



Senior Drivers and Highway Design

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1 INTRODUCTION

As drivers age, they change the type of driving to which they expose themselves. Upon retirement, many older drivers reduce driving during rush hour, inclement weather or at night. With age, drivers also reduce the amount of driving they do (Smiley, MacGregor, Chipman, Taylor, & Kawaja, 1997). Despite all these adjustments, as drivers age their risk per kilometre driven increases, in part because they are more vulnerable to injury and death than a younger vehicle occupant in the same crash (Evans, 1991) (p. 34). The Canadian Automobile Association has requested an identification of infrastructure changes, by means of literature review and interviews with key Canadian stakeholders that would benefit older drivers by reducing their risk of injury and death in motor vehicle crashes.

The literature review involved internet searches using a bibliographic database of transportation research, including Transportation Research Information Service (TRIS) from the U.S. Transportation Research Board (TRB), and International Road Research Documentation (IRRD) from the Organization for Economic Co-operation and Development (OECD). Some of the keywords were: older driver and infrastructure, intersections, traffic signs, freeway, speed, gap acceptance, left turn offset lanes, legibility, accident rates, perception-reaction time, stopping accuracy, braking time, protected permitted left turn phasing, red interval traffic signal cycle, surveys, traffic safety, yellow interval traffic signal cycle, luminance, retroreflectivity, visibility distance, and pavement markings. The results were used to select 22 high quality papers dealing with practical road design solutions.

Stakeholder interviews to determine problem areas for older drivers that might be addressed by infrastructure changes were carried out with:

- Deborah de Grasse, Chief, Road Systems, Road Safety and Motor Vehicle Regulation, Transport Canada
- David Dunne, CAA British Columbia – Foundation for Traffic Safety
- Carol Libman, Canadian Association of Retired Persons
- Scott Wilson, Manager Policy Development and Promotion, Advocacy and Community Services, Alberta Motor Association

In addition, the Traffic Injury Research Foundation provided a recent paper entitled “Collisions Involving Senior Drivers: High Risk Conditions and Locations” which was added to the papers reviewed. The findings of the literature review and the stakeholder interviews are synthesized below. Appendix A provides a bibliography of the papers and Appendix B a summary of each of the stakeholder interviews.

2 LITERATURE REVIEW FINDINGS

Literature review findings begin with a discussion of older driver crash types. Knowledge of the crash types in which older drivers are over-represented is helpful in identifying changes in highway design most likely to assist these drivers. This is followed by a summary of findings with regard to older drivers and:

- Intersection design elements
- Roundabout design and traffic control devices
- Guide and warning signs
- Delineation
- Illumination

Lastly, three reports are reviewed which draw on the older driver and road design literature to provide guidelines on a variety of infrastructure changes that would assist older drivers:

- (Staplin, Lococo, Byington, & Harkey, 2001)
- (Potts, Stutts, Pfefer, Neuman, Slack, & Hardy, 2004)
- (Zein, Dilgir, Rocchi, & Gibbs, 2006)

2.1 Older Driver Crash Types

The crash types in which older drivers are over-involved compared to younger drivers provide a useful beginning point for determining which infrastructure changes would be most beneficial to older drivers. A study by Chandraratna and Stamatiadis examined problem driving manoeuvres of elderly drivers through an analysis of the Kentucky crash database for the period 1995 to 1999 (Chandraratna & Stamatiadis, 2003). Accident involvement ratios of at fault and not-at-fault drivers were measured for younger (under 65 years) and older (65 years or greater) drivers. The comparison of at fault and not-at-fault drivers helps to control for differing exposure of drivers of different ages. Not-at-fault drivers are expected to be randomly selected and so representative of exposed drivers (e.g., if middle-age drivers drive twice as much as older drivers, then twice as many not-at-fault drivers would be middle-age as compared to older drivers).

Accident involvement rates were significantly different for three manoeuvres:

- a) Turning left at an intersection across oncoming traffic
- b) Accepting a gap in traffic where both vehicles are driving straight before the (angle) crash
- c) Lane changing or same direction sideswipes while overtaking or merging

With respect to turning left, older drivers were 3.2 times more likely to be at fault and 2.4 times more likely to be killed in left turn crashes compared to younger drivers ($p < 0.0005$). The absence of streetlights made left turn crashes 1.65 times more likely for older drivers. The presence of a passenger lowered left turn crash risk for older drivers by a factor of 1.56 ($p < 0.0005$). Streetlighting is known to be beneficial in reducing night-time crashes in general (Elvik & Vaa, 2004) (p. 366), and it appears from this study to have a specific benefit for older drivers at intersections.

With respect to gap acceptance, older drivers were 1.9 times more likely than younger drivers to be involved in a crash and 1.8 times more likely to be killed when accepting a gap in traffic ($p < 0.0005$). Drivers 85 years or older were 3.6 times more likely to be involved in gap acceptance crashes compared to drivers aged 65 to 69 ($p < 0.005$). The presence of a passenger lowered the risk of accepting a gap in traffic following a left turn for older drivers by a factor of 1.38. ($p < 0.0005$). Hour of day, light conditions, road characteristics and road surface conditions were not significant.

With respect to lane changes, older drivers (65 years or older) were 1.46 times more likely to be involved in a high speed lane change crash than younger drivers ($p < 0.0005$). The presence of passengers lowered the lane change crash risk among older drivers ($p = 0.003$). Light conditions, location and severity of the crash were not significant.

Based on this study, measures that assist older drivers in making left turns, in assessing gaps when crossing a road with the right of way, and when changing lanes, are candidates for infrastructure change.

Baggett carried out a study of crashes using data gathered from the Arizona Department of Transportation for 1999 to 2001 (Baggett, 2003). Unlike the Kentucky study described above which controlled for exposure by determining driver over-involvement in at-fault crashes, this study analyzed data for all drivers involved in accidents, regardless of fault. Three age groups were used for comparisons: under 25, 25 to 64 and 65 years and older. The under 25 data was not used in comparisons unless explicitly stated, as the crash patterns were considerably different from older drivers. Approximately 4% of the 1.1 million drivers involved in accidents were older drivers (65 years or older).

With respect to crash patterns, older drivers (65 years or older) were significantly more likely than younger drivers (25 to 64) to:

- Have angle (27.8% vs. 20.4%) and left-turn collisions (15.0% vs. 11.6%) but are less likely to have rear-end collisions (35.7% vs. 47.8%)
- Have crashes in daylight (86% vs. 76%) and in rural areas (16.5% vs. 11.2%)
- Have crashes in intersections (51% vs. 44%) and at junctions (36% vs. 27%), stop signs or signals and raised medians (19% vs. 16%)
- Have a crash involving a stop sign (15% vs. 10%) or signal (33% vs. 29%)
- Suffer fatal injuries in an accident (0.48% vs. 0.23%)

Exposure was not considered in determining the relative percentages of older and younger driver involvements. Thus, some differences are likely related to different exposure of younger and older drivers to particular driving situations. Other differences are likely due to increased risk of a given crash type due to age-related performance deterioration. For example the greater involvement of older drivers in daytime and rural crashes is likely related to the fact that they do proportionately more driving during the day and in rural areas as compared to urban areas than do younger drivers. On the other hand, the greater proportion of angle crashes is likely due to declines in information processing and useful field of view skills with age.

Based on the Arizona crash statistics described above, as well as a literature review and a driver survey, Baggett (2003) identified three areas for infrastructure improvement taking into account budget constraints and gradually phasing in changes:

- Modify left-turn phase indicators to improve driver comprehension
- Larger and better-illuminated signs and devices for lane assignment on intersection approach
- Improved signage – size, lighting and contrast and advance distance notification of required tasks on all roadways

As shown by the studies above, as well as numerous earlier studies, intersections are known to be problematic for older drivers. A study by Braitman et al. (Braitman, Kirley, Ferguson, & Chaudhary, 2007) focused specifically on intersection crash types and contributing errors were examined in. Study participants comprised two groups of older drivers – ages 70 to 79 (n = 78), ages 80 and older (n = 76), as well as a comparison group of drivers ages 35 to 54 (n = 73). All

were at fault in intersection crashes involving nonfatal injuries. Police crash reports, telephone interviews with at-fault drivers, and photographs of intersections were used to determine the kinds of driver actions and errors that led to the intersection crashes. Interviews were conducted within 3 to 10 weeks of the crash (mean = 6.7 weeks) almost exclusively by one interviewer (95%).

With respect to driver actions leading to crashes, older drivers (over 70 years old) had significantly fewer rear end crashes than the other two groups. Both older groups were less likely to have run-off-road crashes at the intersection than was the middle age group. As age increased, so did the proportion of crashes as a result of failing to yield right of way.

With respect to errors, drivers aged 80 years and older made significantly more search and detection errors (inadequate search, inattention, distraction, overload, obstruction or other) than the other two age groups combined. Inadequate search errors increased significantly with age, from 27% for middle age to 65% for older age drivers. The old and older groups had significantly fewer distraction errors (11% and 9%, respectively) than the younger group (27%).

Drivers aged 70 to 79 years made significantly more evaluation errors than the other two groups combined and approximately 90% were misjudging other vehicle's actions rather than intersection design (i.e., misunderstood lane designations or right-of-way). Both groups of older drivers made significantly fewer unintended course errors and vehicle action errors (where the vehicle does not respond due to poor weather or vehicle malfunction) than the middle group.

The authors concluded that "factors leading to intersection crashes vary with age, even between two age groups of older drivers". Infrastructure changes proposed to help reduce failure-to-yield crashes at intersections, especially among older drivers, were roundabouts and protected left turn lanes at signalized intersections.

High-risk conditions and locations for older driver collisions were the subject of a literature review by the Traffic Injury Research Foundation in Ottawa, Ontario and the Insurance Institute for Highway Safety in Arlington, Virginia (Mayhew, Simpson, & Ferguson, 2006). The review focused primarily on North American studies published since 1990 and refers to 87 publications, indicating the extent of interest in this field. The authors note that the proportion of the population that is older is increasing and that it has been estimated that drivers 65 years and older will account for one-quarter of fatalities by the year 2030, compared to 14% today (Lyman, Ferguson, Braver, & Williams, 2002). As discussed above, the review found that older drivers are particularly at risk at intersections, with risk increasing with age. The authors quote Hauer (1988) who reported that for drivers 64 and older about 40% of fatalities and 60% of injuries occurred at intersections or were intersection related (Hauer, 1988). Hauer provides data for other age groups; interestingly the equivalent figures for drivers under the age of 64 are 17% of the fatalities and 46% of the injuries, indicating that intersection improvements made for older drivers are likely to be very beneficial for all drivers. Contributing causes to older driver crashes at intersections are failure to yield right-of-way, disregard of the traffic signal or some other traffic violation.

2.2 Driving Difficulties

In addition to analysing crash characteristics, driving difficulties of older drivers can be identified through surveys. Older drivers (more than 65 years of age) living in Arizona were surveyed to determine difficulties experienced while driving (Baggett 2003). Of 121 drivers surveyed, significant percentages rated "very difficult" driving at night (30%), driving on freeways (22%)

and identifying street names (20%). The older drivers rated Arizona roadways “not very good” in lettering for signs (lighting – 64% and size – 44%) and intersection markings and signals (60%). They rated the following improvements as “very helpful”:

- Reflective signs and road-edge markings (83%)
- Consistent naming for streets and routes (77%)
- Dedicated lanes and signals for left-turns (79%)

The improvement rated “most helpful” by older drivers was better illuminated traffic signs (34%).

2.3 Intersection Design Elements

Intersection design elements that have been studied with respect to older drivers include the following:

- Intersection sight distance
- Visibility of opposing traffic in a left turn bay
- Traffic signal comprehension
- Traffic signal stopping behaviour
- Signalized intersection geometrics
- Street and road name signs (considered in Section 2.5).

2.3.1 Intersection Features Contributing to Older Driver Error

“Black-spot” sites for older drivers were identified and analyzed to determine contributing design elements by road authorities in Australasia. First “black-spot” sites for all drivers were identified. The sites were then ranked by the number of older driver crashes (where a minimum of one driver was at least 65 years of age) and 62 sites with the highest number of older driver crashes were selected for further analysis. The selection took into account rural and urban areas. The vast majority of sites selected were intersections (97%) controlled by stop or yield signs (65%) and traffic signals (35%). A multi-disciplinary team then examined the relationship between intersection design features believed to influence the safety of older drivers and the older driver crash experience (Oxley, Fildes, Corben, & Langford, 2006).

The primary causes for each crash site (as a proportion of the sites) assigned by the crash team were:

- Selecting safe gaps when turning across or crossing traffic at intersections (76%)
- High task complexity and the presence of other road users (50%)
- High approach speeds of conflicting traffic (40%)
- High traffic volumes (40%)
- Limited or restricted sight distances (34%)

The remaining probable contributing factors accounted for 8% or fewer contributing factors.

The top three design features contributing to the level of risk of older driver crashes were:

- Lack of separate signal phases to control movements in each turn lane (23%)
- Restricted sight distance at right turns (23%)

- Value <2.5 seconds perception-reaction time for intersection sight distance (23%)

The other design features at issue (ranging from 6 to 10%) were: sight distance and a lack of right-turn offsets for stop control and right turn, width of receiving lane and shoulder, inadequate lane definition, unsuitable traffic signal lamps, insufficient sight distance for speeds above 65 km/h (Note: Right turn in Australasia is equivalent to left turn in North America).

2.3.2 *Intersection Sight Distance*

Intersection sight distance is the minimum sight distance required for drivers to safely negotiate intersections, including those with no control, stop control and signals, and including those for drivers turning left, right and going straight through. Older driver requirements for intersection sight distance have been investigated in an on-road study (Lerner, Huey, McGee, & Sullivan, 1995). The purpose of the study was to measure visual search time and manoeuvre time (turn left, turn right, or travel straight ahead) at stop controlled intersections. Specifically, the investigators were asked to determine whether the assumed values for driver perception-reaction time (PRT) used in American Association of State Highway and Transportation Officials (AASHTO) design equations adequately represent the range of actual PRT for older drivers.

Participants in the study were licensed drivers driving their own vehicles. Three age groups: middle, old and older (25, 27 and 29 drivers aged 20 to 40, 65 to 69 and 70 years of age or older, respectively), about equal with respect to gender, participated. Participants drove 90 km through 14 sites and were instructed to evaluate road quality. When the participants reached an intersection where PRT was to be measured, they looked down at the keypad and rated the road quality. They were not to look up until they received a signal from the experimenter. At that signal they pressed a button which indicated the start of their visual search time. When their vehicle began to move, search time ended and manoeuvre time began. Manoeuvre time ended when the vehicle reached a pre-defined position on the road (depending on task).

Older drivers did not have longer PRT than younger drivers. The 85th percentile PRT closely matched the AASHTO design equation value of 2.0 seconds. The median PRT was 1.3 seconds. The 85th percentile value was about 2.0 seconds. The younger group had 0.2 seconds longer PRT than the older group. ($p < 0.001$). There is always some concern regarding the performance of older drivers when volunteers are used. It is likely that such volunteers represent the more able older drivers and that this effect may increase with age. As a result of their study, Lerner et al. recommended not changing existing standards for the PRT values used in determining intersection sight distances (Lerner et al. 1995).

2.3.3 *Traffic Signal Comprehension*

Canadian provinces differ in traffic signal configurations and even in meaning of the same signal (e.g., flashing green light in British Columbia indicates half-signal intersection whereas the same signal (with a higher flash rate) indicates a protected left turn in Ontario). A study by Drakopoulos and Lyles investigated driver age as a factor in comprehension of left-turn signals by examining 17 different signal face arrangements (Drakopoulos & Lyles, 1997). The experiment involved 191 subjects from four U.S. states. Age groupings were 16 to 30, 31 to 45, 46 to 60 and over 60 years of age.

The participants, seated at desks, were shown stimuli with slide projectors simulating real signal displays using colour, shape (i.e. ball or arrow) and mode of operation (steady or flashing). After each stimulus, participants responded with yes or no to a list of five actions: “(1) Turn left, you have the right-of-way, (2) Turn left without stopping unless you have to wait for a large enough

gap in the opposing traffic, (3) Stop, then turn left when there is a large enough gap in the opposing traffic, (4) Stop, then turn left when there is a large enough gap in the cross street traffic, and (5) Stop, wait until the signal changes to indicate that you may proceed.”

Significant comprehension differences were found among age groups both in terms of correct answers ($p < 0.001$) and serious error rates ($p < 0.03$). Older drivers had the highest serious error rate and lower correct answer rates. Protected (means proceed), permitted (proceed if no oncoming traffic) signals were not well understood, with flashing the least understood (flashing red or yellow were used for nighttime or emergency operations). The protected signal was not well understood, given the findings that the correct response rates for all drivers averaged 64.2% and for older drivers, 48.8% (see Table 1). Red (stop) and change intervals (flashing red or yellow ball or a steady yellow ball indicating prepare to stop) were the best understood types of signal.

Table 1: Comprehension Differences among Age Groups (derived from Drakopoulos and Lyles, 1997)

Stimulus Code	Correct Answer Rate (%)		Serious Error Rate (%)	
	All Drivers	Older Drivers (>60)	All Drivers	Older Drivers (>60)
Red	96.3	91.7	1.0	1.4
Change Interval	74.0	62.9	3.7	8.3
Protected	64.2	48.8	N/A	N/A
Permitted	55.8	38.4	8.3	12.5
Flashing	44.6	32.4	12.6	15.4

For older drivers it appears that comprehension of both the permissive and protected signals is poor. While the protected signal is understood better (48.8% vs. 38.4%), comprehension is still low. It should be noted that safety studies show a considerable improvement in safety where protected phases are used (Elvik and Vaa 2004) (p. 507). This is because the driver is no longer faced with the challenge of judging whether an acceptable gap exists in traffic or of detecting through vehicles in a situation where sight distance is limited due to road curvature or due to offset of the left turn bay.

A second study also examined driver understanding of traffic signal indications. The method used was a computer-based driver survey completed by 2,465 drivers, in seven U.S. States (Noyce & Kacir, 2001; Noyce & Kacir, 2002). Drivers were divided into four age groups: under 24, 24 to 44, 45 to 65, and over 65 and randomly assigned 30 scenarios of traffic signals out of a possible 200 combinations of left turn, through movement indications and protected/permissive left turn display (PPLT) arrangements. Subjects were presented with a computer screen display of an intersection image with left turn and through traffic signals digitally created, animated and placed in the picture. The intersection used for the scenarios had a single left turn lane with two or three through lanes in each direction, a street perpendicular to the main street, and a median. Six photographs were used as background scenes. Five photographs had a vehicle (where it was not determinable if the vehicle was or was not moving) in the opposing through lane of traffic and the sixth photograph, used as a control, had no vehicles in it.

For each scenario drivers were asked “If you want to turn left, and you see the traffic signals shown, you would... (1.) GO, (2.) YIELD – wait for gap, (3.) STOP – then wait for gap, or (4.) STOP. The participants responded with number keys (see Figure 1).

Area Used	Lens Color and Arrangement	Left-Turn Indication	
		Protected Mode	Permitted Mode
Dallas, TX College Station, TX			
Dallas, TX			
Orlando, FL College Station, TX Portland, OR			

Area Used	Lens Color and Arrangement	Left-Turn Indication	
		Protected Mode	Permitted Mode
Cupertino, CA			
Oakland County, MI			
Dover, DE			
Seattle, WA			

* Green or Yellow Bi-modal Lens

Figure 1: Protected-Permitted Left-turn Signal Display Arrangements (Noyce & Kacir, 2001)

A concern raised in previous literature reviewed by Noyce and Kacir (2001) was that drivers, especially older drivers, may misinterpret the meaning of a green ball as meaning left-turn movement right-of-way. An analysis of the protected left-turn indications (68 out of 200 scenarios) showed that drivers over the age of 65 found the flashing permitted indications easier to comprehend and responded more quickly with fewer fail critical errors. Overall, the flashing red ball resulted in the highest percentage of correct responses for permitted left-turn indications (63.8%) and the green ball had the lowest (50.4%).

With respect to signal layout, the least understood PPLT signal layouts were the five section vertical, five section horizontal and five section cluster, probably because of the illumination of two separate signals to create a third indication, e.g., the combination of a green ball and a green arrow meaning a protected left turn. For the horizontal five-section display, a green ball permitted with a green ball through movement indication resulted in 40% of drivers over 65 having a fail critical rate (turned left without right of way) compared to 20% with all other age groups. The combination with the highest fail critical rate (34.3%) was the green ball permitted with a red ball through movement indication. For this combination, drivers over 65 years of age had a 51% fail rate compared to 26.5% for the 24 to 44 age group. The flashing red ball permitted with a red ball through movement indication had the lowest critical rates with none of the drivers over the age of 65 failing critical.

Older drivers took an average of eight seconds to respond, two seconds slower than drivers on average. There was a trend towards driver's place of residence being a significant factor ($p=0.064$) in comprehension.

A second paper focused on an analysis of driver understanding of simultaneous traffic signal indications in protected left turns, using the same data as described above (Noyce and Kacir 2002). With respect to protected left-turn indications, drivers over the age of 65 had significantly lower correct response rates (82%) than drivers between 24 and 44 (87%). The lowest correct response was for the simultaneous green arrow and red ball indication (71%). This was particularly poorly understood by the over 65 group who had a correct response rate of 62%, which was significantly less compared to their other responses:

- 86% for the green-arrow and green-ball combination
- 89% for the green-arrow indication only

The over-65 age group's average response time to the five-section horizontal display with simultaneous green arrow and red ball indications was nearly twice that of the green arrow only displays (see Figure 1), indicating increased potential for error.

In summary, older drivers took on average two seconds longer than younger drivers to decide on a response. When flashing indications were used to indicate nighttime or emergency operation, they were poorly understood by older drivers. However, when flashing indications were used as part of a signal cycle for a protected left turn, older drivers found them easier to understand than steady indications. A steady green ball was poorly understood with respect to a left turn being permitted or not. The use of two signals to create a third is poorly understood (e.g., simultaneous illumination of a green arrow and a red ball to indicate a protected left turn), especially by older drivers. (This approach is rarely used in Canada (Robinson, 2008)).

2.3.4 Traffic Signal Stopping Behaviour

Traffic signal stopping behaviour for younger (less than 40 years), middle-aged (40 to 60 years) and older (more than 60 years) drivers was measured on the approach to a high speed signalized intersection on a private roadway (El-Shawarby, Amer, & Rakha, 2008). Drivers drove an instrumented vehicle with a global positioning system, at a cruising speed of 72 km/h (45 mph) uphill and downhill towards the signalized intersection, 12 times each for a total of 24 runs, encountering four green and 20 yellow indications. The traffic signal was randomly triggered at one of five distances as measured from the front of the car to the approach stop bar: 32, 55, 66, 88 and 111 m. Younger drivers were found to have longer reaction times (accelerator release to touching the brake) in comparison to the older group, but they took less time to stop since they typically braked more aggressively. A lower perception-reaction time was found for drivers who have their foot lifted off the accelerator at the onset of the yellow-phase. Drivers who tried to stop at short times to the stop bar were more likely to stop downstream of the stop line. Older drivers stopped significantly more accurately compared to the other age groups. Drivers who attempted to stop when the time to the stop bar was less than three seconds were likely to do so inside the intersection.

This study indicates that older drivers respond more quickly to a signal change than younger drivers, allowing them to decelerate less aggressively. This may contribute to the finding that older drivers (>70 years) have fewer rear end crashes than younger drivers (Braitman et al. 2007).

2.3.5 Signalized Intersection Geometrics

The effects of intersection geometrics on performance of 200 drivers, divided into three age groups (25 to 45 years, 65 to 74 years and 75 and older) and driving their own vehicles was studied by Tarawneh et al. (Tarawneh, Rifaey, & McCoy, 1998). The specific geometric features evaluated were: (1) the offset between opposing left-turn lanes, (2) the degree of right-turn lane channelization, and (3) the right-turn curb radii. Left and right-turn manoeuvres of subjects were observed at 11 signalized intersections with differences in the geometric features of interest. The posted speed limit was 56 km/h (35 mph).

The positioning of a left-turn bay has a major impact on visibility of through traffic. A negative offset between the two opposing left-turn lanes results in poorer visibility of opposing through traffic for a driver waiting to make a left turn (see Figure 2 showing negative and positive offsets.)

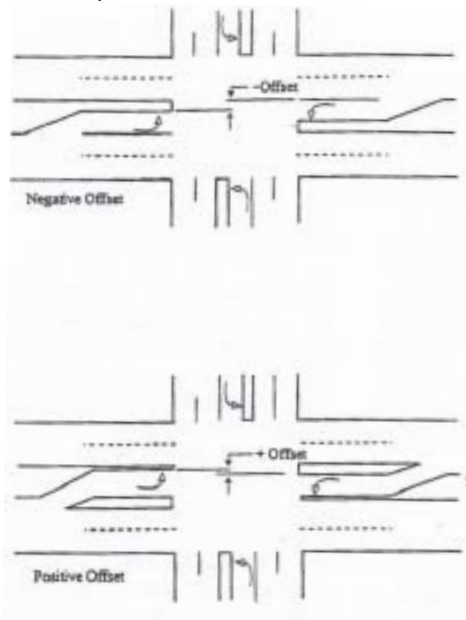


Figure 2: Negative and Positive Offsets of Left Turn Lanes (Tarawneh et al. 1998)

Left-turn lane offsets studied included -4.3, -0.9, 0 and 1.8 metres. Driver performance was measured with respect to, among other metrics, “critical gaps” which were defined as gaps in through traffic having a 50/50 chance of being accepted or rejected by the waiting left-turner.

The oldest drivers (75 years and older) had significantly longer critical gap sizes than the other two groups (which were not significantly different from each other), and were significantly less likely to position their vehicle within the intersection (thereby improving visibility of opposing through traffic) as compared to the other two groups. Offsets of zero or larger were found to be particularly beneficial to older drivers, in that the gaps accepted were longer (i.e., safer) under these conditions. However, the drivers did not recognize this benefit in their subjective assessments of turning difficulty.

The effect of geometry on right-turn manoeuvres was measured at three intersections with curve radii of 4.6, 7.6 and 12.2 metres. Trends observed were that mean speeds tended to

decrease with age and increase with curb radius. Although drivers aged 75 years and older turned slower than other drivers, there was no difference in their turning paths.

The effects of right turn lane channelizations were studied at four intersection sites with varying geometry. Drivers older than 75 years were less likely than younger drivers to attempt to make a right turn on red (RTOR) or make an RTOR without stopping. Despite the expectation that older drivers might use their side mirrors rather than turning their heads to check for gaps in conflicting traffic, this was not found to be the case. These behaviours were not affected by different intersection geometries (presence or absence of an acceleration lane connected with the right hand turn lane), presence or absence of a skew (roads crossing an angle different than 90 degrees). With respect to right turn difficulty, this was rated less difficult for channelized right turns with an acceleration lane, with the exception of middle-aged female subjects who rated this as more difficult. Middle-aged drivers made turns more quickly (mean 29 km/h) than did the older age groups (mean 22 km/h).

In summary, older drivers in particular would benefit from neutral or positive left turn bay offsets. The provision of a channelized right turn lane with, or without, an acceleration lane may increase speed discrepancies between older and younger drivers as they turn.

2.4 Roundabout Design and Traffic Control Devices

Design elements of roundabouts that could be problematic to older drivers were assessed by means of focus groups and structured interviews by Van Schalkwyk et al. (Van Schalkwyk, Lord, Chrysler, & Staplin, 2007). Video footage and animated videos were used to allow participants to assess the measures within context.

In the focus group sessions, participants were exposed to videos which illustrated single/multilane roundabouts, central islands, splitter islands/approach gore, warning and approach guide signs, entrance area signs and pavement markings, and exit direction signing. Specific design elements of concern to the participants included: advance warning signs, lane assignment and advance guide signs, channelization, yield treatment, directional signing, and exit direction signing.

The structured interviews involved a second set of subjects who evaluated ten countermeasures for five design elements (advance warning signs, roundabout lane assignment signs, directional signs, yield treatments and exit treatments). Change from the base conditions in perceived comfort, confidence and safety were used to evaluate the countermeasures. Based on the findings, the use of chevrons at the roundabout is discouraged, and a symbol should be used on the advance warning sign rather than text. Older drivers were found to be confused by the yield line consisting of isosceles triangles pointing toward the approaching vehicles (Shark's Teeth Yield Line Pavement Marking Symbols).

2.5 Guide and Warning Signs

2.5.1 Comprehension

Comprehension and legibility of traffic sign symbols can present problems for older drivers. A study done for the U.S. FHWA (Dewar, Kline, & Swanson, 1994) tested the comprehension of 480 drivers aged 18 to 88 years of age on all 85 symbols in the U.S. Manual of Uniform Traffic Control Devices (MUTCD), many of which are identical to or very similar to those used in Canada. Dewar et al. found that older drivers (60 years of age or older) performed more poorly than did younger ones on symbol comprehension for 39% of the 85 symbols tested. Older

drivers generally had slower reaction times to identify symbols and had more difficulty detecting them in an array of signs.

The specific signs that older drivers (60 years of age or older)performed more poorly on than younger drivers were: Keep Right, Mandatory Seat Belt, Right Curve, Double Head Arrow, Cross Road, T Symbol, Stop Ahead, Yield Ahead, Signal Ahead, Merge, Added Lane, Divided Highway, Divided Highway Ends, Pavement Ends, Advance Flagger, Hospital, Camping, Handicapped, Tourist Information, Emergency Medical Services, Hiking Trail, Train Station, Library, Ranger Station, Rest Rooms, Campfire, Showers, Swimming, Ice Skating, Sledding, Snowmobiling, and R.R. Advance Warning (parallel).

The signs that older drivers understood more poorly than younger drivers, and for which comprehension was below 60% correct for at least one of the two older groups were: Mandatory Seat Belt, Double Head Arrow, Yield Ahead, Pavement Ends, Advance Flagger, Added Lane, Tourist Information, Library, Ranger Station, Showers, Swimming, Ice Skating, Sledding, and Snowmobiling.

2.5.2 Legibility

Awareness of the effects of aging on vision and the aging of the driving population has prompted research on the appropriateness of current traffic sign standards. Four studies were conducted – two static in-vehicle, one moving vehicle, and one walking, to examine legibility for various fonts used on highway signs (Mace, Garvey, & Heckard, 1994). Findings were that older drivers (over 65 years), even those with normal 20/20 vision, have shorter legibility distances than younger drivers (less than 40 years). This is because, with age, sensitivity to contrast declines. Interestingly, older driver legibility is relatively worse than that for younger drivers during the day – the two groups are less different at night. The legibility index for younger drivers was 0.6 to 2.4 m/cm better than older drivers at night, and even greater, 2.4 to 3.6 m/cm better during the day.

Legibility depends on letter series (C, D, E(M)), letter height, and on letter contrast with the sign background (both in terms of colour contrast and retroreflectivity of sheeting – see below). Mace and his colleagues concluded that to provide the letter size needed to accommodate 75% to 85% of older drivers and 95% or more of younger drivers, under both daytime and nighttime conditions, the following legibility indices should be assumed:

- 3.6 m/cm for series C and D letters used on warning and regulatory signs
- 5.4 m/cm for series E modified letters 20 cm in height, and 4.8 m/cm for letters 30 cm in height, used on highway guide signs.

As can be seen, increasing the letter height provides a less than proportionate increase in legibility distance. No effects related to age were identified for changes in letter spacing.

2.5.3 Information Load

Maximum information load on guide signs was assessed by McGarry using the Transportation Research Laboratory driving simulator, and 51 participants divided into two age groups (younger aged 50 to 64 years and older, aged 65 to 75 years) (McGarry, 1996). The driving scenario featured a 3-lane roadway with two vehicles in front of the driver. The other vehicle behaviours were unpredictable and set to a “reasonably demanding” difficulty. Participants driving in the simulator were instructed to maintain a safe distance behind the other vehicles. An experimenter read the destination names, varying the time before the sign appeared;

participants responded promptly by signalling the direction using the indicator stalk. Signs were projected onto the screen for eight seconds using a slide projector. Although it is not stated, test signs appear to have showed a list of names and directions only.

Response times increased as more names appeared on the sign ($p < 0.001$). Based on the graph provided, response times were about 2.5 seconds for signs with three destinations and rose to about 4.25 seconds for signs with 18 destinations. Differences between gender and age groups were also present, but small – on the order of 0.25 (3 names) to 0.5 seconds (18 names). The type of sign (map or stack) did not appear to affect response times.

2.5.4 Retroreflectivity

The impact of retroreflective sheeting on legibility was also examined in the study described above (Mace et al. 1994). Retro-reflective sheeting determines luminance contrast. For regulatory and warning signs that use D letter font, higher-grade retroreflective sheeting can increase legibility from 3.6 m/cm up to 4.8 m/cm. However, too much retroreflectivity can increase glare and actually cause a decline in retroreflectivity (e.g., Type VII letters on a Type I background). Cost comparisons (excluding life-cycle costs) using the data available suggested that larger signs with Type I sheeting were less expensive than smaller signs with Type VII material which provided similar performance. For black on white regulatory signs, brighter sheeting improved detection distances for younger drivers, but made no difference to older drivers.

2.6 Delineation

Four studies of roadway delineation were reviewed (Graham, Harrold, & King, 1996; Parker & Meja, 2003; Ohme & Schnell, 2001; Pietrucha, Hostetter, Staplin, & Obermeyer, 1996). The first two studies addressed the issue of threshold values of delineation retroreflectivity that older drivers consider acceptable for night driving. The third addressed the issues of detection distances for different marking materials, and the effect, if any, of wider edgelines on detection distance. The fourth study (Pietrucha et al. 1996) addressed lane marking combinations (striping, raised pavement markers and post mounted delineators) that gave acceptable visibility with respect to the detection of upcoming curves.

Retroreflectivity levels of in-place roadway markings were made and related to subjective evaluations in order to determine minimum marking retroreflectivity levels desired by older drivers (aged 60 or older) using low beam headlights (Graham et al. 1996). Measures were made at 24 locations, all tangent sections of 60 m in length on a level grade with no nearby streetlighting. One vehicle was used in the testing and the driver drove within posted speed limits, without closely following other vehicles.

Subject passengers rated the markings as (a) less than adequate, (b) adequate, and (c) more than adequate. In the field study more than 85% of 65 subjects aged 60 years and older rated a marking retroreflectance of 100 mcd/m²/lx as adequate or more than adequate for night conditions. A comparison between the results for older drivers and an earlier similar study of younger drivers found that whereas the average subjective ratings were similarly distributed relative to the retroreflectivity of pavement markings, older drivers consistently rated the adequacy of retroreflectivity of markings lower than did younger drivers. However, in practical terms, differences were small – as 90% (vs. 85%) of drivers younger than 30 years of age rated values of 93 mcd/m²/lx or greater corresponding to an “adequate” or “more than adequate”. Marking colour was not a significant predictor of minimum required retroreflectivity.

To allow for windshield and headlight variable cleanliness, the study authors suggest the minimum value should be increased 21% to 121 mcd/m²/lx. Strengths of this study are that it had a large sample of older drivers and took place in real-world conditions. However, the use of one vehicle would not take into consideration the headlight performance of a variety of vehicles. Also no objective measure of the impact of visibility on lane tracking performance was made.

A second study on marking retroreflectivity was prompted by a desire to evaluate the appropriateness of a 3-year fixed-schedule restriping strategy (Parker and Meja 2003). The study involved 72 participants, divided by age into groups with approximately 25% under 33, 50% 33 to 55, and 25% over 55 years of age. Participants drove their own cars which had been inspected for clean windshields and headlights. The test area consisted of 44 half-mile sections on New Jersey highways with retroreflectivity levels ranging from 92 to 286 mcd/m²/lux. The sections consisted of yellow centrelines, white edge lines and skip lines which were marked with pavement marker spray to indicate the start of the section, post number and end of section. The course was relatively flat with horizontal curves ranging between 150-500 metres in radius. Participants were asked to rate the markings for each section as very clearly visible (excellent), visible with no difficulties, visible with some difficulties, visible with great difficulties, and invisible. Marking was considered “acceptable” if it was rated excellent or visible with no difficulties.

The threshold value at which 90% of drivers under 55 years of age rated the retroreflectivity as acceptable for white edgelines, yellow centrelines and skip lines appeared to be between 80 and 130 mcd/m²/lux, rising to 120 to 165 mcd/m²/lux for drivers over the age of 55. Participants older than 55 years required retroreflectivity of at least 160 mcd/m²/lux for white skip lines and at least 165 mcd/m²/lux for yellow centrelines.

A third study compared visibility for various types of markings and edgeline widths (Ohme and Schnell 2001). Driver detection distance was measured for pavement marking edge line widths of 100 mm, 150 mm, and 200 mm, and four pavement marking material types: normal paint+bead, wet-weather tape, ceramic element (Ohme and Schnell 2001). Participants drove on a two-lane rural road, using low beam headlights, on wet and dry roads, and verbally identified the point at which they could see a gap with 95% certainty in the solid lane marking. Ceramic element and wet-weather tape showed statistically significant differences from the paint+beads treatments. ($p \leq 0.015$ and $p < 0.0001$ respectively). However, marking width did not have a significant effect on detection distance (Table 2).

Table 2: Mean Detection Distances (m) by Pavement Marking Treatment

Pavement Marking Treatment	Dry Roadway		Wet Roadway	
	Young	Old	Young	Old
10cm Paint+Beads – Baseline (Standard Deviation)	88.1 (18.7)	79.1 (25.4)	14.3 (7.0)	20.7 (10.1)
15cm Paint+Beads	95.5 (23.6)	82.8 (26.4)	14.0 (8.9)	16.6 (10.8)
20cm Paint+Beads	92.6 (21.7)	78.2 (28.4)	20.4 (15.3)	23.1 (13.6)
Ceramic Element Paint	90.8 (31.2)	88.7 (32.6)	26.7 (10.8)	36.3 (16.8)

Wet-Weather Tape	90.4 (17.4)	68.9 (24.2)	61.3 (24.1)	65.7 (21.7)
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While the analysis showed no significant difference between the two age groups, the sample was small (seven older (65 to 81 years) and seven younger (19 to 26 years)). Also, older drivers who volunteer for testing may have better vision than those not willing to volunteer. A major strength of this study was that it occurred in real world conditions with markings that were installed over one year and exposed to snow plowing operations.

The fourth study of delineation reviewed tested twenty-five delineation/pavement marking treatments (including various combinations of centrelines, edgelines, raised pavement markers, post-mounted delineators and chevrons in a laboratory simulator study in order to select the treatments with the best recognition distance for field testing and comparison with “control” treatments (Pietrucha et al. 1996). Participants viewed a film simulating a speed of 56 km/h (35 mph), while performing a tracking task, and depressed the brake pedal when they were 100% certain of the curve direction ahead. Each treatment was also subjectively rated with respect to how effectively it indicated curve direction relative to the baseline treatment.

Twelve of the pavement marking and delineation treatments were selected for field testing. The field tests were conducted on a closed test track facility, and recognition distance and visual occlusion time were used as dependent measures. There were 33 younger (18 to 45 years old) and 33 older (over 65 years old) participants exposed to eight treatments (two baseline with left and right curve plus six treatments) each. Recognition distance testing occurred in pairs. The vehicle driven by the experimenter started 305 m away from the curve and was stopped every 30.5 m away from the curve for a response. Each participant used answer buttons to indicate the direction of the curve ahead and the trial ended after two consecutively correct responses. The participants rated (1 to 100) the effectiveness of each of the treatments relative to the baseline treatment for indicating the direction of the curve.

Comparing the older group to younger group by treatment for recognition distance revealed that the older participants had shorter distances on all but one of the treatments (treatment 1). The treatments ranked highest for both objective and subjective data sets and for both the simulator and field studies, were the following:

- Yellow centreline with chevrons
- Yellow centreline with high intensity T-posts
- Yellow centreline, centreline RPMs and high intensity T-posts
- Yellow centreline, white edgeline and engineering grade T-posts

The second and fourth were selected on the basis of best overall in performance and most consistent in rankings. A cost-benefit analysis showed that the second treatment had the lowest estimated cost over a 10-year period. However, because the fourth treatment had edgelines, and had the “highest overall recognition distance values for both age groups”, it was recommended for older drivers. The strengths of the study are that a substantial range of delineation treatments were tested with three age groups. The limitations are that the testing did not address lateral position of vehicle on roadway, nor did it address impacts of improved delineation on driver speed choice.

In summary the findings of four recent studies of delineation with respect to older drivers were as follows:

- Wider than standard edgeline markings do not provide increased recognition distance (Ohme and Schnell 2001)
- Mean detection distances varied greatly by delineation type, with ceramic element and wet-weather tape being associated with significantly longer detection distances for both older and younger drivers. Perhaps due to small sample size and the volunteer bias effect, there were no significant differences in detection distance between older and younger drivers (Ohme and Schnell 2001)
- Minimum retroreflectivity that is rated as “adequate” or “more than adequate” by more than 85% of older (over 60 years) drivers is 100 mcd/m²/lx as measured with a Mirolux 12 Retroreflectometer (Graham et al. 1996)
- Minimum retroreflectivity which is rated as “excellent or visible with no difficulties” by 90% of drivers less than 55 years of age is between 80 and 130 mcd/m²/lux, rising to 120 to 165 mcd/m²/lux for drivers over the age of 55. Participants more than 55 years old required retroreflectivity of at least 160 mcd/m²/lux for white skip lines and at least 165 mcd/m²/lux for yellow centrelines (Parker and Meja 2003).
- The best combination of delineation treatments with respect to driver recognition distance is yellow centreline, white edgeline and engineering grade T-posts (Pietrucha et al. 1996)
- The best combination of delineation treatments with respect to cost-benefit is a yellow centreline with high intensity T-posts (Pietrucha et al. 1996)

Caution is advised with respect to the use of T-posts given findings by Kallberg and Bahar (Kallberg, 1993; Bahar, Mollett, Persaud, Lyon, Smiley, Smahel, & McGee, 2004). What is subjectively preferred and gives longer recognition distances for older drivers can lead to increased speeds and substantially increased nighttime crashes when these “improved” delineation treatments are implemented on low standard roads (Smiley, 2008). Bahar et al. (2004) provide guidance in the form of accident modification factors associated with the use of raised pavement markers for tight vs. wide curvature and various traffic volume levels (Bahar et al. 2004). These should be consulted before implementing raised pavement markers or post-mounted delineators.

2.7 Illumination

Mace and Porter published research on the relationships of fixed lighting parameters to the safety and comfort of older drivers (Mace & Porter, 2002). Safety and comfort were defined by measures of visibility, glare, perceived comfort, and driver behaviour. All fixed lighting designs were one-sided arrangements with high pressure sodium lamps. Of particular interest were interactive effects of average pavement luminance and luminance uniformity with respect to minimizing discomfort glare and transient adaptation without sacrificing the visibility of objects within the fixed lighting area.

The testing was conducted along a flat section of a two-lane highway with asphalt pavement and fixed lighting. The fixed lighting was one-sided with a 1.5 metre overhang and had adjustable pole spacing (40, 60, 80, and 120 metres), bracket mounting height (11 to 15 metres) and high pressure sodium (HPS) luminaries (one 150w and one 400w flat glass enclosure and one 400w luminaire with a refractor). Two driver age groups were tested, 25 to 35 years and 65 to 75 years of age. Subjects drove a test circuit at speeds of 40 to 56 km/h and looked for targets (18 cm square, 18% reflectance) along the centreline or lane line. One small target was placed 107 m past the last light to determine the “transient adaptation effect”. A secondary loading task requiring participants to locate green retroreflective markings was used to increase

the visual complexity without interfering with the primary target detection task. Continuous, oncoming headlight glare was simulated for the two-lane roadway by attaching two lamps to the front of the vehicle and directing them at the driver eye.

With respect to the effect of the lighting system on detection distance, the longest detection distances for all drivers were obtained with:

- High luminance and either low or medium uniformity ratio designs (121m)
- Medium luminance and either medium or high uniformity ratio designs (116m and 115m respectively)

Even when older and younger drivers were matched for visual acuity, age still had a significant effect on detection distance. With respect to luminance and uniformity, increased uniformity significantly improved older driver detection performance (84 m for high and 69 m for low uniformity) but had no effect on younger driver detection performance (113 m for high and for low uniformity). There was no difference in detection distance between low and medium uniformity for older drivers.

With respect to lighting spacing for two low-luminance, high-uniformity designs, 80 m pole spacing had significantly shorter detection distance (94 m) than the 120 m spacing (110 m). The authors caution that the 80 m design had a lower pavement luminance and a slightly higher uniformity ratio than the 120 m design and that may have contributed to the result.

With respect to the effect of the lighting system on vehicle speed, older drivers drove slower (52 km/h) than young drivers (53.4 km/h), and the two lighting designs with significantly slower speeds than all others were also those that resulted in the shortest detection distances for older drivers.

With respect to headlight glare, older drivers had significant decreases in detection distance under headlight glare in two conditions: low luminance with low uniformity (-6.4 m) and low luminance with medium uniformity (-9.4 m). All drivers had significant decreases in detection distance in the no lighting condition (-12.2 m). For all other situations (including younger drivers) there were no significant differences in detection distance with and without glare, suggesting that the effects of the simulated headlight glare on visibility were mitigated with medium or higher levels of lighting. Glare was rated as significantly more discomforting without lighting than with lighting.

With respect to transient adaptation, detection distance for older drivers just beyond the last light pole was significantly less than younger drivers: two conditions of low luminance, one with low (56 m) and one with medium (64 m) uniformity had the longest detection distances. The condition in which the streetlights were off increased detection distance for transient adaptation compared to any of the designs with street lighting.

2.8 Older Driver Design Guidelines

Three reports provided extensive guidelines on infrastructure changes that would assist older drivers:

- FHWA Highway Design Handbook for Older Drivers and Pedestrians (Staplin et al. 2001)
- AASHTO Strategic Highway Safety Plan – Older Drivers (Potts et al. 2004)

- Alberta Traffic Safety Guide to Accommodate Aging Drivers (Zein et al. 2006)

The best known of these guidelines is the FHWA Highway Design Handbook for Older Drivers and Pedestrians which was developed by the Federal Highway Administration (FHWA) in 1998. In 2001 it was updated, revised, and expanded by Staplin et al. and re-titled "Highway Design Handbook for Older Drivers and Pedestrians". Five highway design elements are addressed with a total of 31 design recommendations. These cover the areas shown in Table 3. The Handbook is available at <http://www.tfhrc.gov/humanfac/01103/coverfront.htm>. Each design recommendation is described in a page or two, with illustrations. In addition there is a detailed rationale based on literature review for each recommendation.

The handbook also provides guidance as to how to determine when the recommendations should be implemented. The following issues should be considered:

1. Is there a demonstrated crash problem with older drivers or pedestrians?
2. Has any aspect of design or operations at the project location been associated with complaints to officials from older road users?
3. Is the project located on a direct link to a travel origin or destination for which, in the judgment of local planning/zoning authorities or other local officials, older persons constitute a significant proportion of current users?
4. Is the project located in an area that has experienced an increase in the proportion of residents age 65 and older?

Table 3: Table of Contents for Design Guideline Recommendations

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2.8.1 AASHTO Strategic Highway Safety Plan

One of the key emphasis areas of the AASHTO Strategic Highway Safety Plan addresses the reduction of crashes and fatalities involving older drivers (Potts et al. 2004). The research supporting each strategy targeting older drivers was collected with reviews of reference materials, interviews/surveys, workshops and symposiums, and pilot testing. The reference materials included the FHWA Highway Design Handbook for Older Drivers and Pedestrians (Staplin et al. 2001) The AASHTO guide focuses on implementation (rather than on providing detailed literature support for recommendations) and provides engineering, planning, education, and policy guidance to highway agencies that desire to better accommodate older drivers special needs. Table 4 summarizes the recommendations made for older drivers.

Table 4: AASHTO Road Design Strategies for Older Drivers

Road Design Improvement Strategies	Strategy Type*: Proven, Tried, and Experimental	Time Frame**: Short (<1yr) Medium (1-2yrs) Long (>2yr)	Relative Cost***: Low, Moderate and High
Replace painted channelization with raised channelization	P	M	M
Provide advance warning signs	T	S	L
Provide advance guide signs and street name signs	T	S	L
Increase size and letter height of roadway signs	T	S	L
Provide all-red clearance intervals at signalized intersections	T	S	L
Provide more protected left-turn signal phases at high-volume intersections	T	S	L
Improve roadway delineation	T	S	L
Improve traffic control at work zones	T	M	L
Provide offset left-turn lanes at intersections	T	M	M-H
Improve lighting at intersections, horizontal curves, and railroad grade crossings	T	M	M-H
Reduce intersection skew angle	T	M	M-H

***Strategy Type**

- Proven strategies have shown to be effective through testing showing their effectiveness in at least one location.
- Tried strategies have been used and/or set as standards in a multitude of locations yet do not have sufficient studies supporting their use. There is a low probability of a negative impact on safety and a high probability of a positive one.
- Experimental strategies show promise and are being pilot tested in at least one location.

****Time Frame**

- Depends on factors such as:
 - The agency's procedures
 - The need for additional right-of-way

- The number of stakeholders involved
- Policies and legislative issues
- Presence of any controversial situations

****Relative Cost*

- The costs are relative to the other strategies in the table and are dependent on similar factors as in the Time Frame

Costs are based on the most common use of the strategy “especially one that does not involve additional right-of way or major construction, unless it is an inherent part of the strategy.” All of the strategies in the AASHTO plan are also in the Highway Design Handbook for Older Drivers and Pedestrians (Staplin et al. 2001).

2.8.2 Alberta Traffic Safety Guide to Accommodate Aging Drivers

The purpose of the Alberta Traffic Safety Guide, sponsored by the Alberta Motor Association Foundation for Traffic Safety, was “to present a comprehensive list of traffic safety practices that benefit the aging driver” (Zein et al. 2006). A key document reviewed was the FHWA Highway Design Handbook for Older Drivers and Pedestrians (Staplin et al. 2001). Initiatives for Alberta were identified by starting with those included in the FHWA Guides and other literature and from workshop inputs intended to provide local perspective. The report compiled a list of 136 enhancements (for 33 road elements) that improve traffic safety. These enhancements were evaluated against current Canadian and Alberta guidelines and standards.

In the report, each enhancement has a graphic, reference to current standards, relationship to current standards and is coded as to whether it addresses geometric design and operation or traffic control. Related literature showing impacts on driver performance or safety are not provided.

The authors cite the FHWA Older Driver Highway Design Handbook measures as the majority of the enhancements. Enhancements that were relatively low cost with high potential for effectiveness were identified as first priority enhancements and are listed in Table 5. Existing education strategies and enforcement strategies in Canada and the United States were briefly discussed.

Table 5: First Priority Enhancements (from Alberta Traffic Safety Guide to Accommodate Aging Drivers, 2006)

NETWORK COMPONENT	ROAD ELEMENT
AT-GRADE INTERSECTIONS	Channelization
	Slotted (Single) Left-Turn Lane - Geometry, Phasing, Signing, and Delineation
	Traffic Control for Left-turn Movements at signalized Intersections
	Traffic Control for Right-Turn/RTOR Movements at Signalized Intersections
	Street Name Signing
	STOP and YIELD Controlled Intersection Signing
	Traffic Signals
	Roundabouts
ROAD LINKS	Delineation on Horizontal Curves
WORK ZONES	Lane Closure / Lane Transition Practices
	Variable Message Sign Practices
	Channelization Practices (Path guidance)
	Delineation of Crossovers / Alternate Travel Paths
	Temporary Pavement Markings

All of the first priority enhancements are also included in the FHWA Highway Design Handbook for Older Drivers and Pedestrians.

2.9 Recommendations

Over the last two decades there has been considerable research in the area of older driver limitations and impacts on highway design. This research has culminated in the publication of three guides proposing infrastructure changes aimed at assisting older drivers. Their principal recommendations are discussed below. In addition to the recommendations provided by these three guides, recommendations can be made based on the 15 other papers reviewed in this report, most of which were published since 2001, the date of the FHWA guide, that were not considered by the Highway Design Handbook, and thus not by the other two guides either. These are also discussed below.

2.9.1 Recommendations from Guides

The Highway Design Handbook for Older Drivers and Pedestrians (Staplin et al. 2001) was first of these and was developed under the auspices of the U.S. FHWA. Two guides published subsequently, AASHTO's Strategic Plan for Addressing Older Driver Crashes and Alberta Traffic Safety Guide to Accommodate Aging Drivers, drew heavily on the FHWA guide. The FHWA guide addressed five highway design elements: at-grade intersections, interchanges, roadway curvature and passing zones, work zones and highway-rail grade crossings. Half of the 31 design recommendations concern at-grade intersections. Unlike the AASHTO and Alberta guides, each recommendation is supported with literature review. Recommendations are not prioritized.

The AASHTO guide identifies a wide range of enhancements and further, identifies eleven high-priority enhancements, together with indicators of time frame and relative costs. The greatest number of high-priority enhancements addresses intersections.

The value of the Alberta Traffic Safety Guide to Accommodate Aging Drivers is that although the enhancements are drawn from a U.S. source, they were evaluated against current Canadian and Alberta guidelines and standards. The Alberta guide identifies fourteen first priority enhancements. Like the AASHTO guide, the major focus is on at-grade intersections (8 of 14 priority enhancements). The recommended design features are basically the same as those identified in the AASHTO plan, with the one exception of roundabouts, which were not addressed by AASHTO, but are included in the FHWA guide.

2.9.2 Recommendations from Studies Subsequent to Guides

Since the publication of the FHWA guide (Staplin et al, 2001), the major focus area of older driver research in relation to infrastructure has continued to be on intersections. In addition more recent research provides recommendations concerning road links, on delineation, illumination and signage.

At-Grade Intersections

The literature reviewed in this report consistently identifies intersections as high-risk locations for older drivers, with risk increasing as drivers age (Chandraratna and Stamatiadis 2003). The primary cause for collisions at black-spot sites, which were primarily intersections (stop or yield controlled (65%), traffic signals (35%)) for older drivers was "selecting safe gaps when turning across or crossing traffic at intersections", accounting for 76% of the sites (Oxley et al. 2006).

Design features which would assist older drivers at all intersections, both stop and signal controlled, are improved sight distance, designated turn lanes and more legible and consistent street and road name signing. Sight distance requirements at intersections are determined in part by perception-reaction time. A study by Lerner et al. suggests that the perception-reaction time assumed in the U.S. of 2.5 seconds is sufficient for older drivers (Lerner et al. 1995). The Alberta guide recommends adopting this 2.5 second assumption and indicates that this exceeds current Canadian standards.

Required sight distance is also determined by manoeuvre time requirements. A study by Tarawneh et al. found that older drivers did not position themselves within the intersection (both increasing manoeuvre time and resulting in poorer visibility of oncoming traffic) (Tarawneh et al. 1998). This study recommended neutral or positive offsets of left turn bays, a recommendation included in the FHWA, AASHTO and Alberta guides.

At signalized intersections, protected left-turn signals are frequently mentioned as features that would assist older drivers, especially in high volume, high speed situations, where gaps are few and/or are difficult to judge due to high speeds (Chandraratna and Stamatiadis 2003; Braitman et al. 2007; Baggett 2003).

Three U.S. studies reviewed in this report address comprehension of traffic signal displays, and find poor comprehension, especially for older drivers, for many displays, especially for flashing red and amber (when used for late night and emergency purposes) and displays which combined two signals to create a third (e.g., green ball permitted indication (can turn left if gaps permit) combined with red ball for through traffic – fail critical rate of 34.3% (Noyce and Kacir 2001)). Fortunately, this approach is rarely used in Canada (Robinson 2008)). Overall older drivers took eight seconds as compared to six seconds for younger drivers to make decisions about the meaning of a signal (Noyce and Kacir 2002)).

When left turns must be made in protected/permissive situations, the green ball is surprisingly poorly understood (38.4% incorrect for drivers aged 60 or over), with a “serious error” rate of 12.5% (Drakopoulos and Lyles 1997). The findings are “worst-case” in that all these studies were carried out in laboratory situations without real-world cues from other drivers which could in most situations assist drivers in determining what to do. Even though protected turn signals are not well understood either (two studies show about 50% incorrect for drivers aged 60 to 65 or over), it is not possible to make a “serious error” by turning left in this situation (Drakopoulos and Lyles 1997; Noyce and Kacir 2001).

Future research should address the range of traffic signals used in Canada and use U.S. studies to determine likely comprehension rates, in order to make recommendations concerning signal design. The available Canadian guidelines (Zein et al. 2006) only address the use of red and amber arrows, proposing they are replaced by red and amber balls, which are better understood as well as more legible. They also recommend the use of YIELD ON GREEN BALL signs in advance as well as at signalized intersections employing a protected/permissive signal. The use of two signals in combination to create a third, although rarely used in Canada, should be discouraged given the poor comprehension.

Roundabouts

The FHWA and Alberta design guides make a number of recommendations concerning design of roundabouts. More recent work by Van Schalkwyk et al. provides additional recommendations (Van Schalkwyk et al. 2007). Based on video footage and animated videos, which allowed participants to assess the measures within context, specific design elements of concern to the participants included: advance warning signs, lane assignment and advance guide signs, channelization, yield treatment, directional signing, and exit direction signing. Based on the findings, the use of chevrons at the roundabout is discouraged, and a symbol should be used on the advance warning sign rather than text. Older drivers were found to be confused by the yield line consisting of isosceles triangles pointing toward the approaching vehicles (Shark’s Teeth Yield Line Pavement Marking Symbols).

Road Links: Delineation

Four studies reviewed provide recommendations concerning lane marking on road links. Three of these were not considered in the design guides. Recommendations from these three are as follows:

- Wider than standard edgeline markings do not provide increased recognition distance (Ohme and Schnell 2001)
- Minimum retroreflectivity rated as “adequate” or “more than adequate” by more than 85% of older (> 60 years) drivers is 100 mcd/m²/lx as measured with a Mirolux 12 Retroreflectometer (Graham et al. 1996)
- Minimum retroreflectivity rated as “excellent” or “visible with no difficulties” by 90% of drivers less than 55 years of age is between 80 - 130 mcd/m²/lux, rising to 120 – 165 mcd/m²/lux for drivers over the age of 55. Participants over 55 years old require retroreflectivity of at least 160 mcd/m²/lux for white skip lines and at least 165 mcd/m²/lux for yellow centrelines (Parker and Meja 2003).

The recommendations from the Pietrucha et al. (1996) study, reviewed in this report, were considered in the design guides. These were:

- The best combination of delineation treatments with respect to driver recognition distance is yellow centreline, white edgeline and engineering grade T-posts
- The best combination of delineation treatments with respect to cost-benefit is a yellow centreline with high intensity T-posts.

While improving delineation is helpful to older drivers, research completed subsequent to the design guides, has shown that improved delineation can have negative safety impacts. What is subjectively preferred and gives longer recognition distances for older drivers can lead to increased speeds and substantially increased nighttime crashes when these “improved” delineation treatments are implemented on low standard roads (Smiley 2008; Kallberg 1993; Bahar et al. 2004). Bahar et al. provide guidance in the form of accident modification factors associated with the use of raised pavement markers for tight vs. wide curvature and various traffic volume levels. These should be consulted before implementing raised pavement markers or post-mounted delineators on road links.

Illumination

Illumination is known to improve safety at intersections and to reduce pedestrian crashes. However, little research has been carried out on performance of drivers, older or otherwise, in relation to streetlighting levels. Research on the relationships of fixed lighting parameters to the safety and comfort of older drivers was published in 2002 (Mace and Porter 2002). With respect to the effect of lighting system on detection distance, the longest detection distances for all drivers were obtained with:

- High luminance and either low or medium uniformity ratio designs
- Medium luminance and either medium or high uniformity ratio designs

With respect to luminance and uniformity, high uniformity significantly improved older driver detection performance but had no effect on younger driver detection performance. With respect to lighting spacing, for low luminance, high uniformity designs, 80 m pole spacing had significantly shorter detection distance than the 120 m spacing. The effects of the simulated headlight glare on visibility were mitigated with medium or higher levels of lighting.

Signage

Based on literature review, crash analysis and survey results, Baggett recommended improved signage overall with size, lighting and contrast and advance distance notification of required tasks on all roadways (Baggett 2003). Such improvements were also recommended in all three guides (Staplin et al. 2001; Potts et al. 2004; Zein et al. 2006).

An issue not addressed in the FHWA guide (Staplin et al. 2001) is comprehension and legibility of traffic sign symbols. The Alberta guide recommends the use of educational tabs for warning signs “that may not be readily understood by unfamiliar drivers, particularly those that are located only in urban or in rural areas”. Other than the SCHOOL BUS STOP AHEAD given as an example, no specific warning symbols are mentioned. A study done for the U.S. FHWA (Dewar et al. 1994) tested the comprehension of 480 drivers aged 18 to 88 years of age on all 85 symbols in the U.S. MUTCD, many of which are identical to or very similar to those used in Canada. The warning and regulatory signs that older drivers understood more poorly than younger drivers, and for which comprehension was below 60% correct for at least one of the two older groups were:

- Mandatory Seat Belt
- Double Head Arrow
- Yield Ahead
- Pavement Ends
- Advance Flagger
- Added Lane.

3 SUMMARY OF STAKEHOLDER INTERVIEWS

Four stakeholders were interviewed:

- Deborah de Grasse, Chief, Road Systems, Road Safety and Motor Vehicle Regulation, Transport Canada
- David Dunne, British Columbia Automobile Association (BCAA) Traffic Safety Foundation
- Scott Wilson, Advocacy and Community Services, Alberta Motor Association
- Carol Libman, Canadian Association of Retired People

The Traffic Injury Research Foundation was contacted and preferred to provide a recent report in lieu of being interviewed. The Canada Safety Council and the Canadian Medical Association were contacted more than once but did not respond.

The stakeholders interviewed proposed similar improvements to those recommended in the three older driver guides (Staplin et al. 2001; Potts et al. 2004; Zein et al. 2006). These included:

- Better signing (legibility, visibility, standard locations) and delineation (especially at intersections, on curves and in work zones)
- Longer acceleration lanes to assist older drivers who drive more slowly with merging
- Intersections with offset left turn lanes to improve visibility, protected turn signals and brighter, larger red traffic lights

Roundabouts are seen to have a strong safety benefit, but may be potentially confusing to older drivers. The need for warrants to ensure they are implemented where appropriate, as well as standardized signing and education campaigns, was noted.

With respect to over-arching issues, Ms. de Grasse noted that the World Bank has proposed that 10% of the investment in a roadway should be targeted to road safety. This may be high for Canadian decision makers, but the problem is that currently there is no particular target. Transport Canada is currently funding an international road safety countermeasures project and will be presenting the top ten to the engineering research and support committee. They would benefit all drivers including the aging populations. Mr. Wilson noted the need to provide augmented transportation that is accessible and sustainable for those who no longer drive. The AMA would be interested in attending a workshop of stakeholders on infrastructure change and anticipate that the provincial ministry of transportation would also be interested. In Mr. Wilson's experience, associations of seniors and retired persons are more interested in expanded and accessible transportation choices, not just transit necessarily, but may be interested in infrastructure changes for older drivers as well. With regard to where money should be spent on infrastructure, Ms. Libman suspects that there is more driving done by seniors in cities, so design features such as street signs and traffic signals are important.

On specific design issues, Ms. de Grasse noted that design factors are considered well in high traffic areas but older drivers more likely to travel on lower class roads where there are more conflict points and at-grade intersections, and where the older driver's poorer judgment of speed of approaching vehicles comes into play. Mr. Dunne noted the problems of handicapped parking areas, which can be used by seniors who have difficulty making shoulder checks, being near high levels of pedestrian activity. For similar reasons, conflicts between right-turning vehicles and bicyclists can occur. He also noted the problem of glare, especially from after-market headlights that do not meet regulations. The safety of older pedestrians is also a concern. Better lighting, visibility and signage in the area of pedestrian crossings would address this (this is covered in the older driver guides).

When asked about whether older drivers might appreciate photo radar to reduce traffic speeds and driving stress, Ms. de Grasse stated that she thought they would, and that it was an excellent safety tool. Mr. Dunne agreed since seniors are often pushed outside their comfort zone by aggressive drivers. Mr. Dunne also suggested expanded 30 to 40 km/h zones in urban/residential areas with greater concentrations of pedestrians to reduce speed.

4 NEXT STEPS

Based on an examination of three guides to improving road design for the benefit of older drivers, a review of recent literature in this area, and interviews with four Canadian stakeholders, there appears to be strong agreement on the causes and remedies for older driver collisions. Intersection improvements have received by far the most attention, followed by signing and delineation improvements. It is also clear that changes that benefit older drivers will in most cases benefit all drivers. The one exception may be improvements to delineation that inappropriately encourage higher speed when implemented on low standard roadways, leading to an increase in crashes. This underscores the importance of verifying safety benefits through crash studies. Recent publications (Handbook of Road Safety Measures by Elvik and Vaa, 2004) and the soon to be published U.S. Highway Safety Manual should be consulted to determine explicit safety benefits for infrastructure changes intended to assist older drivers. Changes to road name signs, for example, while likely to improve driver comfort, are unlikely to have the substantial impact on injury and fatality rates that implementation of a protected left

turn at an intersection or replacement of an intersection by a roundabout would. Next steps should consider explicit safety in proposing high-priority recommendations.

The Alberta Traffic Safety Guide to Accommodate Aging Drivers (Zein et al., 2004) provides a strong starting point for Canadian jurisdictions interested in improving infrastructure for older drivers. The results of this literature review could be used to update the Alberta guide especially in the areas of traffic signal comprehension, delineation retroreflectivity requirements, legibility indices, traffic sign symbol comprehension and streetlighting. The Guide could be further updated by adding information concerning explicit safety impacts for each of its recommendations.

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APPENDIX A

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Keywords: Accident prone locations; accident rates; accident types; aged drivers; Arizona; cognition; daylight; driving tests; fatalities; freeways; highway design; highway safety; improvements; intersections; left turns; medication; night; physical condition; physical fitness; recommendations; road markings; self evaluation; sidewalks; surveys; traffic signs; vision

Abstract

"The purpose of this research project is threefold: to examine the current knowledge of state-of-the-art highway design practices aimed at increasing the safety of older drivers; assess the crash and fatality data for older drivers in Arizona; and survey older adults regarding their perceptions of Arizona's roadways and possible needs for enhancement. Older adults increasingly make up a larger part of the driving population. Age related declines and complications from medical conditions put older drivers at higher risk of collision, and when in collision, of a fatal injury. Changes in visual acuity, cognition, use of certain medications, and functional impairment may contribute to reduced driving ability. In Arizona we found that, like older adults nationwide, older drivers were more likely have angle and left-turn collisions, to be in collisions involving intersections and junctions, at signalled and unmingled left-turn intersections, and in daylight hours. Older adults surveyed rated driving at night as very difficult, followed by driving on a freeway and identifying street names, feel improvement could be made to lettering for roadway signs, intersection markings and signals, and support increasing the availability of sidewalks. Survey respondents most frequently rated larger and better-illuminated traffic signs as the most helpful design improvement that could be implemented and most frequently rated special senior driver testing programs as most the most effective screening and assessment option. It is recommended that Arizona use locations identified in this study as having high rates of collisions involving older adults to develop test sites for roadway improvements. We also recommend that the state begin to review its screening, assessment and education for older drivers with the intent of developing a more stringent screening and assessment process and develop and implement self-testing for older adults to support improved driving safety."

Method

The report consisted of three sections: a literature review, an analysis of Arizona's older driver crash data and a survey of older adults. The literature review compiled recent literature results with the detailed reviews by Staplin et al. 1999 and Eby et al. 1998. The review discussed older driver demographics, collision rates and fatalities, age-related changes, health factors and recommendations.

The crash data was gathered from the Arizona Department of Transportation for 1999 to 2001. Three age groups were used for comparisons: under 25, 25 to 64 and 65 and older. The under 25 data was not used in comparisons unless explicitly stated, as their accident patterns are considerably different from older drivers. The data was compared to Washington and Oregon and national data for the same time period. Frequencies and chi-square statistics were used for analysis. "For every variable where age of driver was included, the differences between younger

and older drivers was significant at a level greater than 0.0001.” Older adults with temporary residence in Arizona during the winter were not included in the data.

The survey gathered demographic information, ratings of their driving difficulties and suggested improvements from 121 participants. The survey was sent to key senior centres.

Main Findings

Literature Review

- “The largest increase in licensed drivers between 1990 and 1996 occurred in the over 85 population.” The populations of over 75 and over 85 age groups are expected to triple by 2050.
- Older drivers at intersections generally require protected turns, increased visibility (i.e., all-way stops, roundabouts), adequate roadside information on intersection approach (a separate signal for each lane is recommended), and roadway design.
- Older drivers entering or exiting freeways/highways generally require “advance information with adequate size, lighting and glare protection, road design that allows an increased distance to merge with traffic, and separated slip roads to drive into or out of highway traffic.”
- Older drivers in construction zones “need advance and clear roadside information, including increased distance to change or merge lanes with lane closures.”

Crash Data

- 8% (80,000) of 1.1 million drivers involved in crashes were older drivers (≥ 65), 65% (715,000) were 25 to 64 years and 27% (297,000) were under 25 years.
- Older drivers (≥ 65) are significantly more likely than younger drivers (25 to 64), when compared to their respective cohorts, to:
 - Have angle (27.8% vs. 20.4%) and left-turn collisions (15.0% vs. 11.6%) but are less likely to have rear-end collisions (35.7% vs. 47.8%)
 - Have crashes in daylight (86% vs. 76%) and in rural areas (16.5% vs. 11.2%)
 - Have crashes in intersections (51% vs. 44%) and at junctions (36% vs. 27%), stop signs or signals and raised medians (19% vs. 16%)
 - Have a crash involving a stop sign (15% vs. 10%) or signal (33% vs. 29%)
 - Suffer fatal injuries in an accident (0.48% vs. 0.23%)

Survey Data

- Older drivers (≥ 65) rated as “very difficult” driving at night (30%), driving on freeways (22%) and identifying street names (20%)
- Older drivers rated Arizona roadways “not very good” in lettering for signs (lighting – 64% and size – 44%), and intersection markings and signals (60%)
- Older drivers rated the following improvements as “very helpful”:
 - Reflective signs and road-edge markings (83%)
 - Consistent naming for streets and routes (77%)
 - Dedicated lanes and signals for left-turns (79%)
- The improvement rated “most helpful” was better illuminated traffic signs (34%)

Recommendations

- Three areas were identified for improvement taking into account budget constraints and gradually phasing in changes:
 - Modify left-turn phase indicators to improve driver comprehension
 - Larger and better-illuminated signs and devices for lane assignment on intersection approach
 - Improved signage - size, lighting and contrast and advance distance notification of required tasks on all roadways

Strengths and Limitations

Strengths

- Analyzed real world crash statistics

Limitations

- Older driver exposure not addressed/controlled

2. Braitman, K.A., Kirley, B.B., Ferguson, S., & Chaudhary, N.K. (2007). Factors leading to older drivers' intersection crashes. *Traffic Injury Prevention*, 8(3), 267.

Keywords: Accident data; accident rates; aged drivers; Connecticut; countermeasures; error; gap acceptance; failure to yield; left turns; rear end crash

Abstract

“Objectives. Older drivers are over involved in intersection crashes compared with younger drivers, but the reasons are not clearly understood. The purpose of the present study was to identify the factors that lead to older drivers' intersection crashes. **Method.** Study participants were composed of two groups of older drivers – ages 70 – 79 ($n = 78$) and 80 and older ($n = 76$) – and a comparison group of drivers ages 35 – 54 ($n = 73$); all were at fault in intersection crashes involving nonfatal injuries. Police crash reports, telephone interviews with at-fault drivers, and photographs of intersections were used to determine the kinds of driver actions and errors that led to the intersection crashes. **Results.** Drivers 80 and older had fewer rear-end crashes than drivers ages 35 – 54 and 70 – 79, and both groups of older drivers had fewer ran-off-road crashes than drivers ages 35 – 54. Crashes where drivers failed to yield the right-of-way increased with age and occurred mostly at stop sign–controlled intersections, generally when drivers were turning left. The reasons for failure-to-yield crashes tended to vary by age. Compared with drivers ages 35 – 54 and 80 and older, drivers ages 70 – 79 made more evaluation errors – seeing another vehicle but misjudging whether there was adequate time to proceed. In contrast, drivers 80 and older predominantly failed to see or detect the other vehicle. Drivers ages 35 – 54 also tended to make search errors, but theirs were due more often to distraction. **Conclusions.** Factors leading to intersection crashes vary with age, even between two age groups of older drivers. Because the number of older drivers is projected to increase, it is important to identify ways to reduce the frequency and severity of their intersection crashes. Roundabouts and protected left turn lanes at signalized intersections may help to reduce failure-to-yield crashes at intersections, especially among older drivers. Crash avoidance systems may help to reduce crashes for drivers of all ages, but most systems have not been thoroughly investigated using real-world crash data.”

Method

Between August 2003 and October 2004 police crash reports occurring at intersections on public roads were sent semi-weekly to the Connecticut Department of Transportation. Reports were screened for age groups (middle age 35 to 54, old age 70 to 79 and older aged 80 years of age or older) and at least one occupant sustained a nonfatal injury. Crashes were excluded if there were fatalities or there was property damage-only (poorly reported).

At fault drivers whose phone numbers were publicly accessible (44%) were contacted to participate in the study. A random proportion of the middle group crashes were used as a comparison for the older groups. A total of 227 out of 544 participants responded: 73 of 162 middle, 79 of 130 old and 76 of 106 older drivers.

Semi-structured, audio-taped interviews were conducted within 3 to 10 weeks of the crash (mean = 6.7 weeks) almost exclusively by one interviewer (95%). The crash report, on-site visits and telephone interviews were used to code the data for primary error and driver actions prior to

the crash. Previous systems of coding were adapted to suit the study. Two coders were used and their results compared for agreement. Discrepancies were resolved by discussion or settled by a third researcher.

Main Findings

Driver Actions Leading to Crashes

- Older drivers had significantly fewer rear end crashes than the other two groups ($p < 0.001$)
- Both older groups were less likely to have ran-off-road crashes than the middle group ($p = 0.01$)
- As age increased, so did the proportion of crashes as a result of failing to yield right of way ($p < 0.001$)

Error Type

- The older drivers made significantly more search and detection errors (inadequate search, inattention, distraction, overload, obstruction or other) than the other two age groups combined ($p < 0.001$)
- The old drivers made significantly more evaluation errors than the other two combined ($p < 0.001$) and approximately 90% were misjudging other vehicle's actions rather than intersection design (i.e., lane patterns)
- Both groups of older drivers made significantly fewer unintended course errors and vehicle action errors (vehicle does not respond due to poor weather or vehicle malfunction) than the middle group ($p = 0.01$ and $p < 0.001$, respectively)

Search and Detection Errors

- Inadequate search errors increased significantly with age – 27% for middle age to 65% for older age drivers ($p < 0.01$)
- The old and older groups had significantly fewer distraction errors (11% and 9%, respectively) than the younger group (27%). ($p = 0.02$)

Strengths and Limitations

Strengths

- Study analyzed real world crashes
- Consistent interviewer

Limitations

- Subjective determination of error type based on feedback from interviewee
- Selection of participants possibly does not reflect true population distribution

3. Chandraratna, S., & Stamatiadis, N. (2003). Problem driving maneuvers of elderly drivers. *Transportation Research Record (1843)*, 89-95.

Keywords: Accident data; accident rates; aged drivers; countermeasures; gap acceptance; gender; Kentucky; lane changing; left turns; passengers

Abstract

“Older drivers, who are the fastest growing segment of the U.S. population, experience high crash rates. An analysis was performed to evaluate potential problem maneuvers that may lead to higher crash involvement. Left turns against oncoming traffic, gap acceptance for crossing non-limited-access highways, and high-speed lane changes on limited-access highways are identified as such maneuvers. Older and younger driver accident propensities are measured, using Kentucky crash data. The findings of the analysis show that older drivers are more likely to be involved in crashes related with these maneuvers compared with younger drivers; older male drivers are safer than older female drivers in left-turn crashes and gap acceptance-related crashes, and having a passenger beside the older drivers makes for a safer driving environment. Potential countermeasures aiming to reduce the accident rates of older drivers are discussed.”

Method

The Kentucky crash database from 1995 to 1999 was used for the analysis. The assumption for this analysis is that exposure can be determined by the distribution of not-at-fault drivers (ones who were not contributing to the crashes) in the database. This distribution would then represent all drivers exposed to crash hazards. Excluded from the analysis were crashes in which more than one driver was at fault. If drivers were in more than one crash in the 5-year period, only the first crash was used.

The hypothesis that younger (<65 years) and older drivers (≥65 years) are not different was measured by accident involvement ratios for three manoeuvres (0.05 level of significance). This ratio represents the at-fault to the not-at-fault drivers. The two vehicle crash not-at-fault driver distribution and the multiple vehicle crash not-at-fault drivers (excluding the first not-at-fault driver) were compared. The Pearson correlation coefficients showed high correlation of the distributions and concluded they are “true or nearly true samples of the driver population with respect to drivers’ age distribution.” To gather a larger sample size, the crashes with two vehicles were used.

The first manoeuvre tested was at-fault drivers attempting left turns with oncoming traffic traveling straight through the intersection. To be included, the roads had to have two or more lanes. The second movement studied was gap acceptance on non-limited highways where both vehicles are driving straight before the crash. The third element referred to as lane changes as well as same-directional sideswipes while overtaking or merging (to address database discrepancies).

Main Findings

Left Turn

- Older drivers were 3.20 times more likely to be at fault in left turn crashes compared to younger drivers ($p < 0.0005$)
- Older and younger women were 1.25 and 1.12 times more likely to be involved in left turn crashes than their male peers (age and gender interaction, $p = 0.028$)

- Older drivers were 1.65 times more likely to be in an accident turning left with no streetlights compared to their performance in the daytime ($p=0.016$). Younger drivers are 1.11 times more likely to be in an accident at night when there are “highway lights” (streetlights?) than in daytime conditions.
- Older drivers were more likely (1.17 times) to be in a left turn crash in rural areas (population $\leq 25,000$) than urban areas (population $\geq 250,000$) ($p=0.006$)
- Left turn crash fatality for older drivers was 2.41 times higher than younger drivers. ($p<0.0005$)
- For older drivers, left turns onto a one-way street were 1.26 times safer than onto two-way streets ($p=0.026$)
- The presence of a passenger lower left turn crash for older drivers by a factor of 1.56 ($p<0.0005$)

Gap Acceptance

- Older drivers were 1.87 times more likely than younger drivers to be involved in a crash when underestimating gap acceptance ($p<0.0005$)
 - Drivers ≥ 85 were 3.60 times more likely to be involved in a gap acceptance crashes compared to drivers 65-69 ($p<0.005$)
- Older drivers were more likely (1.20 times) in rural areas (population $\leq 25,000$) to be in a gap acceptance crash than urban areas (population $\geq 250,000$) ($p=0.003$)
- Gap acceptance crash fatality for older drivers was 1.78 times higher than younger drivers ($p<0.0005$)
- The presence of a passenger lower left turn crash for older drivers by a factor of 1.38 ($p<0.0005$)
- Hour of day, light conditions, road characteristics and road surface conditions were not significant

Lane Changes

- Older drivers (≥ 65) were 1.46 times more likely to be involved in a high speed lane change crash than younger drivers ($p<0.0005$)
- The presence of passengers lowered the lane change crash risk among older drivers ($p=0.003$)
- Light conditions, location and severity of the crash were not significant

Strengths and Limitations

Strengths

- Study analyzed real world crashes
- Not-at-fault drivers exposure measure

Limitations

- Crash causes assigned from judgement of investigating officer

4. Dewar, R.E., Kline, D.W. and Swanson, H.A. Age differences in comprehension of traffic sign symbols. *Transportation Research Record (1456)* (1994), 1-10.

Keywords: Traffic signs; aged drivers; comprehension; data collection; drivers; innovation; surveys; symbols

Abstract

"Previous research has shown that drivers, particularly elderly ones, do not understand many of the symbolic traffic signs on U.S. highways. Phase I of this research examined comprehension levels of virtually all (85) of the symbols in the U.S. "Manual on Uniform Traffic Control Devices for Streets and Highways" (FHWA, U.S. Department of Transportation, 1988) as a function of age. Subsequently, new versions of 13 of these symbols and 5 novel symbols were tested. Drivers in Texas, Idaho, and Alberta, Canada, participated in the studies. Of the 85 standard symbols, 16 were understood by more than 95% of drivers; however, 10 were understood by less than 40%. Older drivers had poorer understanding than younger ones of 39% of the symbols examined; for the remainder there were no age differences. In Phase II, modifications and redesigns to selected symbols resulted in better understanding of three messages and poorer understanding of four messages. Comprehension of the novel symbols was close to that of the modified and redesigned ones. Again, older drivers had poorer understanding, but there was no systematic relationship between age and changes in comprehension level following revision of the symbols."

Method

Phase 1

Participants were grouped by age: 18 to 39; 40 to 59; 60 to 69; and 70 or older. The ages of the 480 participants ranged from 18 to 88 years. The age groups were equal for gender and numbers. The participants were tested in Texas, Idaho and Alberta.

Drivers completed a questionnaire, read the procedure instructions and were shown a practice sign. They were then shown 85 colour slides (for 30 to 40 seconds each) of traffic signs (six random sign presentations) with one 15-minute break at the midpoint. The participants wrote down the meaning of the sign and their familiarity with that sign (5-point scale).

The answers were marked as correct, partially correct and incorrect. If no answer was given it was scored as incorrect. In the analysis, answers correct and partially correct were both counted as correct. The reliability between the two scorers was 95%.

Phase 2

Based on Phase 1, certain signs were selected for modification and redesign. The participant pool of 219 had the same age categories, gender distribution and locations as Phase 1. A total of 14 signs were presented on colour slides: seven modified signs (same basic spatial layout, same message as MUTCD); 7 redesigned signs (new spatial layout, same message); and 5 "novel" signs (new sign, new message). Drivers performed the same procedure as in Phase 1 without the break.

Main Findings

Comprehension of Standard Symbols (Phase 1)

- Drivers ≥ 60 years had poorer understanding than drivers < 60 for 39% (33 out of 85) of the signs and generally less familiar with the signs than the < 60 drivers
- Railroad and regulatory signs were best understood (91.2% and 81.4%, respectively) with recreation (69.7%) and school (59.2%) signs being the worst understood
 - Poor school sign results were due to confusion between School Crossing and School Advance signs

Comprehension of Modified, Redesigned and New Symbols (Phase 2)

- Drivers ≥ 60 years comprehended less than the drivers < 60 years on 2 modified, 5 redesigned and 3 new signs. Drivers ≥ 70 years were below all other age groups for mean comprehension on each sign except the right curve sign.
- There was no relationship between age and changes regarding symbol comprehension

Strengths and Limitations

Strengths

- A large sample with a wide age distribution was used

Limitations

- Drivers had considerable time to view the sign, more than would be available on the roadway.

5. Drakopoulos, A., & Lyles, R.W. (1997). Driver age as a factor in comprehension of left-turn signals. *Transportation Research Record (1573)*, 76-85.

Keywords: Left turns; traffic signals; comprehension; elderly drivers; driver errors; flashing traffic signal; driver age

Abstract

"An experiment to measure driver comprehension of left-turn signal and sign configurations was conducted as part of a study to investigate the performance of left-turn signals used in various signal strategies. The responses of 191 individuals to 81 stimuli simulating left-turn signal phases were analyzed for the effect of signal message on driver comprehension. Stimuli included 17 left-turn signal displays used for permitted, protected, and protected/permitted left-turn strategies as well as left-turns during nighttime or emergency flashing signal operations. Comprehension in the original study was based on a correct vs. incorrect dichotomy: if the subject's response agreed with a predetermined subset of possible answers, the answer was correct; all other answers were considered incorrect. These data are reanalyzed with three principal variations: (a) individuals' answers are based on a three-level correctness concept whereby answers considered incorrect in the previous study were further categorized into minor errors and serious errors depending on whether subjects incorrectly chose to 'give away' their right-of-way or to violate other drivers' right-of-way, respectively; (b) signal message is introduced in the analysis as an explanatory variable of driver comprehension; and (c) emphasis is placed on older drivers. Youngest, oldest, and female subjects were found to drive fewer kilometers per year than middle-aged males. Comprehension was found to deteriorate with driver age in terms of both higher serious error rates and lower correct answer rates. Flashing signals were the least well understood, whereas change and red interval stimuli were understood best by all age groups."

Method

The experiment involved 191 subjects from four states (Pennsylvania, Washington, Texas and Michigan) The participants, seated at desks, were shown 81 stimuli simulating real signal displays using colour, shape (i.e., ball or arrow) and mode of operation (steady or flashing). Two slide projectors were used to show: (1) the roadway and signal face locations (signal face arrangements (SFAs)) and (2) superimposed the signal light operation over the SFAs. Each stimulus represented a phase of each of the 17 left-turn SFAs including the use of flashing nighttime or emergency signals. "Stimuli were shown in two pre-arranged sequences, not necessarily following the phase ordering of individual signal configurations". After each stimulus participants responded with yes or no to a list of five actions: "(1) Turn left; you have the right-of-way; (2) Turn left without stopping unless you have to wait for a large enough gap in the opposing traffic; (3) Stop; then turn left when there is a large enough gap in the opposing traffic; (4) Stop; then turn left when there is a large enough gap in the cross street traffic; and (5) Stop; wait until the signal change to indicate that you may proceed." The age groups were defined by 16 to 30, 31 to 45, 46 to 60 and over 60.

Main Findings

Comprehension

- Significant comprehension differences were found among age groups both in terms of correct answer ($p < 0.001$) and serious error rates ($p < 0.03$)
- Older drivers had the highest serious error rate and the lower correct answer rate
- The authors concluded age outweighs experience as a factor in comprehension

Signal Face Arrangements Message and Age

- Protected (means proceed), permitted (proceed if no oncoming traffic) SFAs were not well understood, with flashing the least understood SFA
 - Protected was not well understood as the correct response rates for all drivers was 64.2% and for older drivers 48.8%
- Red (stop) and change intervals (prepare to stop) were the best understood types of signal

Stimulus Code	Correct Answer Rate (%)		Serious Error Rate (%)	
	All Drivers	Older Drivers (>60)	All Drivers	Older Drivers (>60)
Red	96.3	91.7	1.0	1.4
Change Interval	74.0	62.9	3.7	8.3
Protected	64.2	48.8	N/A	N/A
Permitted	55.8	38.4	8.3	12.5
Flashing	44.6	32.4	12.6	15.4

Strengths and Limitations

Strengths

- Study exposed subjects across all age groups to same stimulus
- Study took place in the context of a real world environment – i.e., slide depicting intersection context from inside a vehicle

Limitations

- Showing the stimuli out of order may have been more confusing for participants
- Stimuli were not randomized – they were shown in only two prearranged sequences

6. El-Shawarby, I., Amer, A., & Rakha, H. (2008). *Evaluation of driver stopping behavior on high speed signalized intersection approaches*. Paper presented at the Transportation Research Board 87th Annual Meeting, Washington D.C.

Keywords: High speed; signalized; intersection; stopping time; perception time; reaction time; perception-reaction time; braking time; stopping accuracy; older drivers

Abstract

"The research presented in this paper characterizes driver stopping behavior at the onset of a yellow-phase on high-speed signalized intersection approaches using controlled field data gathered from 60 test subjects using an in-vehicle Differential Global Positioning System (DGPS). A total of 745 data records were available for analysis for all drivers who stopped at the onset of the yellow-phase, ranging from a minimum time to the stop bar (TTS) of 1.34 s to a maximum of 6.19 s. Statistical analyses were used to investigate the effects of the time to stop bar, grade (uphill and downhill), age (under 40-years-old, 40 to 59-years-old, and 60 years of age or older), and gender on seven dependent measures of driver performance including perception time, reaction time, perception-reaction time, braking time, stopping time, and stopping accuracy. The study demonstrates that driver perception time is not impacted by TTS while reaction time is dependent on TTS, roadway grade, and driver age. Younger drivers have longer reaction times in comparison to the older group but they are able to stop over a shorter period of time as they typically apply more aggressive braking rates. A lower perception-reaction time was found for drivers who have their foot lifted off the accelerator at the onset of the yellow-phase. Male drivers show slightly higher braking times when compared to female drivers with no significant differences between male and female drivers. Furthermore, the results demonstrate that drivers who try to stop at short TTSS are more likely to stop downstream of the stop line and that older drivers are significantly more accurate when they stopped compared to other age groups."

Method

Participants were licensed drivers split into three age groups "nearly equal" in gender: 16 people under 40 years of age, 12 between 40 and 59 years and 32 who were 60 years or older. They drove three practice runs, or more if required, using an instrumented 2004 Chevrolet Impala (Differential Global Positioning System (DGPS), real-time data acquisition system (DAS) and computer to determine run order) along the 2.6 km two-lane testing area during the day on dry roads (no ice or debris). There were no other vehicles on the road.

Participants were instructed to keep their foot on the accelerator and maintain a cruising speed of 72 km/h (45 mph). If the participant's foot was lifted off the accelerator the data was not used in perception time, reaction time, and cruising PRT analyses. The non-cruising data was included in the overall PRT, braking time, stopping time and stopping accuracy analyses.

Performance Measures were:

- Perception time was measured as time from the start of the yellow signal to the instant at which the driver released his/her foot from the accelerator
- Reaction time was measured as time from the driver releasing their foot from the accelerator to first depressing the brake pedal

- Perception-reaction time (PRT) was measured as time from the start of the yellow signal to first depressing the brake pedal (perception time + reaction time)
- Braking time was measured from the depression of the brake pedal (after yellow signal) until the vehicle came to a complete stop
- Stopping time was measured as the time from the start of the yellow signal until the vehicle was at a complete stop (PRT + braking time)
- Stopping accuracy was measured as the distance away from the inside line of the stop bar and the front of the vehicle. Negative values mean the car was in the intersection

The road had one signalized intersection and was fairly straight with a “substantial” vertical grade of 3%. Participants drove uphill and downhill towards the signalized intersection, 12 times each for a total of 24 runs, encountering four green and 20 yellow indications. The traffic signal was randomly triggered at one of five distances as measured from the front of the car to the approach stop bar: 32, 55, 66, 88 and 111 m. The traffic signal was triggered by the vehicle’s road position (wirelessly communicated by the DGPS in the car accurate to 1.5 cm).

Main Findings

Perception Time

- No significant differences

Reaction Time

- The 40 to 59 year old group had significantly faster reaction times (0.34s) than the younger <40 (0.41s) and older ≥60 group (0.38s). (Overall mean=0.37s, Std. Dev.=0.19s, $p=0.0104$) The authors suggest this result could be the result of a higher deceleration rate for younger drivers.
- “Reaction time increases as the TTS increases.” ($p<0.001$)

Perception-Reaction Time

- No significant age effects

Braking Time

- The two older groups had longer braking times (40 to 59 year olds=7.65s, ≥60=7.54s) compared to the youngest age group (7.33s) ($p=0.002$)

Stopping Time

- The older (8.19s) and middle age (8.22s) drivers took longer to stop than the younger drivers (7.89s) ($p=0.0008$)

Stopping Accuracy

- The two younger age groups were combined as no significant differences were found between them
- Older drivers were more accurate in stopping than the younger combined group ($p=0.011$)
- Drivers that attempt to stop when TTSs are less than 3 seconds are likely to stop inside the intersection. TTS was significant ($p<0.0001$).

Strengths and Limitations

Strengths

- Stringent measurement of distances and times
- Randomization of runs

Limitations

- Drivers experienced more yellow lights and could be more willing to stop than normal
- Drivers did not have any distractions (i.e., traffic) to respond to while performing on the track

7. Graham, J.R., Harrold, J.K., & King, L.E. (1996). Pavement marking retroreflectivity requirements for older drivers. *Transportation Research Record (1529)*, 65-70.

Keywords: Traffic markings; night; retroreflectivity; luminance; elderly drivers; subjective analysis; quantitative analysis; field studies

Abstract

“Traffic pavement markings serve to regulate, guide, and channelize traffic and supplement other traffic-control devices. Because of their retroreflective properties pavement markings are critical for guidance at night, when reference objects near the edge of the roadway are difficult to see. Nighttime luminance levels provided by pavement markings that may be adequate for younger drivers may be less than adequate for older drivers. Both subjective evaluations and quantitative measures of in place roadway markings were made to determine minimum marking retroreflectivity levels required for older drivers. In the field study more than 85 percent of subjects aged 60 years or older rated a marking retroreflectance or 100 mcd/m²/lx as adequate or more than adequate for night conditions. This base value does not include the effects of windshields and headlights that are less than clean or the variability of individual vehicle headlight performance. A comparison between the results for older drivers and the results of a similar 1989 study of younger drivers was also made. It was found that whereas the average subjective ratings were similarly distributed relative to the retroreflectivity of pavement markings, there was a significant difference in the subjective rating made by older and younger drivers. Older drivers consistently rated the retroreflectivity of markings lower than did younger drivers.”

Method

The study measured “retroreflectivity of existing roadway markings and subjective evaluations of their adequacy.” The characteristics of the 24 marking locations were as follows: “1. Tangent section of roadway on a uniform grade”, 2. Length of 60 m, and 3. No supplemental lighting near the roadway.” There were 19 white edgelines and 5 yellow centrelines. The retro-reflectivity of the marking locations was measured with a Mirolux 12 Retroreflectometer and averaged over 4.6 metre intervals.

Sixty-five participants (14 under the age of 50 years, 29 aged 50-69 years and 22 aged 70 years or older) were to remain silent during the testing, wear the corrective lenses they normally wear driving and instructed to promptly circle one of the following responses “(a) less than adequate, (b) adequate, and (c) more than adequate”. “No questions pertaining to the adequacy of roadway markings were allowed.” The participants were also given penlights that were covered with a red translucent plastic to reduce effects on their night vision. The same 1980 Plymouth Volare vehicle and driver were used for all participants. The windshield was cleaned inside and out, and the headlights were cleaned and aligned.

The driver drove a “safe and comfortable speed for prevailing roadway conditions and within posted speed limits”. “No vehicles were closely followed, and low-beam headlights were used at all times.” The tests were performed on clear, cool, dry nights. Three subjects at a time were seated in the front right, rear left and rear right passenger seats.

The study design was kept similar to a 1989 study that had tested younger drivers (<30 years of age) with a similar range of values for retroreflectivity and the same vehicle in order to compare the minimum values required for older and younger age groups.

Main Findings

Comparison with Previous Study

- A Kolmogorov-Smirnov test showed “there was no significant difference in the two distributions [of the average subjective ratings of the current study and 1989 study] at the 95% confidence level.” With similar distributions, the two studies can be compared.
- When age and retroreflectivity are used as independent variables to predict average subjective rating, age “was a significant predictor at a 99% confidence level”

Minimum Required Retroreflectivity

- Marking colour was not a significant predictor. (95% confidence level)
- For > 60 age group the minimum average acceptable value is 100 mcd/m²/lx.
 - Eighty-five percent of the older drivers responded with “adequate” or “more than adequate” to values of 100 mcd/m²/lx or greater.
 - The 1989 study of <30 age group had values of 93 mcd/m²/lx or greater corresponding to an “adequate” rating by 90% or greater.
 - To allow for windshield and headlight variable cleanliness, the study authors suggest the minimum value should be increased 21% to 121 mcd/m²/lx.

Strengths and Limitations

Strengths

- Study occurred in real world conditions
- All participants, even in the 1989 study, used the same vehicle

Limitations

- Use of one vehicle would not take into consideration the headlight performance of a variety of vehicles
- No objective measure of the impact of visibility on lane tracking performance

8. Lerner, N.D., Huey, R.W., McGee, H.W., & Sullivan, A. (1995). *Older driver perception-reaction time for intersection sight distance and object detection. Volume 1. Final report* (Federal Highway Administration No. FHWARD93168; PB95199907). Silver Spring, MD; United States: COMSIS Corp.

Keywords: Driver reaction time; aged drivers; sight distance; intersections; human factors engineering; driver behavior; braking; age factor in driving; visual perception; visual evoked reaction; driver reaction distance; stopping time; driver characteristics

Abstract

Four on-road experiments investigated whether the assumed values for driver perception-reaction time (PRT) used in American Association of State Highway and Transportation Officials (AASHTO) design equations adequately represent the range of actual PRT for older drivers. The Case III (stop controlled) intersection sight distance (ISD) experiment found that older drivers did not have longer PRT than younger drivers; 85th percentile PRT closely matched the AASHTO design equation value of 2.0 s. In the stopping sight distance (SSD) experiment, involving brake reaction times to an unanticipated event (crash barrel suddenly rolling toward roadway), there were apparent differences in the distribution of PRT among age groups. Younger drivers accounted for most of the fastest PRT, but there were no age differences in the 50th or 85th percentiles. All observed PRT were encompassed by the current AASHTO design value of 2.5 s. The decision sight distance (DSD) experiment measured when drivers recognized the need to make a lane change maneuver, from the first visibility of the roadway cue used by the driver. Although observed DSD values were generally longer with increasing driver age, the 85th percentile PRT for all age groups were well below AASHTO design assumptions. The final experiment collected judgments about the acceptability of gaps and lags in traffic."

Method

Participants were licensed drivers in three age groups middle, old and older (20 to 40, 65 to 69 and ≥ 70 years of age, respectively) about equal in gender. The number of participants varied within each age group by experiment as different pools of participants were used. Participants drove their own vehicles in the first three experiments and in the fourth experiment sat in a Chevrolet Astro minivan provided for them. All tests were monitored with video cameras, sensors and input/output devices which captured "roadway locations, traffic events, and driver actions" at an accuracy level of 33ms (30 Hz).

Intersection Sight Distance

The number of participants was 25 middle, 27 old and 29 older drivers. The purpose of this experiment was to measure visual search time and manoeuvre time at stop-controlled intersections (turn left, turn right, or travel straight ahead). Participants drove 90 km through 14 sites and were instructed to evaluate road quality. When the participants reached an intersection where PRT was to be measured, they looked down at the keypad and rated the road quality. They were not to look up until they received a signal on the keypad from the experimenter seated in the rear of the vehicle. At that signal they pressed a button which indicated the start of their visual search time. When their vehicle began to move search time ended and manoeuvre time began. Manoeuvre time ended when the vehicle reached a pre-defined position on the road (depending on task).

Stopping Sight Distance

Immediately following the intersection PRT tasks participants were directed to a 1.1 km roadway closed to normal traffic. Near the midpoint of this 1.1 km road segment a hidden barrel rolled unexpectedly into view from a berm in the median down to the edge of the two-lane road where it was stopped by hidden restraints. The barrel was released when the front of the vehicle, traveling at an average speed of 64 km/h, was about 61 m away. PRT was calculated as the time from the moment the barrel was in view to the application of the brakes. Severity of steering action was subjectively judged by the experimenter.

Decision Sight Distance

This experiment determined the distribution of PRT in “complex geometric or operational conditions where DSD criteria would apply”. The test route was 56 km long and consisted of 13 sites (5 freeway lane drops, 1 freeway left exit, 5 arterial turn-only lanes, 1 arterial lane drop and 1 complex intersection) where the subjects were required to change lanes to avoid a lane drop or a turn-only lane. There were 14 middle, 18 old and 22 older participants during the daytime and at night there were 14, 17 and 13 (only 3 women) respectively.

Participants were instructed to drive straight through intersections and interchanges and were to verbally state when a lane change was necessary and to do so. The experimenter noted on the video the points when the first cue was visible and the lane change was completed. The time from the light activation to the audible cue was used for the decision sight distance PRT. Manoeuvre time was the interval from the initial audible cue from the participant until the lane change was completed. Participants drove through two practice sites to ensure they could verbalize quickly enough.

Gap/Lag Acceptance

The purpose of this experiment was to determine the duration of gaps that were acceptable when planning to turn left, right, or continue straight ahead at an intersection. The test vehicle was parked at an undisclosed location perpendicular to a major roadway far enough away from intersections to remove a heavy platooning effect. The experiment occurred at non-peak times during the day and night.

Experimenters instructed participants in the driver and passenger seats to simulate one of the three tasks. Participants held a button down when they felt it was safe or released the button when it was unsafe to act upon the directed task. The tasks were randomized in presentation, each lasting 10 minutes. The tasks were conducted at one low speed location (48 km/h) and one high speed location (81 km/h). At night the low speed location had streetlights, whereas the high speed did not. Participants were involved in one of three conditions: two day, two night or all four conditions.

Main Findings

Intersection PRT

- Median PRT was 1.3 s. The 85th percentile value was about 2.0s.
- The younger group had 0.2s longer PRT than the older group ($p < 0.001$)
- Gender was significant in PRT ($p < 0.05$)

Stopping Sight Distance

- Age and gender were not statistically significant; however, age and gender interaction was almost significant at $p = 0.055$ (ANOVA) reflecting the short times the

young females group (mean of 1.22s) had compared to the other groups (1.40 to 1.65 s)

Decision Sight Distance PRT

- T-tests of daytime significance (95%) revealed:
 - The decision sight distance PRT of the old group was significantly longer than the middle age group in 4 of the 11 sites
 - The decision sight distance PRT of the older age group was significantly longer than the middle age group in 2 of the 11 sites
- The nighttime test revealed the older age group had significantly longer decision sight distance PRTs in 2 of 11 sites at night compared to the young group (T-tests of 95% significance)
- Manoeuvre time had one significant difference (T-test 95%) on Arterial Right Turn Lane where the younger group (8.38) had a longer time than both older groups (6.12 and 5.95)

Gap/Lag Acceptance

- Gap Acceptance – Overall gap mean=7.1s, 85th percentile=10.6s
- Lag Rejection – Overall lag rejection point mean=5.3s, 50% gap point ≈7.1s

Strengths and Limitations

Strengths

- Real world traffic situations and distractions

Limitations

- Possible interaction of rating task with intersection PRT
- The perception interval dependent on the experimenters vision in the Decision Sight Distance PRT
- Gap/Lag acceptance simulation made from passenger seat not as realistic as from drivers seat

9. Mace, D.J., Garvey, P.M., & Heckard, R.F. (1994). *Relative visibility of increased legend size vs. brighter materials for traffic signs* (FHWA-RD94035; PB95198339). Bellefonte, PA; United States: Last Resource, Inc.

Keywords: Traffic signs; legibility; conspicuity; retroreflectivity; sign size; legend size

Abstract

“Static and dynamic legibility studies were conducted to investigate the effects of level of reflectivity, letter series, stroke width, letter spacing, font, letter height, and driver age. The dynamic study also considered the effect of sign size and retroreflectivity on the level of conspicuity.

As expected, driver age had the largest effect on both legibility and conspicuity. In fact, the daytime legibility for older drivers is almost as poor as night legibility. Level of retroreflectivity, letter series, and letter height all had a significant effect on legibility. Increases in letter height resulted in proportionate increases in legibility up to about 700 ft. (183m). In most cases, stroke width, letter spacing, and font were not significant; however, with fully retroreflective signs, a narrow stroke width significantly increased the legibility of high-contrast signs. Using spacing narrower than the standard spacing did significantly reduce legibility.

With regard to conspicuity, 36-in. (0.91m) signs with type I sheeting were found to have detection distances equivalent to 24-in. (0.61m) signs with type VII sheeting. Black-on-white signs were found to have much shorter detection distances than black-on-orange or white-on-green signs.

Cost comparisons (excluding life-cycle costs) using the data available suggested that larger signs with type I sheeting were less expensive than smaller signs with type VII material which provided similar performance. The effects of other materials with brightness between type I and type VII were not of significant magnitude to provide reliable cost evaluations.”

Method

Four studies were conducted – two static in-vehicle, one moving vehicle, and one walking study. Participants were either older (>65 years) or younger (<40 years) and were tested for visual acuity, contrast sensitivity and colour vision, cognitive and psychomotor performance.

Retroreflectivity and Stroke Width (Study 1)

Stroke width and retroreflectivity for negative and positive contrast signs were tested with 60 (30 younger and 30 older) participants in two groups (15 older and 15 younger).

Two participants were seated in a passenger vehicle during the day, then at night with low-beam headlights on. Signs were shown for 10s at “a number of fixed distances.”, and the furthest distance at which each participant could read them was recorded.

The retro-reflective sheeting used for the negative contrast was Avery’s engineering-grade (ASTM-type number I), Seibulite’s super-engineering-grade (II), Stimsonite’s cube-corner high performance (IV) and 3M diamond-grade (VII). The sheeting used for positive contrast was similar except 3M glass bead high-intensity (III) replaced the Stimsonite sheeting (IV).

For negative contrast testing one group evaluated black letters (20.3 cm high) on a white background (B/W) and the other, black letters (20.3cm high) on an orange background (B/O).

For positive contrast testing approximately half of each group was taken to form another group of 15 older and 15 younger participants to evaluate a 20.3 cm letter height in white letters on green background (W/G). The remaining group evaluated a 30.4 cm letter height of W/G.

The stroke width to height ratio (SW/H) for positive contrast signs was 0.2 on series E(M) letters, then decreased by 25% and 62.5%. The SW/H for negative contrast signs was 0.2 on series E(M) letters, then increased by 25% and 35%.

As well as detection distance, legibility index (LI) was used to compare letter sizes.

Relative Night Time Conspicuity (Study 2)

This study tested sign sizes, retroreflective materials in both day and night conditions and verified legibility conclusions reached from Study 1. There were 53 participants (27 younger and 26 older). Participants rode in the passenger seat as the experimenter drove the car at the speed limit of 56 km/h (35 mph). There were 17 sign sites and all but one sign had a line of sight of at least 305 m and did not have other competing signs except during the B/W condition. Participants were to report when the sign matching the required colour was spotted (threshold detection) and read the word on the sign as soon as they could (threshold legibility). Distance from sign measured with a digital measuring instrument (DMI). Monetary incentives were given for spotting Xs on the left hand side to keep participants from watching the right side only.

Signs with the same colours as Study 1 were sized 0.61 m and 0.91 m square. Half of the 0.91 m B/W signs had 2 words, the others 1 word. Letter height was 20 cm, standard series C and D increased by 35%. W/G signs compared series E(M) to the Clarendon font used by the National Park Service. The six words/sign had the same length and the same start letter.

Site characteristics – day and nighttime complexity was rated differently.

Change in Legibility Index Across Letter Size (Study 3)

This study tested the change in LI across range in letter heights during the day. The sun was overhead or behind the participants.

Two sets of BW signs used highway series C and D, respectively. WG signs were tested using series E(M). Five characters were used for each sign, 4 alphabetic characters (C and E - B,G,M,X & D - C,K,S,Z) all with a Lazy E. Five letter heights were used 15, 20, 25, 30 and 41 cm.

Fifteen younger and 15 older participants started with a viewing distance at the threshold of the person with the best visual acuity, and walked forward in set increments until all participants could read all the letters clearly. Threshold legibility was the larger distance of two consecutively correct answers.

Letter Spacing (Study 4)

This study tested increasing inter-letter spacing to determine if it would affect the night time legibility of a word and if this applied to retroreflective materials, letter series and heights on negative contrast signs. A second purpose was to compare all capitals with mixed case.

Legibility was measured in the same way as in Study 1. Sign size was balanced to reduce learning and fatigue effects.

Main Findings

Retroreflectivity and Stroke Width (Study 1)

- Older drivers had poorer legibility (LI=6.1m/cm) for series C letters and type VII sheeting than younger drivers (LI=6.6m/cm) with type I
 - Older and younger drivers had the same legibility (LI=7cm/cm) with series D letters and the previously mentioned retroreflectivities
- High-contrast combinations with type VII on type I lowered LI by 0.84m/cm compared to other materials for older drivers
- LI accommodating 85% of the older drivers will accommodate almost all younger drivers, except 20 cm letters on W/G signs

Relative Night Time Conspicuity (Study 2)

- There were trends towards:
 - B/O sign stroke width and material ($p=0.08$) for dynamic legibility
 - B/O signs having greater conspicuity than B/W signs of similar brightness
 - Older and younger drivers had improved legibility with Clarendon font

Change in Legibility Index across Letter Size (Study 3)

- Older drivers found the Lazy E less legible than would be expected based on prorating in the 30 cm size
- At distances greater than “183 m increases in legibility cease to be proportional to increases in letter height”
 - Older drivers day and night legibility does not change perhaps due to their visual limits. LI is useful in establishing minimum required visibility distance
- LI was significantly different for letter height and series for both age groups

Letter Spacing (Study 4)

- No age related effects clearly identified
- Type VII material increased performance by 0.6m/cm with series C on B/O and B/W signs. Series D had an improvement of 0.24 – 0.36m/cm
- Letter height was significant for series D on B/O and B/W, with the largest effect on type VII materials where the LI decrease was 0.48 and 0.6m/cm for both colours

Summary and Conclusions

- Legibility
 - Older drivers compared to younger drivers have a very low LI at night (by 0.6m – 2.4m/cm) and during the day (by 2.4 – 3.6m/cm). Younger drivers can see farther during the day than at night.
 - Letter size – for older drivers, increasing letter size produces a proportionate increase in legibility distance up to 30cm letters
- To accommodate 75 – 85% of older drivers and >95% of younger drivers
 - B/W and B/O signs assume LI=3.6m/cm with:
 - Series C letters on any retroreflective material
 - Series D on Type I or II sheeting
 - Series D on Type III or IV increase to 4.8m/cm

- W/G signs assume:
 - LI of 5.4m/cm and 20cm letters
 - LI of 4.8m/cm and 30cm letters
- Conspicuity
 - B/W signs brighter sheeting improved detection distances for younger drivers, but made no difference to older drivers

Strengths and Limitations

Strengths

- Many aspects of sign legibility tested; issue of prorating legibility by letter size examined

Limitations

- Older drivers potentially had difficulty with abstract random letters (Lazy E)
- Mean acuity differences of older groups (study 1) affected colour results

10. Mace, D.J., & Porter, R.J. (2002). *Fixed roadway lighting to benefit older drivers*. Paper presented at the 16th Biennial Symposium on Visibility and Simulation., University of Iowa, Iowa City. 4.

Keywords: Accident rates; aged drivers; daytime accidents; highway safety; highway transportation; human factors; luminance; nighttime accidents; street lighting; visibility distance; visual perception

Abstract

“Although roadway lighting has generally been found to reduce the nighttime motor vehicle accident rate, prior studies have had difficulty developing a relationship between any description of the lighting provided and the extent of accident reduction. Many comparison studies have been made which invariably indicate that the night-to-day accident ratio is reduced when fixed lighting systems are installed. This research aimed to investigate several issues concerning the relationships of fixed lighting parameters to the safety and comfort of older drivers. Safety and comfort were defined by measures of visibility, glare, perceived comfort, and driver behavior. All fixed lighting designs were 1-sided arrangements with high pressure sodium lamps. Of particular interest were interactive effects of average pavement luminance and luminance uniformity with respect to minimizing discomfort glare and transient adaptation without sacrificing the visibility of objects within the fixed lighting area. Methodologies used by prior research resulted in the confounding of average pavement luminance and uniformity. An attempt was made in this work to vary these variables independently of each other.”

Method

The testing was conducted along a flat 720 m section of a two-lane highway with asphalt pavement and fixed lighting. The fixed lighting was one-sided with a 1.5 metre overhang and had adjustable pole spacing (40, 60, 80, and 120 metres), bracket mounting height (11 – 15 metres) and high pressure sodium (HPS) luminaries (one 150w and one 400w flat glass enclosure and one 400w luminaire with a refractor).

Experimenters used a 3x3 incomplete block factorial design of lighting parameters (three levels of pavement luminance and of luminance uniformity ratio) balancing their presentation. The lighting dimming system was used to set the pavement luminance, horizontal illumination and veiling luminance.

The number of participants for each session ranged between 17 and 22 young drivers (25 to 35 years of age) and 32 and 35 older drivers (65 to 75 years of age). Participants were tested and matched for visual acuity and contrast sensitivity to reduce subject variability. Using a 1998 Ford Contour with low-beam headlights, each participant made eight return trips on the test circuit. On each trip two targets (18 cm square, 18% reflectance) were located either along the centreline or lane line. A secondary loading task requiring participants to locate green retroreflective markings was used to increase the visual complexity without interfering with the primary target detection task. Participants were required to maintain speeds between 25 and 35 mph (40 to 56 km/h).

Continuous, oncoming headlight glare was simulated for the two-lane roadway by attaching two lamps to the front of the vehicle and directing them at the driver eye height of 1.3 m (50th

percentile of both males and females). The study included trials with some participants experiencing glare (0.28 lux measured through the windshield at the assumed driver's eye position) and others receiving equal veiling luminance (0.50 cd/m²). If glare was used, subjective measures of the discomfort rated with the DeBoer scale were taken immediately after the lamps were turned on, after the first run and at the end of the experimental trial. One small target was placed 107 m past the last light to determine the "transient adaptation effect".

An adjustment factor of 1.2 seconds was added to target detection distances to account for the reaction times of the participant and experimenter. Subjective questions of lighting designs were asked at the end of each run (two times per trip) to determine which lighting system drivers preferred. After the experimental runs were completed, participants were to rate the level of illumination and driver comfort on a seven point scale.

Main Findings

Effect of Lighting System on Detection Distance

- ANOVA tests showed that "lighting design, age group, and glare condition were significant as was the lighting design by age group interaction ($p < 0.001$). The longest detection distances for all drivers were obtained with:
 - High luminance and either low or medium uniformity ratio designs (DD=121m)
 - Medium luminance and either medium or high uniformity ratio designs (DD=116m and 115m respectively)
- Age group, a significant factor in detection distance ($p < 0.001$), was not independent of visual acuity. A separate ANOVA using young and old drivers with 20/20 acuity revealed age is still a significant factor ($p < 0.001$).
- Luminance and Uniformity:
 - There was an interaction with age. "Older drivers had significantly longer detection distances with high uniformity ratios [84.4m] than low uniformity ratios [68.9m]; however, for younger drivers, the detection distance with high uniformity ratios [113.1m] was not any different than it was with low uniformity ratios [112.5m]."
- There was an interaction between uniformity, luminance and age ($p < 0.001$). Older driver's detection distance for low luminance with poor uniformity was the same as for low luminance with medium uniformity. Younger drivers showed an asymptotic effect responding to luminance.

Comparison of Lighting Spacing

- Two low luminance, high uniformity designs were tested using different pole spacing. The average detection distance showed 80 m spacing had significantly shorter detection distance (DD) (DD = 94 m) than the 120 m spacing (DD = 110 m). ($p < 0.001$). The authors caution that the 80 m design had a lower pavement luminance and a slightly higher uniformity ratio than the 120 m design and that may have contributed to the result.

Effect of Lighting System on Vehicle Speed

- Older drivers drove slower (52 km/h) than young drivers (53.4 km/h) ($p < 0.0001$). Although the difference is small, it does "provide some convergent validity to the study in that the two lighting designs with significantly slower speeds than all others were also those that resulted in the shortest detection distances for older drivers."

Pavement Luminance and Headlight Glare

- Older drivers had significant decreases ($\alpha=0.05$) in their detection distance under headlight glare in two conditions: low luminance with low uniformity (-6.4 m) and low luminance with medium uniformity (-9.4 m). All drivers had significant decreases ($\alpha=0.01$) in the no lighting condition (-12.2 m). For all other situations (including younger drivers) there were no significant differences.
- “These data suggest that the effects of the simulated headlight glare on visibility were mitigated with medium or higher levels of average pavement luminance”
- Rating of glare discomfort:
 - Younger and male participants experienced more discomfort ($p<0.01$)
 - “While lighting design had a significant effect, post hoc tests showed that the effect of lighting design was entirely attributable to the fact that glare was significantly more discomforting without lighting than with lighting.”

Transient Adaptation

- The transient adaptation detection distance by lighting design for older drivers (47 m) was significantly less than younger drivers (62 m) ($p<0.001$). Post-hoc comparisons showed that two conditions of low luminance one with low (56 m) and one with medium (64 m) uniformity had the longest distances.
- The condition in which the streetlights were off increased detection distance for transient adaptation compared to any of the designs with street lighting
- Low luminance and low uniformity (DD=57m and 56m) had significantly longer transient adaptation detection distances than medium or high luminance or uniformity (ranging DD=49m to DD=52m) ($p<0.001$)
 - The interaction between luminance and uniformity ($p<0.005$) was explained as “among designs of equal average pavement luminance, designs with medium and high uniformity ratios must have higher levels of maximum luminance in order for the average to match the luminance of designs with lower uniformity ratios”

Strengths and Limitations

Strengths

- Study occurred in real world conditions with many parameters being varied (pole spacing, mounting height, illumination level, and veiling luminance)
- Older and younger subjects were paired according to their visual acuity and contrast sensitivity

Limitations

- Incomplete block design means subjects were not tested on all lighting designs
- For any lighting system, subjects were only tested on 8 of the 16 targets. This created the potential for bias if the subjects tested on some lighting systems or targets had better vision than those tested on other lighting systems or with other targets.
- Crude measure of detection distance using a constant adjustment factor of 1.2 seconds
- Headlight performance of a variety of vehicles not considered

11. Mayhew, D.R. and Simpson, H.M. (2006) Collisions involving senior drivers: High-risk conditions and locations. *Traffic Injury Prevention*, 7, pp. 117-124.

Keywords: Older drivers, crash characteristics, driver behaviour, alcohol, drugs

Abstract

“Objectives. *To better understand the characteristics of crashes involving senior drivers 65 and older, studies of these crashes were reviewed.*

Methods. *The review focused primarily on North American studies published since 1990. Studies point to important differences between the crashes of senior drivers and those of younger drivers.*

Results. *Numerous studies have found that senior drivers’ crashes are much more likely than crashes of younger drivers to occur at intersections. Senior drivers have particularly high rates of involvement in intersection crashes when they are turning, and even more so when they are turning left. Senior drivers are more likely than younger drivers to have been at fault in these situations, typically because they failed to yield the right-of-way, disregarded the traffic signal, or committed some other traffic violation. Studies also suggest that the extent of overinvolvement of senior drivers in certain types of crashes generally increases with advancing age.*

Conclusions. *The extent to which the distinctive characteristics of senior drivers’ crashes may be due to changing travel patterns associated with aging, or physical or cognitive impairments related to the aging process, is unclear. Further research is needed to understand the pre-crash circumstances of older drivers’ intersection crashes.”*

Method

The review focused primarily on North American studies published since 1990 and refers to 87 publications.

Main Findings

The review found that older drivers are particularly at risk at intersections, with risk increasing with age. The authors note that the proportion of the population that is older is increasing and that it has been estimated that drivers 65 years and older will account for ¼ of fatalities by the year 2030, compared to 14% today (Lyman et al., 2002).

Early investigations were reviewed. The authors quote Hauer (1988) who reported that for drivers 64 and older about 40% of fatalities and 60% of injuries occurred at intersections or were intersection related. Early investigations show that older driver intersection collisions often involved the older driver turning left across the path of an oncoming driver and that these types of collisions were particularly prevalent for drivers 75 and older. Contributing causes to older driver crashes at intersections were found to be failure to yield right-of-way, failure to obey traffic signs and signals, changing direction unsafely, turning improperly or inaccurately, changing lanes improperly and backing improperly.

Contemporary research was examined with respect to environmental and weather conditions, illness and medical conditions, alcohol, driving errors, responsibility, crash characteristics, and intersection crashes.

Studies reviewed that attempted to control for exposure by comparing drivers involved in at fault vs. not at fault crashes found that older drivers were at greater risk of intersection crashes. Contributing factors were failure to yield right-of-way, disregard of the traffic signal or some other traffic violation. These actions may occur because of deteriorating functional capabilities with age (e.g., peripheral vision, speed and gap perception, etc.). The literature indicates that older drivers pose the most serious risk to themselves and their passengers, who are often elderly, rather than to other drivers. While risk increases with age, the review indicated that even the youngest senior drivers (aged 65 to 74 years) have increased risk in many traffic situations as compared to middle-aged drivers.

The authors note the appearance of a number of guidelines and recommendations to address older driver safety problems. Roundabouts are noted as likely to improve intersection safety. A study by Retting et al. (2001) is cited as indicating that roundabouts do not pose a problem for older drivers.

12. McGarry, T. (1996). Vision and the signing needs of older drivers. In A.G. Gale, I.D. Brown, C.M. Haslegrave & S.P. Taylor (Eds.), *Vision in Vehicles V* (pp. 309-316). Amsterdam, Netherlands: Elsevier Science B.V.

Keywords: Traffic sign; vision; driver; elderly drivers; simulation; legibility

Abstract

"The average age of the driving population is increasing. It is therefore likely that the proportion of drivers whose visual and cognitive abilities have started to decline will also be increasing. This awareness has prompted research which seeks to evaluate the appropriateness of current traffic sign standards, especially for the older driver."

The ability of older drivers to extract information from signs has been studied and measurements made of the legibility of signs manufactured with different retro-reflective materials. Some of the newer sign materials were included in these studies to determine the effect of their greater brightness on legibility distances. Volunteer subjects in the 50 – 75 age group were invited to participate in a series of four experiments:

- (1) A test to examine reading times for direction signs of various complexities (using the TRL vehicle simulator).*
- (2) A test to investigate the ability of older drivers to recall information from arrays of warning signs (also using the TRL vehicle simulator).*
- (3) A full scale nighttime legibility experiment using different signing materials and levels of ambient brightness (on the TRL research track).*
- (4) A full scale day-time experiment assessing sign legibility (on the TRL research track)."*

Method

Four experiments were performed with 51 volunteers including 6 replacements. Participants were selected based on their age, annual mileage driven and the characteristics of their vision. The ratio of males to females was based on the proportion of licensed older drivers according to the National Travel Survey (73% male, 27% female). Participants were combined from five National Travel Survey (NTS) age groups (50 to 54, 55 to 59, 60 to 64, 65 to 69 and 70 to 75) into two categories: 43% of them were younger (50 to 64 years) and 57% of them were older (65 to 75 years).

TRL Simulator Setting

The driving scenario featured a 3-lane roadway with two vehicles in front of the driver. The other vehicle behaviours were unpredictable and set to a "reasonably demanding" difficulty. Drivers were instructed to drive their car "appropriately".

Response Time Experiment – TRL Simulator

Participants driving in the simulator were instructed to maintain a safe distance behind the other vehicles. An experimenter read the destination names, varying the time before the sign appeared. Participants responded promptly by signalling the direction using the indicator stalk (left if destination was to the left, right if right, pull back if straight ahead and if not on sign, pull back and say "missing"). The signs were projected onto the screen for 8 seconds using a slide projector. Half of the participants saw one of two carousels first. The slide order in each set was randomized and stratified to avoid sign anticipation.

Destinations required a correct response of left, right or straight ahead an equal number of times. “The sequences were subdivided equally among the 5 NTS age groups and between both sexes to eliminate possible bias.” Each participant was shown 42 signs in total, with a quick rest after the 21st.

Recall Experiment – TRL Simulator

Pictures of the warning signs were given out ahead of time for participants to study in advance of the experiment. The recall experiment was conducted after a 20-minute break from the response time experiment. Participants’ comprehension of the signs was examined during the break to ensure that recall problems were not due to lack of knowledge. The participants were shown the first 11 signs for 2 seconds in arrays of 2, 3 or 4 signs. The exposure time for the last 11 signs was increased to 4 seconds. After the sign was removed the participants were asked for the name of the sign that appeared in a specific position.

Nighttime Legibility Experiment – TRL Research Track

Nighttime legibility distance was tested while the test vehicle was driven by the experimenter from the passenger side at a slow walking pace while the participant sat in the driver’s seat. The sign backgrounds consisted of engineering grade, high intensity or Diamond grade sheeting with both black on white and white on blue signs. The destination names had 7, 8 or 9 characters with similar ascenders or descenders. Participants were asked to read a name or road number in a given position on a sign when they were “reasonably sure” of the answer. If their response was incorrect, they kept trying until a correct answer was given. When a correct answer was given, the car was stopped and the distance was recorded (estimated accuracy of 0.5 metres). Three runs were conducted using different combinations of streetlights and headlights.

Day-time Legibility Experiment – TRL Research Track

Similar to the nighttime experiment, this time only six signs (2x engineering grade, 2x high intensity and 2x Diamond grade) with the same colours were shown to participants. The destinations were randomized to prevent bias.

Main Findings

Response Time Experiment

- Younger men had the shortest response time of the groups (sex of participant, $p=0.012$ and age $p=0.055$)
- Response time increases as more names appear on the sign ($p<0.001$)

Recall Experiment

- Shorter exposure times decreased correctly recalled answers ($p=0.002$)
- The older group recalled fewer correct warning signs compared to the younger group ($p=0.011$)
- For both age groups as cluster size increased, correct responses decreased significantly ($p<0.001$)
- Time/cluster size interaction was statistically significant ($p=0.043$)

Nighttime Legibility Experiment

- Older drivers had a shorter legibility distance ($p=0.002$)

Day-time Legibility Experiment

- Older drivers had a shorter legibility distance ($p<0.001$)
- Bright weather conditions improved legibility distance over dull conditions ($p=0.004$)

Strengths and Limitations

Strengths

- Comprehensive series of experiments, both on-road and using a simulator, examining several different aspects of sign design (comprehension, recall, legibility)
- Despite “younger drivers” being defined as being aged 50 to 64, a significant decline in performance was found for “older drivers” aged 65 to 75
- Response Time Study – Balanced exposure regarding order of presentation of signs

Limitations

- A third age category could have been considered to compare younger to middle aged and older drivers

13. Noyce, D.A., & Kacir, K.C. (2001). Drivers' understanding of protected-permitted left-turn signal displays. *Transportation Research Record (1754)*, 1-10.

Keywords: Aged drivers; comprehension; drivers; drivers with limited education; evaluation and assessment; exclusive permissive phasing; flashing traffic signals; green interval traffic signal cycle; inexperienced drivers; left turns; performance; protected permitted left turn phasing; red interval traffic signal cycle; surveys; traffic safety; yellow interval traffic signal cycle

Abstract

"A comprehensive assessment of protected-permitted left-turn (PPLT) signal displays was performed considering safety, operational performance, and driver understanding measures. The research focuses on a study of driver understanding of permitted left-turn indications. All currently used PPLT display arrangements and permitted indication combinations were evaluated, including those with flashing red and yellow permitted indications. Driver understanding was evaluated through a computer-based driver survey completed by 2,465 drivers. A total of 73,950 survey responses were received pertaining to the 200 different survey scenarios evaluated. The study results indicate that yellow or red flashing permitted indications may lead to higher levels of driver comprehension. Both the flashing red and yellow permitted indications had a significantly higher correct response rate than did the green ball permitted indication. Drivers over the age of 65 found the flashing ball permitted indications easier to comprehend and responded more quickly with fewer fail critical (turning left without the right-of-way) errors. Higher correct response rates with flashing permitted indications were also found in other important demographic groups, including inexperienced drivers and drivers with limited education."

Method

Comprehension studies were conducted in seven U.S. States (Texas, Oregon, Washington, Michigan, California, Delaware, and Florida) to evaluate driver's understanding of PPLT displays currently in use throughout the United States. Drivers were divided into four age groups: under 24, 24 to 44, 45 to 65, and over 65, participated in the comprehension study the survey using a computer display. Drivers were randomly assigned 30 scenarios of traffic signals out of a possible 200 combinations of left-turn, through movement indications and PPLT display arrangements. Subjects were presented with a picture of an intersection with left-turn and through traffic signals digitally created, animated and put in the picture.

The intersection used for the scenarios had a single left turn lane with two or three through lanes in each direction, a street perpendicular to the main street, and a median. Six photographs were used as the background scene. Five photographs had a vehicle in the opposing through lane of traffic and the sixth photograph, used as a control, had no vehicles in it. No signs were used in conjunction with the signals. Signals were shown as five-section signal displays and three-section vertical or horizontal displays.

For each scenario drivers were asked "If you want to turn left, and you see the traffic signals shown, you would... (1.) GO, (2.) YIELD – wait for gap, (3.) STOP – then wait for gap, or (4.) STOP. The participants responded with number keys. Correct responses to the scenarios were the MUTCD's intended permitted action. The response time was recorded for each scenario and used as a secondary measure of driver understanding, not perception-reaction time.

Main Findings

Overall Findings

- Left turn indications
 - Drivers over the age of 65 found the flashing permitted indications easier to comprehend and responded more quickly with fewer fail critical errors
 - Overall, the flashing red ball resulted in the highest percentage of correct responses for permitted left-turn indications (63.8%) and the green ball had the lowest (50.4%)
- Signal layout
 - The least understood PPLT signal layouts were the five section vertical, five section horizontal and five-section cluster, probably because of “the corresponding permitted indications used within each display”
- Horizontal five-section display
 - Green ball permitted with a green ball through movement indication resulted in 40% of drivers over 65 having a fail critical rate (turned left without right-of-way) compared to 20% with all other age groups
 - Green ball permitted with a red ball through movement indication had the highest fail critical rate (34.3%)
 - Drivers over 65 years of age had a 51% fail rate compared to 26.5% for the 24 to 44 age group
 - Flashing red ball permitted with a red ball through movement indication had the lowest critical rates
 - >1% males, >0.1% females failed critical
 - “None of the drivers over the age of 65 failed critical”
- Response time
 - The average response time for all drivers was 6 seconds. The average response time for older drivers was 8 seconds.
- Location and Signal Familiarity
 - “Driver's place of residence was found not to be significant ($p=0.064$)”

Strengths and Limitations

Strengths

- Large study samples spanning seven U.S. states
- Study conditions simulate real world driver's view with animation of display sequence superimposed on real intersection photographs (whether vehicles were visible in background photographs)
- Through movement indications were also included in the viewing area as drivers may use them as cues to predict action of others

Limitations

- Lack of statistical significance of results
- Use of computer display may have led to longer response times for older adults as they would neither be as familiar nor as skilled with the use of that technology, especially dependent upon the method used for selecting the response (i.e. keyboard use). Measures

comparing within age groups may be more indicative as opposed to comparisons across age groups.

14. Noyce, D.A., & Kacir, K.C. (2002). Driver understanding of simultaneous traffic signal indications in protected left turns. *Transportation Research Record (1801)*, 18-26.

Keywords: Aged drivers; comprehension; driver errors; drivers; protected permitted left turns; signal displays; simultaneous traffic signal indications; surveys; traffic signals

Abstract

"A comprehensive assessment of protected and permitted left-turn (PPLT) signal displays was performed considering safety, operational performance, and driver-understanding measures. The research focused on a study of driver understanding of protected left-turn indications. All currently used PPLT display arrangements and protected indication combinations were evaluated, including those with simultaneous green-arrow and red- or green-ball indications and those with the green-arrow indication only. Driver understanding was evaluated through a computer-based driver survey completed by 2,465 drivers. In total, 73,950 survey responses were received pertaining to the 200 different survey scenarios evaluated, 24,863 pertaining to protected left-turn indications. Findings show that the simultaneous illumination of the green-arrow and red-ball indications in a five-section PPLT signal display during a protected left-turn phase significantly reduces driver understanding and increases driver error. This finding is especially true for drivers over the age of 65. Simultaneous illumination of the green-arrow and green-ball indications also resulted in levels of driver understanding lower than the green-arrow-only indication; however, these differences were not statistically significant."

Method

Comprehension studies were conducted in seven U.S. States (Texas, Oregon, Washington, Michigan, California, Delaware, and Florida) to evaluate driver's understanding of PPLT displays currently in use throughout the United States. Drivers were divided into four age groups: under 24, 24-44, 45-65, and over 65. Drivers were randomly assigned 30 scenarios of traffic signals out of a possible 200 combinations of left-turn, through movement indications and PPLT display arrangements. Subjects were presented with a computer screen display of an intersection image with left-turn and through traffic signals digitally created, animated and placed in the picture.

The intersection used for the scenarios had a single left turn lane with two or three through lanes in each direction, a street perpendicular to the main street, and a median. Six photographs were used as background scenes. Five photographs had a vehicle in the opposing through lane of traffic and the sixth photograph, used as a control, had no vehicles in it. No signs were used in conjunction with the signals. Signals were shown as five-section signal displays and three-section vertical or horizontal displays.

For each scenario drivers were asked "If you want to turn left, and you see the traffic signals shown, you would... (1.) GO, (2.) YIELD – wait for gap, (3.) STOP – then wait for gap, or (4.) STOP. The participants responded with number keys. Correct responses to the scenarios were the MUTCD's intended permitted action. The response time was recorded for each scenario and used as a secondary measure of driver understanding, not perception-reaction time. This analysis covers the protected left-turn indications which were 68 out of 200 scenarios.

Main Findings

Overall Findings

- Protected left-turn indications
 - Drivers over the age of 65 had statistically significant lower correct response rates (81.6%) than drivers between 24 and 44 (87.2%)
 - The simultaneous Green-Arrow and Red Ball indication resulted in the lowest percentage of correct responses for permitted left-turn indications (71%)
 - The over 65 group correct response rate of 62% was statistically significant compared to their other responses:
 - 86% for the green-arrow and green-ball combination
 - 89% for the green-arrow indication only
 - When considering only the five-section horizontal display with the simultaneous Green-Arrow and Red Ball indication, the correct response rate for older drivers was 49%.
- Response time
 - "...the average response time increased with driver age."
 - "The over-65 age group average response time to the five-section horizontal display with simultaneous green-arrow and red-ball indications was nearly twice that to the green-arrow-only displays."

Strengths and Limitations

Strengths

- Large study samples spanning seven U.S. states
- Study conditions simulate real world driver's view with animation of display sequence superimposed on real intersection photographs (whether vehicles were visible in background photographs)
- Through movement indications were also included in the viewing area as drivers may use them as cues to predict action of others

Limitations

- Use of computer display may have led to longer response times for older adults as they would neither be as familiar nor as skilled with the use of that technology, especially dependent upon the method used for selecting the response (i.e. keyboard use). Measures comparing within age groups are more indicative as opposed to comparisons with other age groups.

15. Ohme, P.J., & Schnell, T. (2001). Is wider better? Enhancing pavement marking visibility for older drivers. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, 1617-1621.

Keywords: Ergonomics; vision; automobile drivers; pavements; highway markings; safety factor; wetting; personnel testing; degrees of freedom (mechanics); light reflection

Abstract

"A field study was conducted to evaluate the effect of pavement marking edge line width (100 mm, 150 mm, 200 mm) and pavement marking material type (normal paint+bead, wet-weather tape, ceramic element) on forward detection distance when driving on a two-lane rural road under automobile low-beam illumination at night. The aim of the study was to generate a set of recommendations to improve nighttime driving conditions for old motorists, especially under wet weather condition. Prior to the experiment, the markings were purposely worn in situ by traffic for one year to obtain realistic in-service retroreflectances. Fourteen participants, including 7 young drivers (range 19-26 years) and 7 old drivers (range 65-81 years), detected a 60 m gap in each pavement marking treatment under both dry and wet roadway conditions. The width of the edge lines showed no significant effect on detection distance, however, the material type significantly increased detection distance, especially under wet roadway conditions. These results suggest that enhanced pavement marking materials could be useful to improve pavement marking visibility and thus safety of the nighttime motorist, especially in high-risk areas such as extremely sharp curves or other situations where increased forward preview is needed to allow adequate driver reaction."

Method

Two groups, each with seven participants, were divided as young (ages 19 to 26) and old (ages 65 to 81). All participants had normal colour vision and contrast sensitivity, good health, were not under influence of any medication or alcohol and were licensed U.S. drivers. The older group had 20/40 corrected vision or better. The younger group had 20/30 corrected or better.

The test area consisted of 10 km of straight roadway sections with different pavement marking treatments separated by gaps in the markings. The sections had different edge line widths and marking materials: "4-inch (100 mm) paint+beads (baseline), 6-inch (150 mm) paint+beads, 8-inch (200 mm) paint+beads, Ceramic element polyurea based liquid application pavement markings (100 mm), henceforth called "ceramic element", wet-weather tape with enclosed lens, ceramic elements and structure netting (100 mm), henceforth called "wet-weather tape". To imitate wet roadway conditions a water truck was used to spray the road. "Presentation order was balanced by approach direction (east, west)."

Each participant drove with headlights on low beam in wet and dry conditions at "coasting speeds of about 16 km/h." When they could detect the gap with 95% certainty they were to say "gap". At that point the detection distance was measured to the actual start of the gap.

Main Findings

Age Group Comparisons

- ANOVA analysis “showed no significant main effect difference between the two age groups”. ($p=0.62$)
- “The interaction of age with the weather condition was nearly significant”. ($p=0.078$)
 - Generally, in dry conditions younger drivers had a longer detection distance
 - In wet weather conditions it was older drivers who had the longer detection distances
- Ceramic element and wet-weather tape showed statistically significant differences from the paint+beads treatments (p values ≤ 0.015 and p values < 0.0001 respectively)

Table A-1: Mean Detection Distances (m) by Pavement Marking Treatment

Pavement Marking Treatment	Dry Roadway		Wet Roadway	
	Young	Old	Young	Old
10cm Paint+Beads – Baseline (Standard Deviation)	88.1 (18.7)	79.1 (25.4)	14.3 (7.0)	20.7 (10.1)
15cm Paint+Beads	95.5 (23.6)	82.8 (26.4)	14.0 (8.9)	16.6 (10.8)
20cm Paint+Beads	92.6 (21.7)	78.2 (28.4)	20.4 (15.3)	23.1 (13.6)
Ceramic Element Paint	90.8 (31.2)	88.7 (32.6)	26.7 (10.8)	36.3 (16.8)
Wet-Weather Tape	90.4 (17.4)	68.9 (24.2)	61.3 (24.1)	65.7 (21.7)

Strengths and Limitations

Strengths

- Study occurred in real world conditions with markings that were installed over one year and exposed to snow plowing operations

Limitations

- Small sample size of 14 participants
- No measurement of lane tracking performance
- Wet conditions were simulated on the roadway. However, the driver’s windshield was dry and there was no use of windshield wipers.
- Older participants that responded would not likely have “visual deficiencies severe enough to affect nighttime driving performance”

16. Oxley, J., Fildes, B., Corben, B., & Langford, J. (2006). Intersection design for older drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, 9(5), 335-346.

Keywords: Older driver; safety; road design; functional performance; countermeasure; traffic management

Abstract

“Older drivers are currently over-represented in severe injury crashes at intersections due in part to increases in frailty and functional disabilities that occur with age. Moreover, this rate is expected to increase as older people drive more and the population ages. Road design plays a major role in road safety and is likely to contribute to the driving difficulties of the elderly because of the general lack of consideration of the needs of older road users. Intersections, in particular, stand out as a major problem for older road users. This paper reviews age-related performance deficits that affect driving and describes a crash ‘black-spot’ site analysis that examined the relationship between intersection design features (believed to influence the safety of older drivers) and the older driver crash experience in Australasia. A number of intersection design problems for older drivers were identified and recommendations for changes in road design features and traffic management practices that have the potential to reduce crash and injury risk for older drivers at intersections are made.”

Method

The study gathered ‘black-spot’ crash sites identified by road authorities in Tasmania, New Zealand, Victoria and Queensland. The sites were then ranked by the number of older driver crashes (where a minimum of one driver was at least 65 years of age) and 62 sites were selected for further analysis. The selection took into account rural and urban areas and, where possible, geographic clusters. The number of crashes at each site ranged between 3 and 11 for older drivers and 11 to 89 for younger drivers (<65 years) over a period of 5 years (1994 – 1998). To account for relative crash risk, the proportion of crashes to number of licensed drivers by age group (older or younger) was compared.

A site visit by 3 to 5 team members (traffic engineers, human factors psychologists, crash investigators and road safety experts) gathered information about the road design characteristics using a structured questionnaire. Prior to the visit data was collected on the drivers and road environment. The team created a summary of potential main crash factors for each crash site and suggested engineering countermeasures to address the problems.

Main Findings

General Crash Site Characteristics

- The majority of crashes were at intersections (97%) controlled by stop or yield signs (65%) and traffic signals (35%)
- Comparing younger to older drivers, the relative crash risk ratios (by jurisdiction) were 0.3-0.5, showing older drivers were at greater risk

Probable Contributing Factors

- Primary causes for each crash site (as a proportion of the sites) assigned by the crash team were:
 - Selecting safe gaps when turning across or crossing traffic at intersections (76%) worsened by high vehicle speed (40%) and traffic volume (40%)
 - High task complexity and the presence of other road users (50%)
 - Limited or restricted sight distances (34%)

Intersection Design Features

- The top three design features contributing to the level of risk of older driver crashes were:
 - Lack of separate signal phases to control movements in each turn lane (23%)
 - Restricted sight distance at right turns (23%)
 - Value <2.5s PRT for intersection sight distance (23%)
 - Inadequate perception-reaction time distance for the sight distance (23%)
- The other design features at issue were: sight distance and a lack of right-turn offsets for stop-control and right-turn, width of receiving lane and shoulder, lack of lane designation, unsuitable traffic signal lamps, insufficient sight for speed (ranging from 6% to 10%)
- Roundabouts instead of stop or yield signs reduce crash and injury risk.
- Where traffic signals exist, fully controlled left hand turning signals are recommended
- Longer sight distances can be achieved by
 - Removing vegetation, utility poles, etc. that obstruct the view of approaching traffic
 - Offset turning lanes
 - Gentle grades and horizontal alignment
 - Advance warning signs for intersections with poor sight distance
 - Speed reduction measures when approaching intersections

Strengths and Limitations

Strengths

- Comparison of relative crash risk between younger and older driver populations

Limitations

- Difference in exposure of younger and older drivers not considered in estimating crash risk

17. Parker, N.A., & Meja, M.S.J. (2003). Evaluation of performance of permanent pavement markings. *Transportation Research Record*, (1824), 123-132.

Keywords: Age groups; benefit cost analysis; life cycle costing; maintenance management; measurement; multiple regression analysis; new jersey; performance; public opinion; retroreflectivity; road marking materials; road markings; service life; striping; surveys; visibility

Abstract

“As an implementation strategy of the federal retroreflectivity standards requirement for pavement markings, the New Jersey Department of Transportation (DOT) evaluated its 3-year fixed-schedule restriping strategy, to determine if it is consistent with the actual service life of the pavement markings. The methodology and results of the study are presented. Two types of data were collected: measured retroreflectivity by using LaserLux and subjective ratings from a survey conducted with the participation of the New Jersey driving public along a 32-mi circuit. Multiple regression techniques were used to correlate the average scores reported by the study participants for each specific roadway section with the corresponding measured retroreflectivity. The results suggested that the threshold value of an acceptable vs. unacceptable level of retroreflectivity appeared to be between 80 and 130 mcd/m²/lux for New Jersey drivers younger than 55 and between 120 and 165 mcd/m²/lux for drivers older than 55. These results are consistent with conclusions reached by other investigators in similar research, where results generally ranged between 70 and 170 mcd/m²/lux. Interim visibility indices were developed for each age group per pavement-marking type. New Jersey DOT used the indices to determine and prioritize needs and to quantify needed related resources, on the basis of the threshold between acceptable retroreflectivity and unacceptable retroreflectivity, when it developed its pavement-marking management system. This approach also allows for cost-benefit and life-cycle analysis for different pavement-marking materials.”

Method

This study involved 72 participants. They were divided by age into groups with approximately 25% <33, 50% 33 to 55, and 25% >55 years of age. Each group had equal numbers of males and females. After a two hour orientation session participants drove their own cars which had been inspected for clean windshields and headlights after dark along New Jersey highways for 32 miles (51 km).

The test area consisted of 44 half-mile (.8 km) sections with retroreflectivity levels ranging for the whole course from 92.2 to 286.4 mcd/m²/lux. The sections consisted of yellow centrelines, white edge lines and skip lines which were marked with pavement marker spray to indicate the start of the section, post number and end of section. The course was relatively flat with horizontal curves ranging between 150 m (492 ft.) and 500 m (1,640 ft.) in radius.

The start of each section was marked using a cone with a reflector and the end of each section was marked with a cone without a reflector. As a participant entered each section, the interviewer asked them the question designated for that section. There was a selection of five responses to give to the question: very clearly visible (excellent), visible with no difficulties, visible with some difficulties, visible with great difficulties, and invisible. Questions “not directly related” to pavement marking visibility were asked in the off-sections in order to ensure the participants did not focus on pavement markings throughout the whole test area. Marking was considered “acceptable” if it was rated excellent or visible with no difficulties.

Main Findings

Effect of Age

- The threshold value at which 90% of drivers <55 rate the retroreflectivity as acceptable appears to be between 80 - 130 mcd/m²/lux
- The threshold value at which 90% of drivers >55 rate the retroreflectivity as acceptable appears to be between 120 - 165 mcd/m²/lux
- Participants >55 required retroreflectivity of at least 160 mcd/m²/lux for white skip lines and at least 165 mcd/m²/lux for yellow centrelines

Strengths and Limitations

Strengths

- On-road study

Limitations

- Only subjective measures used
- Participants completed the drive encountering the markers in the same order, no control for order of presentation.

18. Pietrucha, M.T., Hostetter, R.S., Staplin, L., & Obermeyer, M. (1996). *Pavement markings and delineation for older drivers. volume I: Final report* (Federal Highway Administration No. FHWA-RD-94-145). McLean, VA: U.S. Department of Transportation.

Keywords: Traffic markings; delineation; elderly drivers; literature surveys; deficiencies; laboratory studies; driving simulators; field tests; recognition distance; visual occlusion time; benefit cost analysis; recommendations

Abstract

"The objectives of this project were: (1) to identify the needs of older drivers and to evaluate the situations in which older driver performance might be improved through enhanced pavement markings and delineation; (2) to identify the range of potentially useful enhanced treatments; (3) to determine the effectiveness of those treatments judged to be most useful for the older driver; and (4) to assess the costs and benefits of the treatment shown to be most effective. Following a literature review to identify older driver deficiencies, 25 delineation/pavement marking treatments (including several "control" treatments) were identified for testing. A laboratory simulator study was used as a means to determine the most effective among the group. The treatments shown to produce better recognition distance, along with several control treatments, were then subjected to field testing. The field tests were conducted on a closed test track facility, and recognition distance and visual occlusion time were used as dependent measures. Of the 66 subjects who participated in the field study, half were over 65 years of age and half were 45 years of age or less. All subjects were involved in both types of measures. Following the field test performance assessment, the treatments were subjected to a cost benefit analysis and recommendations were made regarding the treatments that could benefit older drivers."

Method

Simulator

In order to screen treatments to test in the field 25 treatments (including a control) were tested in a driving simulator. Delineation treatment and driver age (15 people in each group: 18 to 45, 65 to 74 and over 74) were independent variables with headlight position (low, high) as a blocking variable. The control treatment was always the first treatment and low beam was always before high beam sequences. Following that, the low and high beam blocks were further divided into one of two possible sequences of treatments. "The primary dependent measure...was downstream roadway feature recognition." The film was "pushed one stop during processing to present brighter images of the nighttime driving scene."

Participants experienced a speed of 56 km/h (35 mph) and depressed the brake pedal when they were 100% certain of the downstream feature. Each treatment was subjectively rated with respect to how effectively it indicated curve direction relative to the baseline treatment. Drivers performed a tracking task involving keeping a red laser light on the centreline.

Twelve of the pavement marking and delineation treatments were selected from the simulator evaluation and "partly on engineering judgment."

Test Track

The field test was conducted on a closed test facility. Recognition distance and visual occlusion time data were captured electronically. There were 33 younger (18 to 45 years old) and 33 older (over 65 years old) participants exposed to 8 treatments (2 baseline with left and right curve plus 6 treatments) each. A balanced incomplete block design was used taking balance into account within blocks: young and old, the direction of curvature and the order of treatments were randomized.

The treatments were stored off track and changed by placing them on the roadway, ones with enough weight were placed on the road, while "lane-line tape was mounted on flat black boards and were laid end to end for the appropriate length."

Recognition distance testing occurred in pairs. The vehicle driven by the experimenter started 305 m (1,000 ft.) away from the curve and was stopped every 30.5 m (100 ft.) away from the curve for a response. Each participant used answer buttons to indicate the direction of the curve ahead: left, right and "don't know". When the participants answered two consecutively correct responses, the trial was ended. The testing was done statically in order to remove potential confounding regarding decision making time of older drivers.

Visual occlusion testing was performed with the participant driving the test vehicle at a speed of 48 km/h (30 mph) (set on cruise control 305 m (100 ft.) away from curve). The experimenter lowered the shield at 128 m (420 ft.) from the "PC of the curve" and the participant was to press a button to raise the shield when they felt uncomfortable about the location of the curve they were approaching.

After each trial in both tests, the participants rated (1 to 100) the effectiveness of each of the treatments relative to the baseline treatment for indicating the direction of the curve. The participants responded within 45 seconds after the curve recognition response.

Main Findings

Simulator Results

- The results from the high beam illumination condition were not reliable. The low beam illumination resulted in "consistently high proportions of correct responses" for all age groups, thus the "conclusions are based primarily on the low beam data.
- Treatments 15, 18, 19, 22, 23 and 25 were significantly better than baseline for the two older groups of participants
- The subjective ratings did not relate to the objective ratings and were not used to determine what treatments to use in the field studies; however, a suggested improvement to the subjective method or the field study was to include a photo of the baseline treatment for the field comparisons

Field Results

- Recognition distance
 - An ANOVA of the recognition distance revealed treatment, age group, subject, curve direction and the interactions of treatment/curve and treatment/age were significant ($p \leq 0.0571$).
 - ANOVA with only the older group and recognition distance showed treatment, subjects and the interaction treatment/curve ($p \leq 0.0564$)
 - Comparing the older group to younger group by treatment for recognition distance reveals older participants had shorter distances on all but one of the treatments (treatment 1)

- Visual occlusion
 - Confounded by participants' risk-taking behaviour as they knew that there was no cross traffic and that the car was equipped with a second brake controlled by the experimenter. The authors conclude that the visual occlusion gives "little basis for choosing the most adequate treatments for older drivers."

Study Conclusions & Recommendations

- Overall treatments 5 (yellow centreline with chevrons), 10 (yellow centreline with high intensity T-posts), 11 (yellow centreline, centreline RPMs and high intensity T-posts) and 12 (yellow centreline, white edgeline and engineering grade T-posts) were the highest ranked objective and subjective data sets (for both the simulator and field studies). Treatment 12 and 10 were selected as the best overall in performance (for older and younger drivers) and consistency in their rankings.

Cost/Benefit Analysis

- Treatment 10 had the lowest estimated cost over a 10-year period

Overall Conclusions & Recommendations

- Treatment 10 did not have edgelines; however, treatment 12 does and it had the "highest overall recognition distance values for both age groups"
- "To meet all of the guidance needs of the older driver, i.e., both long preview and moment-to-moment tracking, treatment 12 is the logical recommendation [yellow centreline, white edgeline and engineering grade T-posts]."

Strengths and Limitations

Strengths

- Substantial range of delineation treatments were tested with three age groups

Limitations

- Testing did not address lateral position of vehicle on roadway
- Testing did not address impacts of improved delineation on driver speed choice

19. Potts, I., Stutts, J., Pfefer, R., Neuman, T.R., Slack, K.L., & Hardy, K.K. (2004). *Guidance for implementation of the AASHTO strategic highway safety plan. volume 9: A guide for reducing collisions involving older drivers* (NCHRP No. NCHRP500V9; PB2004106504). Washington, D.C.: Transportation Research Board.

Keywords: Highway safety; aged drivers; elderly persons; accident reduction; motor vehicle accidents; accident prevention; motor vehicle operators; implementation; strategies; fatality prevention; populations; transportation safety; highway design; traffic control; AASHTO Strategic Highway Safety Plan

Abstract

"The six major areas of the AASHTO Strategic Highway Safety Plan – Drivers, Vehicles, Special Users, Highways, Emergency Medical Services, and Management – are subdivided into 22 goals, or key emphasis areas, that impact highway safety. One of these goals addresses the reduction of crashes and fatalities involving older drivers. This implementation guide provides engineering, planning, education, and policy guidance to highway agencies that desire to better accommodate older drivers special needs. Older drivers represent a subset of the driving population that deserves special attention. Aging affects a variety of skills needed for safe driving. In particular, the aging population experiences deterioration in physical, perceptual, and cognitive skills: reductions in strength, flexibility, and range of motion caused by arthritis or other conditions can negatively impact driving; many visual functions--including static and dynamic visual acuity, contrast sensitivity, and glare sensitivity--deteriorate with age; and normative aging most often affects cognitive changes, such as working memory, selective attention, and processing speed."

Method

"This implementation guide provides engineering, planning, education, and policy guidance to highway agencies that desire to better accommodate older drivers' special needs." Design improvements are integrated as part of an overall plan. The other supporting measures in design for older drivers were to plan for the aging population, identify older drivers with a higher probability of collisions and intervene, improve older driver competency, and reduce the risk of injury to older drivers and passengers involved in collisions. The research supporting each strategy targeting older drivers was collected with reviews of reference materials, interviews/surveys, workshops and symposiums, and pilot testing.

Main Findings

Suggested Strategies

Application Characteristics of AASHTO Road Design Strategies for Older Drivers

Road Design Improvement Strategies	Strategy Type*: Proven, Tried, and Experimental	Time Frame**: Short (<1yr) Medium (1-2yrs) Long (>2yr)	Relative Cost***: Low, Moderate and High
Replace painted channelization with raised channelization	P	M	M
Provide advance warning signs	T	S	L
Provide advance guide signs and street name signs	T	S	L
Increase size and letter height of roadway signs	T	S	L
Provide all-red clearance intervals at signalized intersections	T	S	L
Provide more protected left-turn signal phases at high-volume intersections	T	S	L
Improve roadway delineation	T	S	L
Improve traffic control at work zones	T	M	L
Provide offset left-turn lanes at intersections	T	M	M-H
Improve lighting at intersections, horizontal curves, and railroad grade crossings	T	M	M-H
Reduce intersection skew angle	T	M	M-H

**Strategy Type*

- Proven strategies have shown to be effective through testing showing their effectiveness in at least one location
- Tried strategies have been used and/or set as standards in a multitude of locations yet do not have sufficient studies supporting their use. There is a low probability of a negative impact on safety and a high probability of a positive one.
- Experimental strategies show promise and are being pilot tested in at least one location

***Time Frame*

- Depends on factors such as:
 - The agency's procedures
 - The need for additional right-of-way
 - The number of stakeholders involved
 - Policies and legislative issues

- Presence of any controversial situations

*****Relative Cost**

- The costs are relative to the other strategies in the table and are dependent on similar factors as in the Time Frame
- Costs are based on the most common use of the strategy “especially one that does not involve additional right-of way or major construction, unless it is an inherent part of the strategy”

Strengths and Limitations

Strengths

- Practical considerations regarding resources
- Separation of strategies as to whether they are proven or simply tried

20. Staplin, L., Lococo, K., Bylington, S., & Harkey, D. (2001). *Guidelines and recommendations to accommodate older drivers and pedestrians* (85D Transportation: Transportation Safety; 85H Transportation: Road Transportation; 92C Behavior & Society: Social Concerns No. FHWARD01051; PB2001108785). Arlington, VA; United States: Scientex Corp.

Keywords: Elderly persons; motor vehicle operators; pedestrians; highway design; highway operations; human factors; vision; attention; perception; cognition; driver age; hazard perception; safety; driver performance; memory; physical ability; risk perception; hazard perception

Abstract

"This project updated, revised, and expanded the scope of the Older Driver Highway Design Handbook published by the Federal Highway Administration (FHWA) in 1998. Development of the updated Handbook (FHWA-RD-01-103) was complemented by a technology transfer initiative to make practitioners aware of the Handbook and assist in applying its recommendations. This effort included the development of a condensed document presenting recommendations and implementation guidelines only, plus printed and electronic materials supporting the conduct of practitioner workshops throughout the United States in the 1999-2001 period. Consistent with the full Handbook, this Guidelines and Recommendations document incorporates new research findings and technical developments and extensive feedback from State, county, and municipal engineers who reviewed and applied recommendations is included, as well as codes that indicate at a glance the relationship of each recommendation to standard design manuals, including the Manual on Uniform Traffic Control Devices and the American Association of State Highway and Transportation Officials."

The Handbook is available at <http://www.tfhr.gov/humanfac/01105/01-051.pdf> and is described as follows:

The main body of the Handbook is organized according to five broad site types, each containing one of more specific roadway features with associated design elements. The top priority is *at-grade intersections*, reflecting older drivers' most serious crash problem area. Next, older driver difficulties with merging/weaving and lane changing operations focus attention on *inter-changes (grade separation)*. *Roadway curvature and passing zones* plus *highway construction/work zones* are included for two reasons: (1) heightened tracking (steering) demands may increase the driver's workload, and (2) there is an increased potential for unexpected events requiring a swift driver response. Finally, *highway-rail grade crossings* are identified as sites. Recommendations for all design elements covered in the Handbook are presented initially, followed by a more lengthy section presenting the Rationale and Supporting Evidence for each recommendation. The recommendations in this *Handbook* are based on supporting evidence drawn from a comprehensive review of research addressing human factors and highway safety.

Table of Contents for Design Guideline Recommendations

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21. Tarawneh, M.S., Rifaey, T., & McCoy, P.T. (1998). Effects of intersection geometrics on driver performance. *Transportation Research Record (1579)*, 43-52.

Keywords: Age; junction; layout; cross roads; staggered junction; durability; turn; radius; driver; skill; road user

Abstract

"The results of a study to determine the effects of intersection geometrics on driver performance are presented in this paper. The specific geometric features evaluated were: (1) the offset between opposing left-turn lanes, (2) the degree of right-turn lane channelization, and (3) the right-turn curb radii. The study involved the observation of left-turn and right-turn maneuvers of 200 test subjects at 11 signalized intersections with differences in the geometric features of interest. The 200 subjects were nearly equal numbers of male and female drivers in three age groups: (1) 25 to 45 years, (2) 65 to 74 years, and (3) 75 years and older. The results of the research indicated that left-turn lane offsets of zero or larger are particularly beneficial to older drivers. Also, the right-turn performance of older drivers was found to be less sensitive than that of younger drivers to the differences in right-turn lane channelization, and the effects of right-turn curb radii was similar for all age groups. Therefore, the performance of older drivers at signalized intersections would be benefited most by increasing the offset between opposing left-turn lanes."

Method

Three studies were conducted in real-world conditions. Two pools of 100 participants were grouped into three age groups: middle (25 to 45 years), old (65 to 74 years) and older (75 years and older). Participants drove their own vehicles on arterial streets in Arlington, Virginia during the weekday between 11:00 a.m. and 3:00 p.m. starting with one practice trip, followed by three test trips. The posted speed limit was 56 km/h (35 mph).

The first study involved left turn lanes at four intersections with lateral offsets of -4.3, -0.9, 0 and 1.8 metres. The first pool of participants consisted of 33 middle, 37 old and 30 older drivers. A video camera recorded the test vehicle as well as vehicles in the opposing left turn and through lanes at the intersections. The camera had a time/date generator that was accurate to the nearest 0.01s. A grid drawn on the ground showed vehicle turn lane positioning data that was observed and recorded by an experimenter on site. The performance measures follow:

- These measures were calculated when the left turn was made with one vehicle in the opposing direction turn lane and the participant's vehicle was positioned within the intersection.
 - "Critical gaps" were defined as having a 50/50 chance of being accepted or rejected
 - "Clearance times" were defined as the amount of time to clear the intersection from a stopped position in the left turn lane
 - "Positioning" was defined as the location in the intersection where the participant waits for a gap in opposing traffic
- "Percentage positioned left turns" were measured as the percentage of vehicles that positioned themselves in the intersection to wait for a gap
- "Turning difficulty" was measured as the response to the question "Based on your experience making left turns at other intersections (other than the study intersections), under similar traffic conditions, the turn at this intersection was: (a)

more difficult than usual, (b) easier than usual, or (c) no different – about the same as usual.”

The second study used three intersections with curve radii of 4.6, 7.6 and 12.2 metres for testing the right-turn curb radii. The second and third studies used the second pool of participants consisting of were 33 middle, 37 old and 30 older drivers. A grid on the ground showed vehicle turn lane positioning data. Measures used for the right turn radii were:

- “Entrance distance” was measured as the distance from the right front wheel and the curb at the beginning of the curve
- “Centre distance” measured as the distance from the right front wheel and edge of the curb from centre of the curb
- “Exit distance” was measured as the radial distance from the right front wheel and the edge of the curb from the end of the curve on the cross street
- “Free-flow speed” measured at the centre of the curb as the time between the right front tire and the rear tire cross the centre reference line using vehicle wheel base lengths (measured for each participant’s vehicle)

The third study, with the same participants as the second study, used four intersections to test right turn lane channelizations including:

- One 65 degree unfavourable skew (traffic is approaching from left at 25 degrees behind perpendicular), with channelized right turn, no acceleration lane
- One 90 degree without channelization, no acceleration lane
- One 90 degree with channelization, no acceleration lane, yield sign, same radii as 4th
- One 90 degree with channelization and an acceleration lane in the cross street

An experimenter riding along with the participants collected the following data:

- Search patterns, including:
 - Percentage attempt at right turn on red (RTOR) involved participants continuously turning their heads and looking in the side mirror to attempt the turn
 - Percentage of drivers not using side mirrors in attempting a RTOR was considered when participants only turned their heads
- Percentage of drivers who made RTOR
- Percentage of drivers who made RTOR without a complete stop
- Free-flow speed
- Subjective turning difficulty

Main Findings

Left Turn Lanes

- The oldest drivers had significantly longer critical gap sizes than the other two groups (which were not significantly different from each other) in a Tukey test after the ANOVA ($p=0.0001$)

- The oldest drivers were significantly less likely to position their vehicle within the intersection as compared to the other two groups ($p=0.0001$). Men were more likely to position their vehicle within the intersection than women ($p=0.0054$).

Right Turn Radii

- All factors and interactions were significant regarding free-flow speed (ANOVA, $p=0.0001$) and trends were not clear
 - Trends observed:
 - Mean speeds tend to decrease with age and increase with curb radius
 - Middle and old drivers turn right at similar speeds

Right Turn Channelization

- The older group (17%) had significantly fewer attempts at RTORs than the other two groups ($p=0.0001$). A Tukey test showed all age groups were significantly different from each other. Males had significantly higher percentages of attempts than females ($p=0.0014$).
- The older group used their side mirrors significantly less than the other two groups when making RTORs (Tukey). There was no difference in side mirror use between middle and old group ($p=0.0006$). The interaction of age and location was significant ($p=0.0069$).
- The older group (15%) made fewer RTORs than old (36%) and middle (80%) drivers. All three age groups were significantly different from each other (Tukey) (overall mean=45%, $p=0.0001$). Females were less likely to make a RTOR than males ($p=0.0124$). The interaction of age and gender was significant ($p=0.0336$). "Further, the gender effect was influenced by age."
- The older group (3%) made fewer RTOR without stopping than the old (25%) and middle (35%) drivers, and all three age groups were significantly different from each other (Tukey) ($p=0.0001$). Significantly fewer females made RTOR than males ($p=0.0246$). The interaction of age and location was significant ($p=0.0009$).
- A Tukey test showed the old and older drivers had a lower mean right turn speed (22 km/h) than the middle-age drivers (29 km/h) ($p=0.0001$). The interaction of age and location was significant ($p=0.0038$). The interaction of age and gender showed a difference between middle-age males and middle-age females with a "practically negligible" difference among the older age groups ($p=0.0001$).
- Subjective turning difficulty:
 - Turning difficulty was significant by location for the old ($p=0.001$) and older ($p=0.015$) drivers
 - Turning difficulty was significant by location for the old-age females ($p=0.031$) and older-age males ($p=0.001$)

Strengths and Limitations

Strengths

- Real world traffic situations with participants driving their own vehicles

Limitations

- Lack of comparable measures between the right turn radius and right turn channelization studies

22. Van Schalkwyk, I., Lord, D., Chrysler, S.T. & Staplin, L. (2007). Older drivers and roundabouts: Assessing traffic control feature characteristics through the use of focus groups and structured interviews. *Transportation Research Board 86th Annual Meeting*, Washington.

Keywords: Accident prone drivers; aged; comfort; drivers; focus groups; intersections; interviewing; operations; roundabouts; traffic control; traffic control devices; traffic flow

Abstract

"The objective of the project was to identify design elements of roundabouts that could be problematic to older drivers with a specific focus on traffic control measures. It introduces a new approach to the evaluation and pretesting of traffic control features through the use of video footage and animated videos.

Focus groups formed the first phase of the project, and structured interviews the second phase. Materials used in the project presented different alternatives from a driver's perspective within the road environment rather than using line drawings of signs in isolation. The animated videos were created by digitally manipulating photographs taken at 10-ft intervals.

Specific design elements that were pertinent to the concerns raised by participants included: advance warning signs; lane assignment and advance guide signs; channelization; yield treatment; directional signing; and exit direction signing. The structured interviews focused on the following elements: advance warning signs, roundabout lane assignment signs, directional signs (one-way indication), yield treatments, and exit treatments.

The use of video footage and animated video materials were successful in allowing participants to assess the measures within context. Specific findings of the study includes that the use of chevrons at the roundabout is discouraged, that a symbol be used on the advance warning sign rather than text, and that older drivers were confused by the yield line consisting of isosceles triangles pointing toward the approaching vehicles (aka. Shark's Teeth Yield Line Pavement Marking Symbols)."

Method

Focus Group

Four separate focus groups in Texas had a total of 41 participants over the age of 65. All participants had over 25 years of driving experience with 31 participants having used forms of traffic circles before. The participants discussed the characteristics of roundabouts, watched an instructional video and were then asked for their opinions (usefulness and concerns) regarding roundabouts. After that, videos and/or pictures and discussion of the following elements occurred: single/multi lane roundabouts; central islands; splitter islands/approach gore; warning and approach guide signs; entrance area signs and pavement markings; and exit direction signing.

Structured Interview

Thirty-one new participants were interviewed by the same experimenter in Texas and Arizona to evaluate 10 countermeasures for 5 design elements (advance warning signs, roundabout lane assignment signs, directional signs, yield treatments and exit treatments). Change from the base conditions in perceived comfort, confidence and safety were used to evaluate the countermeasures.

Interviews lasted 60 to 90 minutes with a fixed set of questions. Each participant was provided with instructions for using a roundabout and a description of roundabout attributes. The second part of the interview had comparisons of two or three alternatives for each design element and questions about the use of roundabouts. Throughout the interview, the interviewer recorded problems brought up by participants about the base condition or countermeasures. The authors noted the materials shown to participants were from the perspective that a participant would be unfamiliar with the roundabout site and its surroundings.

Main Findings

Focus Group

- Drivers' Concerns:
 - Safety impact of missing an exit
 - Understanding yield signs at entrance to the roundabout
 - Multilane roundabouts had a higher perceived crash risk than single lane
 - Guide signs needed to give adequate information ahead of time for lane selection
- Design elements:
 - Advance Warning Signs – The roundabout symbol was preferred over a sign with the words "Roundabout Ahead". Advance roundabout signs with the speed limit and advance signs showing the number of lanes in the roundabout were preferred by drivers.
 - Lane Assignment and Advance Guide Signs – Drivers preferred signs showing lane assignment (for multiple roundabout lanes) compared to signs showing street names exiting the roundabout. Choosing the proper lane was important to driver but they had difficulty understanding some of the signs (see example in Figure 1).



Figure 1: Left – Regulatory Lane Assignment, Right – Advance Guide Sign with Street Names (Difficulty Understanding)

- Channelization – Raised splitter islands without tall shrubs were preferred, some drivers preferred yellow pavement markings on the curb

- Yield Treatment – Drivers preferred yield signs placed on both sides of the entrance and a solid straight yield line. They were confused by the sign “CIRCLE HAS RIGHT OF WAY” and “shark’s teeth yield line” pavement marking symbols.
- Directional Signing – Drivers preferred chevrons or one-way signs used individually, not together
- Exit Direction Signing – Street name signs are preferred on the splitter island rather than prior to reaching the exit. Street name signs with an arrow pointing toward the exit were preferred over signs without the arrow. Drivers preferred guide signs used in combination with street name signs to help lane assignment and navigation. Some drivers thought consistency in signing would aid in navigating the roundabout.
- Other Safety Concerns – Drivers noted too much information was given on one sign and that there were too many sequential signs. Drivers preferred protected left turn signals over roundabouts. Drivers who responded positively to roundabout use had three issues: their familiarity with the driving environment, enough information provided before reaching the roundabout and concerns about other drivers’ speed in the roundabout.

Structured Interview

- Shark’s teeth pavement markings confused drivers. Adding the plaque “TO TRAFFIC IN CIRCLE” below the yield sign in the yield treatment with shark’s teeth pavement markings significantly increased drivers’ perceived level of safety, comfort and confidence ($p < 0.05$).
- Adding an arrow to exit street name signs on a splitter island significantly increased drivers’ perceived level of safety, comfort and confidence ($p < 0.05$)
- Drivers perceived no difference in safety between roundabouts and four-way stop controlled intersections or permitted left turn movements. Drivers thought that protected left turns were safer than roundabouts.

Strengths and Limitations

Strengths

- Consistency in interview structure and facilitator

Limitations

- Opinion rather than actual driving behaviour was measured

23. Zein, S., Dilgir, R., Rocchi, S., & Gibbs, M. (2006). *Alberta traffic safety guide to accommodate aging drivers* (Hamilton-Finn Road Safety Consultants Ltd. No. 4005.13) Retrieved from:
http://www.ama.ab.ca/images/images_pdf/TrafficSafetyGuideforAgingDrivers.pdf

Keywords: Elderly drivers; guidelines; work zones; interchanges/freeways; at-grade intersections; at-grade railway crossings; signing; pavement markings

Abstract

"Canadian data show that, even while overall fatal and injury collisions are decreasing, the involvement of aging drivers in these serious collisions has grown in terms of both proportion and frequency. Aging-driver involvement in collisions can be expected to continue rising as the aging "baby boom" generation forms an increasing proportion of the driving and general population. Canadian data also show that the elderly have substantially higher collision-related deaths per unit population than any other age group except those between 15 and 24. The higher fatality rates associated with older road users reflect the increased fragility of older persons.

Recent trends suggest that aging drivers will likely be travelling longer distances on low-hierarchy roads, usually considered the least safe parts of the transportation system. Given these trends, efforts to make the road environment responsive to the needs of aging drivers can be expected to be beneficial.

To help road agencies in Alberta to identify and implement road safety improvements aimed at assisting aging drivers, the Alberta Motor Association undertook the development of the Alberta Traffic Safety Guide to Accommodate Aging Drivers. The purpose of the Guide was to present a comprehensive list of traffic engineering practices that accommodate the visual, cognitive and motor changes that occur with the natural aging process. The Guide was released in 2006, and is currently the subject of training workshops being held throughout Alberta. While the practices consider the common limitations faced by aging drivers, they are expected to improve safety for all road users." (236 Gibbs, B.F. 2008, April)

Method

Nineteen documents regarding highway design for aging drivers were reviewed. The findings were organized into six categories: at-grade intersections, interchanges/freeways, road links, work zones, at-grade railway crossings, and other general enhancements.

A Stakeholder Committee consisting of "municipal or provincial seniors' groups and associations" and a Technical Review Committee consisting of "Engineering and Law Enforcement representative from various jurisdictions in Alberta" were formed. These committees then participated in a facilitated workshop to provide feedback by identifying, confirming and prioritizing safety enhancements to the roadway.

The information obtained from the literature review and workshop were compared against current standards and categorized as: most conservative design value among available standards, exceeds the current available standards, a device for which no standard currently exists, more widespread or consistent use of a device would be particularly beneficial where

little guidance currently exists, and specific design value where currently only general guidelines exist.

Main Findings

The report compiled a list of 136 enhancements (for 33 road elements) that improve traffic safety (see Table A-2). In the report, each enhancement has a graphic, reference to current standards, relationship to current standards and is coded as to whether it addresses geometric design and operation or traffic control. A sample enhancement description is shown in Figure 1. Related literature showing impacts on driver performance or safety are not provided. The authors cite the FHWA Older Driver Highway Design Handbook measures as the majority of the enhancements. Enhancements that were relatively low cost with high potential for effectiveness were identified as priority enhancements and are listed in Table A-3. Existing education strategies and enforcement strategies in Canada and the United States were briefly discussed.

Table A-2: Summary of Infrastructure Enhancements

NETWORK COMPONENT	ROAD ELEMENT	ENHANCEMENT TITLE
At-Grade Intersections	Channelization	Raised channelization
		Right-turn channelization signing
		Acceleration lane
		Curb type
		Pedestrian refuge island
		Marking, signing and illumination of pedestrian crosswalks
		Longitudinal lines at crosswalks
		Left-turn lane type
	Slotted (Single) Left-Turn Lane – Geometry, Phasing, Signing, and Delineation	Unrestricted sight distance
		Unrestricted sight distance for heavy trucks
		Positive left-turn lane offsets
		Protected-only phasing for left-turn lanes
		Wrong-way manoeuvre prevention at slotted left-turn lanes
	Traffic Control for Left-turn Movements at signalized Intersections	Protected-only operation
		Separate signal heads
		Provide R10-12 sign for protected-permitted operations
		Repetitive YIELD ON SOLID GREEN sign
		Leading protected left-turn phase
		Protected left-turn signal indication
	Traffic Control for Right-Turn/RTOR Movements at signalized Intersections	Double red signal indication
		Signal indication
		Right-turn prohibition signing
		Pedestrian warning sign

NETWORK COMPONENT	ROAD ELEMENT	ENHANCEMENT TITLE
	Street Name Signing	Consistent sign placement
		Overhead placement of street-name signs
		Post-mounted signs
		Mixed-case overhead-mounted signs
		Overhead-mounted borderless signs
		Advance intersection warning sign
		Decorative signs
		Repetitive signing
		Crossroad signing
		Sheeting material
		Use of abbreviations
	STOP and YIELD Controlled Intersection Signing	Minimum sign sizes
		Reflectivity level
		STOP AHEAD sign
		STOP line
		STOP line sign
	Traffic Signals	Transverse rumble striping or rumble strips
		Signal heads
		Signal head placement
		Secondary signal heads
		Tertiary (auxiliary) signal heads
		Backboards
		Pedestrian signal heads
		All-red clearance interval
		Increase intergreen time
		Advance warning flashers for traffic signals
	Roundabouts	Entrance and exit lanes
		Pedestrian crossings
		Raised splitter islands
		Curb treatment
		Roundabout signing
	Skewed Intersections	Intersection angle
		Right-turn prohibition
	Turning Lanes	Separate left-turn lane

NETWORK COMPONENT	ROAD ELEMENT	ENHANCEMENT TITLE
		Minimum receiving lane (throat) width for turning operations
		Perception reaction time
	Intersection Sight Distance and Crossing Requirements	Traffic-activated warning system
	Curb Radius	Corner curb radius
		Tapers and compound curves for heavy vehicle accommodation
	Illumination Installations	Illumination at intersections
		Lamp maintenance
	Treatments/Delineations of Edgelines, Curbs, Medians, and Obstacles	Curb side and surface delineation
	One-Way/Wrong-Way Signing	Divided highway signing
		ONE-WAY sign placement at medians <9m wide
		ONE-WAY sign placement at median 9 to 13m wide
		ONE-WAY sign placement at T-intersections
		ONE-WAY sign placement at one-way/two-way intersections
		DO NOT ENTER and WRONG WAY signs
	Devices for Lane Assignment on Intersection Approach	Lane-use control signs
		Advance lane-use arrow pavement markings
Interchanges/Freeways	Exit Signing and Exit Ramp Gore Delineation	Legibility distance
		Exit speed sign and location
		Diagrammatic guide signs
		Exit gore delineation
		Object marker
	Acceleration/Deceleration Lane Design Features	Acceleration lane length
		Acceleration lane design
		Exit ramp delineation
		Exit ramp location
	Interchange Lighting	Interchange lighting
	Traffic Control devices for restricted movement	Lane control signal indications
		Prohibited movement signing
		Wrong-way arrow pavement marking
		Signing at entrance ramps
		Crash attenuators (cushions)
Road Links	Delineation on Horizontal Curves	Raised pavement marker spacing/centreline rumble strips

NETWORK COMPONENT	ROAD ELEMENT	ENHANCEMENT TITLE
		Chevron alignment signs
		Post-mounted delineation device spacing
	Pavement Width on Horizontal Curves	Lane and shoulder width
	Vertical Curves	Stopping sight distance
	Passing Zone Length, Passing Sight Distance and Passing/Overtaking Lanes on Two-Lane Highways	Passing sight distance
		Passing/overtaking lane intervals
Work Zones	Lane Closure / Lane Transition Practices	Flashing arrow panels
		Advance signing for lane closures
	Variable Message Sign (VMS) Practices	Variable message sign phasing
		Phase duration
		Single phase information display
		Two phase information display
		Two phase split information display
		Variable message sign pixels arrangement
	Channelization Practices (Path guidance)	Channelizing device dimensions
		Channelizing device spacing (non-crossover application)
		Side reflector spacing
	Delineation of Crossovers / Alternate Travel Paths	Concrete barriers
		Channelizing device spacing
	Temporary Pavement Markings	Raised pavement markers
At-Grade Crossings	Railway Passive Crossing Control Devices	Grade crossing signing
		Grade crossing illumination
		Grade crossing delineation
Other General Recommendations	Pavement Markings	Durable pavement markings
		Wider pavement markings
	Signing	Highly reflective sheeting material
		LED technology
		Warning of surface change
		Minimum 20/70 visual acuity
		Educational tabs for warning signs
		Mixed-case font
		Clearview font for guide and information signs
	Rumble Strips	Shoulder (grooved rumble strips)

Table A-3: First Priority Enhancements

NETWORK COMPONENT	ROAD ELEMENT
At-Grade Intersections	Channelization
	Slotted (Single) Left-Turn Lane – Geometry, Phasing, Signing, and Delineation
	Traffic Control for Left-turn Movements at signalized Intersections
	Traffic Control for Right-Turn/RTOR Movements at signalized Intersections
	Street Name Signing
	STOP and YIELD Controlled Intersection Signing
	Traffic Signals
	Roundabouts
Road Links	Delineation on Horizontal Curves
Work Zones	Lane Closure / Lane Transition Practices
	Variable Message Sign Practices
	Channelization Practices (Path guidance)
	Delineation of Crossovers / Alternate Travel Paths
	Temporary Pavement Markings


AT-GRADE INTERSECTIONS	
A. SKEWED INTERSECTIONS	
A.2 Right-Turn Prohibition	
<p>ENHANCEMENT</p> <p>At skewed signalized intersections where the approach leg to the left intersects the driver's approach leg at an angle of less than 75 degrees, the prohibition of right turn on red (RTOR) is recommended.</p> <p><i>Enhancement provides more specific guidance than current standards.</i></p>	 <p>RIGHT TURN ON RED PROHIBITION AT SKEWED INTERSECTIONS</p>
CURRENT STANDARDS	
<u>MUTCDC [Section A2.4.7]</u>	<u>The City of Calgary, Traffic Control Policy Manual [Page 1-1-27]</u>

Figure 2: Sample Infrastructure Enhancement

Strengths and Limitations

Strengths

- Comparisons and relationships with existing guidelines are provided.

Limitations

- Related literature showing impacts on driver performance or safety are not provided

APPENDIX B

STAKEHOLDER INTERVIEWS

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Ms. de Grasse's background is highway infrastructure. In general, her view is that there has been much infrastructure spending on mobility and capacity building but that there is a need to spend to improve safety not just mobility. The World Bank has proposed that 10% of the investment in a roadway should be targeted to road safety. This may be high for Canadian decision makers, but the problem is that currently there is no particular target.

Transport Canada would like to see jurisdictions implementing pilot projects targeted to improving ease of movement for older drivers. We are currently funding an international countermeasures project and will be presenting the top ten to the engineering research and support committee. We are recommending that they implement one or some of these as pilot projects. They would benefit all drivers including the aging populations.

Older drivers have problems with complex locations especially in high speed areas, and would benefit from better delineation and channelization in intersections. For example, older drivers have problems finding the beginning of a left turn lane. Older drivers are over-represented in intersection crashes involving failure to yield, and this can be due to not knowing that they were required to yield. With respect to the over-representation in intersection crashes, Ms. de Grasse offered to look for information on exposure of older drivers to intersections, since their greater exposure might in part explain the over-representation.

Older drivers also experience difficulties with acceleration and merging lanes. Merging is an issue because older drivers drive more slowly and take longer to merge. Their slow driving can also lead to frustration by other road users and so another project deals with improvements in passing sight distance to give other drivers more opportunity to pass older drivers.

I then asked Ms. de Grasse about roundabouts, road sections and work zones. With respect to roundabouts, Ms. de Grasse was very positive about their safety impacts but noted that they are confusing to many drivers, especially older drivers. A sign of confusion is loss of control crashes when drivers do not reduce speed and hit the centre island. There is now a project at the Transportation Association of Canada to standardize signing and marking for single and multi-lane roundabouts. Older drivers especially need clear guidance and advance warning in complex areas such as roundabouts. Roundabouts are increasing popular, but are not always appropriately implemented. Warrants are needed to ensure they are implemented appropriately.

With respect to road sections, Ms. de Grasse noted that older drivers needed improved delineation of lanes. They need better guidance in curves, by means of high visibility markings, such as chevrons. They need better sight distance and warning signs of upcoming conditions.

With respect to work zones, Ms. de Grasse noted the need for better visibility of jersey barriers, better visibility of cones, and better delineation.

Overall, Ms. de Grasse is of the opinion that design factors are considered well in high traffic areas but older drivers more likely to travel on lower class roads where there are more conflict points and at-grade intersections, and where the older driver's poorer judgment of speed of approaching vehicles comes into play. When asked about whether older drivers might appreciate photo radar to reduce traffic speeds and driving stress, Ms. de Grasse stated that she thought they would, and that she thought it was an excellent safety tool but that politicians are reluctant to implement it. She noted that older drivers want to follow the rules and would be very accepting of photo radar. She agreed that the current concern over gasoline prices might make photo radar more palatable.

DAVID DUNNE

British Columbia Automobile Association (BCAA) Traffic Safety Foundation

With respect to traffic safety risk, it is important to look at different road situations, e.g. urban/rural/ parking areas and at different types of drivers since seniors are not a homogeneous group and face different challenges depending on their limitations (none, cognitive, physical, multiple). Initiatives need to be designed for seniors who can and wish to continue driving, and also for seniors who need to start driving cessation. Improvements are needed to help traffic flow and to make driving a more enjoyable experience. Most changes can benefit all drivers, not just seniors.

An important infrastructure element relating to risk for seniors is the design of left hand turn lanes in suburban/urban intersections. Sightlines are sometimes poor – left turn bays need to be offset. Protected signals should be used more often especially at high risk intersections. Advance signals are non-existent in many intersections. It may be advisable to limit sections with no left turn lanes, particularly where there are three lanes of traffic per direction. BCAA advises seniors to take three rights and plan routes that minimize or eliminate left hand turns (particularly at dangerous intersections) – note that courier companies design routes to minimize left turns since they waste time and fuel while drivers wait.

At intersections seniors face pressures to make judgments and responses quickly. Advanced warning signals (AWS) indicating the light is about to change are helpful. Mr. Dunne was not aware of long distance detection technology but thought it would be helpful to all drivers as well as seniors.

For night driving, seniors need more visible road signs and markings, especially street name and guide signs. Trying to locate and read signs can be distracting. Seniors need oversized brighter red traffic lights since this part of their visual spectrum disappears.

While roundabouts can be confusing, they do limit the potential for angle collisions, and the consequences of accidents in roundabouts are less catastrophic.

Parking can be a challenge especially with new aerodynamic vehicles, where one can not see the end of the vehicle, resulting in bumpers being caught. The difficulty is exacerbated by tight parking spaces. Another concern is that handicapped parking is closest to the areas with the high pedestrian activity and seniors who need to back out and find shoulder checks difficult present a risk to pedestrians. Although BCAA recommends pulling through to pull out, this is not always possible.

A frequent concern in Victoria is right hand turns with bicycle lanes. When seniors neglect shoulder checks, conflicts with bicycles result. The variation in modes of transportation is increasing, e.g., bicycles with electric engines which go up to 30 km/h mixed with standard bicycles make the driving environment more complex. The marked bicycle lane can give a false sense of security to bicyclists.

On highways, longer merge lanes are needed, especially in urban areas. Bridges can limit the length of lane available. In some situation drivers must start from a standing start and get up to high speed.

Work zones have been identified as a concern but not specifically by seniors. Rail crossings have not been raised as a concern. Splash in wet weather conditions related to being passed by larger vehicles may be a concern for seniors. Certain pavement surfaces seem more prone to this problem.

The highest priority infrastructure improvements would be urban intersection improvements to ease left hand turns in particular. In addition larger brighter traffic lights are needed. On rural highways, merging lanes are inadequate. At night, seniors have difficulty with glare, especially from new after market headlights which don't meet government specifications.

On rural highways rumble strip warnings are very beneficial not only to older drivers who may be susceptible to fatigue, but for all drivers.

Over 7,000 seniors have attended BCAA workshops. The message to seniors is that they have to cope with a lot of bad engineering and they are more vulnerable to it than others. This takes some of the pressure off seniors who feel traffic safety problems are their fault. Seniors are encouraged to develop a safety bubble, choose cars that fit them, use safety features, recognize routes vary in safety, use safer travel times and routes (e.g., freeways vs. undivided highways), plan route to not turn left.

Seniors feel considerable pressure to keep up with traffic and generally would support reductions in speed. Mr. Dunne agreed that they might support photo radar for this reason. They are often pushed outside of their comfort zone by aggressive drivers. This exacerbates other problems leading to bad judgments.

Seniors would benefit from more practical warnings in relation to weather and road conditions. A more specific description of when it is not safe to travel would allow them to make better decisions, e.g., risk of an accident is so many times higher in these conditions. Older drivers have more flexibility as to when and if they travel as compared to other drivers and such information would be valuable.

One additional concern is pedestrian safety. This is a significant concern as a disproportionate number or percentage of seniors are injured or killed as pedestrians. Greater visibility, lighting, markings, and signage indicating drivers are entering a pedestrian crossing, as well as removing and/or limiting driver distraction and increasing pedestrian visibility would also contribute to increased safety.

While it is not an official position of BCAA, expanded 30 km/h or 40 km/h zones in urban/residential areas with greater concentrations of pedestrians may be effective in reducing pedestrian/bicycle incidents or minimizing their consequences. A speed of 50 km/h (which in reality translates into 70 km/h) is quite fast for urban and residential areas considering reaction time and stopping distance (and increased likelihood of surprise encounters with cyclists and pedestrians). This would benefit both older drivers, by reducing speed. In addition, it would benefit older pedestrians, who need more time to safely navigate an intersection or crosswalk, before a speeding, distracted driver appears.

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Ms. Libman has worked for CARP since 1988, and at 80 years of age is a senior driver who has been driving for a long time. She interacts with senior drivers who call CARP with respect to traffic safety concerns, especially in regard to test requirements. With respect to what infrastructure changes seniors would they most benefit from, Ms. Libman said that merging onto a freeway can be a problem to the point that some older seniors do not drive on freeways. The main concern is that some acceleration lanes are too short, giving drivers insufficient time to merge. Being able to exit the highway comfortably is also important. At highway speeds long distances are required to change lanes. In construction zones (south at the 427 south to the Gardiner), drivers are sometimes asked to change lanes to exit very suddenly.

With respect to driving in rural areas at night, the most seniors are probably not doing this. However, some must and so lights at intersections would be helpful as would advance signs warning of situations such as bridges.

Ms. Libman did not feel that seniors had any problem understanding traffic signals. She felt that more dedicated left turn lanes would be helpful, and that having a protected left turn signal would be ideal.

Street signs are sometimes missing or absolutely invisible. Major streets need an advance sign. Signs need to be visible enough to be seen at night.

With regard to where money should be spent on infrastructure, Ms. Libman suspects that there is more driving by seniors in cities, so street signs and traffic signals are important. High design standards for highways are important (Highway 407 is a good example).

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With respect to priority of infrastructure changes for older drivers, signage would be the first priority. In Alberta particularly drivers encounter a great variety of signage. Improving signage is easier and less costly than other infrastructure changes. Improving signage would be a quick and easy win for older drivers and would also benefit other drivers.

Another opportunity for infrastructure change is that jurisdictions usually have mechanisms (e.g., in service reviews or road safety audits) for identifying problems with current infrastructure, e.g., potentially confusing design, such as an atypical intersection with five corners or on a skew, which may be particularly difficult for older drivers (e.g., requiring difficult shoulder checks, or overwhelming the driver with choices).

A third concern is the need for high speed corridors to be designed to facilitate entry (availability of gaps and ability to get up to speed) and exit (sufficient distance to change lanes prior to the exit).

When asked about implementation of protected left turns, Mr. Wilson responded positively but had not mentioned them because it is taken for granted that drivers would like that. Channelization at intersections is also helpful for older drivers.

Roundabouts are beginning to be implemented in Alberta and overall these are expected to be very beneficial. There are some with too much signage, and some where traffic lights are used, which increases complexity. Roundabouts are working well. Mr. Wilson did not know of any issues with older drivers although there may be. Roundabouts are a bit of mystery for all drivers, so education campaigns such as have been offered by local municipalities are important.

As the “age wave” approaches, even Alberta, which has a lower age than the rest of the country, needs to provide augmented transportation that is accessible and sustainable for those who no longer drive. There will be challenges in providing transit that address driver differences, such as urban versus rural needs, and which address the specific needs of older drivers, e.g., door-to-door services.

The Alberta Traffic Safety Guide to Accommodate Aging Drivers funded by AMA, has been submitted to the Transportation Association of Canada (TAC) and is being considered for a national standard. Another group (Next Solutions) is developing an on-line tool based on this guide to provide road safety training for engineers. The Centre for Transportation Engineering and Planning (CTEP) is also using this report.

With respect to next steps, the AMA feels they have done their part, but plans to work with consultants and CTEP in their work with Transport Canada to get them to endorse this guide as best practice which would legitimize the guide at the federal level.

The AMA would be interested in attending a workshop of stakeholders on infrastructure change and anticipate that the provincial ministry of transportation would be interested and could talk

about what they are doing. In Mr. Wilson's experience, associations of seniors and retired persons are more interested in expanded and accessible transportation choices, not just transit necessarily, but may be interested in infrastructure changes for older drivers as well.