Motion Extrapolation of Car-Following Scenes in Younger and Older Drivers

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Objective: The objective was to determine whether distortions occur in motion extrapolation of car-following scenes in younger and older drivers. **Background:** Drivers cannot see an entire traffic scene clearly with one glance. They must extrapolate the motion of surrounding vehicles while scanning other parts of the scene. Further, abilities relevant to motion extrapolation decline with age. Thus, it is important to evaluate age differences in motion extrapolation. **Method:** Displays simulated car-following scenes. After an interruption, the scene reappeared at the correct position in its trajectory or at a position that was more advanced or less advanced than the correct position. Drivers reported whether the scene reappeared at the correct position. **Results:** When the virtual self moved faster than the lead car, older drivers' judgments were biased toward less advanced reappearance positions. Younger drivers' judgments were biased toward more advanced positions. The implication is that older drivers extrapolated the motion slower than did younger drivers. **Conclusion:** Distortions occurred in motion extrapolation of car-following scenes, and age differences occurred in such distortions. **Application:** Potential applications of this research include traffic safety. Age differences in motion extrapolation are useful to consider in differential accident patterns of younger and older drivers. Future research should investigate the relationship between accidents and the ability to extrapolate motion, particularly during driver distractions.

INTRODUCTION

Because of limits in visual acuity, drivers cannot see an entire traffic scene clearly with a single glance. They scan the scene with successive eye movements and store information from each glance in memory as they scan other parts of the scene (Knoblauch, Nitzburg, & Seifert, 1997). Drivers and the vehicles around them are in motion. Thus, drivers also must extrapolate the motion of vehicles that are not continuously in view.

Consider a car-following situation. The driver looks at the lead car to estimate its distance and speed. The driver uses this information to extrapolate the car's future position while scanning other parts of the scene. Concurrently, the driver extrapolates the future position of his or her own vehicle in relation to the lead car and decides whether to slow down to avoid a rear-end collision. It is reasonable to expect an accident to occur if the driver's memory of the lead car's position or the driver's extrapolation of the lead car's motion is not accurate. For example, if the driver extrapolates the motion of the lead car to be faster than its actual speed while scanning other parts of the scene, the driver would expect the lead car to be farther than it actually is and may adopt an insufficient headway. This would increase the risk of rear-end collisions. It is critical that drivers accurately remember the spatiotemporal properties of a traffic scene and accurately extrapolate the motion of vehicles in the scene. However, memory for position and extrapolation of motion is distorted in systematic ways.

Distortions in Memory for the Position of Moving Objects

Freyd and Finke (1984) reported a memory distortion termed *representational momentum* in which observers remembered the final position

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of a moving object as being more forward in its motion trajectory than was actually viewed. In a representative experiment, observers viewed three presentations of a rectangle that depicted implied rotation in the picture plane. After a brief delay, a fourth test stimulus was presented. It was in the same position as the rectangle's third position or was in a position that was forward or backward relative to the third position. When observers were asked whether the test stimulus was in the same orientation as the third position, they often reported that the forward test position was the same as the third position. Memory for position was distorted along the rectangle's motion direction. Subsequent studies showed that representational momentum occurred with simulations of self-motion in depth (DeLucia & Maldia, 2006; Munger, Covington, Minchew, & Starr, 1999; Thornton & Hayes, 2004).

Distortions in Extrapolation of Moving Objects after a Visual Interruption

Cooper (1989) reported a distortion in the extrapolation of a moving object after a visual interruption. In a representative experiment, a computer-generated object rotated and then disappeared briefly. It then reappeared either at the correct position in its motion trajectory or at a position that was more advanced (*overshoot*) or less advanced (*undershoot*) than the correct position. When participants were asked whether the object reappeared at the correct position in its trajectory, they often reported an undershoot as the correct position. That is, observers expected the object to reappear in a position that was less advanced in its trajectory than it actually was. Subsequent studies showed that distortions in motion extrapolation occurred with approaching objects (DeLucia & Liddell, 1998).

Representational momentum and distortions in motion extrapolation have important implications for traffic safety because drivers cannot see an entire traffic scene with a single glance. They must remember the spatiotemporal properties of a traffic scene and extrapolate the motion of vehicles as they scan different parts of the scene. Thus, it is important to determine whether distortions occur in motion extrapolation of traffic scenes. Moreover, because spatial abilities that are relevant to motion extrapolation decline with age, it is important to determine whether there are age differences in motion extrapolation.

Age Differences

Age-related declines have been observed in spatial abilities that are important for the extrapolation of motion, including abilities to remember and mentally manipulate objects (for comprehensive reports on aging, see Fisk & Rogers, 1997; Salthouse, 1982). For example, age differences in the speed with which a figure was mentally rotated increased monotonically from ages 20 to 60 years; mental rotation slowed with age (Berg, Hertzog, & Hunt, 1983). Performance on the spatial abilities subtests of the Wechsler Adult Intelligence Scale decreased by 5% to 10% per decade starting at 25 to 30 years of age (Salthouse, 1982), and the efficiency of processing information in working memory declined gradually from ages 20 to 70 years (Morrow & Leirer, 1997). Consistent with these age-related declines, age differences were observed in judgments of the future position of moving objects and in judgments of collisions. Fifty-year-olds took longer than 20-year-olds to decide whether simulated airplanes were on a collision course (Crook et al., 1957; cf. Salthouse, 1982). Similarly, older adults (M = 70 years) exhibited less sensitivity than did younger adults (M = 23 years) in the detection of collision during simulations of self-motion toward a stationary obstacle (Andersen, Cisneros, Atchley, & Saidpour, 2000). Finally, older women (M = 61 years) had higher thresholds for collision detection than did younger women (M = 20 years) when they reported whether a (simulated) approaching object would hit them (DeLucia, Bleckley, Meyer, & Bush, 2003).

Analyses of driving accidents indicated that drivers older than 65 years are more likely to be involved in left-turn accidents and less likely to be involved in rear-end collisions as compared with younger drivers (between 25 and 64 years; Baggett, 2003). Because left-turn maneuvers and car-following tasks require drivers to extrapolate the motion of surrounding vehicles, age differences in driving accident patterns may reflect age differences in abilities that are important for motion extrapolation. We return to this in our Discussion section.

Rationale and Objectives

Prior research indicated that motion extrapolation and memory for the position of moving objects are distorted in systematic ways. In addition, it was reported in separate studies that college students with relatively slower mental rotation rates exhibited less representational momentum (Munger, Solberg, & Horrocks, 1999) and that older adults exhibited slower mental rotation speeds than did younger adults (Berg et al., 1983). The implication is that when older adults must keep track of or extrapolate vehicles as they scan traffic scenes, they may remember a vehicle's position as less advanced in its trajectory and extrapolate motion slower, as compared with younger adults. Prior research demonstrated distortions in memory for the position of the self during a simulated drive on a road (age differences were not a concern; Thornton & Hayes, 2004). Here, our aim was to measure motion extrapolation of car-following scenes in younger and older adults. We focused on two questions. First, do distortions occur in extrapolation of motion in simulations of car-following scenes? Second, does motion extrapolation differ between younger and older adults?

METHOD

Participants

Age-related declines in sensory, perceptual, cognitive, and motor performance have been well established, particularly by 50 years of age (Kausler, 1991; Salthouse, 1982). Thus, we compared the performance of drivers younger than 50 years with that of drivers 50 years or older. The younger drivers consisted of 12 volunteers 18 to 41 years of age (M = 21.75 years, SD = 6.33 years) who were students at Texas Tech University, had normal or corrected visual acuity, and received credit toward a psychology course. Of these, 5 were younger than 20 years, 6 were in their 20s, and 1 was 41 years of age. The older drivers consisted of 12 volunteers 50 to 72 years of age (M = 58.33 years, SD = 7.09 years) who were paid for their participation. Of these, 8 were in their 50s, 2 were in their 60s, and 2 were in their 70s. Older participants were recruited primarily by placing advertisements in local newspapers, posting flyers in the community, and contacting senior citizen organizations. To minimize confounds between differences in age and visual health, we eliminated older adults who reported that they had been diagnosed by a physician with any of the following: amblyopia; cataracts; color blindness; glaucoma; impairments in contrast sensitivity, depth perception, and peripheral vision; macular degeneration; retinal degeneration and retinal detachment; Parkinson's disease; seizure and nervous system disorders; and strabismus. Among the older participants, 75% had had an eye examination within 1 year of our experiment and all had been examined within 3 years.

Apparatus

Computer simulations were generated by a Pentium III 550 MHz computer with a Tornado-3000 graphics card and were presented in 640 × 480 pixel resolution at an update rate of 18 frames/s. Displays were rear-projected onto a 1.83-m high × 2.44-m wide screen with a Sharp XG-NV4SU LCD projector. Displays consisted of perspective drawings of three-dimensional scenes. As represented in Figure 1, scenes depicted self-motion behind a lead car.

Displays

After the car-following scene was presented for 2.78 s, it was interrupted for 222 ms or 1.39 s and then reappeared while moving. These interruption durations were selected for several reasons. First, it takes about 250 ms to plan and execute a saccadic eye movement (Hochberg, 1978). Second, representational momentum peaks with delays between 200 and 300 ms (Freyd & Johnson, 1987). Third, distortions in motion extrapolation have been reported with interruptions between 150 ms and 3.2 s (Cooper, 1989; DeLucia & Liddell, 1998). Thus, our interruptions were within the range that allowed us to observe distortions in memory and motion extrapolation and represented enough time for a driver to execute as many as five eye movements.

After the scene reappeared, it was presented for 2.3 s. On half of the trials (144), the virtual self reappeared at the correct position in its motion trajectory, assuming that the motion was the same speed before and during the interruption. On the remaining trials (144), the virtual self reappeared at a position that was either more advanced in its trajectory than the correct position (overshoots) or less advanced in its trajectory than the correct position (undershoots). Six incorrect reappearance positions were created by varying the deviation between the optical size of the lead car's rear bumper when the virtual self

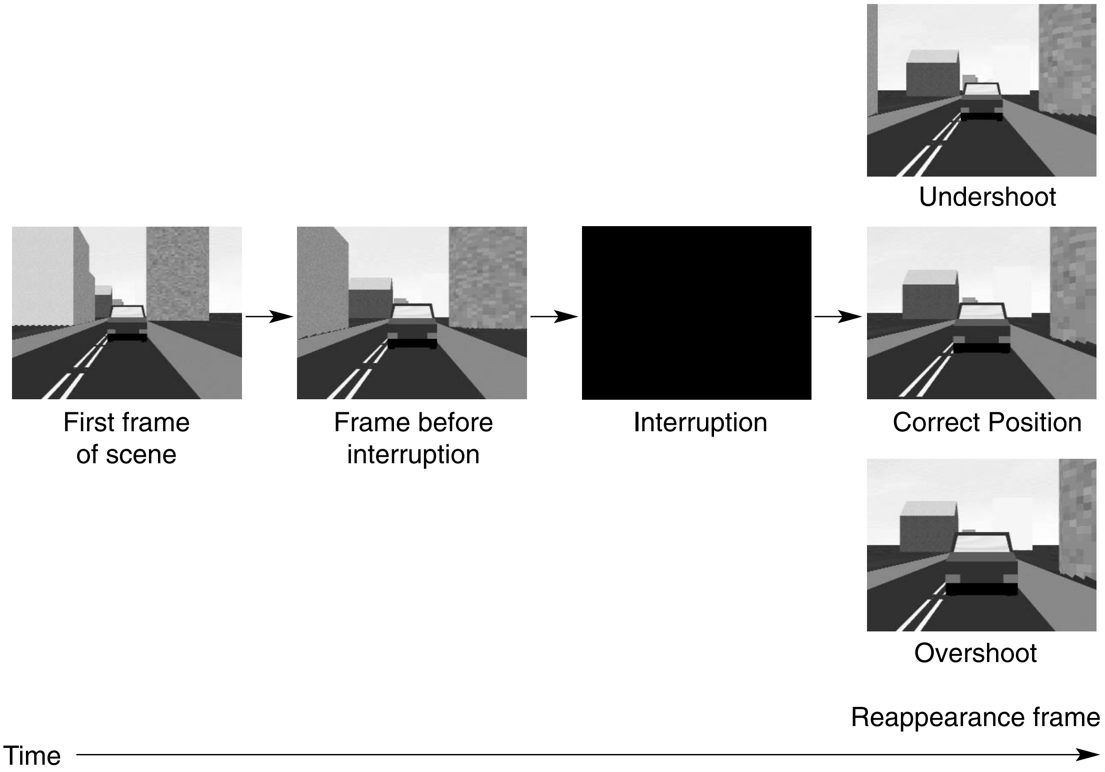

Figure 1. Schematic representation of a car-following scene in which the virtual self moved faster than the lead car and the interruption was 1.39 s. Actual scenes were in color.

reappeared at the correct position and the optical size when the virtual self reappeared at the incorrect reappearance position. The bumper's optical size was 0.5°, 1.0°, or 2.0° larger (overshoot) or smaller (undershoot) than that in the correct reappearance condition. Finally, the relative velocity between the virtual self and the lead car was manipulated. On one third of the trials, both moved at the same speed (2 units/frame). In this case, when the scene reappeared in the correct position, the size of the car's image was the same before and after the interruption. On the remaining trials, the virtual self moved faster than the lead car or slower than the lead car — that is, the velocity of the self remained constant and the car's velocity was 1.8 units/frame and 2.2 units/frame, respectively.

Procedure

With both eyes, the observers viewed the displays from 1.22 m. Participants were instructed to press mouse buttons to indicate whether the scene reappeared at the correct position, assuming that self-motion was the same speed before and during the interruption. They were instructed to respond as rapidly and as accurately as possible, and feedback was not provided. We measured the percentage of trials in which participants reported that the scene reappeared at the correct position (percentage reported "correct"). Trials in which the participant responded before the scene reappeared were omitted. Each participant viewed all scenes in a random order. Twenty-four practice trials were provided but were not analyzed.

Interpretation of Percentage Reported "Correct"

If participants report that the scene reappears at the correct position in its motion trajectory when the scene actually reappears at a position that is more advanced than the correct position, the implication is that the participant's extrapolation of motion during the interruption is faster than the actual motion. This represents a bias toward overshoots. If participants report that the scene reappears at the correct position in its trajectory when the scene actually reappears at a position that is less advanced than the correct position, the implication is that the participant's extrapolation of motion during the interruption is slower than the actual motion. This represents a bias toward undershoots. Finally, if participants report that the scene reappears at the correct position in its trajectory when the scene actually reappears at the correct position, the implication is that the participant's extrapolation of motion is the same speed as the actual motion. This represents no response bias.

RESULTS

Results are summarized in Figures 2 and 3. We evaluated whether responses were biased toward undershoots or overshoots, or whether there was no response bias. To do so, we used analyses established in prior studies of motion extrapolation and representational momentum (Cooper, 1989; DeLucia & Liddell, 1998; DeLucia & Maldia, 2006; Hubbard, 1996). Specifically, we computed the percentage of trials in which participants reported that the scene reappeared at the correct position as a function of the actual reappearance condition. These results are represented by the response distributions in Figure 2. We used the percentages to compute a weighted mean of the response distribution for each participant and experimental condition (see Vinson & Reed, 2002, for method of calculation). The weighted mean indicates whether the distribution of "correct" responses is biased toward overshoots or undershoots. A positive weighted mean represents a bias toward overshoots. A negative weighted mean represents a bias toward undershoots. A weighted mean of zero represents no bias. We conducted two-tailed *t* tests to determine whether the overall weighted mean was significantly different from zero. Finally, to examine the effects of our independent variables on performance, we conducted a 2 × 3 (Interruption Duration × Relative Velocity) ANOVA on the weighted means.

Younger Drivers

Results of ANOVA indicated a main effect of relative velocity, $F(2, 22) = 35.08$, $p < .0001$. Tukey's HSD tests indicated that the weighted mean differed between scenes in which the virtual self moved faster than the car and scenes in which the self moved slower than the car or moved at the same speed, $p < .05$. Respective means were 0.26°, –0.21°, and –0.12°. The effect of interruption duration was not significant. Thus, we averaged the weighted means across the two interruption durations prior to conducting *t* tests. When the virtual self and car moved at the same speed and when the virtual self moved slower than the car, participants reported that the scene reappeared at the correct position when it actually reappeared in a less advanced position. A significant bias toward undershoots occurred: same speed, $M = -0.12°$, $t(11) = -3.0$, $p < .0117$; slower speed, $M = -0.21°$, $t(11) = 4.16$, $p < .0016$. When the virtual self moved faster than the car, participants reported that the scene reappeared at the correct position when it actually reappeared in a more advanced position. A bias toward overshoots occurred, $M = 0.26°$, $t(11) = 7.67$, $p < .0001$. The results were the same with α adjusted for the number of tests (.0167).

Older Drivers

Results of ANOVA indicated that effects of relative velocity and interruption duration were not significant. The weighted means were not significantly different from zero in any condition. Although a weighted mean that is not significantly different from zero could occur when a response curve is symmetric around the correct reappearance position (i.e., no response bias), it also could occur when the response curve is flat. The latter indicates poor discrimination among the reappearance positions. We conducted trend analyses (e.g., Keppel, 1991) to determine whether the quadratic component of each curve was statistically significant, thereby indicating a peak (i.e., is not flat). When α was adjusted for the number of tests ($p < .008$), results of older drivers indicated a significant quadratic component in all conditions except when the virtual self moved faster than the lead car and the interruption was 1.39 s. For younger drivers, the quadratic component was significant in all conditions. Thus, when the virtual self moved faster than the lead car and the interruption was relatively long, discrimination among the reappearance positions was poorer for older drivers.

Comparison of Age Groups

Results of a 2 × 2 × 3 (Relative Velocity × Interruption Duration × Age) ANOVA on the weighted means indicated an interaction between relative velocity and age, *F*(2, 44) = 7.95, $p < .0063$, $\omega^2 = 15.24\%$. Analyses of the simple main effects indicated that when the virtual self moved faster than the car, the weighted mean differed significantly between older and younger adults (respective means were –0.26° and +0.26°). As represented in Figure 3, older drivers were biased toward undershoots or less advanced reappearance positions and younger drivers were biased toward overshoots or more advanced reappearance positions. To determine whether these results were attributable to the two 70-year old adults in the older group, we repeated these

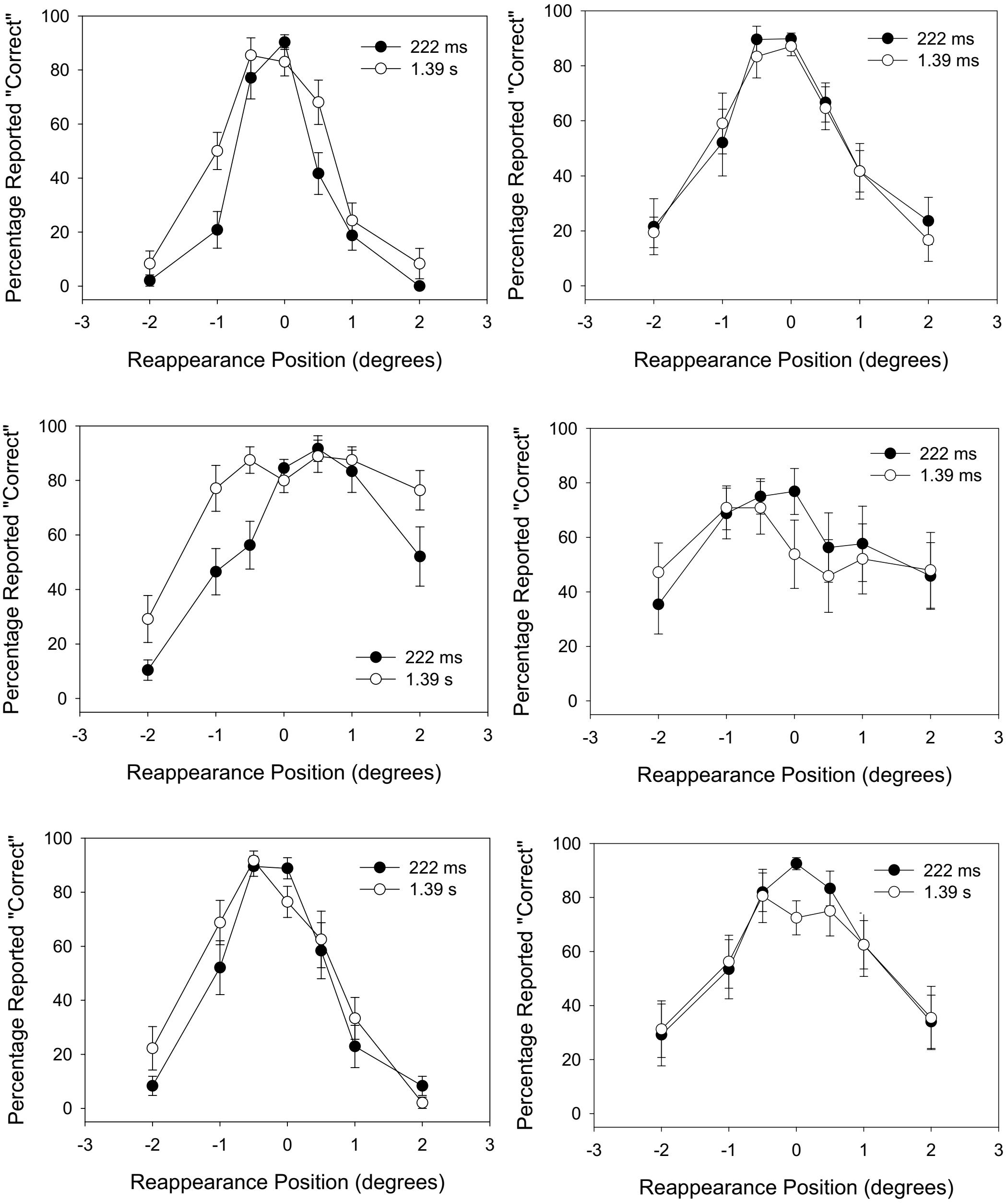

Figure 2. Mean percentage of trials in which younger drivers (left column) and older drivers (right column) reported that the scene reappeared at the correct position as a function of the actual reappearance position for each interruption duration. Top panels: Virtual car and self moved at the same speed. Middle panels: Virtual self moved faster than the car. Bottom panels: Virtual self moved slower than the car. Negative and positive values on the horizontal axis represent undershoots and overshoots, respectively. Error bars indicate ±1 standard error of the mean.

analyses after omitting the 2 oldest adults in each age group; the pattern of results was the same.

Although the effect of interruption duration was not significant for either age group when analyzed alone, the effect was significant when averaged across age groups (which increased statistical power). The weighted mean was greater when the interruption was 1.39 s ($M = -0.10°$) than when it was 222 ms ($M = -0.01°$), $F(1, 22) = 7.56$, $p < .012$, $\omega^2 = 1.2\%$. This indicates a larger bias in motion extrapolation with longer interruptions, consistent with prior studies (Cooper, 1989; DeLucia & Liddell, 1998). However, our study was not designed to determine the basis of this effect. For example, the short interruption was within the limits of iconic memory (Averbach & Sperling, 1960) and may have resulted in a response strategy different from that for the longer interruption. In any case, the effect of interruption duration did not interact with age, suggesting that both groups used the same strategy. Further, iconic memory – often measured with static stimuli – may be less useful in our task because the scene moved before and after the interruption.

DISCUSSION

We measured motion extrapolation of car-following scenes in younger and older drivers and focused on two questions. First, do distortions occur in extrapolation of motion in simulations of car-following scenes? The weighted means were significantly different from zero for younger drivers. For older drivers the weighted means were not significantly different from zero, but discrimination among reappearance positions was poorer for older drivers when the virtual self moved faster than the lead car and the interruption was 1.39 s. Thus, the answer to our first question is *yes*. Second, does motion extrapolation differ between younger and older adults? When the virtual self moved faster than the car, the weighted mean differed significantly between older and younger adults. Judgments were biased toward less advanced reappearance positions in older adults and toward more advanced reappearance positions in younger adults. The implication is that older drivers extrapolated the motion slower than did younger drivers. The answer to our second question is *yes*.

Implications for Traffic Safety and Avenues for Future Research

The present results have several implications for traffic safety. First, distortions can occur in motion extrapolation of car-following scenes. Thus, the ability of drivers to keep track of or extrapolate the motion of surrounding vehicles is useful to consider in the analyses of accidents.

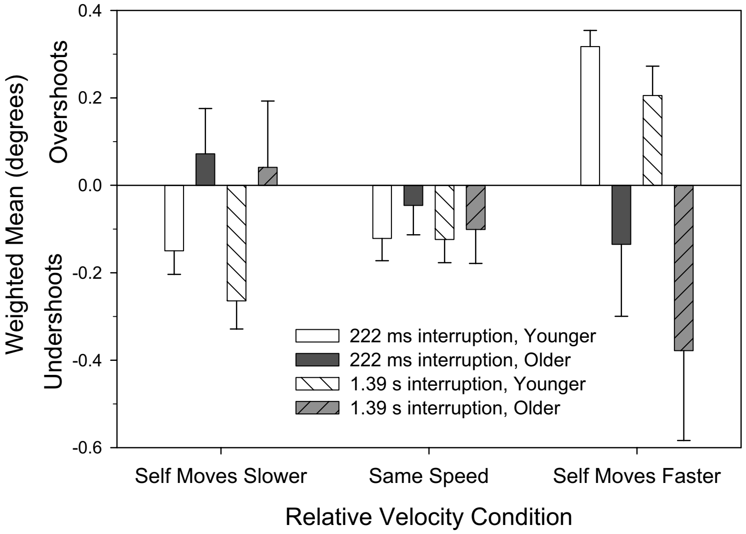

Figure 3. Weighted means as a function of age, interruption duration, and relative velocity. Negative and positive values on the vertical axis represent undershoots and overshoots, respectively. Error bars indicate ±1 standard error of the mean.

Second, when the virtual self moved faster than the lead car, older drivers extrapolated the motion slower than did younger drivers. This is consistent with age-related declines in spatial abilities that are important for motion extrapolation, such as slower mental rotation rates (Berg et al., 1983) and less efficient information processing in working memory (Morrow & Leirer, 1997). Relatedly, when the virtual self moved faster than the lead car and the interruption duration was 1.39 s, discrimination among the reappearance positions was poorer for older drivers. Although older drivers did not exhibit a significant response bias in the remaining relative velocity conditions, and thus potentially were more accurate, the variance in their weighted means also was relatively greater. The implication is that age differences in motion extrapolation are useful to consider in differential accident patterns of younger and older drivers.

For example, as noted earlier, older drivers are less likely to be involved in rear-end collisions and more likely to be involved in left-turn accidents as compared with younger drivers (e.g., Baggett, 2003). Such age differences are consistent with our hypothesis that older drivers extrapolate motion more slowly than do younger drivers. In a car-following scenario, this would lead older drivers to expect a lead car to be relatively closer and consequently to adopt a greater headway compared with younger drivers. In a left-turn scenario, this would lead older drivers to expect an approaching vehicle to be relatively farther and to turn sooner than would younger drivers. However, these interpretations of our results are speculative and require further research. Moreover, there are other factors that can lead to age differences in accident patterns. Younger drivers engage in relatively more risk-taking behaviors (Jonah, 1990) and maintain shorter headways and faster travel speeds (Smiley, 2004). Older adults engage in fewer risky behaviors and maintain larger headways and slower speeds (Smiley, 2004) as they employ strategies to compensate for age-related deficiencies in performance such as slowing in mental operations and response time.

Finally, bias in motion extrapolation increased (performance deteriorated) when interruption duration increased. The implication is that the difference between a driver's expectation of a vehicle's location and the vehicle's actual location increases with the time that the driver takes his or her eyes off the vehicle, potentially increasing the risk for collision. Moreover, the interruptions used here are relevant to any situation in which drivers take their eyes off a vehicle. This includes distractions attributable to the use of cell phones, navigation systems, and other peripherals. Thus, accidents related to the use of such devices may be attributed, at least in part, to inaccuracies in extrapolation of motion during the distraction. Future research should investigate errors in motion extrapolation during driver distractions.

Limitations

There are several limitations to our study and, consequently, we interpret our results with caution. First, our sample of drivers is small and limited in age. In particular, the mean age of our older adults was younger than that of prior studies of age differences in driving performance (e.g., Baggett, 2003). This limits the scope of our conclusions. Further, the relatively young age of our older drivers would decrease our chances of finding significant age differences and may account for our finding that age differences were significant in only one of our conditions. Moreover, our older drivers were healthy and active. Indeed, 9 out of 10 older adults who completed a follow-up questionnaire reported that they drove every day. Only 2 of the 10 reported being involved in an accident within a year preceding the experiment; one was convicted of a moving violation. Age differences may not occur when comparisons are made between young adults and healthy, active older adults (Vercruyssen, 1997). However, including older adults who are not healthy, in order to increase age differences, can pose a confound in age group comparisons (see Hertzog, 1996).

Second, the generalizability of our results to driving performance is limited because we did not measure actual driving behavior. In contrast to our relatively simple laboratory task, which measured one isolated judgment, driving involves many perceptual, cognitive, and motor skills. Thus, we cannot conclude from our data that biases in motion extrapolation account for driving accidents. Rather, our results suggest that it would be worthwhile in future research to measure the relationship between accidents and the ability to extrapolate motion. If errors in motion extrapolation are associated with accidents, it becomes important to determine whether drivers could be trained to compensate for a speeding or slowing in motion extrapolation.

Finally, our study was not designed to identify the mechanisms underlying distortions in motion extrapolation. For example, extrapolation may involve a cognitive representation of an object's motion. That is, observers may use an internal model of the object's visible motion to extrapolate the motion after it disappears (Jagacinski, Johnson, & Miller, 1983). Deficits in memory needed to maintain the model, or deficits in the model itself, could lead to errors in motion extrapolation. Future studies are required to identify processes that underlie such errors.

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