Initiation and Inhibition of Saccadic Eye Movements in Younger and Older Adults: An Analysis of the Gap Effect

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In order to interact successfully with a complex environment, people often need to extract more visual information than is available from a single fixation. This is because the part of the eye capable of extracting detailed visual information, the fovea, receives input from only a small portion of the visual field. Thus, in order to view a complex scene, the fovea must often be moved to new fixation locations. Such changes in fixation are typically accomplished by executing quick, abrupt eye movements known as saccades. The role of saccadic eye movements in our everyday lives is pervasive: They are used in scanning scenes and images (e.g., Goldberg, Eggers, & Gouras, 1991), while reading (e.g., Rayner & Pollatsek, 1988), when reaching for or pointing to an object (e.g., Abrams, Meyer, & Kornblum, 1990), and when rapidly reorienting foveal vision (and with it visual attention) toward abrupt changes in the visual field or locations of interest (e.g., Posner, 1980).

Despite the importance of saccadic eye movements in everyday life, relatively little research has examined age-related differences in these movements. Instead, most of the research regarding age-related differences in motor behaviors has focused on the planning and execution of various types of limb movements (e.g., Amrhein, Goggin, & Stelmach, 1991; Haaland, Harrington, & Grice, 1993; Pratt, Chasteen, & Abrams, 1994). The few studies that have examined eye movements have yielded a consistent pattern of results — older adults have longer saccadic reaction times (RTs) than do younger adults (Abel, Troost, & Dell’Osso, 1983; Carter, Obler, Woodward, & Albert, 1983; Sharp & Zuckon, 1987; Spooner, Sakala, & Baloh, 1980; Warabi, Kase, & Kato, 1984). This finding is consistent with previous work that has found that older adults have longer latencies in a variety of motor tasks (e.g., pointing, Warabi, Noda, & Kato, 1986; aimed hand movements, Amrhein et al., 1991; Haaland et al., 1993; choice button pressing, Saltlhouse & Somberg, 1982).

Although only a handful of researchers have examined age-related differences in saccadic eye movements, considerable work has been done on other factors that may affect saccades. One phenomenon that has recently received a great deal of research attention was first reported by Saslow (1967). Saslow found that the removal of a visual fixation point shortly before the appearance of a peripheral target resulted in shorter latencies for saccades directed at the target than when the fixation point remained on. Since Saslow’s original work, the temporal interval between the offset of the fixation stimulus and the onset of the peripheral target stimulus has come to be termed the “gap” and the corresponding decrease in saccade latency the “gap effect” (e.g., Abrams & Dobkin, 1994; Kingstone & Klein, 1993a, 1993b; Reuter-Lorenz, Hughes, & Bendrich, 1991). The precise neural and psychological mechanisms underlying the gap effect are still the subject of some debate. However, a growing body of research implicates two components: First, a generalized warning effect afforded by the advance offset of the fixation point, and second, a “fixation release” component afforded by the absence of an object at fixation (Abrams & Dobkin, 1994; Kingstone & Klein, 1993a, 1993b; Reuter-Lorenz et al., 1991; Reuter-Lorenz, Onon, Barnes, & Hughes, 1995; Tam & Ono, 1994; Tam & Stelmach, 1993). The general warning effects attributable to fixation offset would be expected to reduce latencies of any response — not just eye movements, and such a result has been observed (Bekkering, Pratt, & Abrams, 1996). The fixation release component is believed to arise from the release of inhibition in the superior colliculus that serves to otherwise prevent eye movements during active fixation (e.g., Munoz & Wurtz, 1992; Schiller, Sandell, & Maunsell, 1987). This component is thought to be specific to the
appropriate responses and suppressing irrelevant information readily generated in response to the appearance of a target. However, evidence from a number of sources indicates that as people age they become less skilled at inhibiting inappropriate responses and suppressing irrelevant information (e.g., Hasher & Zacks, 1988). For example, younger adults are slower to respond to a target when it shares certain features in common with the distractor from the previous trial ("negative priming"; e.g., Tipper, 1985). However, older adults apparently do not inhibit the distractors as fully, and as a result they do not show the same negative priming effects that younger adults do (Connelly & Hasher, 1993; Tipper, 1991). Also, older adults are less good at ignoring distracting tones during a task that involves attending to an auditory message, compared to younger adults (McDowd & Filion, 1992). If a reduced ability to inhibit is a general consequence of increasing age, then older adults may be less able to suppress saccades during active fixation. As a result, the release from inhibition afforded by the advance offset of fixation might be less beneficial for older adults than for younger adults. Interestingly, if this is true, then older adults might produce longer overall latencies, but have a reduced effect of fixation point offset relative to younger adults (i.e., a smaller gap effect). However, no evidence is presently available that would address this issue — and that was the focus of the present experiment.

Overview of Experiment

The present experiment was designed to obtain data regarding the gap effect for saccadic eye movements of older adults. Our goal was first to determine whether the advance offset of fixation had an effect on saccades of older adults, and second to compare the magnitude of the effect, if any, with that for younger adults. Older and younger participants fixated upon a central fixation dot and then directed their gaze as quickly as possible to the location of a suddenly appearing peripheral target dot. The fixation dot was removed either 200 msec before (gap condition) or simultaneously with (no-gap condition) the onset of the peripheral target. Previous work has indicated that the gap effect is maximal when the gap is approximately 200 msec (e.g., Fendrich et al., 1991; Kingstone & Klein, 1993b; Reuter-Lorenz et al., 1991). Also, an auditory warning tone was always presented 200 msec before the onset of the peripheral target stimuli in order to reduce the possibility that the reduction in RTs was not simply due to the general warning effect supplied by the offset of the fixation point in the gap condition (e.g., Reuter-Lorenz et al., 1991).

METHOD

Participants. — Two groups of 14 participants each served in the experiment. The younger adult group consisted of Washington University students, 9 females and 5 males, ranging in age from 18 to 22 years (mean = 20.2 years). The older adults (9 females and 5 males), obtained through the Washington University Aging and Development Volunteer Pool, ranged in age from 60 to 83 years (mean = 70.9 years). The older participants had a mean of 13.9 years of education. All of the participants could read words presented in a standard font on a video monitor at a distance of 44 cm without corrective lenses. Each person participated in a single hour-long session and was paid $10 for his or her participation.

Apparatus and procedure. — The experiment was conducted in a dimly lit, sound-attenuated booth. Participants were seated in front of a video monitor with their heads held steady by a head/chin rest. The distance between the head/chin rest and the video monitor was 44 cm. Participants wore a spectacle frame fitted with a scleral-reflectance eye movement monitor (Model 210, Applied Science Laboratories, Bedford, MA). Each trial began with the participants fixating on a plus sign at the center of the monitor. The plus sign was displayed for 300 msec, and then changed into a dot. Eight hundred msec later, a warning tone (1000 Hz, 100 msec duration) was presented. On the no-gap trials, the dot remained on the display for another 200 msec, after which time it jumped to one of two possible peripheral locations (7° to the right or left of fixation). On the gap trials, the dot was removed from the display immediately after the warning tone, and it reappeared 200 msec later in either the left or right peripheral location (with the time interval between the dot’s disappearance and reappearance being the “gap”). Participants were instructed to look to the location of the peripheral dot as soon as possible after it had appeared.

Eye-movement recording and analysis. — We used an eye-monitoring procedure similar to one that we have used in the past (e.g., Abrams, Meyer, & Kornblum, 1989). The analog output from the eye-movement monitor was digitized and recorded at a rate of 1000 Hz. After the experimental session the recorded signal from the eye-movement monitor was filtered and differentiated using a low-pass filter with an 80 Hz cutoff. The resulting velocity profiles were then analyzed to identify the presence of saccades. The initiation of a saccade was defined as the first moment after the presentation of the peripheral target dot at which the velocity of the eye exceeded 10°/sec assuming that the velocity subsequently reached 35°/sec or more for at least 10 msec. The eye-movement monitor was calibrated at the beginning of each session, and the calibration was checked at the beginning of each trial.

Design. — The single session consisted of 5 blocks of 40 trials each. Half of the trials within each block were gap trials and the other half were no-gap trials. The trials were randomly ordered. The peripheral dot was equally likely to appear to the left or right for both gap and no-gap trials.

RESULTS

The mean RTs for each age group are presented in Figure 1. The mean RTs were analyzed with a 2 (age group: young
or old) × 2 (trial type: gap or no-gap) × 2 (target location: right or left) analysis of variance (ANOVA). Older adults had longer RTs \( F(1,26) = 7.1, p < .02 \) than did younger adults, and gap trials were faster than no-gap trials \( F(1,26) = 61.5, p < .0001 \). Importantly, the interaction between age and trial type was reliable \( F(1,26) = 5.0, p < .05 \), indicating that the gap effect was larger for older adults than for younger adults. There were no reliable main effects of target location \( F(1,26) < 1 \), nor were there any other reliable interactions \( F(1,26) < 3.0, p > .05 \).

The observed interaction is an over-additive one, and thus it is possible that the gap effect was greater for older adults as a direct result of the overall slower responses of the older adults. To examine this possibility, we reevaluated the responses from the experiment after each of two different kinds of conversions. First, we computed the gap effect size for each subject as a proportion of their no-gap latency. This type of correction would yield equivalent effect sizes for old and young if the difference between age groups was due entirely to an overall ("general") slowing of the older participants, and if the function relating old to young processing speed was a linear one with an intercept of zero (Faust, Balota, & Ferraro, 1996). While such assumptions may not be true in general, some authors have argued that they are reasonably close over a limited range of latencies, such as in the present experiment (e.g., Hartley & Kieley, 1995). The results from the proportional conversion revealed that eye movements on gap trials were initiated 8% faster than eye movements on no-gap trials by the younger participants and 11% faster for older adults than for younger adults. There were no reliable main effects of target location \( F(1,26) < 1 \), nor were there any other reliable interactions \( F(1,26) < 3.0, p > .05 \).

In light of the possible limitations of a proportional correction noted previously, we also converted the present data using a different technique involving a conversion of the latencies to their corresponding z-scores. To perform the conversion, each participant’s correct responses were first pooled together, ignoring any differences between conditions, and then the latencies were converted to z-scores based on the subject’s overall mean and standard deviation. We then computed the mean z-score for each subject in the gap and no-gap conditions, and these latter values were subjected to an ANOVA similar to the analyses we reported in the preceding sections. The z-score conversion effectively converts all individual effect sizes to units that are relative to each individual’s mean latency (e.g., Bush, Hess, & Wolford, 1993; Faust et al., 1996). The results of this analysis, displayed in Table 1, show that the gap condition affected latencies, with participants faster under gap than under no-gap conditions \( F(1,26) = 94.5, p < .0001 \). However, there were no differences between the two age groups, nor was there an Age by Condition interaction \( F(1,26) < 1 \).

We analyzed the percentage of correct responses by performing a 2 (age) × 2 (trial type) × 2 (target location) ANOVA as we had done for the RTs. These data appear in Table 2. Overall, error rates were very low, and no reliable main effects nor an interaction were found \( F(1,26) < 2.0, p > .15 \).

**Table 1. Mean Latencies (After z-score Conversion) for Gap and No-Gap Trials**

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Gap Condition</th>
<th>No-Gap Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger adults</td>
<td>-1.68</td>
<td>.209</td>
</tr>
<tr>
<td>Older adults</td>
<td>-1.59</td>
<td>.201</td>
</tr>
<tr>
<td>Mean</td>
<td>-1.64</td>
<td>.205</td>
</tr>
</tbody>
</table>

*Note: Gap and no-gap conditions were significantly different from one another \( p < .0001 \), but there were no effects of age.*

**Table 2. The Percentage of Correct Trials for Both Age Groups**

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Gap Condition</th>
<th>No-Gap Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger adults</td>
<td>93</td>
<td>94</td>
</tr>
<tr>
<td>Older adults</td>
<td>92</td>
<td>93</td>
</tr>
</tbody>
</table>

Figure 1. Mean saccadic RTs for younger adults (open circles) and older adults (closed squares) in gap and no-gap conditions.
Dobkin, 1994; Fendrich et al., 1991; Kingstone & Klein, 1993a, 1993b; Reuter-Lorenz et al., 1991), the younger participants showed a decrease in saccadic RT when the visual fixation point was removed slightly before the presentation of the peripheral target stimulus. Importantly, the results indicated that the older adults also showed a robust gap effect.

Although it is clear that both groups exhibited a gap effect, the determination as to whether the effect differed between the two age groups is not as straightforward. With regard to the absolute size of the gap effect, the older adults benefited more from the removal of the fixation dot than did the younger adults (33 msec and 18 msec, respectively). However, when the facilitation afforded by fixation offset was calculated as a percentage change in latency relative to the no-gap trials, or when the latencies were converted to z-scores, a different pattern emerged. After those corrections, the magnitude of the gap effect was the same for both groups of participants. Thus, the absolute size of the gap effect varied between age groups, but the relative decrease in RT due to the removal of the fixation dot remained constant. This finding is consistent with the general slowing hypothesis, which suggests that age-related deficits are due to an overall slowing of information processing with increasing age, rather than deficits incurred by specific tasks (e.g., Cerella, 1990; Hale, Lima, & Myerson, 1991).

The present results also bear on issues regarding age-related changes in inhibitory processing more generally. As noted earlier, evidence exists showing an age-related decline in the ability to inhibit inappropriate information or responses in a number of different situations. Because the gap effect is believed to arise from a release of inhibition, we argued that individuals with decreased inhibitory processing generally should have a gap effect with a reduced magnitude. However, not only did the older adults have proportionally the same size gap effect as young adults, but the absolute magnitude of the effect was actually greater for older than for young. These results suggest that the deficits in inhibitory processing noted earlier do not reflect deficient inhibitory processing globally — but instead the inhibition related to some functions may remain intact.

The finding of equivalent reductions in eye movement latencies due to the removal of the fixation point in younger and older adults is consistent with a growing body of research that suggests that age-related deficits in inhibition do not occur in tasks that involve responses based on the spatial locations of targets. For example, Hartley and Kieley (1995) examined age-related differences in inhibition of return, a phenomenon in which the latency to respond to the onset of a target is slower at a previously attended location than at a novel location. Inhibition of return is generally thought to be due to a mechanism that inhibits attention from returning to previously attended locations. Hartley and Kieley found inhibition of return effects at least as large in older adults as those found in younger adults. The findings of no age-related differences in the gap effect and inhibition of return may not be surprising given the fact that the superior colliculus appears to be intimately involved in both the production of eye movements (e.g., Munoz & Wurtz, 1992) and movements of attention (e.g., Posner & Petersen, 1990).

Connelly and Hasher (1993) also found evidence suggesting that location-based inhibitory function remains intact with advancing age. They found that younger and older adults showed inhibited responses to a target that occurred in the same location as did a previously presented distractor, but only younger adults showed inhibited responses to a target that was the same identity as a previously presented distractor. From their results, Connelly and Hasher proposed that age-related deficits in inhibition will occur in tasks in which the response is based on object identification but not in tasks where the response is based on the spatial location of an object. They note that this age-related distinction in inhibitory function fits well with neurophysiological evidence indicating that one visual pathway processes the identity of objects (the ventral pathway) while another visual pathway processes the spatial location of objects (the dorsal pathway). It may be that inhibition arising from activity in the dorsal pathway may remain relatively intact over the life span, whereas inhibition arising from activity in the ventral pathway may decline with advancing age. The lack of an age-related difference in the gap effect found by the present study, where the response was based solely on the location of the target, is consistent with this proposed distinction in age-related differences between identity and location-based responses.

The present findings are also consistent with some other recent findings from our laboratory that indicate that older adults produce saccadic eye movements in fundamentally the same way as younger adults. Abrams, Pratt, and Chasteen (1996) examined detailed kinematic features, such as time at peak acceleration and peak velocity, of saccades of varying distances produced by younger and older adults. They found only minor differences between the two age groups, suggesting that many of the mechanisms involved in the control of saccadic eye movements are essentially the same for younger and older adults. Taken together, the two studies provide some converging evidence that the mechanisms of the oculomotor system that are involved with the production and control of saccadic eye movements may be somewhat resistant to degradation with advancing age.

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