Advances in Technology Used to Assess and Retrain Older Drivers

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K. K. Ball, V.G. Wadley, J. D. Edwards, Advances in Technology Used to Assess and Retrain Older Drivers, Gerontechnology 2002; 1(4): 251 - 261. Society's investments in medical research and improved healthcare have produced gains in length of life that must be supplemented with investments in technological solutions that support continued mobility, autonomous functioning, and a high quality of life for older adults. This paper reviews promising advances in the technology available to assess and remediate sensory, physical, and cognitive declines with age--declines that often threaten quality of life and independence. We focus on the assessment and rehabilitation of individual variables related to mobility in general and to driving in particular. While many gains have been made in the identification of risk factors for decrements in driving skills and motor vehicle collisions, only recently are gains being made in the development of effective interventions to restore driving skills. With the benefit of current technology, these programs have the potential to enhance both personal wellbeing and public safety.

Keywords: driver training, Useful Field of View, aging, driver safety, mobility

Technological advances have made longer life expectancies a reality. Our society has invested billions of dollars to improve sanitation, nutrition, and health care. In return, we have reaped increased longevity[1], from an average life expectancy of only 47 years of age for an individual born in 1900 to a life expectancy of 75 years for an individual born in 1990. Life expectancy is projected to steadily increase to 80 years of age or older by the year 2050[2]. With these trends toward increased longevity, maintaining functional abilities into older age is of critical importance. Advanced age can bring about sensory, physical, and cognitive declines that threaten independence and quality of life. Therefore, those substantial investments in medical research and health care that have produced gains in length of life must now be supplemented with equal investments in technologies and social-behavioral solutions that support autonomous functioning and a high quality of life for older adults.

One functional domain that is crucial for maintaining quality of life is mobility. Mobility ensures access to social contacts and health care as well as continued independent functioning. However, mobility can be jeopardized with declining sensory, physical, and cognitive functioning. Almost 20% of adults over the age of 65 report mobility difficulties[3], and these difficulties have been shown to increase the need for formal and informal care[4]. Thus, there is increasing concern that as the percentage of older adults in the population rises over the next 30 years, there will be a concomitant increase in the number of older adults who cannot function independently.

Driving is a vital means of maintaining mobility in many countries and is therefore integral to independence and quality of life. Most older adults in the United States rely primarily upon the personal automobile for maintaining mobility[5]. As individuals age, however, their driving skills may become compromised or called into question. Driving cessation poses a severe threat to mobility and can lead to negative consequences such as less access to volunteer or employment opportunities, religious and social activities, and health care services[6]. Public concerns for safety and autonomy call for both effective evaluation of driving risk and proven rehabilitative programs for those at risk.

The past 10 to 20 years have been marked by technological advances in both evaluation and intervention approaches aimed at extending safe driving among older adults. The purpose of this paper is to review some of the technological contributions that are serving the interest of public safety while sustaining older adults' years of autonomous functioning.

Although highway safety researchers have long sought to determine the characteristics that make some drivers, young and old alike, safer than others, until recently this research has met with limited success. Historically, the reason for this lack of success is that few measures have adequately captured the individual characteristics underlying differences in driving performance. Over the past decade, however, research has pinpointed several factors that reliably predict decrements in driving performance and increased risk for crash.

ADVANCES IN DRIVER ASSESSMENT

Technological advances have occurred in the assessment of vision, higher order information processing, cognition, and driving behaviors via increasingly refined and computer-based measurement tools as well as simulator-based technology. These advances have contributed to our knowledge both of what should and what should not be measured in the quest to identify and intervene on behalf of at-risk drivers.

Visual Sensory Function

Obviously, a basic level of visual function is necessary for safe driving. Until very recently, many licensing agencies have screened predominantly for visual acuity impairments, while some have required no visual assessment whatsoever for license renewal. In those licensing agencies where assessment of visual acuity is required, measurements may vary greatly from having the candidate read an eye chart, many times without strict control of luminance conditions or other important parameters affecting the outcome of testing, to novel computerized assessments.

Originally, visual acuity assessments were designed for clinical use to detect and monitor the progression of disease. Thus, assessment measures were not designed to reflect the visual complexity of driving or other everyday activities[7]. State-of-the-science visual acuity testing has progressed from the eye chart on the wall to the light box to, most recently, software programs that may have distinct advantages for driver licensure. For example, automated vision tests can improve efficiency in heavy volume settings by eliminating the need for one-on-one manual testing. Results with automated tests are automatically scored and saved, reducing personnel time and the possibility of transcription errors. Automated vision tests may also be integrated with other functions at a licensing agency such as knowledge-based testing, digital photo capture, and biometric recognition systems. Furthermore, randomized test designs make vision test memorization impossible. Since test results are automatically stored, they can be easily integrated into existing data management systems, and changes and trends in each individual's vision can be saved and flagged if substantial visual decline is noted. Finally, automating the visual acuity test has the potential to enable licensing agencies to test far more than visual acuity, possibly adding other visual or cognitive test measures that are predictive of driving competence, thereby improving the overall assessment process. While vision test software is still relatively new, companies that market professional vision assessment software are beginning to gain acceptance in license agency settings.

Despite technological advances in the measurement of vision, evidence generally suggests that traditional tests of vision such as visual acuity and disability glare are either not independently predictive of crash involvement[8-11] or are only weakly related[7,12-13]. Visual function measures such as contrast sensitivity and visual field sensitivity may be better predictors of crash involvement than visual acuity, but even so, the relationships are relatively weak[7,10,13-14]. Because driving involves complex visual information processing abilities, it is unlikely that an assessment of visual function alone is sufficient to identify the majority of individuals at elevated risk for crash involvement.

Visual Information Processing

Visual information processing skills are emerging as strong predictors of safe driving. Impaired visual attention abilities, for example, have long been suspected to play a role in automobile crashes[15-16], and this relationship has been extensively explored in recent years[12, 17-18]. Through advances in the use of computerized testing to measure visual information processing abilities in drivers, new tests have been developed which have proved much better at identifying crash-involved drivers than visual sensory measures alone. The useful field of view, an index of higher-order visual processing which also incorporates cognitive processing speed, has shown exceptional promise as a predictor of various driving outcomes among older drivers. Accordingly, a substantial portion of this paper is devoted to the research related to measurement, associations, and potential for improvement of this ability.

USEFUL FIELD OF VIEW

The concept of the useful field of view was originally described by Sanders[19], who used the term 'functional visual field' to define the visual field area over which information can be acquired in a brief glance without eye or head movements. The term 'useful field of view' was first used by Ball and colleagues and subsequently has come to be most widely known as a specific test administered via computer with touch screen technology (the UFOV® test, Visual Awareness, Inc., Chicago, IL, USA). In the earliest version of this test individuals' performance on a central information-processing task was shown to be largely intact irrespective of age. However, performance in the presence of visual distractors resulted in an increased error rate and increased divergence between the performances of young and older individuals at greater eccentricities of the visual field. Subsequent research demonstrated that increasing central task difficulty resulted in increasing decrements in performance for middle-aged and older individuals[20].

The concept of the useful field of view and its measurement were further refined as research in the area of visual information processing progressed during the 1980s and 1990s. For instance, research demonstrated that the diameter of an area that can be searched either serially[21] or in parallel[22] is directly related to both target/distractor similarity (conversely known as conspicuity) and stimulus duration. That is, more conspicuous targets are recognized at further eccentricities than less conspicuous targets, given a constant duration, and targets presented for longer stimulus durations are recognized at further eccentricities given a constant conspicuity. Thus, the size of an individual's useful field of view can be manipulated by varying stimulus duration, conspicuity, and central task difficulty, and these variables interact with both age and stimulus eccentricity in a variety of ways.

The influence of age on the size of the useful field of view has been evaluated in a number of ways. Ball and colleagues[23] evaluated three mechanisms for possible age-related changes in performance on the UFOV® test: (a) reduced speed of visual processing in older adults, (b) reduced ability to divide attention, and (c) greater susceptibility to distractors. They then used an individual-differences approach to evaluate performance across the range of obtained scores. While age alone accounted for approximately half of the variance in UFOV® test scores, individual information related to abilities such as processing speed, difficulty dividing attention, and susceptibility to distractors accounted for 91% of the variance in scores. In other words, once information on these three attributes is known, age becomes superfluous information. Thus, the general age trends observed on the UFOV® test are due to a higher prevalence of age-related decrements in information processing abilities among older adults rather than a generalized age-related decline. Comparing average values of young and older adults can mask the fact that many older adults do not experience any of these age-related decrements. Furthermore, comparing average performance across age groups obscures the unique reasons for performance limitations in different individuals.

As noted earlier, much of the interest in the useful field of view in general (and in the UFOV® test in particular) derives from its utility as a predictor of driving outcomes, particularly among the subset of older individuals who demonstrate UFOV® impairment. Multiple studies have been conducted examining the relationship between the UFOV® test and driving. These studies have used a variety of outcome measures including state-recorded accident reports, driving simulator performance, and road test performance.

UFOV“ and state recorded crashes

In one of the first studies examining the relationship of UFOV® performance to state-recorded vehicle crashes[11], potential risk factors including the health status of the visual system, visual sensory function, visual attention skills (UFOV®), and mental status were examined. These potential risk factors were correlated with participants' state-recorded crashes during the previous 5 years. Only mental status and UFOV® test performance were significantly related to crash frequency. Together, these measures accounted for 20% of the variance in crash frequency. Intersection crashes, the most frequent type of crash, also were best predicted by UFOV® test performance and mental status, together accounting for 29% of the variance.

This study provided the basis for a larger evaluation of a multi-level model of crash prediction. Ball and colleagues[12] employed a methodology similar to that of the previous study in terms of assessing eye health, visual function, visual attention, and mental status. However, this study involved a stratified sample balanced with respect to age and crash frequency over the previous five years. Drivers with at least one crash in the prior five-year period were over-sampled in order to obtain a range of crash involvement. Results revealed that, again, visual information processing and mental status were related to at-fault state-recorded crashes. Of all the measures, UFOV® test performance was most strongly correlated with at-fault crashes.

In an additional analysis using the same sample of drivers, injurious crashes from the prior five-year period were examined[13]. Three groups were compared including: (a) those who had incurred at least one vehicle crash resulting in an injury, (b) those who had been involved in at least one vehicle crash that did not result in any injury, and (c) the remaining drivers who were not crash involved. Logistic regressions revealed that UFOV® impairment was independently associated with crash risk. UFOV® reductions of 22.5-40%, 41-60%, and >60% were associated respectively with 5.2, 16.5, and 21.5-fold increases in risk for

an injurious crash, compared to those drivers with UFOV® reductions of <22.5%. These findings indicate that UFOV® impairment is an even stronger predictor of injurious crashes than of non-injurious crashes.
A final retrospective analysis was conducted using this stratified sample of older drivers[24]. UFOV® was compared to traditionally used paper-and-pencil neuropsychological measures as predictors of state-recorded, at-fault crashes. Results indicated that adding cognitive measures above and beyond the UFOV® assessment measure did not increase accuracy in the prediction of at-fault crashes. The UFOV® measure was most strongly related to crash involvement, with high levels of sensitivity (86.3%) and specificity (84.3%).

Another retrospective study[25] examined the associations between mental status, UFOV® performance, medical and functional variables, and at-fault car crashes in a sample of older drivers aged 55 to 90 years. This study compared drivers who had experienced between one and seven at-fault crashes during the preceding six years to drivers who had experienced none. Results included a modest association between mental status score and crash history. Individuals with 40% or greater UFOV® reduction were 6.1 times more likely to have incurred at-fault crashes than those without this degree of impairment.

In a prospective follow-up study, Owsley and colleagues[13] found that older drivers with a 40% or greater UFOV® impairment were 2.2 times more likely than those with intact UFOV® to incur a crash during three years of follow-up. Again, UFOV® impairment was the only type of visual deficit found to be related to future crash involvement.

In summary, each of these studies found the UFOV® assessment measure to be a reliable predictor of crashing as measured by state-recorded reports. Furthermore, as compared to a number of other visual and cognitive measures, the UFOV® measure was consistently found to be the strongest predictor of crashing. In general, older drivers with a UFOV® reduction of 40% or greater were more likely to have a crash and were particularly likely to be involved in at-fault and injurious crashes.

UFOV® and driving simulator performance
Studies examining the relationship between the UFOV® measure and driving simulator performance have been conducted with young adults, middle-aged adults, healthy older adults, and older adults with Alzheimer's disease.

Roenker and colleagues, in a study described by Ball and Owsley[26], examined the relationship of UFOV® performance to driving simulator performance in the context of a training study. Older adults with intact visual acuity and contrast sensitivity were assessed in a Doron Model L-225 driving simulator. Results of this study identified a significant relationship between UFOV® performance and simple reaction time to brake lights as well as choice reaction time to varying traffic signs. Individuals with greater UFOV® impairment demonstrated slower choice reaction times.

Rizzo, Reinach, McGehee, and Dawson[27] conducted a study examining driving simulator performance in older adults with Alzheimer's Disease (AD). Twenty-one individuals with AD and 18 age-matched controls without dementia participated in the study. Participants' visual acuity and contrast sensitivity were assessed as well as their UFOV® performance. Participants 'drove' on a simulated rural two-lane highway in the Iowa Driving Simulator, SIREN. (The SIREN is a four-channel, 150 degree forward view and 50 degree rear view high-performance simulator that provides a dynamic driving scenario. Roadway types, pedestrian behavior, and the visual and auditory environments can be controlled and modified.) The simulator course included four events associated with crashes. Simulator equipment recorded steering wheel position, normalized accelerator and brake position, lateral and longitudinal acceleration, headway, time to collision, speed, and number of crashes. Driver performance errors were recorded and classified, and potential injury severity was calculated.

There was no difference between AD patients and controls in visual acuity; however, the AD group tended to have poorer contrast sensitivity than controls. Six of the 21 AD participants experienced 'crashes' in the driving simulator, while none of the controls experienced crash. Performance on Trails B, a test of executive function and selective attention, was modestly associated with simulator crashes assessed across both groups. While the AD group demonstrated greater UFOV® impairment than did controls, no participant with intact UFOV® experienced a crash, irrespective of dementia diagnosis. Indeed, UFOV® impairment proved to be an even stronger predictor of simulator crashes than the diagnosis of AD (OR = 18.13 for UFOV® impairment; OR = 8.91 for AD)[27].

Findings from simulation studies correspond to the findings associated with state records of automobile crashes. Specifically, UFOV® impairment is related to slower response times, a greater number of dangerous maneuvers, and a greater number of simulator crashes. Older adults demonstrate greater reductions in UFOV® and poorer driving simulator performance than younger adults, and healthy elderly demonstrate better performance than do individuals with AD.

UFOV® and on-road testing

Several studies have examined the relationship between the UFOV® assessment and on-road driving performance. Some of these studies have been conducted among participants with no known neurocognitive impairments[26,28], whereas others have been conducted among patients with physical and/or cognitive impairments resulting from conditions such as AD and stroke[29-30].
Roenker and colleagues[26] conducted a study of community-dwelling individuals 55 years and older who were given a vision screening, the UFOV® assessment, simple and choice reaction time tests, and an on-road driving test. A driving instructor directed the participant along the route while two trained evaluators rated the driver. Results included a strong correlation between UFOV" performance and global driving ratings.

In another study of on-road driving[31], Cushman examined a sample of adults over 55. Cognitively intact participants were recruited from the local community, along with patients with early AD. Participants were given a driving questionnaire, a road test knowledge exam, a response time test, vision screening, road skills assessment, and a series of neuropsychological tests including the UFOV® assessment measure. The road test consisted of a progression from low demand maneuvers in a parking lot to high demand maneuvers in moderate to heavy traffic. Individuals with UFOV® reductions greater than 40% had significantly poorer on-road performance than less impaired individuals. Using 40% reduction or greater in UFOV® as the cutpoint for failing the UFOV® test, 82% of drivers who failed the UFOV test also failed the road test, and 86% of those who passed the UFOV® test passed the road test.

Ducheck and colleagues[29] also conducted a study with healthy controls and patients with very mild and mild AD. All participants were administered the Washington University Road Test (WURT), a 45-minute road test consisting of both closed and open courses assessing skills such as maintaining speed, obeying traffic signs, signaling, turning, changing lanes, and negotiating intersections. All participants were administered a two-hour psychometric battery, and a subset of participants was also administered the UFOV® assessment along with tests of visual search and monitoring. Results indicated that participants with mild AD demonstrated greater UFOV® reduction and more false alarms on the visual search and monitoring tasks compared to controls and participants with very mild AD. Poorer driving scores were associated with increased dementia severity as well as greater UFOV® reduction.

Myers and colleagues[30] conducted a study examining the relationship between the UFOV® assessment and on-road driving performance among patients referred to a driving rehabilitation program. The most common referral diagnosis was cerebrovascular accident (CVA); other diagnoses included Parkinson's disease, hypertension, memory problems, traumatic brain injury, subarachnoid hemorrhage, hydrocephalus, seizures, right hip fracture, and subdural hematoma. Patients were administered a battery of visual and cognitive tests as part of a screening evaluation prior to the driving evaluation consisting of secondary roads, a suburban highway, a shopping center parking lot, and downtown traffic. Participants' driving performance was rated as pass, fail, or questionable.

Visual tracking, visual acuity, reaction time, split attention, visual organization, and UFOV® were all significant individual predictors of performance on the road test. These significant predictors were combined into a single model and compared to a model including UFOV® alone. The model including multiple variables was not significantly better than the model with UFOV® alone. In addition, one's risk of failing the road test increased linearly as UFOV® reduction increased. For UFOV® reductions less than 40%, the probability of failing the road test ranged from 8% (no UFOV® reduction) to 31% (30% UFOV® reduction). For UFOV reductions of 40% and above, the probability of failing the road test ranged from 44% (40% UFOV® reduction) to 93% (90% UFOV® reduction).

Another recent study also sought to identify cognitive factors related to driving difficulties in older adults[32]. Participants from 65 to 96 years of age who were referred for driving fitness evaluations were administered a battery of neuropsychological tests as well as an on-road driving test. Tests of visuoperceptual function, visuospatial function, UFOV®, cognitive flexibility/ reaction time, selected and divided attention, and mental flexibility were included. The on-road driving test was performed along a standardized, course involving real-world traffic situations. An instrument consisting of eleven multi-item scales was used by occupational therapists to evaluate participants' driving maneuvers, and performance was then compared to neuropsychological functions. A four-test neuropsychological model accounted for 64% of the variance in total driving scores. This model included movement perception (accounting for 53% of variance in the global road test score), UFOV® (44%), cognitive flexibility (30%), and selective attention (19%).

In summary, greater restrictions in UFOV® are consistently related to poorer on-road driving performance, poorer driving simulator performance, and vehicular crashes. An individual's UFOV® performance appears to be a stronger predictor of crash risk than visual acuity, mental status examination performance, or a diagnosis of early dementia.

ADVANCES IN TECHNOLOGY FOR DRIVER REHABILITATION

We have described advances in the assessment of risk factors for impaired driving and the careful research that has pinpointed the major risk factors. Now we turn to the question of what can be done to either reverse or compensate for these factors.

Vision Interventions

Cataracts are the leading cause of vision impairment for adults 60 years of age and older and have been associated with decreased driving exposure and increased crash risk[33]. Due to technological advances in surgical techniques and intra-ocular lens design, vision impairment due to cataracts is largely reversible[10]. Such technological advances then have potential for enhancing older adults' functional abilities and increasing the likelihood of maintaining safe mobility with advancing age.

Educational interventions

Educational interventions offer another approach for enhancing driver safety. Recently, Owsley and colleagues[34] found that an educational intervention for older drivers experiencing decline either in visual sensory function and/or Useful Field of View was effective in changing self-perceptions about vision and attitudes toward driver safety. Furthermore, the intervention led to modification of driving habits such that challenging driving situations were more often avoided and safety-enhancing, self-regulatory practices were more often practiced. The intervention included instructions on how to avoid challenging driving conditions (such as turning left at traffic lights with arrows or driving one block further and making three right-hand turns) and information about the relationship of particular vision or visual processing impairments to safe driving. While effective educational interventions may be administered in classrooms or one-on-one, advances in technology offer clear advantages for broad dissemination. As many as thirty percent of older adults are now using the internet, and this proportion will no doubt increase dramatically in the near future[35] . Thus, online courses could be made available that educate older adults about safe driving practices. Furthermore, advances in technology are making it easier to provide on-line assessments in addition to information over the web. For those older adults with impairments in higher order visual and cognitive processing abilities, very recent work is applying the technological advances in assessing these risks to innovative programs of cognitive retraining.

Cognitive interventions

Several ongoing and recently completed studies are evaluating the impact of a speed of processing training program on cognitive performance and driving outcomes[26,36]. Speed of processing training employs a 10-session, computer-based program targeting improvement in the useful field of view. While the training protocol has been described elsewhere[36-37], a brief summary is provided here. Based upon a UFOV® screening, an individual receives speed of processing training with tasks customized to his or her ability. Trainees with baseline UFOV® impairments practice a single task alone at progressively faster presentation speeds and levels of complexity (target detection, target identification, same/different judgments). As an individual becomes proficient at relatively brief target durations, training progresses to divided and selective attention exercises involving simultaneous central and peripheral task demands. With mastery, training progresses to more complex central tasks, a larger visual field, and briefer display durations.

In a study of older adults who were evaluated before and after either speed of processing training or simulator-based training, only speed of processing training was successful in improving UFOV® performance[26]. Furthermore, this training significantly reduced reaction time to changing road signs in a driving simulator and also significantly reduced the number of hazardous maneuvers during a follow-up drive on the road. However, speed of processing training did not transfer to driving skills that are primarily based upon driving knowledge, such as the appropriate use of turn signals and the proper stopping position relative to other vehicles. Individuals assigned to simulator training rather than speed of processing training were specifically instructed in these behaviors and did improve in these information-based driving skills.

An 18-month follow-up testing of these drivers showed that those individuals who retained improved UFOV" test performance still exhibited fewer dangerous maneuvers during driving than did simulator-trained individuals or speed of processing-trained individuals whose UFOV" test performance had returned to pre-training levels. A similar pattern was found for reaction time to changing road signs in the driving simulator.

Ongoing studies are examining the effects of speed of processing training, relative to various types of control training incorporating the social contact and computer exposure components of speed of processing training, on driving simulator performance, driving habits, on-road performance in a state-of-the-science instrumented car, and other mobility outcomes. Preliminary findings suggest that speed of processing training not only improves UFOV" test performance, but may transfer to other cognitive functions as well as to functional abilities, including certain aspects of driving[26, 36]. For example, preliminary data suggest that while performing in a driving simulator, drivers' speed in detecting moving targets originating in the periphery and moving toward central vision may improve with training, while their detection of static targets originating in central view may not. In summary, some driving tasks appear to benefit from speed of processing training (detection of moving targets, avoidance of hazards), while others (detection of static targets) do not. This research holds promise for establishing a much-needed intervention for drivers whose useful field of view impairment puts them at risk for crashes. Furthermore, as technology becomes more widely available in the homes of older adults, the ability to disseminate such training programs for home use can be expanded through web delivery systems and other mechanisms.

DISCUSSION

Identification and assessment of risk factors for impaired driving among older adults is a field that recently has been marked by a number of encouraging technological advances. These advances currently are being disseminated 'where the rubber meets the road': to state Departments of Motor Vehicles and, in some states, to the medical advisory boards empowered to make licensing decisions and to refer at-risk individuals for further evaluation and rehabilitation. Medical and behavioral intervention research is a relatively new but promising area. For this reason, the long-term outcomes of intervention programs are not yet known. What is known, however, is that research in this area has great potential to extend mobility and autonomous functioning in the elderly, thereby improving the quality of older adults' lives while also serving the goal of public safety for all.

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References

1. Coughlin JF. Technology needs of aging boomers. Issues in Science and Technology; www.nap.edu/issues/16.1/coughlin.htm; 1999
2. United States Census Bureau. Statistical abstract of the United States. Washington, DC: U.S. Government; 1996
3. Guralnik JM, Fried LP, Salive ME. Disability as a public health outcome in the aging population. Annual Review Public Health 1996;17:25-46
4. Ettinger WH, Jr. Immobility. In: Hazzard WR, Bieman EL, Blass JP, Ettinger WH, Jr., Halter JB, editors, Principles of geriatric medicine and gerontology. 3rd edition. New York: McGraw Hill; 1994; pp1307-1311
5. Jette AM, Branch LG. A ten-year follow up of driving patterns among the community dwelling elderly. Human Factors 1992;34:25-31
6. Marottoli RA, Mendes de Leon CF, Glass TA, Williams CS, Cooney LM, Berkman LF. Consequences of driving cessation: Decreased out-of-home activity levels. Journal of Gerontology: Social Sciences 2000;55:S334-S340
7. Owsley C, McGwin G. Vision impairment and driving. Survey of Ophthalmology 1999;6:535-550
8. Johansson K, Bronge L, Lundberg C, Persson SM, Viitanen M. Can a physician recognize an older driver with increased crash potential? Journal of the American Geriatrics Society 1996;44:1198-1204

9. Marottoli RA, Cooney LM, Wagner DR, Doucetter J, Tinetti ME. Predictors of automobile crashes and moving violations among elderly drivers. Annals of Internal Medicine 1994;121:842-846
10. Owsley C, Stalvey B, Wells J, Sloane M, McGwin G. Visual risk factors for crash involvement in older drivers with cataract. Archives of Ophthalmology 2001;119:881-887
11. Owsley C, Ball K, Sloane M, Roenker D, Bruni J. Visual/cognitive correlates of vehicle accidents in older drivers. Psychology and Aging 1991;6:403-415
12. Ball K, Owsley C, Sloane M, Roenker D, Bruni J. Visual attention problems as a predictor of vehicle crashes in older drivers. Investigative Ophthalmology and Visual Science 1993;34:3110-3123
13. Owsley C, McGwin G, Ball K. Vision impairment, eye disease, and injurious motor vehicle crashes in the elderly. Ophthalmic Epidemiology 1998;5:101-113
14. Johnson CA, Keltner JL. Incidence of visual field loss in 20,000 eyes and its relationship to driving performance. Archives of Ophthalmology 1983;101:371-375
15. Barrett GV, Greenawalt JP, Thorton CI, Williamson TR. Adaptive training and individual differences in perception. Perceptual and Motor Skills 1977;44:875-880
16. Kahneman D, Ben-Ishai R. Relation of a Test of Attention to Road Accidents. Journal of Applied Psychology 1973;58:113-115.
17. Ball K, Owsley C. Identifying correlates of accident involvement for the older driver. Human Factors 1991;33:583-595
18. Owsley C, Ball K, McGwin G, Sloane ME, Roenker DK, White MF, Overley ET. Visual processing impairment and risk of motor vehicle crash among older adults. JAMA 1998;279
19. Sanders AF. Some aspects of the selective process in the functional visual field. Ergonomics 1970;13:101-117
20. Ball KK, Beard BL, Roenker DL, Miller RL, Griggs DS. Age and visual search: Expanding the useful field of view. Journal of the Optical Society of America A-Optics and Image Science 1988;5:2210-2219
21. Scialfa CT, Kline DW, Lyman BJ. Age differences in target identification as a function of retinal location and noise level: Examination of the useful field of view. Psychology and Aging 1987; 2:14-19
22. Bergen JR, Julesz B. Parallel versus serial processing in rapid pattern discrimination. Nature 1983;303:696-698
23. Ball KK, Roenker DL, Bruni JR. Developmental changes in attention and visual search throughout adulthood. Advances in Psychology 1990;69:489-508
24. Goode KT, Ball K, Sloane M [authors to be added]. Useful field of view and other neurocognitive indicators of crash risk in older adults. Journal of Clinical Psychology in Medical Settings 1998;5:425-440
25. Sims RV, Owsley C, Allman RM, Ball K, Smoot TM. A preliminary assessment of the medical and functional factors associated with vehicle crashes in older adults. Journal of the American Geriatrics Society 1998;46:556-561
26. Ball K, Owsley C. Increasing mobility and reducing accidents of older drivers. In: Schaie KW, Pietrucha M, editors, Mobility and Transportation in the Elderly. New York: Springer; 2000; pp 213-251
27. Rizzo M, Reinach S, McGehee D, Dawson J. Simulated car crashes and crash predictors in drivers with Alzheimer disease. Archives of Neurology 1997;54:545-51
28. Wood JM, Troutbeck R. Elderly drivers and simulated visual impairment. Optometry and Vision Science 1995;72:115-124
29. Duchek JM, Hunt L, Ball K, Buckles V, Morris JC. Attention and driving performance in Alzheimer's disease. Journals of Gerontology: Psychological and Social Sciences 1998;53:130-41
30. Myers RS, Ball KK, Kalina TD, Roth DL, Goode KT. The relationship of useful field of view and other screening instruments to on-road driving performance. Perceptual and Motor Skills 2000; 91:279-290
31. Cushman LA. Cognitive capacity and concurrent driving performance in older drivers. IATSS Research 1996;20:38-45
32. De Raedt R, Ponjaert-Kristoffersen I. The relationship between cognitive/neuropsychological factors and car driving performance in older adults. Journal of the American Geriatric Society 2000;48:1664-1668
33. Owsley C, Stalvey BT, Wells J, Sloane M. Older drivers and cataract: Driving habits and crash risk. Journals of Gerontology: Biological and Medical Sciences 1999;54A:M203-M211
34. Owsley C, Stalvey BT, Phillips JM. The efficacy of an educational intervention in promoting self-regulation among high-risk older drivers. Accident Analysis and Prevention in press
35. Newburger E. Home computers and Internet use in the United States. Washington, DC: US Census Bureau; 2001; pp1-9
36. Edwards JD, Wadley VG, Myers RS, Roenker

DL, Cissell GM, Ball KK. The transfer of a speed of processing intervention to near and far cognitive functions. Gerontology in press
37. Jobe JB, Smith DM, Ball K, Tennstedt SL, Marsiske M, Willis SL, Rebok GW, Morris JN, Helmers KF, Leveck MD, Kleinman K. ACTIVE: a cognitive intervention trial to promote independence in older adults. Controlled Clinical Trials 2001;4:453-479