EFFECT OF LUMINANCE ON NIGHT DRIVING PERFORMANCE OF YOUNGER-OLD AND OLDER-OLD ADULTS

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ABSTRACT

Little research has been conducted to understand the difference in driving performance between younger-old adults (60-75 years) and older-old adults (76+ years), or simply younger olds and older olds. The main objective of this study was to determine if a minimal increase in road light level (luminance) differently affects the performance of these two distinct age groups. Older adults were tested in a driving simulator following vision and cognitive screening. Comparisons were made for the performance of simulated night driving of the two age groups under two road light conditions (0.6 cd/m^2 and 2.5 cd/m^2). At each light level, the effects of participant age were examined along with the vision/cognitive performance. It was found that increasing road light level from 0.6 cd/m^2 to 2.5 cd/m^2 resulted in different effects on night driving performance depending on the age of the participant. It is concluded that while increasing road lighting may be helpful to some older adults, younger and older olds vary in terms of cognition, attention, and confidence and these factors need to be considered in road lighting design.

Keywords: *Driving, Older adults, Night, Road lighting, Attention, Simulation, Curves, Signs.*

1. INTRODUCTION

Easa et al. found that night driving performance of older adults was affected by minimal changes in lighting [1]. Increases in road lighting led to improvements in some driving situations and losses in others. Negative changes in driver ability were related to increases in driver confidence, which in turn reduced driver attention. Older participants in Easa et al.'s study ranged in age from 63 to 84 years and the performance of these individuals was contrasted to younger and middle aged drivers. However, not all older drivers experienced the same level of difficulties and the level of difficulties may be related to the age and cognitive/vision status of the older drivers.

In Canada and the United States drivers over the age of 75 represent a growing population [2, 3]. While driving represents a considerable challenge for older adults due to age-related losses in vision and cognition [4], it may represent a stronger challenge for the oldest adults (aged 76+). All older adults experience declined visual abilities including acuity, contrast, depth, visual attention and cognitive abilities such as processing speed. Age-related losses in those abilities are linked to some driving difficulties for older adults [5].

Several researchers have shown that significantly more individuals over the age of 75 (older olds) experience vision and cognitive losses than do those between 60-75 years (younger olds) [6]. Beyond the increased numbers of the oldest drivers that experience these difficulties, the average vision and cognitive abilities are declined relative to younger olds (65-74 years) [4, 7]. In summary, a higher proportion of the oldest drivers experience losses that are more severe than those of the younger olds. Thus, it is also important to understand the impact of this advanced age on night driving where visual abilities further decline with night luminance levels [8]. At night older drivers have difficulties with sign recognition, road edge excursions, maintaining appropriate driving speeds, steering accuracy, and navigating curved sections of the highway [1, 9]. As a result, many older drivers restrict their night driving [10]. Charlton et al. [10] shows that the oldest drivers (76+) are more likely to avoid driving at night than younger olds. However, this driving avoidance leads to further night driving difficulties in some driving situations [1].

Easa et al. showed that there were both positive and negative changes in older driver ability with minimal increases in road light [1]. That study had a single sample of older drivers. It is possible, however, that the negative outcomes are more associated with the older olds than younger olds. Direct comparisons between simulator driving performances of younger and older olds at varying road lighting levels could lead to insights that relate back to recommendations on road lighting for seniors.

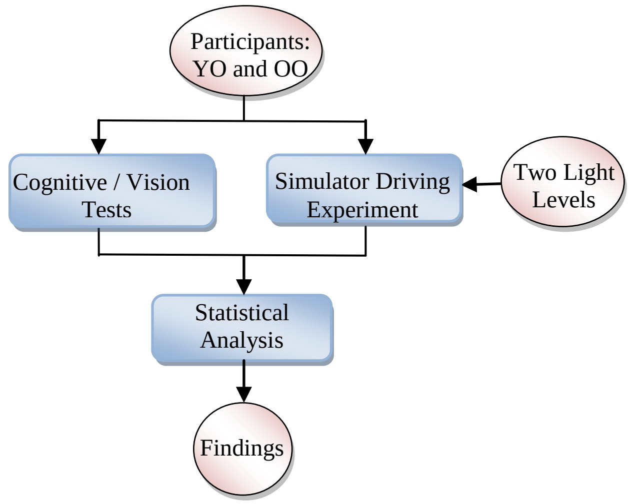

Fig. 1 Major elements of the study

The objective of this study is to determine the relative effects of minimal changes in road lighting on the driving performance of younger and older olds. The main elements of the study are shown in Fig. 1 and include experimental design (participants, vision/cognitive screening, driving simulator experiment), statistical analysis, and discussion and findings.

2. EXPERIMENTAL DESIGN

2.1 Participants

The participants included 20 younger-old adults (range = 60–75 years, Mean = 67.4 years) and 20 older-old adults (range = 76–87 years, Mean = 79.5 years), who volunteered to participate in this study. The older adults were members of Ryerson's LIFE (Learning is For Ever) Institute, a continuing education program for older adults. Overall, 50% of these respondents were male (younger old = 50%, older old = 50%). All participants were licensed to drive in Ontario and 50% reported that they avoid night driving (younger olds = 55 %, older olds = 45%).

2.2 Cognitive and Vision Tests

Cognitive Processing Speed Test. This test was performed using the Trails Test [11]. In Trails A test, the ability of the participant to scan a page where numbers are printed in a random fashion on different parts of the paper is measured. The participant must start at the number 1 and draw a line connecting 13 numbers in order. Trails B is similar except that the participant must connect both numbers and letters in an ordered fashion (e.g. 1-A, 2-B, 3-C), thus the participant must not only scan, but also switch attention from numbers to letters during the task. This test assesses speed of processing, mental flexibility, visual searching, attention switching and scanning. The time in seconds it takes to complete the task is measured.

Visual Attention Processing Speed Test. This test was performed using the computerized Useful Field of View (UFOV) test [12]. In this test, participants were given the following sub-tests: processing speed (target identification alone), divided attention (identification while performing a secondary task), and selective attention (identification while performing a secondary task in the presence of distracters). In this test participants must identify a target. The fastest presentation time (in milliseconds) leading to a correct response is recorded.

Static Visual Acuity (96% contrast) and Low Contrast Acuity Tests. These tests (25% and 11% contrast) were measured by the Regan Contrast Letter Charts (Paragon Services Inc.). Binocular far acuity was measured under optimal lighting of 100 cd/m^2 (typical optometric levels) and at low luminance of 0.6 cd/m^2 (typical highway road light level in Ontario).

Stereo-acuity (depth) Test. This test was performed using the Stereo Fly Test/Graded circle test (SO-001-Stereo Optical Co.). This test measures the stereo ability between 40 seconds of arc (best performance) and 800 seconds of arc (worst performance).

Dynamic (in motion) Acuity Test. This test was performed using the high Contrast (96%) Regan Letter Chart during controlled head motion. The participants moved their head laterally at 80 degrees/second (entrained by the beat of a metronome) while reading the eye chart. This speed of head motion was selected because it results in retinal motion that is typical in every day driving situations [13]. Every participant practiced this head motion prior to conducting the experiment. Once the participant was able to comfortably move his/her head laterally at the required speed, he/she was asked to read the eye chart under optimal lighting and then at low luminance.

2.3 Driving Simulator Experiment

The STISIM Driving Simulator (Systems Technology Inc.) at Ryerson University was used to create the driving scenarios. Participants sat in an experimental passenger car where the throttle, steering wheel, and brakes are connected to the driving simulator system. The system measures driver's response to the events of the scenarios programmed in the computer that are projected on a screen. Further, a button located on the steering wheel allowed participants to respond when they recognized roadside signs. Drivers were asked to drive as they normally do in real life, obeying driving rules.

Two levels of lighting (0.6 cd/m^2 and 2.5 cd/m^2) were used for measuring driver performance. The lower light level was chosen because it is typical of Ontario highways and the higher light level was chosen because it is minimally higher than the maximum luminance in most jurisdictions. Typically the maximum luminance varies between 1.2 and 2 cd/m^2 [14, 15]. The light levels were achieved in the simulation environment using neutral density filters (Rosco Cinigel Filters). The light measurements were taken from the road pavement according to the standard in light measurements on Ontario highways.

The simulated road included three segments: freeway segment, transition segment, and rural segment (Fig. 2). The freeway segment had a posted speed of 100 km/h and two lanes in one direction. The segment had four letter signs, each with a single letter and one of the letters (target letter) was to be visually identified by the participants. The letter sequence in the low light level was F, B, E, and P and that in the higher light level was B, E, F, and P. While driving on this segment the driver was asked to hit a button attached to the steering wheel when he/she identified the target letter (E in the low light condition and F in the higher light condition). Note that the sign to be identified was always the third sign (unknown to participants) to ensure consistency for both light conditions. The posted speed signs were typical of those on Ontario highways, having a white background and black lettering. In the lower light condition, the luminance of the letter signs and speed signs (for all parts of the scenario) was 1.2 cd/m^2, which is the typical recommended luminance for road signs [16]. In the higher road light conditions, the luminance was 4.6 cd/m^2. In this segment, vehicle speed and the distance to the identified sign were measured.

The transition segment, which lies between the freeway and rural segments, was accomplished through a reverse horizontal curve. This segment consisted of a right circular curve (radius R = 95 m) followed by a left circular curve (R = 110 m) with an intermediate tangent, and was intended to represent a typical interchange off ramp. In the transition segment, the participants were required to reduce their speeds from 100 km/h to 50 km/h (the design speed of the right circular curve) by following a series of yellow advisory speed signs. The sign luminance for the advisory speed signs was 0.8 cd/m^2 in the lower light scenario and 2.2 cd/m^2 in the higher light scenario. The

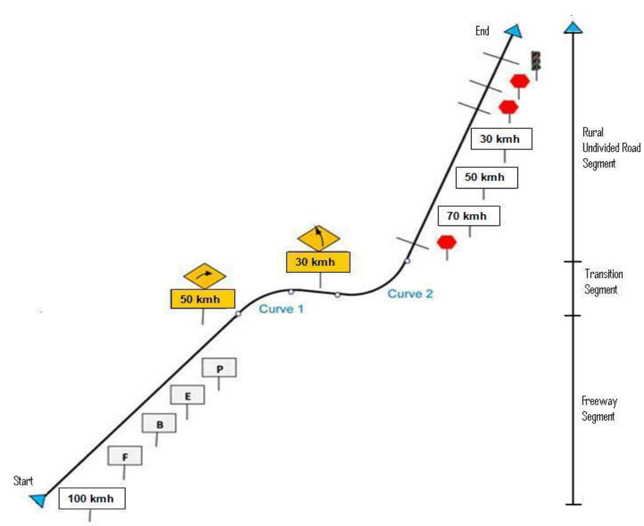

Fig. 2 Road geometry for driving simulator scenarios

variables measured in that segment included driver's mean curve position (accuracy) and individual variability in curve position (precision) at different time intervals, mean speed, distance from the posted speed sign at which the participants began to slow, and reaction time to brake (RTB). The RTB is defined as the time taken for the driver to move his/her foot from the accelerator to the brake. On the circular curve to the left, the participants were required to slow to 30 km/h. The variables measured were the same as those of the right circular curve.

The rural segment was a four-lane undivided road (two lanes in each direction) and had a series of stop signs and posted speed signs with varying speed limits. In that segment, the drivers changed the speed after coming to a stop sign, where the posted speed signs change from 70 km/h to 50 km/h and then to 30km/h. Two variables were measured. The first variable is the distance from the sign where the driver removes the foot from the accelerator and the second variable is the difference in time between the removal of the foot from the accelerator to the brake which is considered as a measure of the reaction time to brake. The number of stop signs missed was also recorded. The scenario ended with a traffic signal.

The number of times the driver exceeded the posted speed limit was recorded throughout the entire scenario along with the number of times the driver crossed the lane edge marking of the pavement shoulder. The road lighting was counterbalanced among participants, where some participants started with the low light scenario followed by the high level scenario, and vice versa for the others.

3. ANALYSIS RESULTS

All collected data were statistically analyzed using the analysis of variance procedures to determine whether driving performance is affected by the increase in light level or older adult age. Only the variables that were affected by the changes in the road light level or by age group (younger olds vs. older olds) are reported here. The Alpha parameter was set at 0.05. Trends for significance levels between 0.05 and .09 were also reported. Both correlation analyses and standard regression techniques (backward) were used to examine the relationships between driving performance and vision/cognitive performance.

In four situations the age jointly with road lighting impacted driving behavior, including mean curve position during the transition segment, mean distance to roadside sign identification, mean number of times the driver exceeded speed limits, and mean number of incidents where the driver crossed the lane markings to pavement shoulder. A summary of the differences between younger and older adults is presented in Table 1.

3.1 Mean Curve Position

The accuracy of the mean curve position was calculated as a difference score using the mean driving curvature of the vehicle relative to the actual road curvature, given by ($1/R$). For convenience, difference scores (difference between vehicle curve and road curve) are converted into meters as shown in Fig. 3. Similar to Easa et al. [1] road lighting affected curve accuracy. For the flatter curve (R = 110 m) the lower light level resulted in smaller differences between the actual and mean vehicle curve (greater accuracy) ($F(1, 38) = 8.74$, $P = 0.01$). In addition, no differences in curve accuracy were found between older olds and younger olds ($F(1, 38) = 0.15$, $P = 0.70$). However, younger olds were more precise (less variable) than older olds on this flatter curve ($F(1, 38) = 4.10$, $P = 0.05$). In

Table 1: Findings for younger vs. older olds.

Element	Finding
Curve Accuracy: Sharper Curve	• Younger olds less accurate in lower light • Older olds more accurate in lower light
Curve Accuracy: Flatter Curve	• Younger and older olds equally accurate
Curve Precision: Flatter Curve	• Younger olds more precise than older olds
Reaction to Road Signs	• Older olds must be closer the sign to react to it or identify it
Compliance with Posted Speed	• Younger olds exceed speed limits more often in higher light • Older olds exceed speed limits equally at both light levels
Road Edge Excursions	• Younger olds do not often make road excursions • Older olds make more road edge excursions in higher light

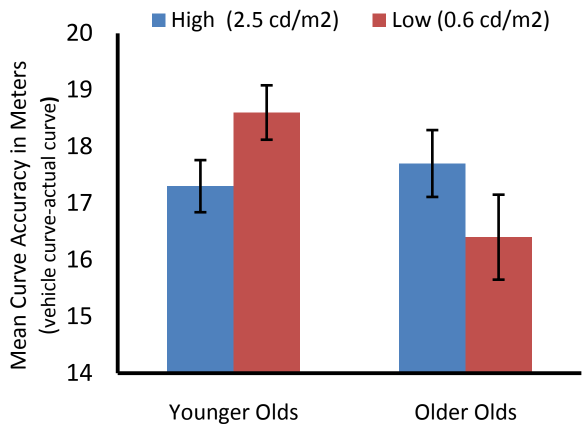

Fig. 3 Mean curve position relative to actual curve position for younger old and older old adults

contrast, on the sharper curve (R = 95 m), accuracy was affected by age and lighting as shown by a significant interaction (F (1, 38) = 7.21, P = 0.01). As shown in Fig. 3, the younger olds are slightly less accurate in the lower light level, where the older olds are slightly more accurate in the low light level.

To explore the effect of vision and cognition on curve accuracy, the correlation between these variables and the mean curve position was analyzed (see Table 2). On the sharper curve, there were no significant cognitive or vision predictors of performance. However, for the flatter curve, under the higher light level, small and moderate correlations were found between mean curve positions, and high and low contrast acuity, ranging from -0.34 to -0.58. This suggests that people with the poorest acuity had the least accurate curve position in the higher light condition on the flatter curve. On the other hand, acuity did not have a significant effect on accuracy on the same curve under the lower light level. The high and low contrast acuity differed significantly between the younger and older olds (all P < 0.04). Correlations were then recalculated for the higher light condition by age group. No significant correlations were found between accuracy of the flatter curve position and visual acuity for the younger olds. However, moderate significant correlations were found between the accuracy in the flatter curve position and high and low contrast night acuity for older olds (r = -0.55 and -0.71, P < 0.01, where r is correlation coefficient and P is associated P-value). This suggests that changes in vision lead to stronger effects on curve position accuracy for the older olds.

Mean vehicle curve accuracy for the flatter curve, in the higher light condition was also influenced by visual attention processing speed and attention switching processing speed (r = -0.69 and -0.35, respectively, P < 0.03). This suggests that as processing speed increases, the accuracy of curve position decreases. These two processing speed measures did not differ between the younger and older olds, suggesting that processing speed in both groups is a significant predictor of curve accuracy.

As previously reported, a significant group effect was found for precision when driving on the flatter curve (F(1, 38) = 4.10, P = 0.05). The oldest olds were less precise (more variable) in their driving position along this curve than were the younger olds. On this flatter curve significant correlations were found between precision in the higher light condition and dynamic acuity (r = 0.60, P = 0.01) and selective attention processing speed for the younger olds (r = 0.48, P = 0.04) but not for the older olds. This shows that for the younger olds, those with the poorest dynamic acuity and slowest processing speed also have the poorest precision. However, the vision and cognitive variables do not predict precision for the oldest olds.

To better understand the impact of the vision variables on curve design, a multiple regression was conducted to predict the difference in accuracy performance between the high and low light conditions. For this analysis, the difference in mean vehicle curve accuracy was calculated as the difference between mean curve position for driving in the lower light level from the mean curve position for driving in the higher light level for each circular curve segment individually. In the sharper curve, the age, cognitive and vision variables were not predictive of curve accuracy. However, in the flatter curve, 51.1% of the variability in these data was predicted by the age and low contrast acuity (taken at low light levels). To further investigate this relationship, another regression analysis was conducted. This analysis examined the performance across both light levels for both highway curve segments. For this analysis, the difference in the mean vehicle curve accuracy (mean curve position for driving in the lower light level and that for driving in the higher light level) was the predicted. Overall, 24.4% of the variance in these data could be predicted by night contrast acuity and the curve radius. This analysis was re-run for the younger olds and older olds independently and the results were equivalent. The relationship is given by

$$\Delta_C = 0.039\, LCA + 2.83\, I - 4.06 \qquad (1)$$

where Δ_C = difference in mean vehicle curve accuracy, LCA = low contrast acuity taken at night light levels, and I = dummy variable representing the reverse curve transition segments (0 for the right circular curve and 1 for the left circular curve). The measured acuity ranged from 20–30 (normal acuity) to 40–160 (poor acuity).

Similar to Easa et al. [1] this regression equation suggests that regardless of the age group, on the sharper circular curve (R = 95 m), older adults who have normal to poor contrast vision (e.g. 20–100) show curve positions that are slightly more accurate in higher light than lower light level or are similar at both light levels. However, in the flatter circular curve (R = 110 m), those with normal acuity show curve positions that are equal at both light levels, while those with poorer acuities tend to show more accuracy at the lower light level.

3.2 Mean Distance to React to Road Signs

A trend suggested that the oldest olds needed to be closer to a road sign (mean = 48.01 m) on the highway segment (posted speed = 100 km/h) than did younger olds (mean = 77.9 m) ($F(1, 25) = 3.12$, $P = 0.09$). In addition, while significant differences were found in reaction to the posted speed signs in the rural segment (all $P < 0.048$) based on the light level (higher light resulted in reaction from further away), only one marginal effect of age was found in reaction to a change in speed from 100 km/hr to 50 km/hr, where younger olds responded further away from the sign than older olds ($F(1, 22) = 3.55$, $P = 0.07$).

Correlations were found between sign identification distance in the lower light condition and both acuity (high, contrast and dynamic) and processing speed (all $r > -0.36$, $P < 0.044$). Those with the poorest processing speeds and poorest acuity needed to be closer to the sign to identify it. However, when considering age groups, no cognitive or vision variables predicted the outcomes for the younger olds, and acuity predicted the distance to sign recognition for the oldest olds. The oldest olds with the poorest contrast and the low light acuities had to be closer to the sign to recognize it (all $r > -0.5$, $P < 0.03$).

Some small but significant correlations were found between *reaction* to speed signs (distance from the sign when the foot is removed from accelerator) and some vision and cognitive variables (all $r > 0.39$, $P <.03$) at both light levels. Acuity (taken under low light) and visual attention (selective attention) predicted this distance. For the younger olds, those with poor visual attention or poor acuity needed to be closer to the sign to react to it. For the older olds, cognitive processing speed predicted this distance. Those with longer processing speeds needed to be closer to the sign to react to it than did those with faster processing speeds (all $r > 0.60$, $P < 0.03$).

3.3 Compliance with Posted Speeds

As Easa et al. [1] found, overall older adults exceed speed limits more often in the higher than the lower light level ($F(1, 38) = 13.01$, $P = 0.001$). However, the results showed that the pattern of exceeding speed limits varied by age group ($F(1, 38) = 3.51$, $P = 0.08$). This pattern indicates that younger olds exceed speed limits more often in the high light level and older olds exceed the posted limits at about the same rate in both light levels (Fig. 4). No

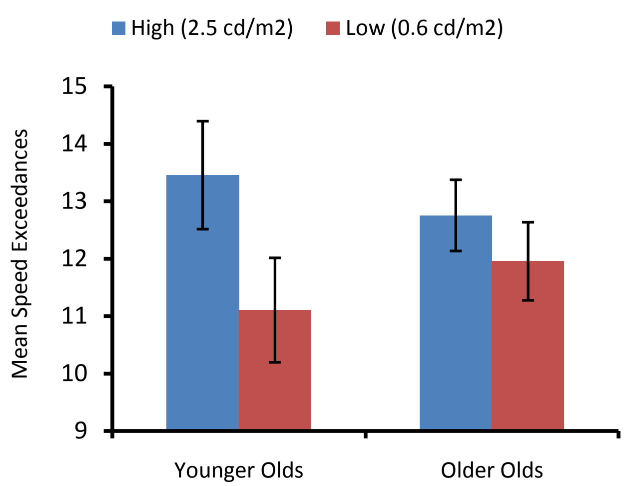

Fig. 4 The mean number of speed exceedances during the driving scenarios of younger old and older old adults

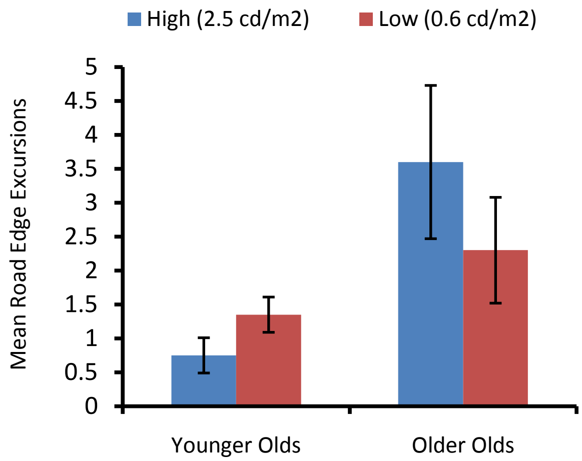

Fig. 5 The mean number of road edge excursions for younger old and older old adults

significant correlations were found between the number of times a driver exceeded the posted speed and any vision or cognitive variable under either the high or the low light condition.

3.4 Number of Road Edge Excursions

The number of road edge excursions was affected by both light level and age group. While younger olds made fewer road edge excursions than older olds at both light levels ($F(1, 38) = 4.06$, $P = 0.05$), younger olds made more excursions in the low light level and older olds made more in the high light level ($F(1, 38) = 8.02$, $P = 0.01$; Fig. 5).
Under both light levels, those with the poorest high and low contrast acuity (taken at low light levels) also showed the most road excursions ($r = 0.35$-0.58, $Ps < 0.03$). Visual attention processing speed was also correlated with road edge excursion under both light conditions ($r = 0.55$ and 0.32, respectively, $P < 0.05$). Those with the poorest processing speed had the most road excursions. When dividing these data by age group in the higher light condition, low contrast acuity remained correlated with edge excursions for the older olds ($r = 0.54$, $P = 0.01$), but not for the younger olds and visual attention processing speed remained correlated with edge excursion for the older but not younger olds ($r = 0.52$, $P = 0.02$).

4. Discussion And Findings

Numerous studies have examined crash statistics in older-old drivers. The outcomes of these studies have been mixed, but most suggest that injury and fatality rates are increased in some instances for these drivers [17, 18]. These fatality rates have been predicted by vision and cognitive variables [19], yet it is not clear from these studies how driving in everyday situations might be affected by aging for these older-old adults. Even less clear is how luminance affects the driving of these adults. While a few studies have suggested some driving difficulties for these seniors [20], the current study uniquely examined the effects of aging in older adults on night driving at varying road lighting levels. The results of the current study suggest that driving behaviours among the oldest age groups of drivers depends on driving attention, confidence, road lighting, driving situation, and vision and cognitive performance.
The current study shows that older drivers represent at least two unique driving groups based on their age. As such, changes in road luminance have unique effects on driving behaviours of the younger and older olds. For example, in the lower light condition, younger olds were less accurate in curve position than in the higher light condition, while older olds were more accurate in the low light than the high light condition and losses in accuracy seemed to be related to acuity for the oldest participants.
In addition, older olds were less precise on some curved segments at both light levels than were younger olds. These data suggest that increases in road luminance benefit younger olds while driving on curves. However, while the older olds do change driving behaviours with light level they appear to drive with more attention (thus better accuracy) in the low light situation. Increased light level, however, do not compensate for vision losses in the older olds, given their lack of precision, regardless of road light level.

Table 2: Vision and cognition measures for predicting various elements by age

Element	Predicted by
Road accuracy: higher light on the flatter curve	• Acuity for the older olds • Processing speed for younger and older olds
Road precision: higher light on the flatter curve	• Dynamic acuity and visual attention for younger olds
Sign recognition, lower light	• Acuity for the older olds
Reaction time to signs	• Visual attention and acuity for younger olds • Cognitive processing speed for older olds
Road edge excursions: higher light	• Low contrast acuity and visual attention for older olds

The current study also shows that many driving behaviours in both younger and older olds are affected by visual attention processing speed and cognitive processing speed. One positive impact of this relationship is that cognitive variables such as processing speed can be trained and improved in even the older olds [21-22]. Further, Yang, Reed, Russo and Wilkinson [23] showed that training is transferable between similar cognitive tasks (e.g. new test items) and training is evident even six months later [24]. Several researchers have argued that mediating assistance programs (e.g. road tests) do not result in improved safety for the older olds [25, 26]. Owsley et al. [26], for example, showed that drivers who take a discussion-based education program do not improve in their driving safety but do increase their self restriction of driving. Yet, it is possible that some types of training could impact on driver safety for the older olds. Beyond vision and cognitive variables studied here, Horswill et al. have shown that the older olds have difficulty anticipating dangerous traffic situations [32] and Bakos et al. [27] have shown that older olds have difficulty in making proper decisions in complex and emotional situations (such as driving). If training of processing speed is combined with training of hazard perception, there might be benefits to all older driver safety. Roenker et al. [28] found that training of visual attention processing speed resulted in fewer dangerous driving maneuvers. In contrast, they also showed that in-simulator training improved some driving maneuvers.

Younger-old drivers identified signs further away than the older olds. The difficulty in identification was due to vision loss. On the other hand, when reacting to a sign (rather than just identify it), younger olds with poor acuity and vision attention losses were slow to react, while the older olds with poor processing speeds were slow to react. These findings suggest that identifying and reacting to signs require different processes and these processes are affected by the age of the older adults.

Different results were also found between younger and older olds when examining the number of times the posted speed limit was exceeded throughout the scenario. Young olds exceeded speed limits more often in higher light. This suggests that the increase in the light level may reduce driver caution. Older olds exceeded speed limits about the same amount regardless of the light level suggesting that for the oldest drivers vehicle speed is not moderated by the light level.

In contrast, younger olds show very few road edge excursions in either light level suggesting good driving control. However, older olds made more road edge excursions in the high than low light level and their road edge excursion were correlated with their acuity and visual attention. This suggests that a mix of variables may be affecting the oldest drivers. In higher light these drivers may be reducing attention and that, in combination with a loss of visual attention processing speed and acuity, results in more excursions. This implies that changes in lighting as an aid to vision loss for older drivers must consider the relationship between attention behaviours and acuity.

5. CONCLUDING REMARKS

This study has examined the difference in driving performance between younger old and older old adults. The main finding of this study is that road lighting has different effects on night driving behaviours of older adults depending on the age of the older participants (YO or OO). One of the limitations of the study, however, is the heterogeneous nature of older drivers. Beyond age, individuals vary in their vision and cognitive processing, health, attention levels, driving avoidance, caution, and driving habits. To date the authors have examined a number of these variables and have found complex relationships between these variables and driving situations.

The driving simulation scenarios in this study were limited to rural road and freeway driving. It is possible that these two groups of old drivers would perform quite differently in urban scenarios given the environmental clutter that could distract them [29] and the level of practice that old adults might experience given that their driving is often related to short trips in urban centers [2]. Scenarios involving urban driving, turns, urban distractions, interaction with objects, traffic signals, and higher traffic volume might reveal further differences between younger and older olds with changes in road lighting.

Future research may also examine the effect of a combination of training of processing speed and simulator training in higher risk situations, like night driving, and such training may benefit the oldest driver population. Changes in road lighting have associated risks that seem to be related to the age of older adults. Younger and older olds seem to vary in terms of vision, cognition, attention, and confidence and these factors should be considered in road lighting design.

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