Evidence-Based Perspective on the Effect of Automobile-Related Modifications on the Driving Ability, Performance, and Safety of Older Adults

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KEY WORDS
• automobile
• driving
• modifications
• older adults

A systematic review of literature related to the impact of modifications made to automobiles on the driving ability, performance, and safety of older adults was completed as a part of the Evidence-Based Literature Review Project of the American Occupational Therapy Association. This review evaluated research on high-tech options, such as advanced technology systems (Intelligent Transportation Systems) currently in active development by manufacturers and researchers and the effect of features such as the instrument panel and window tinting. Although the evidence related to Intelligent Transportation Systems is inconclusive, studies have indicated that older adults would use selected technology options. Aftermarket window tinting negatively affects older adults’ driving performance, and no evidence demonstrates that hydrophobic window treatment improves driving performance. The implications for occupational therapy practice, research, and education also are discussed.


Evaluating the evidence related to the automobile becomes extremely important given the central place of the car in today’s society. According to Gartman (2004) and Urry (2004), sociologists no longer view the car as a consumer product and instead regard it as a system of interlocking social and technical practices that have changed society. Sheller (2004) wrote, “Car consumption is never simply about rational economic choices, but is as much about aesthetic, emotional and sensory responses to driving, as well as patterns of kinship, sociability, habituation and work” (p. 222).

Driving and the use of a car allow older adults to maintain an active and meaningful lifestyle because they are easy and convenient and allow for access to those occupations and daily activities that require leaving the house (Rosenbloom, 2004; Vladeck, 2005). According to Wood and Owsley (2005), the present cohort of older drivers is driving more miles per year, and it is estimated that they make approximately 90% of all their trips outside the home using a car, either as driver or passenger (Rosenbloom, 2004). This, in combination with the expectation that the number of adults 65 years or older will double by the year 2030 (Pike, 2004), is likely to result in many more elderly drivers in the next few decades. In addition, reports of driving cessation as an independent risk factor of depressive symptoms in elderly people (Marottoli et al., 1997; Ragland, Satariano, & MacLeod, 2005) point to the central importance of driving a car in the lives of older adults.

Engagement in occupation is the overarching objective of the occupational therapy process (American Occupational Therapy Association [AOTA], 2002). Community mobility, or “moving self in the community using public or private transportation,” is a component of community participation that requires the ability to engage in this activity safely and independently. The purpose of this review is to provide an evidence-based perspective on the effects of automobile-related modifications on the ability, performance, and safety of older adults. The key question addressed in this review is, “What evidence supports the use of automobile-related modifications to assist older adults in driving?”

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transportation such as driving” (AOTA, 2002, p. 620) is an instrumental activity of daily living, one of the areas of occupation. In all areas of occupation, the tools one uses to develop performance skills and performance patterns are important. For older adults, the main tool or product associated with driving is the automobile. According to Robertson (1998), decisions made regarding the design characteristics of a product can influence the rate of injuries associated with that product. As cars become increasingly more complex and at the same time more automatic, it is important to evaluate both safety and performance features. It is also necessary to understand whether these car–driver interactions are different between older and younger adults.

From a practical perspective, understanding older adult driving practices requires a good knowledge base of what features of the automobile can facilitate or hinder driving. For example, although an individual may be able to perform the motor and process skills involved in driving (e.g., posture, coordination, strength), features related to the car (e.g., size of the car, ability to get in and out of the car, ease of moving the seat forward) may ultimately affect these performance skills and limit the older adult’s ability to drive.

Background Literature

Available literature related to the interaction between older adults and automobiles encompasses both a review of challenges older adults experience when using an automobile and a summary of low-technology and high-technology options that are available at this time. Ellis and Talbot (2005) observed that current automobile design is based on research development from the 1950s, when the car was made to fit a typical consumer profile of a young couple in their 30s with two or more young children. Although these models may have continued to meet the needs of some segments of the population, the requirements of older adults were not consistently considered in this model. According to Steinfeld, Tomita, Mann, and DeGlopper (1999), car manufacturers often resolve problems with vehicle interiors by making compromises among conflicting design goals. For example, although the length of the steering column or position of the pedals in relationship to the car seat may accommodate body proportions of the majority of drivers, not all statures may be accommodated properly. The process of making decisions on design issues becomes increasingly complex as designers incorporate goals of safety, cost, and style.

According to Wood (2002), several changes associated with aging may affect driving performance. They include increased reaction time (Marottoli & Drickamer, 1993), visual changes (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999), cognitive changes (Stutts, Stewart, & Martell, 1998), and the ability to turn one’s head when driving (Isler, Parsonson, & Hansson, 1997). These impairments may result in performance problems such as difficulty driving in unfamiliar areas, limited ability to turn the steering wheel, difficulty reading traffic signs, and anxiety about ability to cope with a breakdown. A survey by James (1985) in the United Kingdom reported that older adults and persons with disabilities experienced difficulties getting in and out of cars. Several factors restricted ease of use, such as low doorway height, raised door sills, a narrow clear opening between the front seat and the edge of the door opening, and a low seat height relative to the vehicle floor. At the time the James (1985) study was completed, there were no cars in the United Kingdom with features resolving these difficulties.

Steinfeld et al. (1999) conducted focus groups and a survey to obtain information about use of automobiles among older adults with disabilities. Participants reported difficulties getting in and out of the car, both as a driver and as a passenger. The most frequently reported difficulties were in the performance skills and activity demands of getting one’s legs in and out of the car, fastening seat belts, sliding in and out, access to the rear seat, stepping either up or down into the vehicle, reaching the doors to close them, storing mobility devices, and bending the head to get in the door. Very few participants reported any problems using the equipment necessary for driving, such as the steering wheel and rearview mirror. These results are consistent with those reported in an AARP survey of older licensed drivers (Ritter, Straight, & Evans, 2002). Those ages 75 or older were seven times more likely to state that inconsiderate drivers as opposed to design features of the interior of the car were a large problem for them.

Automobile modifications fall into three general categories: (1) adaptive equipment, which includes intelligent transportation systems (ITSs) and lower technology adaptive equipment; (2) modifications to improve visibility during driving; and (3) changes to the automobile that improve safety in the event of a crash. ITS technologies developed for the general driving population, combining advances in wireless communication technology, electronics, computing, and global positioning systems. ITS technologies that have potential to improve the driving performance of the older adult include, for example, route guidance, emergency vehicle location and response, vision enhancement systems, adaptive cruise control, and collision warning systems (Molnar, Eby, & Miller, 2003). Survey research (Henk & Kuhn, 2000) has indicated that older adults would use ITS technology if it were available.

In addition to high-technology solutions for difficulties with driving, older adults report that low-technology adaptive equipment would be useful in reducing the demands of
driving. For example, cushions are available to improve seating while driving, and clip-on mirrors for rear- and side-view mirrors may expand older adults’ useful field of view (Steinfeld et al., 1999). Steering wheel spinner knobs and extension loops on the parking brake handle can provide assistance for manual dexterity. Steering wheel column extensions and a small steering wheel with a spinner knob can be used for older adults with limited range of motion in arms and shoulders (Molnar et al., 2003; Stav, Hunt, & Arbesman, 2006).

As adults grow older, visual changes such as decreased visual acuity, reduced light sensitivity, and increased glare sensitivity (Haegerstrom-Portnoy et al., 1999) may make it more difficult for them to compensate during driving. These issues can take on greater importance at night. In a survey of older adults, participants reported that glare from oncoming headlights can be a problem during night driving, and others mentioned difficulty seeing things behind them at night (Steinfeld et al., 1999). Research has indicated, however, that although accurate maintenance of headlight aim can be helpful to resolve this type of problem, older adults have little incentive to make such changes to the headlights (Mace, Garvey, Porter, Schwab, & Adrian, 2001). Antiglare mirrors also have been reported to be helpful (Mace et al., 2001), and other features of the automobile that may affect glare include windshield visibility, windshield rake angle (mounting angle of the windshield), dashboard glare, and window tinting.

Although the equipment discussed here is concerned with ease of use and comfort of operation, it does not relate, however, to how well a vehicle sustains impact and protects occupants in a crash. Crashworthiness refers to the safety performance of a vehicle and includes a range of features, such as seat belts, airbags, seat design, and head restraints (Pike, 2004). According to Mackay (1988), although performance of these features in motor vehicle crashes is well documented, less is known about how tolerance in a crash varies among populations at risk. If, for example, cars are designed to prevent death among young men, it may not be known whether the needs of older adults fit within the parameters of well-established designs. This discrepancy between the needs of older adults and what is available is important not only because the number of miles driven is increasing for all age groups but also because fatality rates are higher for adults ages 75 or older (Pike, 2004). Age-related changes that may reduce the ability to tolerate a crash include decreased bone strength; reduced extensibility and strength of collagen in bones, ligaments, cartilage, and muscles; decreased respiratory performance; changes in the spine and vascular system; and increased prevalence of arthritis (Keall & Frith, 2004; Mackay, 1988). This increased fragility needs to be considered not only in the design of automobiles but also in the design of specific features such as seatbelts, head restraints, airbags, and windshields (Keall & Frith, 2004; Mackay, 1988).

Methods for Conducting the Evidence-Based Review

The portion of the older driver evidence-based literature review reported in this article addressed the impact of automobile-related modifications on the participation of older adults. Detailed information about the methodology 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. It should be kept in mind that the literature presented here is from the engineering field, specifically in the ergonomics and human factors areas. For this reason, information may not be presented in the same manner as is generally found in occupational therapy literature. For example, reliability and validity of outcome measures were rarely reported in the methodology section of the articles and are not included in this review. Only one study included a power analysis, and none reported effect sizes.

Results

Table 1 summarizes the 22 articles reviewed and includes information about the objectives, design, procedures, findings, and limitations of the review studies. Two categories of evidence resulted from the systematic review, and no studies were located that examined crashworthiness. The first category included seven studies that examined modifications made to an automobile to determine whether they improve visibility and driving. Four were Level I studies, and three used a Level II design. Evidence from a Level I study (Freedman, Zador, & Staplin, 1993) and a Level II study (LaMotte, Riddler, Yeung, & De Land, 2000) indicates that aftermarket window tinting negatively affects older adults’ driving performance; no evidence at this time indicates that hydrophobic window treatments improve driving performance (Sayer, Mefford, Flannagan, & Sivak, 1999). Evidence from a Level I study (Schumann, Flannagan, Sivak, & Traube, 1997) indicates that small windshield rake angle and low dashboard reflectance can help reduce veiling glare from reflected sunlight that can be superimposed on the image of a road scene when driving.

The results of a Level I study by Laux (1991) indicate that older adults need a longer period of time than younger drivers to become familiar with the controls in an unfamiliar environment.
Table 1. Evidence Table: Automobile-Related Modifications

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<tr>
<td>Allen et al.</td>
<td>Establish the effectiveness of a navigation system in early prompting to drivers for an alternate route for avoiding traffic congestions</td>
<td>II—Mixed-factor, nonrandomized control trial</td>
<td>Intervention groups: one of four navigation systems (static navigation system, dynamic map system, advanced map system, or route guidance system)</td>
<td>50% of drivers diverted with slowing of traffic with use of navigation system. Middle-age drivers were most likely to divert. 50% diversion by drivers noted, with delay time reaching 18 min. Diversion was done more frequently during pleasure-related trips than daily commutes.</td>
<td>Limitations include weak analytical methodology; low sensitivity and specificity of outcome measures; applicability to real-life situations is limited; no test of significance among groups; number of older drivers participating in the study not reported.</td>
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<td>Caird et al.</td>
<td>Establish the effectiveness of a navigation system in early prompting to drivers for an alternate route for avoiding traffic congestions</td>
<td>II—Mixed-factor, nonrandomized control trial</td>
<td>Control group Outcomes: Prequestionnaire: Information about participants’ background, commuting patterns, and opinions about commuting Postquestionnaire: Past diversion behavior, factors for congestion avoidance, anticipated delay time, and human-factor issues of navigation system Response to traffic congestion scenario</td>
<td>50% of drivers diverted with slowing of traffic with use of navigation system. Middle-age drivers were most likely to divert. 50% diversion by drivers noted, with delay time reaching 18 min. Diversion was done more frequently during pleasure-related trips than daily commutes.</td>
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<td>Burns et al.</td>
<td>Determine whether road safety is compromised in drivers with tinted front car windows, reducing the visible light transmittance (VLT) to 35%</td>
<td>II—Mixed-factor nonrandomized control trial</td>
<td>Experiment I: six trials for each of the six possible combinations of two luminance and three VLT outcomes: Inspection time in each viewing condition for identification of objects presented</td>
<td>Experiment I: In optimal driving conditions, the driving performance was not affected by the VLT for the elderly individuals. However, under marginal viewing conditions a VLT of 63% was reported to affect the driving. For young adults, the deterioration in driving was reported with VLT at 20%.</td>
<td>Participants were not randomized to treatment conditions; results of testing in a simulator may not generalize to on-road driving conditions.</td>
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<td>Caird et al.</td>
<td>Determine the effectiveness of the Vision Enhancement System (VES) on the performance of older and younger drivers and identify which aspects in the traffic system (e.g., other vehicles, pedestrians) should be enhanced to improve traffic conditions</td>
<td>I—Randomized control trial Two groups, pretest–posttest</td>
<td>Group 1: Conformal visual enhancement system used in different contexts (e.g., baseline, daytime, fog), which is in the form of a blue bar on front and rear bumpers</td>
<td>Although the use of VESs was reported to be more effective during hazardous conditions such as fog, it was not effective during daytime everyday driving. VES was of questionable usefulness for parked and oncoming cars, and highlighting may not be sufficient for a driver to identify an object and react appropriately.</td>
<td>The results reported in the study are not conclusive; therefore, the applicability of the VES in real-world driving in improving safety is limited.</td>
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Table 1. Evidence Table: Automobile-Related Modifications (continued)

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| De Waard et al.      | Determine the effectiveness of a driving offense detecting system in improving compliance of drivers with laws and determined whether such a system has any secondary effect on driving behavior | II—Nonrandomized mixed-factor design  
(N = 37 (21 participants ages 30–45 and 16 participants ages 60–75)) | Intervention was use of the DETER (Detection, Enforcement, and Tutoring for Error Reduction) system in a driving simulation environment with feedback about traffic violation in both audio and visual forms. Four trials were conducted, with feedback only during the second and third trials.  
Outcomes:  
- Effectiveness of system: Changes in driver behavior  
- Driving performance: Control over vehicle’s lateral position  
- Rating scale mental effort: To determine mental workload  
- Heart rate and energy expenditure  
- Subjective opinion about the system | Speeding violations were reported to decline significantly for all age groups with feedback from Sessions 1 to 3.  
With elders, this was significantly lower even in the fourth trial. Numbers of stop violations decreased in Trial 3.  
A difference was observed in the feedback versus no-feedback groups in terms of control over vehicle’s lateral position.  
No difference was detected in mental workload for feedback versus no-feedback groups.  
No difference in heart rate and energy expenditure was observed for the two groups.  
Acceptance and satisfaction with the system were higher for the older drivers compared with the younger drivers. | A learning effect cannot be ignored in the fourth trial, which might be accountable for improvement in safety in spite of no feedback; reliability of the measurement system was not reported; the outcome was a combined effect of both visual and auditory system. Preference of one system over the other is not conclusive; participants were not randomized to treatment. |
| Dingus, Hulse,       | Investigate effects of age, experience with navigation system, and navigation technique on driving with the Advanced Traveler Information System (ATIS) | II—Nonrandomized mixed-factor design  
Study 1: N = 18  
(six participants ages 16–18, six participants ages 35–45, and six participants ages 65–73)  
Study 2: N = 12  
Study was limited to high-mileage drivers in Orlando, FL.  
Study 3: N = 1,203  
(220 participants ages 25–35, 431 participants ages 35–44, 319 participants ages 45–54, 130 participants ages 55–64, and 50 participants ages 65 and older)  
Studies 1 and 2: six navigation configurations were used: (1) turn-by-turn guidance with voice guidance, (2) turn-by-turn guidance without voice guidance, (3) route map with voice guidance, (4) route map without voice guidance, (5) textual paper direction list, and (6) conventional paper map.  
Four types of roadway configurations were used: (1) residential streets, (2) two-lane arterial, (3) multilane arterial, and (4) freeway.  
Study 3: Naturalistic driving by participants with rental cars  
Outcomes:  
- Studies 1 and 2  
- Driving performance  
- Navigation performance: Driving safety  
Study 3  
- TravTek: Driver interactions with the vehicle, vehicle location, and speed heading  
- Subjective experience with ATIS | Older drivers consistently showed decreased performance in navigating, eye duration, scanning behavior, and planning and trip times and made significantly more safety-related errors than younger drivers.  
Results do, however, show that older drivers can substantially benefit from use of ATIS configurations, especially from the route planning and guidance functions of the ATIS. Older drivers benefited more from turn-by-turn information rather than full route information. Older drivers also did better with redundancy of information (i.e., use of auditory and visual information). Youngest drivers had an easier time learning and using the TravTek, likely because of the computer experience advantages of these users. In the naturalistic study, the majority of drivers used the ATIS when given the choice, but it was unclear whether drivers selected the configuration that was most usable and resulted in the safest driving or were simply not motivated to change from the default condition. | Lack of randomization was a limitation. |


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<td>Dingus, McGhee et al. (1997)</td>
<td>Evaluate the effects of headway maintenance and of collision avoidance (CAS) on driving performance of older and younger drivers</td>
<td>I—Randomized mixed-factor design</td>
<td>Experiment 1: Participants followed a confederate lead vehicle that controlled the braking for the study. Three visual displays (car, bars, blocks) were presented to alert drivers of dangerous following circumstances. Outcome: * Mean and minimum headway. Experiment 2: Participants followed a confederate lead vehicle, and false alarms were interspersed among the CAS signals that indicated the confederate vehicle was actually braking or turning.</td>
<td>Experiment 1: The displays helped participants maintain larger, safer headway distances without a display. The displays also helped decrease frequency of driving too closely. No differences between age groups were reported. Experiment 2: Younger drivers tended to drive closer to the confederate vehicle but increased the headway between the two cars when more false alarms were experienced. Older drivers were more insensitive to false alarms; the authors stated that this may be due to a tendency to maintain greater distance between cars under all conditions.</td>
<td>Longer-term field studies would be necessary to establish the full effects of false alarms on driver performance.</td>
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<td>Fancher et al. (1998)</td>
<td>Test the effectiveness (use and satisfaction) of adapted cruise control (ACC) for older and younger drivers</td>
<td>Level III—pretest–posttest design</td>
<td>Participants drove a test vehicle for either two or five weeks. The ACC system installed in the test vehicle included a “sweep” sensor that detected distance and rate of closure to the vehicle ahead and a “cut-in” sensor that detected when other vehicles cut in front of the driver. Outcomes: * Driving styles questionnaire. * Outcome measures included impact of driving task, utilization choice, comfort, and convenience.</td>
<td>Drivers used the system 20%–100% of the time when conditions were favorable. Older drivers used the ACC more than younger drivers, and it was used most frequently for all age groups for speeds over 55 mph (88.5 km/hr). In general, older drivers set the system for longer headways than younger drivers, and ACC usage by older drivers was greater at the beginning than at the end of the study. Ninety-five percent of older drivers favored the use of ACC and stated that they would use the system in the future.</td>
<td>Lack of control group was a limitation.</td>
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<td>Freedman et al. (1993)</td>
<td>Investigate effects of low transmittance of rear window on low/medium contrast visibility in a passenger car</td>
<td>I—Randomized mixed-factor design</td>
<td>Four transmittance levels and five roadside objects with different levels of contrast were projected onto the rear- and side-view mirrors of a simulated vehicle. Outcomes: * Measure of target detection: Localization identification of the target. * Object detection: Both location and identification of the object presented. * Response time in identification.</td>
<td>Performance generally decreased with increasing age and with decreasing transmittance and contrast. Safety of backing maneuvers may be significantly reduced for all drivers in cars with tinting that decrease rear window transmittance to a level of 53% or less. Older adults may have an increase in risk of not detecting low-contrast objects with reduced transmittance windows below 70%. Use of simulator may make it difficult to generalize to on-road conditions and may underestimate errors of detection. Age-related deficits may have been underestimated for detection due to this sample having a higher level of low-contrast sensitivity than a more randomly sampled broader population.</td>
<td>Use of simulator may make it difficult to generalize to on-road conditions and may underestimate errors of detection.</td>
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<td>Gish et al. (1999)</td>
<td>Investigate the efficacy of a vision enhancement system (VES) as a countermeasure for preventing night driving crashes and to determine whether there is a relationship between risk perceived by a driver and driving speed</td>
<td>II—Nonrandomized mixed-factor design</td>
<td>Two groups: (1) VES present and (2) VES absent; each group was presented with 32 trials, which were combinations of different factors, such as age, glare, location, task, and target. Outcome: * Distance for detecting target. Target onset distance.</td>
<td>Detection of the target was higher with the use of VES than with no use of VES only for glare condition and target location. The younger drivers were more enthusiastic about the usefulness of the display and generally more willing to use it, whereas the older drivers were more cautious and less positive about the benefits of the display. Limitations included the small sample size and that it was not randomized. Study was conducted on an abandoned Air Force base, so it may be difficult to generalize the results to on-road conditions. Period of VES use may have been too short to be accepted by older adults.</td>
<td>Reference: Dingus, T. A., McGhee, D. V., Manakkal, N., Jahns, S. K., Carney, C., &amp; Hankey, J. M. (1997). Human factors field evaluations of automotive headway maintenance/collision warning devices. Human Factors, 39, 216–229. Reference: Fancher, P., Ervin, R., Sayer, J., Hagan, M., Bogard, S., Bareket, Z., et al. (1998). Intelligent Cruise Control Field Operational Test (Final Report, Report No. UMTRI-98-17). Ann Arbor: University of Michigan, Transportation Research Institute. Reference: Freedman, M., Zador, P., &amp; Staplin, L. (1993). Effects of reduced transmittance film on automobile rear window visibility. Human Factors, 35, 535–550. Reference: Gish, K. W., Staplin, L., &amp; Perel, M. (1999). Human factors issues related to use of vision enhancement systems. In Research on intelligent transportation systems, human factors, and advanced traveler information system design and effects (Transportation Research Record 1694). Washington, DC: Transportation Research Board.</td>
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<td>Imbeau et al.</td>
<td>Explore which of the instrument panel illumination colors, brightness, and character sizes are most suitable for night driving</td>
<td>II—Nonrandomized mixed-factorial design, N = 24 (eight participants ages 19–30, eight participants ages 31–50, and eight participants ages 51–73)</td>
<td>All groups received interventions in a simulator laboratory.</td>
<td>There was a statistically significant difference between age groups.</td>
<td>The result of the study might be masked because of interaction and/or confounding effects of several variables. Use of a simulator may limit generalizability of results to on-road driving.</td>
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<td>Laux (1991)</td>
<td>Evaluate how older drivers used Tetra Star, an advanced-traveler information system</td>
<td>III—Pretest–posttest, N = 102 (34 participants ages 19–29, 34 participants ages 30–64, and 34 participants ages 65–80)</td>
<td>Participants drove a project-lease vehicle for 28 days that was equipped with Tetra Star.</td>
<td>Older drivers were less likely than other participants to use the Tetra Star system for commuting. In addition, older drivers took more of their trips in the morning than did younger drivers. Although older drivers had less difficulty understanding directions than younger drivers, older participants also reported that the information from the guidance system was presented too far in advance.</td>
<td>Lack of a control group is a limitation.</td>
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<td>Kostyniuk et al.</td>
<td>Determine the effect of aftermarket tinting on driving vision</td>
<td>II—Nonrandomized mixed-factorial design, N = 20 (10 participants ages 20–29 and 10 participants ages 60–69)</td>
<td>Tinted side windows either without aftermarket film 82% transmittance (control group), medium tints of 57% transmittance, or dark tints with 18% transmittance.</td>
<td>For age group 20–29, contrast sensitivity between the control and dark tint was significant, as was contrast sensitivity between medium and dark tints. For age group 60–69, the medium tints reduce contrast sensitivity for middle and high spatial frequency.</td>
<td>Use of a nonstandardized instrument for measuring contrasts sensitivity and small sample size could minimize the applicability of the results to the overall population of elderly people.</td>
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<tr>
<td>LaMotte et al.</td>
<td>Determine the effect of aftermarket tinting of rear and side windows on driving vision</td>
<td>I—Randomized mixed-factorial design, N = 38 (16 participants ages 19–27 and 22 participants ages 60–87)</td>
<td>Drivers’ expectancies for 14 controls and 4 displays were assessed first in the participant’s car, and then participants were given 3 different cars to drive.</td>
<td>Significant differences in terms of time for locating controls/displays were reported among the three vehicles and between age groups. Older participants were slower than younger ones to locate controls and displays. Older drivers were slower on controls/displays that they would likely not use or need in an everyday driving situation.</td>
<td>Study is of good quality.</td>
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| Liu (2001)              | Explore whether drivers’ reactions and performance are affected by the multimodality display in ATIS and to explore differences in driving performance due to age of the driver | I—Randomized mixed-factor design  
N = 32 (16 participants ages 18–25 and 16 participants ages 65–73) | Both groups completed six driving scenarios (approximately 60 min) on a simulation with feedback: audio only, visual only, multimodality only, and driving (high- and low-load driving).  
Outcomes:  
- Data from the simulator, including response time, number of missed button pushes, and total of correct turns  
- Assessment by a rater on navigation-related errors, turn direction, and name of turn street  
- Subjective Workload Assessment Technique and preference rating by drivers | For both age groups, users of the multimodality display produced fewer misses than those in the auditory condition or the visual condition. The visual display accounted for the largest number of missed turns, and the multimodality display accounted for very few navigation-related errors. There was a significant difference in performance for older and younger groups for all study tasks. The results indicate that the visual display led to less safe driving, because it imposed higher demands on participants’ attention. | Implementation of the results obtained from these experiments into a clinical protocol has not been clearly stated in the study, and its effectiveness might be questionable. |


| McKnight & McKnight (1992) | Evaluate the effectiveness of in-vehicle navigation systems in enhancing safety by reducing the distraction involved in looking at maps and searching for street signs | Level I—Randomized mixed-factor design  
N = 150 (50 participants under age 25, 50 participants ages 25–50, and 50 participants over age 50) | Video-based simulation evaluated driver performance using five alternative navigation information sources: (1) area map, (2) strip map, (3) strip map with position indicator, (4) directional guidance with an audible signal, and (5) a combination of position indication and directional guidance.  
Outcomes:  
- Total time looking at navigation displays  
- Appropriate traffic responses | The results indicate that older drivers failed to anticipate turns more frequently and had a higher cumulative glance duration than younger participants. The guidance system, which produced an alarm and a directional arrow before a turn, had the lowest error rate and total looking time but was ranked as least preferred of the navigational displays. | Use of a simulator limits the ability to generalize to on-road driving. |


| Mollenhauer, Dingus, & Hulse (1995) | Investigate the efficacy of in-vehicle technologies integrated into a heads-up display (HUD) to help elderly drivers compensate for age-related degradation in driving performance | II—Nonrandomized mixed-factor design  
N = 32 (16 participants ages 65–69 and 16 participants ages 70 and older) | To navigate from one destination to another (while doing tasks such as finding street cross sections, following vehicles, and passing vehicles) using either a paper map or a HUD under two types of conditions: (1) baseline events and (2) navigation with braking  
Outcomes:  
- Driving performance  
- Navigation performance measures: Number of correct turns and navigation time  
- Collision avoidance performance measures  
- Subjective Workload Assessment Technique: Measuring mental workload | Drivers had more correct turns when using HUD compared with the standard display and paper map.  
Subjective Workload Assessment Technique: No significant difference in mental workload was reported between HUD display and standardized display.  
Results from a satisfaction questionnaire indicated that the older adults would use an integrated HUD. | Impact of the HUD on other aspects, such as attention and confusion, was not reported; generalization of the outcomes to real-world driving situation may be limited. |

Table 1. Evidence Table: Automobile-Related Modifications (continued)

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Study Objectives</th>
<th>Level/Design/Participants</th>
<th>Intervention and Outcome Measures</th>
<th>Results</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pohlmann &amp; Traenkle (1994)</td>
<td>Investigate the effectiveness of the TRAVELPILOT navigational system in improving navigation performance, driving performance, and reducing mental workload in older drivers</td>
<td>II—Nonrandomized mixed-factor design (N = 48) (24 participants ages 35–50 and 24 participants ages 61–70)</td>
<td>All the participants received three forms of intervention: (1) use of TRAVELPILOT navigational system, (2) use of map, and (3) experimenter giving directions.</td>
<td>Participants in both age groups were significantly more likely to have slight and severe lane deviations when using TRAVELPILOT than in the road map condition ((p &lt; .001)). The lane deviations that occurred while using TRAVELPILOT were reported to result in a high accident risk due to the requirement of turning the head to fixate on the display or compensatory reactions when turning the head to one side and steering to another.</td>
<td>Lack of randomization was a limitation.</td>
</tr>
<tr>
<td>Sayer et al. (1999)</td>
<td>Investigate the potential benefits of hydrophobic treatment on the driver-side window and exterior rearview mirror on improving distance judgment for drivers</td>
<td>I—Randomized mixed factor (N = 24) (12 participants ages 20–28 and 12 participants ages 66–83)</td>
<td>Four experimental conditions with treated/untreated mirrors and windows. Water was used to simulate a rain effect.</td>
<td>There was no difference in distance estimates to target vehicle with the application of hydrophobic treatment to the driver-side window and exterior rearview mirror for older and younger participants.</td>
<td>The study determined only perception of the distance from target vehicle, which may not be an actual measure of driving performance.</td>
</tr>
<tr>
<td>Schumann et al. (1997)</td>
<td>Determine the effects of windshield rake angle and dashboard reflectance on different veiling glare and driving performance and object detection</td>
<td>I—Randomized controlled trial (N = 16) (eight participants ages 18–30 and eight participants ages 66–76)</td>
<td>Nine combinations of three rake angles and three dashboard reflectances were presented with two levels of contrast of pedestrian.</td>
<td>Both windshield rake (mounting) angle and dashboard reflectance had measurable effects on visual performance, and effects were particularly pronounced if there was a large rake angle combined with high dashboard reflectance. Although there was no significant difference in detection time between the two age groups, the missed-response rate was higher for elderly participants compared with younger participants.</td>
<td>Other extraneous variables, such as dashboard gloss, texture, and inclination angle, which might have some influence on veiling glare, were not controlled for.</td>
</tr>
<tr>
<td>Steinfield &amp; Green (1995)</td>
<td>Examine driver performance with a simulated heads-up display (HUD) that might be used for navigation as compared to a conventional instrument panel (IP) display.</td>
<td>Level I—Randomized mixed-factors design (N = 12) 6 younger (18–20, mean age, 21) (M-3, F-3) 6 older (65+ years, mean age, 73) (M-3, F-3)</td>
<td>In 15 blocks of trials (practice and test), participants sitting in an automobile mock-up were presented with a slide of a road scene concurrently with a slide of a navigation system display appearing either on IP or HUD. The driver compared the two images and pressed either “same” or “different” on key on right-hand armrest.</td>
<td>Although the response times of older drivers overall were longer than those of younger drivers, both groups had significantly shorter response times using HUD than IP.</td>
<td>Limitations included small sample size, use of simulator may make it difficult to generalize results to on-road conditions.</td>
</tr>
</tbody>
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Table 1. Evidence Table: Automobile-Related Modifications (continued)

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<td>Tan &amp; Lerner (1995)</td>
<td>Evaluate a variety of auditory warnings that could be used in crash avoidance systems</td>
<td>Level I—Randomized mixed-factor design</td>
<td>Twenty-eight auditory warnings were presented in a simulator while participants heard two levels of vehicle noise (truck and sedan). Auditory warnings were presented at 6 dB (A) above the vehicle noise level. Participants judged each sound for preference on a Likert scale.</td>
<td>Four warnings were preferred and include a low-fuel warning (a rapid siren) and a continuous, low-pitch ambulance siren. Overall, older listeners preferred all sounds more than younger participants. Older adults rated four sounds lower, and the authors reported that age-induced hearing loss may have affected the perception of these sounds.</td>
<td>Generalization of the outcomes to real-world driving situation may be limited.</td>
</tr>
<tr>
<td>Wolffsohn et al. (1997)</td>
<td>Determine the influence of cognition and age on factors such as accommodation, detection rate, and response times when using a car head-up display (HUD).</td>
<td>Level II—Nonrandomized mixed-factor design</td>
<td>All three age groups received three types of cognitively demanding tasks: (1) low, (2) medium, and (3) high.</td>
<td>With increase in cognitive demands, there was increase in accommodative response in all age groups. The accommodative response was significantly different for day and night situations. A significant increase in response time was reported with an increase in cognitive demands for all age groups.</td>
<td>Lack of randomization was a limitation.</td>
</tr>
</tbody>
</table>


vehicle. This extended period of time is needed for both regularly and infrequently used controls. In addition, results indicate that, although older adults can read an instrument panel with larger characters more easily, brightness of the instrument panel is only important for older adults when smaller characters are used (Imbeau et al., 1989).

The second category of results included studies related to adaptive equipment. Although no studies evaluating lower technology adaptive equipment were located as a result of the search, 15 studies examined the effect of ITS on older adults’ driving performance, including in-vehicle navigation systems, heads-up displays (HUDs), visual enhancement systems that enable the driver to see critical hazards, adapted cruise control that adjusts to the speed and distance of a vehicle ahead, and collision avoidance systems that use sensors to monitor vehicle surroundings. Of the studies, 6 were Level I, 7 were Level II, and 2 were Level III.

The results indicated that the evidence for the use of ITS is inconclusive. Mixed results have been observed, for example, in a Level I study (Caird et al., 2001) and a Level II study (Gish et al., 1999) examining visual enhancement systems that provide enhanced visual contrast to drivers.

Some evidence indicates that the HUD, a display that presents data without blocking the driver’s view, is effective in promoting older adults’ driving performance. In a Level II study, Mollenhauer et al. (1995) reported more correct turns using HUD, and in a Level I study Steinfeld and Green (1995) reported shorter response time. In a Level II study, however, Wolffsohn et al. (1997) indicated that response time using HUD increases as the cognitive demands of a driving task increase. This increased response time occurs, for example, when comparing the difference in response time between day and night driving. Other studies examining the cognitive demands of driving for older adults have indicated that simpler versions of ITS are better than those that are more complex. In a Level II study, for example, Dingus et al. (1997) reported that turn-by-turn information as opposed to full-route information is better for older adults using route guidance. Older adults also did better with redundancy of information, such as when the driver is presented with both auditory and visual information.

Although successful performance is an important outcome of ITS, researchers in the area of human factors also consider whether the technology would be acceptable to a given population. Satisfaction surveys were incorporated into several outcome studies in the systematic review, and the results indicated that older adults would be willing to use selected ITS equipment. Although older adults stated that they would be likely to use driving offense detection equipment (de Waard et al., 1999) and adapted cruise
control (Fancher et al., 1998), other research has indicated that older adults would more cautiously accept vision enhancement systems (Gish et al., 1999) and were less likely to use an advanced traveler information system such as TetraStar (Siemens Automotive Corporation, Auburn Hills, MI) for commuting (Kostyniuk et al., 1997). TetraStar provides drivers with turn-by-turn route guidance through visual and auditory commands.

Discussion
The research presented here has both global and public health implications as well as specific implications for occupational therapy practice. As mentioned previously, the use of a car is central to health promotion because it allows the older adult to maintain an active lifestyle. Evidence from the National Household Travel Survey (Collia, Sharp, & Giesbrecht, 2003) indicates that the motor vehicles driven by older adults typically are older than those driven by younger adults. Driving an older car is advantageous to the older adult because it is less expensive and having the experience of driving one car for many years may reduce the demands of driving. Older cars, however, may have fewer safety features and also lack the technological upgrades and advanced crash protection of newer cars. Except for the use of ITS, the results of the evidence presented here are consistent with the reported spending practices of older adults (Collia et al., 2003). Window tinting and hydrophobic treatments, which would require the additional outlay of funds, have been shown to either have no effect or be detrimental to older adults’ driving performance. Moreover, research indicates that additional time is required for an older adult to adapt to the use of a less familiar vehicle with added equipment (Laux, 1991).

Although it has been shown that older adults can learn to use ITS and respond favorably (de Waard et al., 1999; Dingus et al., 1997; Fancher et al., 1998; Gish et al., 1999; Henk & Kuhn, 2000; Steinfeld & Green, 1995), cost may be a limiting factor in their use. Older adults may be unwilling and unable to purchase additional technology as the costs of new cars and gasoline rise. As the technology is developed further and is featured in a wider range of automobiles at a variety of price ranges, ITS use may increase as younger adults will purchase these motor vehicles and continue to use them in their later years. According to Ellis and Talbot (2005) and Molnar et al. (2003), it is important for car designers to view the needs of older adults through the perspective of universal design. Making cars that are accessible to greater number of drivers will allow drivers to continue to use automobiles for longer periods of time, whether they are experiencing age-related changes and a decline in the ability to drive a motor vehicle or not.

Limitations
Studies included in this review may have been limited by small sample size, lack of control group and randomization, and limited length of follow-up. In addition, the results of studies conducted in a driving simulator or other experimental situations may not generalize to on-road conditions, and studies with healthy participants may not reflect the composition of the older adult population with health-related conditions. Also, several studies did not control for extraneous variables in the statistical analysis.

Because of the complex nature of the interaction of motor vehicle and driver in a given environment, it is difficult to consistently predict an older adult’s occupational performance. Using a car presents visual, cognitive, and motor demands that can facilitate or be a barrier to restoration, maintenance, or compensation of participation in driving. For example, an older adult may be able to adequately drive a motor vehicle but have difficulty getting in and out of it and may experience fatigue. Fatigue may, in turn, result in the limitation of driving for instrumental activities of daily living tasks or social engagements. Another example of multiple challenges presented by using a motor vehicle can be seen in the older adult who is independent in driving but does not have adequate room to store his or her wheeled mobility device (Steinfeld et al., 1999).

The evidence for adaptive equipment in general, and ITS in particular, indicates that older adults can successfully incorporate equipment into their driving routines if it is simple, and adequate training in its use is available. This use of ITS is consistent with published recommendations (Hunt, 2001; Molnar et al., 2003; National Highway Traffic Safety Administration, 2001; Stav et al., 2006; Steinfeld et al., 1999) that effective modification of a motor vehicle incorporates selecting suitable equipment, installing it appropriately, monitoring it for fit and comfort, and providing people with opportunities to achieve mastery in its use. This training also is important to reduce potential fears regarding technology and should incorporate general compensation techniques such as adjusting seats, mirrors, and steering wheel to provide optimal positioning for driving. Molnar et al. (2003) recommended that successful ITS applications be affordable and work to enhance safe driving rather than produce additional distractions that can increase risk of a crash. Equipment is most effective when its use is seamlessly incorporated into the vehicle’s operation and does not become a divided-attention task. It must be kept in mind...
that research presented here was with older adults without cognitive deficits, and it is unknown whether use of adaptive equipment is effective for older adults experiencing even minor cognitive changes.

Occupational therapists and occupational therapy assistants also need to take a role in making sure that players at local, state, and national levels are aware that car modifications can have a positive impact on older adult driving. As the number of older adults increases, policymakers will continue to weigh the costs of acceptable public transportation for older adults with the costs of simple adaptive equipment that permits an older adult to drive. Occupational therapists need to provide policymakers with evidence regarding driving and community mobility.

Occupational therapy practitioners also can be effective advocates to automobile companies locally, nationally, and internationally. On a local level, they can provide assistance to local car dealerships to guide older adults in purchasing cars that will meet their needs. In addition, they can help car dealerships selling adapted vehicles to customers with disabilities understand the modifications needed to accommodate changes as individuals age. This knowledge also is important as occupational therapists and occupational therapy assistants consult with automobile manufacturers to develop motor vehicles that meet the needs of older adults.

On another level, evidence presented here encourages occupational therapy practitioners, educators, students, and researchers to broaden their perspectives on older adult driving. Although motor vehicles can be viewed simply as tools that enable older adults to drive, older adults’ emotional attachment to their vehicle often encourages them to overcome cognitive, motor, and visual challenges to using the vehicle. The results presented here should encourage more research regarding the impact of automobiles on older adults’ participation not only in community mobility but also in other areas of occupation and daily life. It is not known, for example, what impact low-technology adaptive equipment has on older adults’ driving ability, performance, and safety. Although occupational therapists frequently recommend this type of equipment and evidence suggests that older adults might be interested in using it (Steinfeld, et al., 1999), no evidence demonstrates that it makes a difference in older adults’ participation in driving. In addition, many of the studies presented here were conducted with a driving simulator. It is unknown whether the results of the studies conducted in a simulator might be different from those conducted in a natural environment.

Another possible area to explore is the meaning of the automobile in older adults’ occupational lives. Although this type of research question may not be considered a typical evidence-based question, it will serve to develop the knowl-

dge base within occupational therapy. This strengthening of research in the area of older adult driving will then allow for increased collaborations between those in occupational therapy and others involved in designing the motor vehicles of the future. ▲

Acknowledgments

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