CRASHING UNDER PRESSURE: AN EXAMINATION OF OLDER DRIVER'S REACTIONS TO SIMULATED CHALLENGING ROAD EVENTS

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Summary: The driving reactions of 20 older and 20 young adults to two surprising events with varying levels of complexity was examined. Cognitive measures of workload, divided attention and reaction time were also collected. The results revealed that older adults experienced more difficulties when confronted with a surprising event that was more complex and required a rapid reaction. Crash risk was found to be associated with self-reported cognitive workload and divided attention (UFOV) results. The obtained results are in line with current cognitive models of the aging driver.

INTRODUCTION

Accident analyses have revealed that older drivers tend to crash in complex driving situations where there is a limited time execution, like turning left at an intersection or when changing lanes (Chandraratna & Stamatiadis, 2003). Some researchers have reproduced *in vivo* complex situations in order to better understand the underlying causes of older drivers' errors (Chaparro et al., 2005; Merat et al., 2005; Rizzo et al., 2004). Overall, they observed that older drivers tend to use compensatory strategies, such as slowing down as complexity and road demands increase. Erratic behaviors (i.e., important swerving, dangerous maneuvers) were rarely observed and participants responded rather well when their driving was assessed with the use of a dual task. It has been suggested that authentic complex situations are not sufficiently demanding to generate errors that are typical of older drivers. In order to create more complex driving situations without jeopardizing driver's security simulators were employed. (Horberry et al., 2006; Rizzo et al., 2001). Accordingly, Rizzo et al. (2001) exposed healthy older adults and patients suffering from Alzheimer's disease to complex surprising events with the use of a driving simulator. Described briefly, the surprising event consisted of an unexpected car incursion coming from the side at an intersection, requiring participants to deviate from their lane. They observed that six of the 18 older drivers suffering from Alzheimer's disease crashed, whereas none of the 12 control participants did. More recently, Horberry et al. (2006) submitted young and older participants to three surprising events of increasing complexity: pedestrian standing on the side of the road, a car reversing towards the road and a pedestrian crossing the road. They observed an increase in compensatory behaviour (i.e., driving more slowly) during the more difficult surprising events, but did not report any crashes. Results obtained suggested that complexity and time pressure were not high enough to induce crash.

Various driving models partly explain the differences that are expected between young and older drivers in complex time-pressured situations (Lee & Strayer, 2004; Sheridan, 2004). According to these models, older drivers would preserve their operational behaviours (e.g., manipulation of the steering, brake, etc.) in daily routine driving situations. However, difficulties are foreseen when unexpected and complex driving situations are faced, as they require instant modification and proper monitoring and coordination of the behavioural reactions.

From a cognitive standpoint, complex and time-pressured driving events tap multiple cognitive processes, like cognitive load, attention and reaction time (Anstey et al., 2005). Cyr et al. (2006) have shown that mental workload is influenced by road-event complexity as well as the driver's cognitive resources (see also Horberry et al., 2006). Moreover, attentional capacities as assessed by UFOV were found to be predictive of crash during complex and time-pressured events in participants with Alzheimer's disease (Rizzo et al., 2001). Considering the inherent time-pressure component of surprising events, reaction time is also a cognitive candidate that cannot be neglected as an explanatory variable of older drivers' performance (Anstey et al., 2005).

The goal of the present study was to investigate how older drivers react to road events of various complexities by means of a driving simulator. Based on the above findings, it was hypothesized that older adults would react differently than younger adults (crashes, swerving, braking, acceleration, etc.) during complex surprising events but not while driving under standard road conditions. More precisely, it was expected that for events where complexity and time pressure reach their peak, older drivers would perform worse than their younger counterparts. Due to the challenging cognitive nature of the surprising events, it was also expected that the drivers' performance would be related to their results on various cognitive tests. Measures of cognitive load, (NASA-TLX), attention (UFOV) and reaction time (computerized simple and choice reaction time tasks) were selected.

METHOD

Participants

In this study, there was a convenience sample of 40 volunteer participants, including 20 young adults (M = 29.5, SD = 4.32) and 20 older adults (M = 73.4, SD = 5.17). The young adults sample consisted of 10 men and 10 women between the ages of 24 and 42 years of age. The older adults sample included 9 men and 11 women between the ages of 65 and 83 years. Initially, 52 drivers (21 young and 31 old) participated in the study. However, 12 participants (one young and 11 old) did not finish the testing due to symptoms of simulator adaptation syndrome. All participants were experienced drivers (at least 5 years of driving). At the onset of the study, all participants reported good mental and physical health with no antecedents of neurological, psychiatric or substance abuse problems. All participants were residents of the Ottawa area and were compensated twenty dollars in exchange for their participation.

Materials

Apparatus. A low-fidelity STISIM driving simulator (version 1) produced by Systems Technology, Inc., was used to examine the behavioural reactions of participants in simulations.

The STISIM driving simulator displays a virtual roadway environment on three wide screens by means of three NEC projectors, giving the driver a field of view of 105 degrees. The software was run on a Windows NT operating system and Intel x86 Family model computers. The virtual environment is supplemented with realistic audio effects providing acceleration cues. The simulator records the steering wheel angle, lateral acceleration, heading angle, lane position, brake pedal pressure, throttle pedal pressure, longitudinal acceleration, longitudinal velocity and other driving-related parameters. In addition, the driving simulator provides the option of presenting stimuli that can be used for dual-task testing. In a previous publication, data pertaining to the secondary task were analyzed (see Cyr, et al., 2006).

Scenarios. Participants drove five scenarios, each with approximately eight kilometres of simulated suburban road with interactive traffic. The scenario consisted of a two-lane road gradually becoming a four-lane highway, punctuated with five stops, 10 traffic lights, and with three left and two right turns. There was also cross traffic and oncoming vehicles, as well as pedestrians, which varied depending on the scenarios. Participants first drove through the control scenario, which did not include an unexpected event. In all other versions of the scenario, an unexpected event was incorporated (for details about the unexpected scenarios see Cyr et al., 2006). In this section, drivers' reactions to two high-time-pressured scenarios that varied in terms of complexity are described. *Car doubling:* in the third quarter of the scenario, the drivers are approaching an oncoming bus positioned in the other lane that is occluding a vehicle behind it. The occluded vehicle swiftly moves into the driver's lane in an attempt to pass the truck, thus blocking the driver's path. In this scenario the driver has to react quickly but also has to swerve in the right direction. *Pedestrians crossing:* in the second quarter of the scenario, the driver approaches a group of static pedestrians on both sides of the road. Two pedestrians from the sideline of the road abruptly run across the street in such a way that the participant has to react quickly in order to prevent a collision with the pedestrians, by mainly pressing on the brake.

Cognitive measures. The UFOV, a measure of visual attention, is known to be a valid and reliable test in order to predict older drivers' crashes and at-fault accidents (Ball et al., 2006). Additionally, simple and choice reaction times were assessed through computerized tasks. The Simple Reaction Task consisted of pressing the space bar when the participants perceived a black triangle. Whereas, in the Choice Reaction Task, the participant was required to look at two circles and press the number one on the keyboard if the left circle shifted shape to a square and the number three if the right circle did. The NASA-TLX was chosen as a measure of subjective cognitive load. The NASA-TLX is a standard subjective workload measure and it is regarded to be a sensitive and reliable measure, more so than other subjective rating scales (Hart & Staveland, 1988). This instrument is comprised of six subscales (mental demand; temporal demand; physical demand; effort; frustration; performance) with possible scores ranging from one to ten.

The experimentation started with a 20-minute training session of increasing complexity, which enabled participants to familiarize themselves with the manoeuvres of the simulator. Thereafter, participants were exposed to the control scenario. The remaining four scenarios followed and the testing sequence was counterbalanced between participants. For all scenarios, a recorded voice instructed the participants through a specific route. This route was identical throughout all four scenarios. If the participants crashed, the simulation would reload and resume at the collision location. After each scenario, participants were asked to complete the NASA-TLX in regards solely to the unexpected events.

RESULTS

In this study, the reactions of younger and older adults in the presence of surprising events were compared. The surprising events were segmented into six time periods. More precisely, there was a time zero, which was the period just before the onset of the surprising event, representing the baseline for each group. During the surprising event, five periods of time were analyzed (time one to time five). Each of the six time periods in the *pedestrians crossing* and the *car doubling* scenarios were 500-ms long. For all the scenarios several variables were analysed, including steering angle, lateral acceleration, heading angle, lane position, brake pedal pressure, throttle pedal pressure, longitudinal acceleration, and longitudinal velocity. Specifically, all variables were analysed using a mixed factorial Analysis of Variance (ANOVA) design with Age (young vs. old) as the between-subjects factor and Time as the repeated factor (Time 0 through Time 5). Due to the fact that crashes occurred during the c*ar doubling* scenario (19 drivers crashed out of 40), this variable (Yes or No crash) was included as a factor. The cognitive measures (UFOV, NASA-TLX, Reaction Time Simple and Complex) were analysed through different ANOVAs. In all the analyses, the Hundt-Felt correction for violations to the assumption of sphericity was applied. The degrees of freedom reported in the result section are adjusted when the correction was used. The significant interactions were further dissected by simple effect tests using the Bonferroni alpha correction.

Car doubling

The first analysis examined the presence of crashes amongst young and older drivers. A Chi square with Crash occurrence and Age, revealed a lower number of crashes for young drivers (6 drivers out of 20), $\chi^2(1, N = 40) = 5.61$, $p < 0.05$ compared to older participants (13 drivers out of 20). The steering angle variable was found to be significant for the interaction Time x Crash, $F(2, 71.92) = 15.20$, $p < 0.001$. Simple effects contrasts revealed that participants who had a collision swerved less to the right at Time 4 and Time 5 (see Figure 1). However there was no Time x Age effect. This difference in car swerving behaviour was also found to be significant with lateral acceleration [$F(1.9, 68.55)= 19.62$, $p < 0.001$)], heading angle [$F(1.31, 47) = 26.76$, $p < 0.001$] and lane position [$F(1.31, 47.15)= 8.17$, $p < 0.01$)]. The brake pedal pressure variable led to a significant Time x Crash interaction, $F(1.56, 56.04) = 3.76$, $p < 0.01$. Participants who did not crash braked more at Time 3 and Time 4. Moreover, the longitudinal acceleration analysis also led to a significant interaction involving the same factors, $F(1.59, 52.65) = 4.64$, $p < 0.05$. Surprisingly, the longitudinal velocity analysis also yielded a Time x Crash interaction, $F(1.29, 46.6) = 6.85$, $p < 0.01$, indicating that participants who crashed drove slower at Time 0 and Time 1.

Pedestrians crossing

The analyses performed for the *pedestrians crossing* scenario revealed only one significant interaction. Specifically, the Age x Time interaction on the brake pedal pressure variable, $F(2.63, 100.2) = 1693.24$, $p < 0.001$, was found to be significant. Through simple effects contrasts, it was found that younger participants press significantly harder on the brake at Time 1, Time 2 and Time 3, as shown on Figure 2. Time 5 revealed an opposite result, as younger drivers pressed less hard than older drivers. Moreover, the analyses of the *pedestrians crossing* scenario were performed comparing older drivers who crashed and older drivers who did not crash during the *car doubling scenario*. These analyses revealed a brake pedal pressure interaction, between Crash x Time, $F(2.03, 36.49) = 3.36$, $p < 0.05$. Simple effects contrasts revealed that older drivers who did not crash in the *car doubling scenario* pressed significantly harder on the brake pedal at Time 4 and Time 5 of the *pedestrians crossing* scenario then those who crashed.

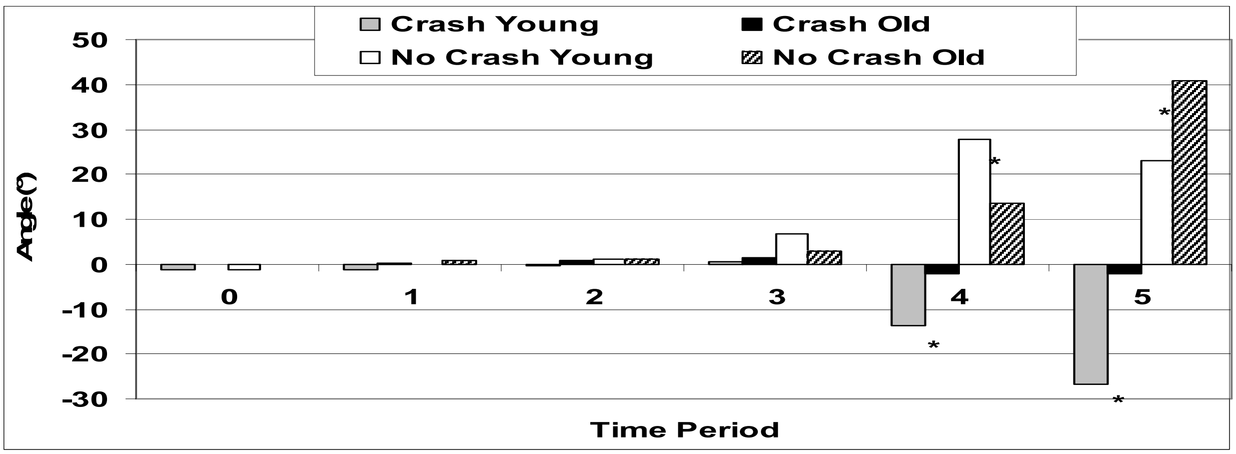

Figure 1. Steering angle in the car doubling scenario

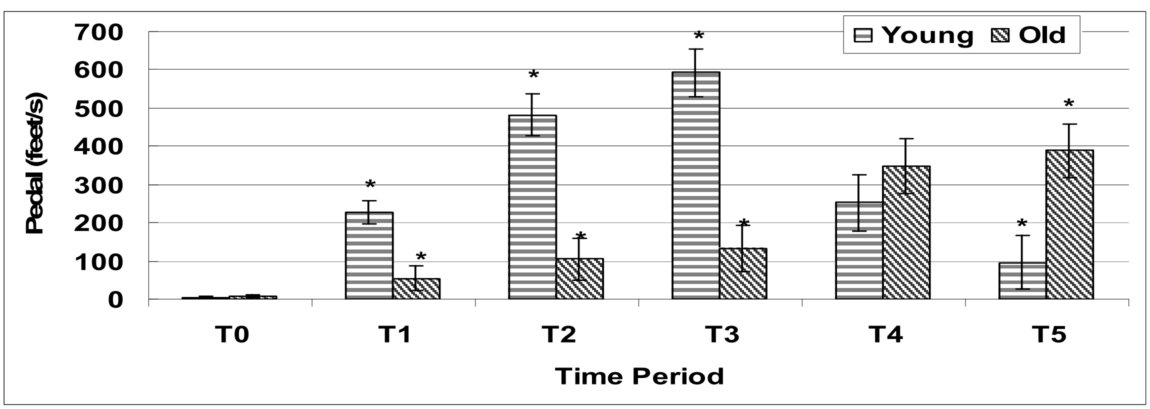

Figure 2. Brake pressure in the pedestrian crossing scenario

Cognitive measures

For the analysis of cognitive measures, the groups were separated according to the presence of crash in order to determine if there were significant differences in UFOV scores for those who had experienced a crash in the *car doubling* scenario. A significant difference was found between the non-crash group and the crash group for UFOV subtests, including visual processing speed [$F(1, 38) = 10.19$, $p < 0.01$], divided attention [$F(1, 38) = 13.74$, $p < 0.01$] and selective attention [$F(1, 38) = 23.59$, $p < 0.001$]. Moreover, the NASA-TLX analysis revealed that during the *car doubling* scenario participants who crashed judged their physical demand as higher [$F(1, 38) = 6.84$, $p < 0.05$], their performance as worse [$F(1,38)= 25.52$, $p<0.01$], and their frustration as higher [$F(1, 38) = 7.81$, $p < 0.01$]. However, Reaction Time Simple and Choice did not show a Crash group difference. Further analyses for the c*ar doubling* scenario were performed considering only older participants who crashed. The ANOVAs were significant for the UFOV divided attention subtest [$F(1,18) = 8.63$, $p<0.01$] and the selective attention subtest [$F(1,18)= 14.02$, $p<0.01$]. The NASA-TLX analyses were significant for physical demand [$F(1,18)= 4.97$, $p<0.05$], temporal demand [$F(1,18)= 9.57$, $p<0.01$] and performance [$F(1,18)= 6.84$, $p<0.05$].

DISCUSSION

Our findings demonstrate that older drivers' reactions vary according to the complexity and time-pressure aspect of the surprising events. Indeed, during the *car doubling* scenario, where complexity and time pressure were at their highest, older adults crashed significantly more than younger participants. A detailed analysis of the participants' reactions indicated that those who crashed did not swerve in the appropriate direction and failed to brake. Interestingly, crash was also observed in participants who initially drove slower, indicating that this compensatory strategy was not sufficient to prevent crash. Participants who crashed also demonstrated poorer results across all subtests of the UFOV. For older drivers, only results on the divided attention and the selective attention subtests of the UFOV discriminated between those who crashed and those who did not. The NASA-TLX results showed that participants who crashed perceived the physical and the temporal demand as higher and their performance as worse.

The *Pedestrians crossing* scenario is a good example of a surprising event that does not have the necessary elements that would lead to increase crash risk in older drivers. Compensatory strategies (driving slowly and planning) were sufficient to reduce crash risk. Nevertheless, the two age groups reacted differently to the event. Indeed, it was found that younger participants pressed more heavily on the brake than older drivers. The data from this scenario was used to cross-validate the results obtained in *the car doubling* scenario. This was achieved by comparing older crashers and older non-crashers on their braking reactions. Surprisingly, older drivers who crashed during the *car doubling* scenario applied less pressure on the brake during the *pedestrians crossing* scenario compared to older drivers who did not experience a crash. Therefore, older adults who are more susceptible to crash in a complex simulated environment also react differently in a scenario of lesser complexity.

Interestingly, both young and older participants did not differ in respects to the driving parameters before the occurrence of the surprising events in the simulated drive (i.e., at Time 0). Therefore, in standard simulated road situations, the two age groups display similar behavioural reactions.

In sum, the results support driving models advocating for an increased age effect during more complex and time-pressured road situations. The results are in concordance with Bieliauskas (2005), who posits that older drivers would tend to show less flexibility in adapting rapidly to complex driving situations, as shown in the *car doubling* scenario. Also, participants are aware of their simulated driving performances, as revealed by the NASA-TLX. Indeed, older drivers expressed increased workload in that scenario. The cognitive results reinforce the usefulness of the UFOV, especially the divided attention and selective attention subtests for the assessment of older drivers' performance.

ACKNOWLEDGMENTS

This research was supported by grants from the Ontario Neurotrauma Fondation and the Natural Sciences and Engineering Research Council of Canada (NSERC) to Sylvain Gagnon. The authors would also like to thank NSERC who awarded a scholarship to Alexandre Bélanger, the Fonds Québécois de la Recherche sur la Société et la Culture who awarded a scholarship to Stephanie Yamin, and CanDRIVE who awarded a scholarship to Andrée-Ann Cyr.

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