Critical Review and Analysis of the Impact of the Physical Infrastructure on the Driving Ability, Performance, and Safety of Older Adults

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KEY WORDS
• driving
• infrastructure
• older drivers
• roadway design

Literature on the impact of physical infrastructure on older adult safe driving performance was reviewed in 2005 as part of the American Occupational Therapy Association’s Evidence-Based Literature Review Project. Existing guidelines for driving environments, related to changes in visual, cognitive, and psychomotor abilities associated with the aging process (as published in the Highway Design Handbook for Older Drivers and Pedestrians, Federal Highway Administration, 2001), are exhaustive, but the authors made no attempt to critically assess the strength of the study design or level of evidence. In laboratory studies since 1999, the interventions lacked applicability to real-life driving environments. Further investigation of the effectiveness of best practice interventions and how the driving environment can better accommodate the needs of older drivers is needed. Occupational therapy interventions that focus on the occupation of driving and compensation and education strategies that allow older adults to drive safely as long as possible are included.


As the population of older Americans continues to grow, an increasing number of drivers ages 65 or older will be using U.S. roadways. This increase has implications for road safety because evidence from crash statistics has indicated that elderly drivers are at higher risk for collisions per distance traveled than younger drivers (Wood, 2002). Many studies have investigated aspects of driving performance in older drivers to try to explain the differences in crash statistics, but the reasons are not clearly evident. Age-related changes in vision, cognition, and mobility and medical conditions most often are associated with the increased risks. The problem seems to be compounded when driving environments become more cluttered or complex.

Understanding how environmental influences facilitate or inhibit safe performance in driving for older adults may provide insight for developing intervention strategies that will allow them to drive more safely. Engagement in occupation to support participation in context is the objective of occupational therapy intervention (American Occupational Therapy Association [AOTA], 2002). Thus, occupational therapy is ideally positioned to identify barriers to safe driving and to develop environmental strategies that support older drivers in the context of their communities.

Background Literature

A review of literature related to the impact of the physical environment infrastructure (e.g., roadways, signage, lighting) on older adults’ driving ability, performance,
and safety was completed as a part of AOTA’s Evidence-Based Literature Review Project. This topic was selected because there has been a tremendous growth in the elderly population of the United States over the past few decades. It is estimated that by 2030, there will be 70 million Americans older than age 65, or about 20% of the United States population (Pike, 2004). It is clear that in coming years, older adults will compose a major part of the clinical population referred to occupational therapy. As this segment of the population increases, there will be increasingly more drivers 65 or older using the roadways in the United States. Although many Americans drive less as they age, driving often is viewed as a necessity because acceptable alternatives are not available (Molnar, Eby, & Miller, 2003). Older drivers are increasingly more likely to be involved in automobile crashes and to be injured when they are in these incidents (Wang, Kosinski, Schwartzberg, & Shanklin, 2003). These increased risks most often are associated with age-related changes in vision, cognition, and mobility and with health-related issues (Wang et al., 2003). In addition, evidence has indicated that fragility steadily increases with age (Li, Braver, & Chen, 2003) and that older drivers have a higher fatality rate per mile driven than any other age group except drivers under age 25 (National Highway Traffic Safety Administration, 2003). Clearly, this segment of the population will require services from occupational therapists and occupational therapy assistants to maximize occupational performance in driving and to maintain independence for community participation.

Like most Americans, older drivers consider driving as essential to their independence and quality of life. In recent years, there has been an increased focus on traffic safety efforts to assist older drivers to continue to drive safely rather than to restrict all older drivers regardless of their ability to drive. The American Association of State Highway and Transportation Officers proposed an ambitious strategic highway safety plan to focus efforts on sustaining older drivers’ proficiency by improving the highway infrastructure to safely accommodate them and assist with older driver safety (as reported in Molnar et al., 2003). Additionally, the U.S. Department of Transportation (1997) established policy objectives aimed at facilitating individuals’ driving as long as they are able to do so safely, promoting technology and training to help drivers compensate for functional changes, and providing alternative transportation for individuals who should no longer be driving. Occupational therapy, with its emphasis on person–occupation–environment fit, is ideally situated to be a leader in identifying barriers to safe performance of driving and developing environmental strategies to support older drivers in the community.

Occupational therapy recognizes driving as a complex instrumental activity of daily living that requires visual, cognitive, and psychomotor abilities. Changes in visual function—including reductions in light sensitivity, increased glare sensitivity, and reduced visual acuity (Haegerstrom-Portney, Schneck, & Braby, 1999) and the increased prevalence of ocular disease (glaucoma, cataracts, and age-related maculopathy; Klein, Wang, Klein, Moss, & Meuer, 1995)—may compromise older adults’ ability to detect environmental and safety cues. Cognitive abilities such as information processing, selective attention, divided attention, and attention switching may be compromised by age or as a consequence of the various medical conditions (e.g., Alzheimer’s disease) often accompanying age and may lead to less efficiency in processing environmental cues that support safe driving and increase the risk for crashes (Stutts, Stewart, & Martell, 1998). Changes in strength, flexibility, sensitivity, and range of motion (particularly head and neck mobility) are a few of the psychomotor abilities that may limit the older driver’s ability to access and effectively respond to environmental cues (Molnar et al., 2003). The impact of these changes varies for each driver. Many older adults are able to compensate for their changing abilities by not driving at night, driving on less traveled roads, limiting driving in unfamiliar areas, or enlisting the assistance of a passenger to navigate or read road signs. As abilities continue to change, older drivers may have difficulty responding to road signs and traffic signals, yielding to oncoming traffic, staying in traffic lanes, positioning the vehicle for turning maneuvers, adjusting speed to keep up with traffic flow, maintaining speed or judging distances for safe stopping, and passing other cars or merging into traffic. These problems are compounded when the driving environment becomes more complex or cluttered. Knowledge of environmental influences that facilitate or inhibit safe performance of driving is critical to the development of occupational therapy intervention strategies for those older adults who demonstrate diminished ability to drive as a result of age-related changes or medical conditions.

With a lack of research within occupational therapy regarding how the physical infrastructure supports driving, it was necessary to examine research from other disciplines. Thus, the purpose of this article is to (1) describe research linking design and operational and traffic engineering enhancements to the declining functional performance of older drivers, (2) assist occupational therapists and occupational therapy assistants in identifying compensation strategies for older adults to maximize independence and safety in driving, and (3) use an occupational perspective to facilitate engagement of older drivers in safe driving practices.
Method for Conducting the Evidence-Based Review

The portion of the older driver evidence-based literature review reported in this article addressed the impact of modifications of the physical infrastructure on the participation of older adults in driving activities. Detailed information about the methodology followed for the entire older driver evidence-based literature review can be found in the article “Background and Methodology of the Older Driver Evidence-Based Systematic Literature Review” (Stav, Arbesman, & Lieberman, 2008) on pages 130–135. Literature included in this review was identified in the engineering field, specifically in the human factors area, because the occupational therapy field lacks research regarding how the physical infrastructure supports driving. Information before 1999 was taken from the Highway Design Handbook for Older Drivers and Pedestrians (Federal Highway Administration [FHA], 2001), which provides guidelines for highway design for communities across the United States. Although this document is exhaustive, it is not based on an evidence-based review of the literature and may not reflect the most current thinking about the effects of aging as not being particularly deficit based. It should be noted, however, that the document accurately represents the state of the science in the engineering and human factors industry before 1999, and the guidelines in the document remain important.

Results

This review and analysis focused on the question “What is the evidence for the effect of modifications of the infrastructure of the physical environment (e.g., roadways, signage, lighting) on the driving ability, performance, and safety of the older adult?” Table 1 summarizes the review of the eight articles published since 1999 and includes information about the objectives, design, procedures, findings, and limitations of the review studies. Literature included in this review was identified primarily in human factors engineering sources. These studies investigated elements of roadway design, including legibility of roadway signage, use of color and retroreflective coatings to increase legibility and detection of signage, lettering size and font used for signage, and lane-marking treatments. Authors of each of these reports provided detailed engineering specifications for implementing their recommendations. Specific measurements, layouts, and engineering design characteristics are available by referencing the individual articles. The Highway Design Handbook for Older Drivers and Pedestrians (FHA, 2001) also was included. Even though this handbook is not based on an evidence-based review of the literature, the recommendations for intersection design, roadway interchanges, roadway curvature and lanes, construction zone features, and highway–rail grade crossings have been widely accepted in human factors engineering circles as the definitive resource for roadway design as it relates to the older drivers.

The findings are organized according to the five roadway environments that are generally accepted as being the most problematic for the older driver: (1) intersections, (2) interchanges, (3) roadway curvature and passing zones, (4) construction zones, and (5) highway–rail grade crossings. Negotiation of intersections is of primary concern because a longstanding relationship exists between injuries and fatalities at intersections as a function of age (as reported in FHA, 2001). Freeway interchanges have design features that commonly cause drivers, especially older drivers, to make erratic maneuvers that place them more at risk for collision and injury. Roadway curvature and passing zones and construction zones are included because each of these environments often requires increased steering of the vehicle, especially for sudden maneuvers in response to unexpected events. Highway–rail grade crossings, particularly ones with passive controls, are potential sites for older driver conflicts as a result of the sensory changes associated with increasing age. For the purposes of this review, the design elements are discussed in terms of how each affects the older driver experiencing age-related changes in functional performance.

Intersections

The FHA (2001) provided recommendations for a variety of design elements to accommodate the needs and enhance the performance of older drivers as they approach and negotiate intersections. The design elements discussed here include

- The skew of the intersection (the angle at which roadways meet),
- The design of turns,
- The design for roundabouts (road junctions at which traffic streams circularly around a central island),
- Sight-distance requirements,
- Signage and roadway markings,
- Traffic control signals, and
- Fixed roadway lighting.

When additional literature for these design elements is included, a reference to the author and year of publication is noted.

Skew of the Intersection. Intersecting roadways should meet at a 90° angle to provide optimal conditions to detect
Table 1. Evidence Table: Infrastructure Effects

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Study Objectives</th>
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<td>Carlson (2001)</td>
<td>Compare the effectiveness of different microprismatic retroreflective sheetings on legible nighttime distance for reading Clearview signs and alphabets mounted on the roadside</td>
<td>I—Randomized controlled trial, mixed-factor design N = 60 (20 participants ages 18–34, 20 participants ages 35–54, and 20 participants ages 55 and older)</td>
<td>Two cars were used: a 2001 Chevrole Blazer with halogen headlights and a 1991 Ford Crown Victoria with headlights with a more vertical focus. Signs were positioned either at shoulder height or mounted overhead, in accordance with current signing practices. Twenty-one test words were placed on the signs, 1 word per sign per trial.</td>
<td>For both shoulder-height and overhead-mounted signs, the Clearview signs were significantly more visible than other types. This benefit was more pronounced for older drivers than for younger drivers.</td>
<td>Applicability of the results to real-world driving situations is limited, because the differences between the two types of alphabets and legibility distance is marginal.</td>
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| Carmeli, Coleman, Omar, & Brown-Cross (2000) | Determine the influence on environment on walking speed in elderly people | Level I randomized mixed-factors design | Participants took part in four randomly assigned trials, two indoors and two outdoors. In one indoor and one outdoor trial, participants were told to cross at preferred pace, while in other trial, participants were told to walk as quickly as possible. Indoor trials were conducted on the level, tilted walkway, and the outdoor trials were on a simulated crosswalk. | Participants required more time in outdoor gait trials to walk a standard distance than they did in indoor trials. In addition, participants were less able to increase speed during “as-fast-as-possible” outdoor pace trials than in indoor case. The authors reported that these differences may be due to environmental factors such as uneven terrain and variability in lighting, temperature, humidity, and wind. | Strict exclusion criteria for participant selection does not reflect the composition of the older adult population. |


| Chrysler et al. (2002) | Determine effects of font color, and retroreflective sheeting type on nighttime legibility distance | I—Randomized mixed-factor design N = 24 Age range: 55–75 years | A Chevrolet 1998 Lumina with low-beam headlights was used. Forty-eight signs were used for identification. Four sign colors were used: green, orange, white, and yellow. Half were printed with the Highway Series D font. The remaining green signs were printed with Clearview Road Condensed font, and the remaining yellow, orange, and white signs were printed with the D-Modified font. Three types of retroreflective sheeting were used: Type III, Type VIII, and Type XI. | A significant difference in terms of color and type of sheeting used was reported: Yellow was the most effective, with a legibility distance of 190 ft (58 m), and orange was worst, with legibility distance of 164 ft (50 m). Type VIII and Type XI (M = 184 ft [56 m]) were reported to be the best of all, whereas Type III sheeting (M = 174 ft [53 m]) was the worst. Series D font yielded a significantly higher legibility distance (187 ft [57 m]) than the Clearview Condensed font (171 ft [53 m]). | The fact that the study was conducted on an Air Force base may limit the generalizability of the results. |


| Guerrier & Fu (2002a), Test 1 | Evaluate the effectiveness of different traffic control devices for older drivers | III—Pretest-posttest N = 51 participants over ages 55 and older | All participants drove during the daytime on a fixed route in Miami, FL. Participants took cognitive assessments, visual assessments, and visual acuity tests before taking part in the study. | Larger text on overhead and advance street signs could be read from a greater distance than smaller text, and the authors recommend the use of 12-in. (30.5-cm) lettering. Six-in. (15-cm) lane markings were generally more visible than 4-in. (10-cm) lane markings. The authors reported the need to maintain upkeep of markers, because there was difficulty identifying worn lane markings in some conditions. There was no difference in preference of participants for traditional or offset left-turn lanes. | Insufficient information regarding features of intersections. |

Limitations include lack of randomization; recall bias, because participants were asked to compare current lane markings to those previously encountered; and time delays between markings were not reported. |

Table 1. Evidence Table: Infrastructure Effects (continued)

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| Guerrier & Fu (2002b), Test 2A | Evaluate the legibility distance for identifying street names with the use of the Clearview, Highway C, and Highway D fonts | I—Randomized mixed-factor design
N = 37 participants ages 65 and older | Ground-mounted signs: Two signs using only Highway C and Clearview 6-in. (15-cm) fonts. These signs were placed on the medians of four-lane arterials with a speed limit of 30 mph (48 km/hr).
Advance signs: Three signs using the Clearview, Highway C, and Highway D 8-in. (20-cm) fonts. These signs were placed on the side of two-lane roadways with a speed limit of 30 mph (48 km/hr).
All drivers used high-beam lights in after-sunset driving conditions.
Outcome:
- Legibility distance for reading the signs: Measured as distance between the vehicle and signs
Ground-mounted signs: Even though the Clearview font had a larger mean legibility distance \(110 \text{ ft} (33.5 \text{ m})\) than Highway C and D, the difference was significant only for Highway C.
Advance signs: There was no significant difference between the Clearview and Highway C fonts.
Divided-attention skill of the participants was a significant predictor of distance for reading road signs. Age was not a significant predictor for being able to read signs. | The use of high-beam lights limits the generalizability to on-road daytime driving.
Varying ambient light: The authors reported the presence of different ambient light conditions during driving testing, which might had some effects on reading distances. |
| Guerrier & Fu (2002c), Test 2B | Evaluate the visibility of different lane marking treatments for older drivers | III—Pretest–posttest
N = 22 participants ages 65 and over | Participants were passengers in a car on the Florida Turnpike. Different marking tapes were applied to half-mile sections of the turnpike. Participants took cognitive assessments, visual assessments, and visual acuity tests before taking part in the study.
Outcome:
- Participants reported directional shifts of road (left, right, straight ahead)
- Rating of overall and relative visibilities of lane markers
There were no significant differences between any of the treatments tested. | Lack of randomization; test was conducted under a limited set of roadway conditions (clear and dry), and thus the results may not be generalizable to other road conditions. |
| Ho et al. (2001) | Investigate the effects of age, clutter, and scene luminance on the identification of traffic signs | I—Randomized controlled trial
Experiment I: N = 28 (14 participants ages 56–71 and 14 participants ages 20–27)
Experiment II: N = 28 (14 participants ages 54–79 and 14 ages 18–30) | Experiment I: Images were classified on the basis of clutter (high/low and luminance (day/nighttime)). The participants were then asked to classify low-clutter daytime images and high-clutter daytime images, low-clutter nighttime images, and high-clutter nighttime images.
Experiment II: The images from Experiment I were presented to participants, and the task was to identify whether traffic signs were present or absent in these images.
Outcome:
- Error rate
- Reaction time
- Number of eye fixations
- Duration of last fixation
- Average fixation duration
The error rate was higher for the following:
- Older than younger drivers
- High-clutter than low-clutter trials
- Target-present trials than target-absent trials.
Reaction time was slower for the following:
- Older than younger drivers
- High-clutter trials than low-clutter trials
- Target-present than target-absent trials.
Eyes fixation was higher for the following:
- Older than younger drivers
- High-clutter than low-clutter trials
- Fixations for target-present trials than target-absent trials
Last fixation duration was longer for target-present trials than for target-absent trials.
Average fixation duration was longer for older than younger drivers. | Images were static and two dimensional, with no time limit, not mimicking the real-world driving situation and thus minimizing the applicability of the results. |


(continued)
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<td>Kline et al.</td>
<td>Whether the ability to identify optically blurred text could be affected by</td>
<td>I—Randomized controlled trial</td>
<td>Experiment I: Participants looked at traffic signs under three levels of visual acuity and two</td>
<td>Legibility thresholds were lower for older participants than younger</td>
<td>Optical blurring of a sign that does not physically change size is not</td>
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<td>(1999)</td>
<td>either daytime or nighttime conditions</td>
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<td>luminance levels: daytime and nighttime</td>
<td>participants. Also, familiar objects (standard signs) had lower</td>
<td>the same as physically increasing the distance between an observer and a</td>
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<td>Experiment II: Participants looked at traffic and novel signs under three levels of visual</td>
<td>thresholds than unfamiliar signs. Legibility was higher for day-</td>
<td>sign. This makes it difficult to generalize the results to on-road</td>
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<td>light condition compared with nighttime.</td>
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<td>Outcomes:</td>
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and make judgments about oncoming vehicles and to provide increased maneuvering time for navigation of the intersection (FHA, 2001). Optimal viewing is especially important because of changes in head and neck mobility that may accompany aging (Isler, Parsonson, & Hansson, 1997).

**Design of Turns.** The FHA (2001) concluded that wider turning lanes facilitate better positioning of the vehicle within the lane in preparation for turning, and wider receiving lanes minimize the chances of encroachment on other lanes (i.e., swinging too wide to lengthen the turning radius and minimize rotation of the steering wheel). For older drivers, this design allows more opportunity to remain within the boundaries of their assigned lanes during turning maneuvers secondary to the diminished ability to share attention and to turn the steering wheel sharply enough, given their traveling speed, to negotiate the turn (FHA, 2001). For left turns, raised channelization (a raised zone that constrains traffic movement) provides additional cuesing to older drivers (FHA, 2001). Materials that reflect light toward the car and driver when the headlamps illuminate its surface (retroreflective markings) can be used to increase the visibility of the channelization (FHA, 2001). Applying retroreflective markings to raised channelization increases visibility for drivers experiencing age-related changes in visual acuity and contrast sensitivity that challenge their ability to detect or recognize pavement lane markings. Retroreflective pavement markings, used to indicate the turning path, provide additional cueing to minimize encroachment on other lanes. Wider lanes, raised channelization, and retroreflective pavement markings are especially important for high-traffic areas or areas that have a demonstrated crash problem.

Right-turn movements are facilitated by an adequate curb radius that minimizes the chance of hitting the curb (FHA, 2001). The size of the curb radius affects the size of vehicle that can turn at the intersections. Because older drivers tend to drive larger cars at slower speeds (Chu, 1994) and larger cars require a greater turning radius, the curve radius should be adequate to ensure that the older driver does not hit the curb or encroach on other lanes of traffic while maneuvering around the corner.

Lane-use devices should provide enough preview time so that the older driver is less prone to erratic maneuvers, such as lane weaving, that result from late detection. If lane-use control signs are used to provide lane assignment on intersection approach, they should be consistently positioned overhead on signal mast arms or span wire where they are more easily viewed (FHA, 2001). Pavement markings indicating lane use should be positioned in advance of the signalized intersection.

**Design of Roundabouts.** Modern roundabouts give priority to traffic already in the circle (Flannery & Datta, 1996). Jacquemart (1998) suggested that the installation of modern roundabouts addresses the problems some older drivers have with judging speeds and gaps to maneuver through turns by reducing the speed of vehicles entering the circle, completely eliminating left turns, simplifying the decision process, and reducing the number of conflict points; they also provide a large curb radius to improve maneuverability (FHA, 2001). Roundabouts thereby simplify the decision-making process for the driver (FHA, 2001). One-lane entrances and exits, one-lane circulating traffic, and designed deflection to create safer merges with the circulating traffic stream minimize potential conflicts with other vehicles.

**Sight-Distance Requirements.** An unobstructed view of the entire intersection and sufficient lengths of roadway should allow more time for the older driver to make decisions about whether to proceed, slow, or stop to avoid a collision with potentially conflicting vehicles (FHA, 2001).
When turning maneuvers are involved, the sight-distance requirements are especially important for the older driver, who may take significantly longer to perceive that a vehicle is moving closer at a constant speed before making a decision about whether to proceed with the turn (FHA, 2001). For left turns, the sight distance can be increased by shifting the opposite left-turn lane to the right so that the left-turning drivers do not block each other’s view of oncoming traffic (FHA, 2001). On the basis of previous work by Staplin, Harkey, Lococo, and Tarawneh (1997), this positive offset of opposing left-turn lanes provides a margin of safety for older drivers, who may not position themselves within the intersection before initiating a left turn.

**Signage and Roadway Markings.** In general, safe driving behavior depends on the driver’s ability to rapidly search driving environments, extract critical information, and respond appropriately to the information obtained. One of the major ways in which drivers obtain information to anticipate a response appropriate to the driving situation is by detecting roadway signs and markings and recognizing their meaning or direction. Older adults are slower and less accurate and require more fixations to acquire the traffic signs (Ho et al., 2001; Level I). Moreover, older drivers may be able to recognize familiar road signs even though their acuity may reflect age-related changes (Kline et al., 1999; Level I). Both of these studies were conducted in laboratory settings; thus, the results reported by both research teams may have limited applicability to actual driving situations. Kline et al. (1999; Level I) also suggested that legibility thresholds were lower for older versus younger participants and for familiar (standard) signs versus unfamiliar signs and that older drivers use an age-related compensatory ability to acquire sign messages; however, the optical-blurring technique that they used in the laboratory did not physically change the distance between the observer and the sign as would be seen when actually driving. The results of this study need to be repeated in a field study before definitive conclusions can be made.

It has been suggested that larger text on street signs can be read from greater distances, advance street signs provide warning of intersections and more time for a driver to decide what to do at the intersection, 6-in. lane markers were generally more visible than 4-in. lane markers, and offset left-turn lanes (i.e., a separate lane for left-turning traffic) were not preferable to traditional lanes (Guerrier & Fu, 2002a; Level III). Although these recommendations might provide an advantage for older drivers to successfully negotiate an intersection, the lack of operational definitions and flaws with the design of the study and presentation of results raise questions as to the application of these reported outcomes to driving environments.

The design of signage and roadway markings must address issues of legibility and reading time. The FHA (2001) provided recommendations for using mixed-case fonts with more character openness and smaller intercharacter spacing to improve legibility. Additional studies published after 2001 have examined issues of legibility related to size and types of fonts, color of signs, and types of coatings to improve legibility.

The most widely accepted standard for sign fonts is the Clearview™ font family. This font system, developed by Meeker & Associates and tested by the Pennsylvania Transportation Institute (Garvey, Pietrucha, & Meeker, 1997) opens the shape of individual letters without changing the actual letter height or width. Using this font system improves legibility and recognition about 20% without having to increase sign size. The Clearview font improved guide sign legibility for older drivers, although its use provided only marginal increases in available reading time and legibility distance (Carlson, 2001; Level I). Under nighttime driving conditions, there was a performance benefit for older drivers when the Clearview font was used rather than the traditional Series E (modified) font (Carlson, 2001). Although Carlson’s (2001) findings were significant, the effects noted may not be meaningful in actual applications because the Clearview font may provide only marginal increases in available reading time and legibility distance.

The Clearview font also outperformed Highway Series C and D fonts in terms of the legibility distance for advance street signs (Guerrier & Fu, 2002b; Level III). For ground-mounted signs, there was no detectable impact on legibility distance when comparing the Clearview and Series C fonts; however, the differences in ambient lighting and the use of high-beam rather than low-beam headlights may have confounded these results (Guerrier & Fu, 2002b; Level III). When the Clearview, Highway Series D, and Series D Modified fonts were evaluated in an experimental setting that closely represented the actual task of reading signs while driving at night, there was no appreciable difference in reading time for the various fonts (Chrysler et al., 2002; Level I). Although it is unclear whether using the Clearview font offers any legibility advantage during nighttime driving, some evidence suggests that the use of the Clearview font may provide some advantage for older drivers’ acquisition of traffic sign messages (Chrysler et al., 2002; Level I).

When the effects of sign color on nighttime legibility distance of roadway signs were examined, older drivers performed more poorly when reading the orange signs typically used in construction zones (Chrysler et al., 2002; Level I). When microprismatic retroreflective sheeting was applied to the work zone signs with orange backgrounds, it provided greater legibility distance. The other types of retroreflective
sheeting (Type II, Type VII, and Type IX) examined provided no functional difference in legibility. Even though Chrysler et al. (2002; Level I) noted significant legibility benefits from using orange signs with Type VII or Type IX coatings, some questions remain regarding how much of a safety benefit can be expected from the relatively small improvements in legibility distance.

No appreciable difference appears to exist among the types of pavement marking tapes treated with various types of coating with retroreflective properties; however, markings that were in good repair were more visible than those in poor repair (Guerrier & Fu, 2002c; Level III). This finding would suggest that lane marker treatments should be well maintained and kept in good condition if they are to be clearly visible to drivers of all ages, including older drivers with age-related visual deficits.

Older drivers have a high potential for wrong-way maneuvers at intersections where initiating a left turn too soon may result in the vehicle entering the wrong lane, especially when positive offset left-turn lanes exist (as reported in FHA, 2001). Signs indicating DIVIDED HIGHWAY CROSSING, WRONG WAY, DO NOT ENTER, KEEP RIGHT, and ONE WAY should be oversized and treated with retroreflective sheeting to increase their conspicuousness and legibility to older drivers (FHA, 2001). The use of retroreflective pavement markings indicating the turn path and retroreflective wrong-way arrows in the through lanes reduce the likelihood of entering the wrong lane (FHA, 2001). Additionally, retroreflective treatment applied to median noses increases their visibility and provides older drivers with more cues to assist their understanding of the intersection design.

Marking curbs, medians, and obstacles on their vertical face and a portion of the top surface decreases the likelihood of collision with the raised surfaces by making them more conspicuous to older drivers with decreased contrast sensitivity, reduced useful field of vision, increased decision time, and slower vehicle control movement execution (FHA, 2001). Providing older drivers with a clear delineation between the marked edge of the roadway and the road surface can be achieved by maintaining a minimum in-service luminance contrast of 2.0 or higher at intersections with overhead lighting and 3.0 or higher at intersections without overhead lighting (FHA, 2001).

Street-name identification signs must be detected and legible if they are to provide guidance to drivers. Detection is improved by the placement of the sign and its contrast with the surrounding background (FHA, 2001). For example, at major intersections there should be overhead-mounted street name signs because overhead signs are more likely to be seen before those located on either side of the roadway. Redundant signage in the form of advance street name signs (black lettering on a yellow sign panel) should be placed upstream of the intersection at the midblock location (FHA, 2001). Detection is less of a problem on streets with a lower volume of traffic and on which traffic speeds do not exceed 25 mph. In these cases, post-mounted street name signs may be used, but a minimum letter height of 6 in. should be used to accommodate the reduced visual acuity associated with age (FHA, 2001).

Legibility of signs is determined by character variables (contrast, luminance, color and contrast orientation, font, letter height, letter width, case, and stroke width). Retroreflective treatments that increase sign conspicuousness and legibility at the widest available observation angles accommodate older drivers who experience age-related visual acuity loss (FHA, 2001). FHA suggested that using mixed-case fonts with more character openness and smaller inter-character spacing such as the Clearview font improves legibility distance; however, Carlson (2001; Level I) found the improvement to be marginal. Although the FHA (2001) suggested that using larger letter-height fonts (30% larger than standard highway character size) allows older drivers to read the signs far enough in advance of the intersection to make decisions about negotiating the intersection, no recent experimental studies have confirmed this recommendation.

Some older drivers who have difficulty abstracting information and making quick decisions often require more effective and more conspicuous signs to alert them to wrong-way movements (FHA, 2001). Accommodation for glare sensitivity and restricted peripheral vision should be provided by multiple or advance signs and by changes in size, luminance, and placement of signs (FHA, 2001). Wider intersections, especially divided roadways, require additional ONE WAY signs be placed on the divider median to increase conspicuousness. Additionally, DO NOT ENTER and WRONG WAY signs may be needed. Retroreflective treatments increase visibility of signs, and high contrast provides better legibility.

Age-related changes in vision and attention necessitate improved stop control and yield control at nonsignalized intersections (FHA, 2001). At intersections where greater visibility or emphasis is needed, STOP sign size (standard 30 in.) should be increased to 36 in., and YIELD sign size (standard 36 in.) should be increased to 48 in. (FHA, 2001). Background retroreflective levels for STOP and YIELD signs should be sufficient to provide conspicuous and timely detection (FHA, 2001). Rumble strips or transverse pavement striping upstream of the stop-controlled intersection serve as an alert when sight restrictions or high approach speeds are
present. Additionally, a stop ahead sign can be installed to provide a minimum preview distance and ensure adequate time to stop (FHA, 2001).

Traffic Control Signals. The FHA (2001) reviewed previous research before reaching the conclusion that older drivers need increased levels of signal luminance and contrast to perceive traffic signals, but at the same time, the signals should not cause a disabling glare. Signal intensity generally does not compensate for the increased reaction time with age; however, ensuring signal strength is maintained through a wide viewing angle provides longer visibility distances, making the signal information more accessible over longer intervals (FHA, 2001). A large, black surround behind the signal (backplate) provides improved contrast, especially where the potential for sun glare problems exists (FHA, 2001). Intervals between phases should be based on perception-reaction time, with a longer yellow interval to accommodate older drivers (FHA, 2001).

Protected-only operations, ideally leading protected left turns, are recommended to reduce the crash rates of elderly drivers at signalized intersections (FHA, 2001). Overhead left turn yield on green signs alert drivers to the signal, and redundant signs indicating left turn at signal, positioned at an adequate preview distance before the intersection, allow the driver to position the vehicle in the left turn lane. Because older drivers often have difficulty integrating time and distance information to estimate approaching vehicle speeds, it is important that the timing of the left turn signal be of sufficient length to provide adequate decision-making (go–no go) time for the older driver (FHA, 2001). The green arrow signal light should terminate into a yellow before going to a steady red to allow a buffer for slower moving vehicles to complete the turn across oncoming traffic lanes before that traffic begins to enter the intersection.

Right-turn-on-red should be prohibited at intersections where the skew of the intersecting roadways limits sight distance (FHA, 2001). Prohibiting right-turn-on-red is particularly important for older drivers whose restricted head and neck motion places them at a disadvantage for perceiving approaching conflicting traffic (Isler et al., 1997). When right turns are not permitted, a steady circular red indicator should be used along with a no turn on red sign positioned overhead where it is most conspicuous (FHA, 2001). When right turns are permitted, the stop line for the right turn lane should be offset 6 to 10 feet forward of the other lanes to provide better sight distance (FHA, 2001). Additionally, turning traffic must yield to pedestrians signs should be used at intersections where turning vehicles conflict with pedestrians who are using the crosswalk.

Fixed Roadway Lighting. Fixed lighting on a roadway increases the visibility of the roadway and the immediate surrounding area. Roadway lighting permits drivers to maneuver more safely and efficiently, particularly in environments of shifting lane alignments, turn-only lane assignments, or pavement-width transitions that force a path following adjustment or at intersections. Yellow-tint or high-pressure sodium lighting installations address the age-related declines in ocular transmittance and the exaggerated intraocular scatter of light (as reported in FHA, 2001). Maintenance of lighting installations ensures that lamp lenses are regularly cleaned and replaced when their output falls below 80% of peak performance (FHA, 2001).

Interchanges

Highway exits require drivers to process a large amount of directional information during a short period of time and at high speeds while trying to maintain or modify the vehicle’s position in the traffic stream. Because this constitutes a major change in tracking of the vehicle, older drivers often find exits to be problematic, especially if they are in an unfamiliar location (FHA, 2001). Exit signs provide visual cues to drivers, but they must be detectable and legible to be effective. Redundant overhead placement of exit signs upstream from the exit ramp facilitates detection (FHA, 2001). Retroreflective treatments increase sign conspicuousness and legibility to accommodate drivers with age-related visual acuity loss (Chrysler et al., 2002 [Level I]; FHA, 2001). As with overhead street signs, the use of mixed-case fonts with more character openness and smaller intercharacter spacing (e.g., Clearview) improves legibility distance. Mixed-case fonts such as Clearview also should be used for ground-mounted signs to increase reading distance of all highway destination signs (FHA, 2001). A conservative standard for character height should correspond to 20/40 vision to accommodate a greater proportion of older drivers under a wider range of viewing conditions (FHA, 2001). The use of larger letters aids the older driver in reading unfamiliar words or word combinations. To minimize confusion, arrow shafts appearing on upstream diagrammatic guide signs should match the number of lanes on the roadway at the sign’s location (FHA, 2001).

When the exit is not illuminated or is partially illuminated, the gore (the triangular piece of land between the main roadway and the exit ramp) should be marked with partially retroreflective flexible posts and partially retroreflective pavement markers to assist drivers in identifying the exit lane boundaries (FHA, 2001). These markers provide an outline of the location of the gore, especially at night when drivers cannot rely on a direct view of the ramp. For older drivers with limited night vision, the partially retroreflective
flexible posts are more effective than other types of markers (FHA, 2001).

Diminished capability to accurately and reliably integrate speed and perceived distance information for moving vehicles, reduced neck and trunk flexibility, and age-related deficits in attention-sharing capabilities place the older driver at higher risk for collisions in acceleration and deceleration lanes (FHA, 2001). This is particularly problematic when traffic volume is high. To allow the older driver the greatest advantage for successfully negotiating entrance onto a highway, it is advisable that acceleration lane lengths be increased and that a parallel design for entrance ramps be used to allow enough time for gap search and decision-making processes (FHA, 2001). For exit ramps, it is advisable to locate the ramp exits downstream from sight-restricting vertical or horizontal curvature of the main road (FHA, 2001).

Age-related changes in capabilities (particularly selective attention, divided attention, visual acuity, and contrast sensitivity) contribute to wrong-way movements on highways just as they do on other roadways (FHA, 2001). Preventative measures to reduce the frequency of wrong-way movements by older drivers include modification of ramp and roadway design, signing and pavement markers, and use of warning and detection devices and vehicle arresting systems (FHA, 2001). For example, overhead land-control signal indicators for prohibited movements (red X) provide conspicuous warning. Guide sign panels marking freeway entrances provide positive guidance. Additionally, median separators with retroreflective markings reduce the change of crossover in areas in which entrance and exit ramps are adjacent to each other.

The effects of aging on the visual system compound the effects of darkness and increase the risk of collision for older drivers, particularly around interchange areas. Most notably, declines in visual acuity, contrast sensitivity, glare recovery, and peripheral vision make night driving more difficult for older drivers, and increased illumination at interchanges significantly reduces vehicle crashes (FHA, 2001). Complete interchange lighting is preferred but may not always be feasible. Where complete interchange lighting is not feasible, a partial interchange lighting system may be used.

Roadway Curvature and Passing Zones

Pavement markings and delineation devices provide information about road alignment. Under daylight conditions, the markings and delineations should have a high enough effective luminance contrast to the roadway surface to be easily distinguished by older drivers, who may have diminished contrast sensitivity (FHA, 2001). The use of thick, slightly raised, retroreflective stripes is recommended because they reflect more light back to the driver during nighttime driving under both dry and wet pavement conditions (FHA, 2001). Raised pavement markers applied along the centerline are recommended for sharper curves (FHA, 2001). Additionally, the use of chevron alignment signs and roadside post-mounted delineation devices provide more information about road curvature. For the older driver with difficulties keeping within the lane and diminished motor abilities, these pavement markings and delineations can provide needed guidance.

Older drivers often have developed strong expectations about where and when they will encounter road hazards (FHA, 2001). With well-established expectations and slower reaction time to unexpected information, older drivers often are slower to override an initially incorrect response with a correct response to the hazard. When paired with physical changes, older drivers may have diminished ability to execute rapid vehicle control when an emergency maneuver is required. Signing that forewarns drivers of upcoming potential hazards can decrease the risk of collision (FHA, 2001). For example, advance warning signals paired with yellow placards with PREPARE TO STOP in black cue drivers that they are approaching a signalized intersection that may be obscured by vertical or horizontal curvature of the road.

The most conservative minimum required passing sight distance should be used to accommodate age-related changes in judging gaps, longer decision making, and protracted reaction times exhibited by older drivers (FHA, 2001). Retroreflective centerline pavement markings supplemented with yellow NO PASSING ZONE pennants at the beginning of no passing zones are recommended (FHA, 2001). When passing—overtaking lanes (in each direction) are included in two-way highway design, they should be placed at sufficiently long intervals to avoid midlane collisions (FHA, 2001).

Construction Zones

Construction zones have the potential to be problematic to all drivers, especially older drivers who may not be as quick to respond to these unexpected events (FHA, 2001). Advance warning of lane closure, changes in direction of the lateral shift in the travel path, and lane drop must be provided in sufficient time for drivers to make timely decisions about the most appropriate maneuver (FHA, 2001). Advance warning is important for older drivers who require increased time to prepare and initiate a safe merging maneuver rather than an erratic vehicle movement that results in conflicts between motorists (FHA, 2001). For a work zone on high-speed roadways and divided highways, a supplemental, portable changeable message sign displaying a one-phrase message (such as LEFT LANE CLOSED) should be located upstream of the lane closure (FHA, 2001). At the taper for each lane.
closure, a flashing arrow panel indicating lane closure is recommended (FHA, 2001). Redundant static signing with high retroreflectance is recommended throughout the entire time period of the lane closure (FHA, 2001).

In addition to advance warning, speed through work zones should be reduced, and positive barriers in transition zones and positive separation (channelization) between opposing two-lane traffic on all roadways except residential ones should be used (FHA, 2001). Channelization devices such as traffic cones with bands of retroreflective material for nighttime operation, tubular markers with a band of retroreflective material, striped vertical panels, chevron panels, and drums with high-brightness sheeting for orange and white retroreflective stripes can be used to accommodate the needs of older drivers (FHA, 2001).

In crossover areas, side reflectors or retroreflective sheeting on plastic glare-control louvers should be used (FHA, 2001). On high-volume roadways, the plastic louvers should be mounted on top of concrete channelization barriers. These measures minimize the chance of crossover into opposing traffic lanes.

Changeable message signs are effective only if they are conspicuous, legible, and placed where there is the least likelihood of their being blocked from a motorist’s view (FHA, 2001). The exposure time, or available viewing time, also determines whether the driver acquires the message. The needs of the older driver should dictate character and letter legibility and legibility distance and placement. Character and message legibility of changeable message signs should reflect the same considerations as for static signs (i.e., contrast, luminance, color and contrast orientation, font, letter height, letter width, case, and stroke width; FHA, 2001).

**Highway–Rail Grade Crossings**

Older drivers with decreased contrast sensitivity and the need for increasing levels of light for night-driving tasks benefit from increasing the detectability and conspicuousness of railroad crossing signing and added illumination to passive crossings. Detectability and conspicuousness can be increased by use of crossbuck posts with white, high-brightness retroreflective sheeting, advanced retroreflective pavement markings, post-mounted delineators with high-performance retroreflective sheeting, and the addition of luminaries (FHA, 2001).

**Discussion**

The first part of this review concentrated on the specific guidelines for the physical infrastructure of driving environments as related to the changes in visual, cognitive, and psychomotor abilities associated with the aging process. Although none of the studies included in this review were authored by occupational therapists, these studies provide insight into the rationale for roadway designs that may assist practitioners in understanding how driving environments can facilitate or hinder their clients’ safe driving behaviors. For example, this information may allow occupational therapists and occupational therapy assistants to identify compensation measures that will allow them to continue to drive safely in the communities in which they live or to adjust their seat, mirrors, and steering wheel to provide optimal positioning for driving. An understanding of how the physical environment infrastructure impacts of driving ability, performance, and safety of older adults will allow occupational therapists and occupational therapy assistants to assume advocacy and consultant roles working with community planners and human factors engineers. Because the federal guidelines are recommendations rather than requirements, occupational therapy practitioners can use their advocacy and consulting roles to increase awareness of the importance of implementing the recommendations for the safety of older drivers and all road users. Additionally, practitioners can advocate for the development of new systems for communities designed specifically for older adults. This information also may provide a basis for occupational therapy practitioners to develop interventions, including the development of compensatory and educational strategies that will allow older adults to drive safely for as long as possible.

Molnar et al. (2003) suggested that many people drive less as they grow older. Even though their time on the road may be limited, they are proportionally more likely to be involved in collisions (Wood & Mallon, 2001), especially when negotiating intersections; making left turns across traffic; and merging, exiting, or changing lanes. For the most part, these collisions are related to the older driver’s failing to recognize and yield to oncoming traffic, difficulty in searching and scanning the roadway environment, failing to respond to road signs and signals, failing to maintain position in traffic lanes, poorly positioning the vehicle for turning, difficulty maintaining regular speeds and responding to changes in traffic flow, and difficulty judging distances for passing other cars and stopping (Molnar et al., 2003). Because each of these problems can be linked to issues related to the driver, the occupation of driving, and the physical context in which driving takes place, it is important that the occupational therapy profession and occupational therapy practitioners develop strategies to minimize the mismatch between these factors.

Given the emphasis of the U.S. Department of Transportation (1997) on sustaining proficiency in older drivers, occupational therapists and occupational therapy assistants are ideally situated to become leaders in developing environmental strategies to support older drivers in the community. As
advocates, occupational therapy practitioners can assist policymakers and community planners by providing guidance to facilitate physical infrastructure changes to better support the occupation of driving for older adults. For example, improving signage so that older drivers are able to better detect roadway signs and recognize their meaning or direction can be facilitated by using a larger text on street signs (Guerrier & Fu, 2002b; Level III), using Clearview font to increase sign legibility (Carlson, 2001; Level I), using retro-reflective sheeting with an orange background on workzone signs to increase legibility (Chrysler et al., 2002; Level I), and maintaining pavement markings in good repair to make them more visible (Guerrier & Fu, 2002c; Level III). By focusing efforts on improving roadway infrastructure to support the occupation of driving, it may be possible to assist older adults with continuing to drive safely in their communities.

If occupational therapy practitioners are to effectively assume the role of advocates in new roadway construction and old roadway adaptation, it will be necessary to educate future therapists about the age-related changes that can affect safe driving by older adults and about how roadway design factors can support the occupation of driving. Molnar et al. (2003) suggested that the focus of education should be on “what is known about age-related declines, how they affect driving, and what can realistically be done to address the declines” (p. 21). Additionally, it is important for future practitioners to understand concepts of roadway design that can be applied to address problems resulting from age-related changes. The FHA (2001) suggested, for example, that wider turning and receiving lanes facilitate older drivers’ staying in their assigned lanes through turns. Moreover, marking curbs, medians, and obstacles with retroreflective materials can make the raised surfaces more conspicuous to older drivers with decreased contrast sensitivity. This type of information will allow occupational therapy practitioners to provide input into the design of new roadways and modification of exiting roadways to address the age-related changes faced by older drivers.

The U.S. Department of Transportation’s (1997) policy objectives included emphasis on the promotion of technology and training that helps older drivers compensate for functional changes. The occupational therapy profession can play a critical role in developing the technology and training to keep people driving as long as they are able to do so safely. To do this, occupational therapists and occupational therapy assistants must be able to recognize behaviors that place older drivers at increased risk. Practitioners also must be able to assess driving as an instrumental activity of daily living to determine behaviors that are needed for the older driver to continue driving safely, to assist the older driver to identify compensation measures when needed, and to recognize situations in which older drivers are no longer safe in performing driving tasks.

Kline et al. (1999; Level I) suggested the existence of an age-related compensatory ability that may allow older drivers to recognize familiar road signs by shape and color even though declines in visual acuity may increase the time that it takes to acquire the printed message on the signs. This familiarity with road signs may allow the older driver to negotiate roadway systems more safely. Other compensation methods may include the presence of a passenger to assist the driver with acquiring sign messages or to negotiate complex intersections (Vollrath, Meilinger & Kruger, 2002), choosing to drive on less traveled roadways where speed and volume are lower (FHA, 2001), or guided practice in negotiating roadways to increase familiarity with the driving environment. Additionally, practitioners can assist older drivers by adjusting their vehicles to provide the best positioning for viewing the driving environment and using rearview and side mirrors, teaching older drivers to reduce speed in advance of the intersection, encouraging use of vehicles with power steering to assist those drivers who may have restricted motion that limits their ability to maneuver the vehicle, restricting driving to times of the day when traffic volume is lower, or teaching older drivers to consciously identify stationary objects in the driving environment that will assist them in perceiving how quickly a vehicle is moving closer to help compensate for difficulties in judging gaps between vehicles.

Further investigation of promising evaluation and intervention strategies to identify barriers to safe driving and to facilitate the performance of driving activities needs to occur. Current and future practitioners need to be taught to recognize behaviors that place older drivers at risk and how to develop intervention strategies that include guided practice of driving tasks, compensation techniques for responding to driving environment demands, and methods of matching cars and drivers to support safe driving. Once intervention strategies are identified, they need to be tested to determine best practices for addressing the environmental influences that facilitate or inhibit safe performance of driving for those adults who demonstrate diminished ability to drive because of medical conditions.

Summary

The physical infrastructure of driving environments can facilitate or inhibit safe driving by older adults. Although design standards for new roadway construction may accom-
moderate the age-related changes of older drivers, expense alone prohibits adaptation of existing roadway environments. Unfortunately, this means that many older drivers will be driving on roadway systems that may not fully support safe engagement in the occupation of driving. As the older adult population continues to grow, occupational therapists and occupational therapy assistants will be challenged to address issues related to driving that will allow older adults to maintain this occupation as long as possible. Until the infrastructure can be changed to accommodate older drivers’ needs, occupational therapy practitioners will need to develop intervention strategies that include compensation techniques. Future research in occupational therapy should focus on how the driving environment can better accommodate the needs of elderly people and determining the efficacy of compensation strategies and education to address the changes in driving performance associated with the aging process. ▲

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