order as between-subjects variables and condition as a within-subjects variable.

Saccade direction accuracy. The participants looked in the correct direction more often in the prosaccade condition (M = 94.1%) than in the antisaccade condition [M = 80.9%; $F(1,28) = 51$, $MS_e = 0.011$, $p < .01$], and younger adults (M = 91.5%) were more accurate than older adults [M = 83.5%; $F(1,28) = 10.5$, $MS_e = 0.0196$, $p < .01$]. Figure 2 contains the mean saccade direction accuracy for each age group by condition. Younger and older adults made saccades in the correct direction most of the time in the prosaccade condition (Ms = 96.3% and 91.9%, respectively), but in the antisaccade condition, the young adults were more accurate than the older adults (Ms = 86.7% and 75.0%, respectively). This interaction approached significance [$F(1,28) = 3.99$, $MS_e = 0.011$, $p < .06$].

The effect of condition order was also significant [$F(1,28) = 7.1$, $MS_e = .0196$, $p < .02$], indicating that, when prosaccade trials were performed first, saccade direction was less accurate across both conditions (M = 84.2%) than when antisaccades were completed first (M = 90.8%). Age group interacted with condition order [$F(1,28) = 3.85$, $MS_e = .0196$, $p < .06$], so that older adults who performed antisaccade trials first were more accurate across both conditions (M = 89.2%) than were older adults who started with the prosaccade block (M = 77.7%), whereas the performance of the younger adults was similar for each condition order (Ms = 92.4% and 90.6%, respectively). This last finding is discussed below.

Latency of correct saccades. Antisaccade latencies were slower (M = 369 msec) than those of prosaccades [M = 282 msec; $F(1,28) = 84.8$, $MS_e = 64{,}515$, $p < .001$]. In addition, older adults' saccade latencies were slower than those of younger adults [Ms = 339 and 305 msec, respectively; $F(1,28) = 4.24$, $MS_e = 226{,}986.9$, $p < .05$]. The mean latencies of correct saccades by age group and condition are presented in Figure 3. The interaction was not significant ($F < 1$). Although older adults had a harder time suppressing their reflexive responses to the peripheral onsets, when they were able to stop their reflexive saccades, their antisaccades were delayed for the same amount of time as were the antisaccades of younger adults (delays of 82.8 and 91.7 msec, respectively). Condition did interact with condition order, however [$F(1,28) = 6.63$, $MS_e = 64{,}515$, $p < .02$]. The difference in the mean latency of antisaccades and prosaccades was greater when

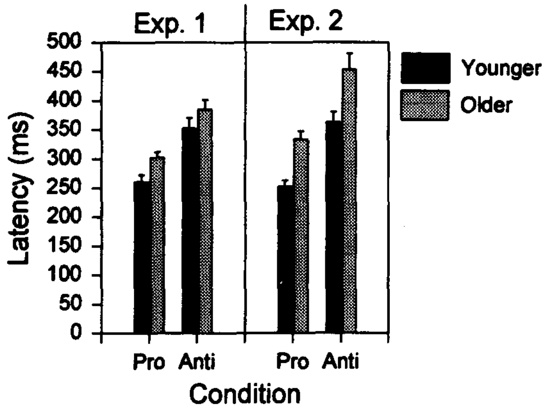

Figure 3. Mean latency of initial correct saccades in milliseconds by condition and age group. The error bars are standard errors. Exp, experiment; Pro, prosaccade condition; Anti, antisaccade condition.

the antisaccade trials were performed first (difference = 101.1 msec) than when the prosaccade trials were performed first (63 msec).

Distance of correct saccades. Saccade length was not affected by the difficulty of the saccade task [$F(1,28) = 1.57$].[4] Figure 4 shows that younger adults reached the target location with their first saccade ($M = 8.5°$; distance from fixation to box containing target = 8.5°), but older adults fell short of the target [$M = 8.0°$; $F(1,28) = 3$, $MS_e = 33{,}781.3$, $p < .1$]. Age group also interacted with condition order [$F(1,28) = 6.02$, $MS_e = 33{,}781.3$, $p < .03$], so that younger and older adults who performed antisaccade trials first had similar mean saccade lengths (*M*s = 8.2° and 8.4°, respectively), whereas when prosaccades were performed before antisaccades, older adults made shorter saccades ($M = 7.5°$) than did younger adults ($M = 8.9°$). As with the saccade direction accuracy data, older adults were more negatively influenced when they performed prosaccades before performing antisaccades.

Discussion

Of primary interest for our hypothesis, older adults showed a greater increase in the frequency of saccade direction errors from the prosaccade to the antisaccade condition than did younger adults, indicating that older adults had more difficulty suppressing their reflexive responses to the onsets than did younger adults. Despite the difficulty experienced by the older adults in suppressing reflexive saccades in the antisaccade condition, their correct antisaccade latencies were not delayed to a greater extent than were the latencies of younger adults in relation to the prosaccade condition. Consistent with previous research, saccade direction accuracy decreased and saccade latencies were slowed in the antisaccade condition, as compared with the prosaccade condition, for both age groups. However, contrary to earlier findings, the length of the initial saccade was unaffected by saccade condition. In addition, older adults' saccades were initiated more slowly and were shorter in length than younger adults' saccades.

Although these results seem straightforward, the exclusion of 9 older participants who could not identify the direction of the arrow during the practice session may have produced a confound. Initially, these older individuals were thought to be experiencing general eye movement control problems, but in retrospect, it appears that they were primarily having problems in the antisaccade condition. This conclusion is based on the observation that 8 of the 9 excluded participants began the experiment with the antisaccade condition, suggesting that these older adults were at a disadvantage when the antisaccade condition was combined with little practice on the task.[5] To address this possible confound, Experiment 2 compared young and older adults on a less demanding version of the antisaccade task.

EXPERIMENT 2

To ensure that the effects found in Experiment 1 were not the results of selection bias, a second experiment was run, in which eye movements were emphasized as being most important and responding to the target arrow was specified as a secondary task. In addition, all the participants began the experiment with a practice block of prosaccade trials, so that they could become familiar with the stimuli and timing parameters. We hoped that these changes in the instructions and procedures would reduce the frustration and failure experienced by the older adults at not being able to identify the direction of the arrow and, thus, would allow us to retain a larger proportion of the sample of older adults. In addition to these changes, two blocks of trials were completed in each condition in Experiment 2, to enable us to examine the influence of practice on prosaccade and antisaccade perfor-

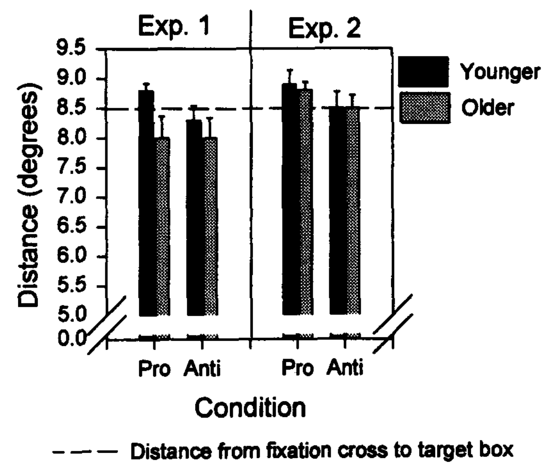

Figure 4. Mean distance of initial saccades by saccade condition and age group. The error bars are standard errors. Exp, experiment; Pro, prosaccade condition; Anti, antisaccade condition.

mance. The predictions were the same as those made for Experiment 1.

Method

Participants. Sixteen older and 17 younger adults, who did not participate in Experiment 1, completed this experiment. These participants were drawn from the same populations as were the participants in Experiment 1. The data of one younger adult were omitted from the analyses, because his mean prosaccade latency was 650 msec, indicating saccade initiation in response to the presentation of the target instead of the onset. All of the older adults who began the experiment were able to complete it and were included in the analyses. The mean and range for age, education level, and Shipley Institute of Living Scale–Vocabulary Test score (Shipley, 1940) for each group are presented in Table 1.

Procedure. The procedures used in this experiment were the same as those used in Experiment 1, except for the following changes. Each participant began the experiment with 10 practice prosaccade trials. In addition, participants completed four blocks of trials, two 40-trial blocks of antisaccade and prosaccade trials presented in an ABBA or a BAAB order. Half of the participants in each age group received the prosaccade condition first, and half received the antisaccade condition first. As in Experiment 1, 10 antisaccade practice trials were performed before the first block of antisaccade trials.

Some participants in the previous experiment reported making buttonpress errors because they pushed the button that was in the direction of their saccade, rather than in the direction of the arrow. To reduce this problem, the left and right arrows were replaced with up and down arrows. The participants pressed the left button if the arrow was pointing up or the right button if the arrow was pointing down.

Results and Discussion

Using the same criteria as those in Experiment 1, more trials from older adults ($M = 20\%$) were eliminated than from younger adults ($M = 13.1\%$). An analysis of these eliminated trials by the criteria used for exclusion indicated that older adults were more likely to look away from the center cross before the onset was presented. This result is consistent with the findings of Faust and Balota (1997): Older adults had a harder time suppressing all eye movements before the onset was presented than did young adults.

Each dependent measure—saccade direction accuracy, latency, and distance—was submitted to a 2 (age group) × 2 (condition order) × 2 (condition) × 2 (practice) mixed ANOVA, with age and condition order as between-subjects variables and condition and practice as within-subjects variables. The condition order variable distinguished participants who saw the ABBA order from those who saw a BAAB order. Note that this variable is different from the anitsaccade condition first versus prosaccade condition first comparison made by the condition order variable in Experiment 1. The practice variable was a comparison of the first and second blocks of trials performed in each condition.

Saccade direction accuracy. Initial saccades in the correct direction were more likely in the prosaccade condition ($M = 97\%$) than in the antisaccade condition [$M = 75.1\%$; $F(1,28) = 53.67$, $MS_e = .0288$, $p < .001$]. In addition, young adults looked in the correct direction more often than did older adults [Ms = 92.4% and 79.7%, respectively; $F(1,28) = 12.62$, $MS_e = .0411$, $p < .01$]. As can be seen in Figure 2, young adults were more successful at executing antisaccades than were older adults (86.8% and 64.3%, respectively), whereas both groups almost always looked in the correct direction in the prosaccade condition [98% and 96%, respectively; $F(1,28) = 12.77$, $MS_e = .0288$, $p < .01$]. As in Experiment 1, older adults had a harder time suppressing their reflexive saccades than did younger adults.

The main effect of practice was not significant, but this variable did enter into a significant interaction with age group and condition [$F(2,56) = 10.6$, $MS_e = .0161$, $p < .001$]. Except for younger adults' prosaccade trials, saccade accuracy increased slightly from the first to the second block of trials (+3.1%). The accuracy of younger adults in the prosaccade condition actually declined from the first to the second block (−1.1%). However, because of the small size of the difference and the probable ceiling effects in the prosaccade condition, little can be made of this interaction. Condition order did not affect saccade direction accuracy (ps > .1).

Latency of correct saccades. As was found in Experiment 1, older adults' saccade latencies were slower ($M = 375$ msec) than those of younger adults [$M = 304$ msec; $F(1,28) = 14.5$, $MS_e = 423{,}246$, $p < .001$]. Also, mean antisaccade latencies ($M = 408$ msec) were slower than those of prosaccades [$M = 293$ msec; $F(1,28) = 109.5$, $MS_e = 99{,}330$, $p < .001$]. The interaction of age group and condition was again not significant ($F < 1$). Figure 3 shows that the antisaccades of older adults were slowed to the same extent as were the antisaccades of younger adults, when compared with the prosaccade baseline (delays of 118 and 101 msec, respectively). The failure to observe this interaction was not due to a speed–accuracy tradeoff in prosaccade performance, because young and older adults made an equal number of saccade direction errors in that condition.

The effect of practice was marginally significant [$F(2,56) = 3.46$, $MS_e = 29{,}825$, $p < .08$], so that saccades in the second block of trials in both conditions were initiated faster than saccades in the first block (Ms = 335.7 and 343 msec, respectively). The main effect of condition order was not significant ($F < 1$). The only interaction involving condition order that approached significance was that with condition [$F(2,56) = 3.07$, $MS_e = 99{,}330$, $p < .1$].

Distance of correct saccades. Figure 4 illustrates that antisaccades were shorter than prosaccades [Ms = 8.5° and 8.9°, respectively; $F(1,28) = 7.27$; $MS_e = 6{,}541$, $p < .05$], but younger and older adults made saccades of similar lengths in both the antisaccade and the prosaccade conditions ($F < 1$). The variables of practice and condition order did not affect initial saccade distance (ps > .1).

GENERAL DISCUSSION

In these experiments, the ability of older adults to suppress a prepotent response in an antisaccade task was investigated. In both Experiments 1 and 2, older adults made more antisaccade direction errors in the antisaccade condition than did younger adults. Thus, older adults experienced more frequent failures of inhibitory control over a prepotent response. This finding supports the Hasher and Zacks (1988; Hasher et al., 1999) model of cognitive control, which posits a decline in the effectiveness of inhibitory processes with age.

Although the reduced effectiveness of the mechanism responsible for reflexive saccade suppression led to more frequent saccade direction errors in older adults, this reduction did not affect the latency or the distance of their antisaccades. Across both experiments, saccade latencies increased about the same amount for older and younger adults from the prosaccade to the antisaccade condition, and saccade distances were unaffected by the eye movement condition. This result may be explained by a speed–accuracy tradeoff. Older adults could have been sacrificing antisaccade direction accuracy in order to program antisaccades more quickly. Alternately, the effect of declining inhibitory efficiency on older adults' antisaccade direction accuracy, but not on latency or distance measures, may indicate two independent mechanisms. The efficiency of the suppression mechanism determines whether a saccade direction error occurs in the antisaccade condition, and this mechanism declines with age. A separate process controls the programming of the intentional antisaccade and is unaffected by age or the inhibitory mechanism. The independent mechanisms hypothesis is favored over the speed–accuracy tradeoff explanation for two reasons. First, as was discussed earlier, young and older adults had equal error rates in the prosaccade condition of Experiment 2, indicating no speed–accuracy tradeoff in that condition and suggesting that no tradeoff would be made in the antisaccade condition either. Second, the independent mechanisms hypothesis has received support in other studies (J. Fukushima et al., 1990; Guitton et al., 1985).

Investigating the suppression mechanisms involved in eye movement control offers another window on the nature of inhibitory processes in general, a topic that has been of great interest of late (e.g., Dagenbach & Carr, 1994). As was noted in the introduction, inhibition has been implicated in other aspects of eye movement control. Unlike our own findings, however, an age comparison of the ability to inhibit active fixation indicated that this inhibitory mechanism is not impaired in older adults (Pratt et al., 1997). The divergence of this result with our own indicates that these inhibitory mechanisms are distinct (see, also, Forbes & Klein, 1997) and points to the need for further research in which the characteristics of inhibitory mechanisms are examined.

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NOTES

1. J. Fukushima et al. (1994) did report the antisaccade and prosaccade latencies for the younger and older control subjects. Although the difference between antisaccade and prosaccade latencies was greater for the older control subjects (74 msec) than for the younger adults (50 msec), this trend is difficult to interpret, because older adults had slower saccade latencies than did the younger adults in all the conditions. The larger difference between the antisaccade and the prosaccade latencies of the older adults may be a function of their slower responding and unrelated to the increase in saccade direction errors (Salthouse, 1996).

2. Subsequent research in our lab has indicated that the secondary task enhances age differences in saccade direction errors. This finding may account for apparent discrepancies between our results and the lack of age differences in antisaccade direction errors reported by Munoz, Broughton, Goldring, and Armstrong (1998).

3. Latencies less than 100 msec would indicate that programming of the saccade began before the onset occurred.

4. Saccade distance in pixels was used as the dependent measure for this analysis, but to aid in the interpretation of the data, saccade distances will be reported in visual angles throughout the paper.

5. The exclusion of 8 older participants who started the experiment in the antisaccade condition could also explain why the remaining older adults made more accurate and longer saccades than did the older adults starting in the prosaccade condition.

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