11

Enhancing Mobility in the Elderly:
Attentional Interventions for Driving

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It is intuitively obvious to most individuals that we can attend to only a very small percentage of the many stimuli around us at any given time. It is also obvious that some objects are easily noticed (i.e. are conspicuous), whereas other inconspicuous objects may require considerable time and effort to locate. These common experiences capture the basic distinction between the two processes proposed in many models of attentional processing. Although they go by different names in different models (ambient vs. focal, automatic vs. effortful, parallel vs. serial), we adopt the terms *preattentive and attentive systems of processing* as used by Neisser (1967, 1976) and Julesz (1981).

In most previous descriptions, the preattentive system functions as a guide for the attentive system. In the visual domain, it makes use of rapid parallel processing over large spatial areas to alert or orient the attentive system to locations in space where there is relevant or changing information. Once the preattentive system has alerted the attentive system about where to look, the attentive system can then be used to discern detail, identify, or recognize stimuli. The attentive system thus represents a concentration of attentional resources within a small visual area, whereas the preattentive system represents a diffuse allocation of resources to a much larger spatial extent (considered by some to have no capacity limitations other than sensory).

One research technique that was extensively used to investigate attention and these two systems of information processing is visual search. In this technique observers must search for one item, or target, amid varying numbers of other items, or distracters, presented simultaneously (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Treisman & Gelade, 1980). Under some conditions, the entire stimulus array is processed simultaneously (i.e., preattentively) and the relevant target is conspicuous, or "pops out," regardless of the number of elements in the display. In other conditions, however, it appears that items must be processed sequentially (i.e., attentively) such that the number of other items in the display becomes a critical factor in the time required to locate or identify the target.

ATTENTION IN A TECHNICAL SOCIETY

Situations in which an individual must localize relevant information or objects in a visually cluttered environment are numerous and range from simply locating a certain restaurant sign on a busy section of highway, to detecting defects in products on a production line, to detecting enemy tanks on an active battlefield. In such environments, the observer must search for an object, make a decision about the relevance of the object to the search, release the object from attention if appropriate, and locate (attend to) additional objects. Key elements of this process are the ability of the observer to have his or her attention attracted to relevant objects (preattentive search) and the ability to switch attention voluntarily between objects (attentive search). The technological changes since the 1980s have made such searches more, rather than less demanding. For example, with the advent of stealth aircraft and sophisticated camouflage in the military, it has become almost impossible to visually detect the presence of relevant targets. Automobile manufacturers are considering the production of vehicles with "heads up displays" (HUD) in which traffic and other types of information may be displayed on the windshield, thus demanding dual attention to this information as well as the highway. Car phones can result in an additional attentional demand while navigating a vehicle. More and more people are driving, resulting in congestion in most large cities with resultant increases in attentional demand. It is unlikely that many such situations can be changed in ways to make the observer's task less difficult (the enemy is unlikely to paint his or her tanks pink). Rather, it seems more prudent to attempt to understand the capabilities and limitations of the observer, with an eye to increasing or expanding these abilities.

The difficulties associated with localizing a target in a cluttered environment are exacerbated by decreases in viewing time. Finding a sign becomes even more difficult when traveling rapidly down the road. The world of the pilot is one filled with multiple sources of information and rapidly presented stimuli requiring detection, attention , and the release of attention to new objects. Professional athletes must also be constantly aware of the location and movements of other players on the field.

Some individuals function more effectively in high-demand environments than others. For example, those individuals with exceptional attentional skills will function more effectively as air traffic controllers than will those with minimal skills. These individual differences become extremely relevant where ineffective function can result in injury. Safety is a particularly important issue for attentionally demanding activities or occupations for two populations of individuals: special populations with diminished function (e.g., due to head injury, stroke, dementia, attentional deficit disorders, or age-related declines), or special occupations that require exceptional performance (e.g., fighter pilots or tankers; air traffic controllers; power plant operators; emergency vehicle operators of firetrucks, ambulances, or police cars; and professional athletes). These populations fall at the two extremes of the continuum of attentional function where assessment of functional abilities becomes relevant for a determination of fitness for duty or competence to continue an everyday activity such as driving.

Whereas most people agree that attention is critical for the performance of many daily activities, there is not widespread agreement on how to measure it. The Useful Field of View (UFOV)® paradigm is a new approach developed to assess the functional attentional skills required for daily activities such as driving and attentionally demanding occupations, and to train those skills when they are lacking or when exceptional performance is required. The following studies describe the validation of this new technique with respect to crash risk among older drivers.

ATTENTION AND DRIVING

There is little doubt that under most circumstances driving is an attentionally demanding task, especially if one's attentional capabilities have declined. Over the past several years, we found that the likelihood of a decline in attentional ability increases with age (Ball, et al., 1993). For example, although approximately 7% of individuals between the ages of 55 and 60 experience attentional decline, close to 50% of those over age 85 have diminished attentional function. Furthermore, throughout the transportation literature since the mid-1970s, researchers found that most older drivers have excellent driving records, but those who crash do so because of an inability to attend to relevant cues in the driving environment (Barrett, Mihal, Panek, Sterns, & Alexander, 1977; Kahneman, Ben-Ishai, & Lotan, 1973; Mihal & Barrett, 1976; Shinar, 1978). Thus, older individuals who drive represent an ideal population for evaluating new attentional measures and understanding individual differences in attentional capabilities in an everyday context. Furthermore, such studies provide an opportunity for investigating the amenability of attentional skills to training.

Although the understanding of attention may be a worthwhile goal in and of itself, understanding the older driver's limitations addresses a larger social issue. Several years ago, we began a program of research whose ultimate goal was to enhance the mobility of older adults without sacrificing safety concerns (Ball et al., 1993; Ball & Owsley, 1991, 1993; Owsley & Ball, 1993; Owsley, Ball, Sloane, Overley, & White, 1994; Owsley, Ball, Sloane, Roenker, & Bruni, 1991). The need to solve the problems of older drivers has appeared at the top of many national agendas (Barr, 1991; Federal Highway Administration, 1989; National Highway Traffic Safety Administration, 1989; National Research Council, 1985; Transportation Research Board, 1988), and thus our research on mobility problems in the elderly began by focusing on driving. A number of trends referenced in these reports document the need for research in this area. For example, the elderly represent the most rapidly growing segment of the driving population, both in the total number of drivers on the road, and the number of miles driven annually per driver. It is estimated that by the year 2024, one out of four drivers will be over age 65. Older drivers as a group have more traffic convictions and crashes and incur more fatalities per mile driven than most other age groups. For every 100,000 miles driven, crash rates for older drivers are double those of younger drivers. Vehicle crashes are the second most common reason for an emergency room visit by the elderly. Finally, like other age groups in our society, older adults rely on the personal automobile for transportation. Although the stereotype of the impaired older driver may be true for some older adults, there are many older drivers who have excellent driving skills. We viewed our research task as determining what factors place some older drivers at risk for crash involvement, and then to use this information to develop interventions that could be use to minimize their crash risk.

Our research to date has three implications. First, tests of higher order visual abilities, such as the assessment of useful field of view size, are better predictors of driving problems in the elderly than are tests of visual sensory abilities, such as measures of acuity and peripheral vision. The size of the useful field of view depends on several types of visual skills, such as spatial resolution, light sensitivity, contrast sensitivity, divided attention, selective attention, and the speed by which visual input is processed, and thus is a more global or "encompassing" measure of visual ability. A breakdown in one or more of these skills will negatively impact performance in the useful field of view task.

The second implication of our research is that it generates suggestions for possible interventions to be evaluated in terms of their ability to minimize driving problems in the elderly. For example, if poor vision (e.g., acuity, contrast sensitivity) and poor visual attentional skills are associated with an increased risk for crashes, then improving vision and attentional skills should reduce risk. Evaluating these types of interventions is an important step in our research program. Because identifying the mechanisms underlying older adults' visual performance problems is not enough, we must also develop feasible solutions. Although work is ongoing in this area across multiple sites, we have preliminary evidence for transfer of improved visual attentional skills to better driving performance.

The third implication is broader in scope and relevant to older adults' visual performance problems in general, not just driving problems. In our efforts to understand the basis of older adults' difficulties with everyday tasks, vision scientists tended to dwell almost exclusively on visual sensory mechanisms. Yet most visual tasks depend on much more than visual sensory skills, such as resolution and contrast sensitivity. Most daily tasks are performed in a visually cluttered environment with auditory distraction, involve the simultaneous use of central and peripheral vision, and require the execution of primary and secondary tasks. Performance is not only limited by visual and cognitive factors but can be influenced by musculoskeletal problems, medication usage, cardiovascular problems, and other systemic conditions such as diabetes, all of which are relatively prevalent in the elderly population. Thus, it is important for us to realize at the outset that the causes of older adults' performance problems in complex visual tasks, driving or otherwise, are likely to be multifactorial in origin.

Because driving is a highly visual task, the conventional wisdom was that the increased prevalence of vision impairment and eye disease in the elderly is the primary cause of their driving difficulty. However, previous studies showed only weak correlations between visual sensory function and the number of crashes incurred over some period of time (Henderson & Burg, 1974; Hills & Burg, 1977; Shinar, 1977). These correlations are typically statistically significant, documenting that there is an association between, for example, acuity and crashes, but they account for only a small amount of the crash variance in the sample. There are undoubtedly many reasons why the earlier studies failed to find a visual factor that strongly differentiates crash-involved drivers from those who are crash-free, and we and others have discussed these reasons at length elsewhere (Ball & Owsley, 1991; National Highway Traffic Safety Administration, 1989; Shinar & Schieber, 1991).

One aspect of the earlier work we thought was particularly troublesome was the failure to include reliable assessments of higher order visual skills, such as visual attention abilities. Previous studies on older drivers focused on primarily one potential correlate at a time (e.g., visual sensory variables, cognitive variables, diseases, or higher order variables such as decision time). Only rarely was a measure of visual attention measured, yet visual attentional skills seemed to be highly relevant in a complex visual task such as driving. Furthermore, previous work was consistent with this notion. Several studies on commercial drivers found an association between selective attention problems and increased number of crashes (Mihal & Barrett, 1976). In another study of police accident reports, most crashes by older drivers were caused by alleged driver inattention (Shinar, 1978). Therefore, in our own studies, we assessed visual attentional skills in older drivers, but we also included visual sensory tests because the ability of the visual system to adequately register visual stimulation had to be a necessary starting point. Finally, it is well-known in the gerontological literature that deficits in visual sensory and visual attentional skills are prevalent in the older adult population (Ball, Roenker, & Bruni, 1990; Owsley & Sloane, 1990; Parasuraman & Nestor, 1991; Plude & Hoyer, 1985). One advantage of examining both visual sensory and higher order skills within the same sample is that it permits one to assess the impact of these deficits, both separately and in combination on crash risk.

Methods

Our sample consisted of 294 older drivers (range 56–90 years, $m = 71$ years) who were recruited from the population of drivers age 55 and over in Jefferson County, Alabama. The sample was age stratified, in that it included approximately equal numbers of individuals in each 5 years of life, between 55 and 90 years. We wanted to make sure the sample included the "oldest old." The sample was also stratified with respect to the number of crashes on record with the state over the previous 5-year period. This was important because we wanted to ensure that the sample included problem drivers (i.e., drivers who had a history of multiple crashes), as well as drivers with good records (i.e., drivers with no crashes on record). The details of our sampling procedures and rationale were previously discussed (Ball, et al., 1993).

All subjects participated in the following protocol during a single visit to the laboratory in 1990. The main elements of this protocol are listed in Table 11.1. The protocol consisted of tests that evaluated different aspects of the visual information processing system including visual sensory func-

TABLE 11.1
Main Evaluations Included in the Protocol

Category	*Functional Ability*	*Test*
Visual sensory function	Acuity	ETDRS chart
	Contrast sensitivity	Pelli–Robson chart
	Color discrimination	D–15
	Disability glare	VisTech MCT–8000
	Night acuity	VisTech MCT–8000
	Stereoacuity	Randot Frisby TNO
	Central field sensitivity	HFA Program 30–2
	Peripheral field sensitivity	HFA Program 60–2
Cognitive function	General mental status	MOMSSE Rey–Osterreith Trailmaking test Block Design (WAIS-R)
Visual attention/speed of processing	Useful field of view size	Visual attention Analyzer
Eye health	Central retinal health Peripheral retinal health Ocular media	Sum of 3-pt. rating of each category: 0 = no problem 1 = mod. problem 2 = severe problem

tion, cognitive status using a test specifically designed to measure cognitive deficits in the elderly, eye health examination, which assessed the presence or absence of ocular disease on a 3-point scale, and a measure of the size of the useful field of view.

The visual sensory function tests consisted of visual acuity (both day and night), contrast sensitivity, disability glare, stereopsis, color discrimination, and visual field sensitivity. Visual acuity was measured with the Bailey–Lovie Chart (Ferris, Kassoff, Bresnick, & Bailey, 1982), and expressed as log minimum angle resolvable (log MAR). Contrast sensitivity was measured with the Pelli–Robson Contrast Sensitivity Chart (Pelli, Robson, & Wilkins, 1988), and expressed as log contrast sensitivity. Disability glare was measured with the MCT–8000 (Vistech Consultants), and defined as the difference in letter acuity (logMAR) under conditions of glare versus no glare. Stereopsis was measured with three clinical tests (Randot, TNO, and Frisby, described in Simons, 1981). Color discrimination was measured with the enlarged D-15 test (Farnsworth, 1947). Visual field sensitivity was measured with the Humphrey Field Analyzer using the screening program for the central 60 degrees with the quantify defects option (Haley, 1987).

All tests were binocular except the visual field test, in which each eye was tested separately (Humphrey Prog. 30–2, 0–60 deg). For most tests, subjects wore their own habitual optical correction because their everyday visual performance was of interest. However, if a test of visual function specifically called for a near-correction in the standard instructions for administering the test, we followed those instructions (e.g., Humphrey Field Analyzer, Pelli–Robson chart). These specific tests were chosen because they represent major aspects of visual sensory function and have good test–retest reliability.

Mental status was assessed by the Mattis Organic Mental Status Syndrome Examination (MOMSSE), specifically designed to assess cognitive status in the elderly (Mattis, 1976). This test provides a composite score of cognitive function that reflects performance in several categories such as abstraction, digit span, verbal and visual memory, and block design. Additional cognitive tests were carried out to evaluate visuospatial abilities (Lezak, 1983) and included the Rey–Osterreith test, the Trailmaking test, and the block design of the Wechsler Adult Intelligence Scale (Revised).

A questionnaire was administered that asked about the subject's driving habits such as: (a) driving exposure (e.g., how many miles per year, how many days per week, how many trips per day), (b) avoidance of potentially challenging driving situations (e.g., left-hand turns across traffic, driving alone), and (c) number of crashes incurred during the previous 5-year period where the police came to the scene. In addition to this self-report crash information, crash frequency during the previous 5-year period was obtained for each subject from the state computer of the Alabama Department of Public Safety. Following completion of data collection, the written accident reports (filed by the officer at the scene) for all subjects were obtained from the State, which detailed the circumstances surrounding each crash.

All subjects received a detailed eye health examination by an ophthalmologist, which included direct and indirect ophthalmoscopy after dilation, biomicroscopy, applanation tonometry, a refraction for distance, and an assessment of external eye health. A 3-point rating scale, as described in our earlier study (Owsley et al., 1991), was used to determine to what extent clinical changes in the eye would be expected to cause a functional problem in each of three broad categories—central vision problem, peripheral vision problem, and ocular media problem. In addition, each subject was assigned to a primary diagnostic category (e.g., normal, cataract, macular disease).

The protocol included a measure of the size of the useful field of view, which assesses the visual field area over which one can rapidly use visual information (Ball et al, 1993). Ball and colleagues developed a rapid and reliable method for evaluating the useful field of view size (Ball & Owsley, 1993; Ball, Roenker, & Bruni, 1990), and is particularly useful in clinical studies. To summarize, the paradigm consists of a radial localization task in which a person must identify the radial direction of a target presented up to 30 degrees in the periphery, simultaneously discriminating two targets presented in central vision. By varying the eccentricity of the peripheral target, the visual field area over which a subject can rapidly use information can be estimated. In some trials the peripheral target is embedded in distracting stimuli. Thus the task has both divided attention components (i.e., the subject must perform a central discrimination task at fixation while localizing the simultaneously presented peripheral target) and a selective attention component (i.e., the subject must indicate the radial direction of the peripheral target even though it is embedded in other distracting stimuli in the periphery). An additional variable that is manipulated is the duration of the display, which is varied from 40 to 240 ms. A subject's overall performance across trials is evaluated in terms of his or her ability to localize the peripheral target at various eccentricities as a function of three variables: (a) their ability to successfully divide their attention between central and peripheral tasks (divided attention), (b) their ability to localize the peripheral target when it is embedded in distracters (selective attention), and (c) the minimum duration by which they can perform these tasks (speed of processing). Performance in the useful field of view task is expressed in terms of percent reduction of a maximum 30 degree field size; a 30 degree field was considered as the maimum field size for baseline purposes because this was the largest field size allowable by the screen size and viewing distance in our apparatus.

We were interested in how visual sensory function, cognitive function, useful field of view size, and eye health status—as assessed in the protocol—are related to the number of vehicle crashes incurred by our older drivers. Crash data on all subjects were obtained from the Alabama Department of Public Safety, which compiles records on all drivers licensed by the State. This data included the written accident report, filed by the officer at the scene, which detailed the circumstances surrounding each crash. For the purposes of our study, we defined crashes as including only "at-fault" crashes and eliminated those crashes from the database where our driver was clearly not at fault. Fault was determined by three independent raters. Although the raters did not always agree on the degree of fault (concordance = 83%), the three raters always agreed that our driver was at least partially at fault (Ball et al., 1993).

There was a retrospective portion to our study and a prospective portion to the study. The retrospective study consisted of relating performance in the protocol in 1990 to the number of crashes incurred by our drivers in the previous 5-year period. In this aspect of the study, the goal was to predict older drivers with a *history* of crash problems (Ball et al., 1993). The prospective component of the study focused on relating performance in the protocol in 1990 to the number of crashes incurred in the subsequent 3-year period (Owsley, 1994; Owsley et al., 1994). The goal in the prospective study was to predict which older drivers are at risk for *future* crashes.

Results

The goal of this study was to evaluate a battery of measures relative to their usefulness in predicting crash frequency in older drivers. The results of the retrospective study are discussed first. As a first step in data analysis, we examined how our various independent variables correlated with each other, the dependent variable, and the number of at-fault crashes in the previous 5-year period (see Table 11.2). As discussed in the previous section, the independent variables to be evaluated in model development were various aspects of central vision, peripheral vision, eye health, useful field of view size, and mental status. Because the protocol included more than one type of assessment of central vision and peripheral vision (which were highly intercorrelated), we chose for inclusion in model development that measure of central vision and of peripheral vision with the highest zero-order correlation with number of crashes.

The variables used in model development and their intercorrelations are listed in Table 11.3. Eye health, central and peripheral vision, UFOV® size, and cognitive function were all significantly and positively related to crashes. The useful field of view test was the most strongly correlated with crashes, $r = 0.52$, as compared with Pearson correlation coefficients in the .2s and .3s for the other visual and cognitive variables. These data were used to construct a LISREL model (Byrne, 1989; Joreskog & Sorbom, 1989) for predicting crash frequency. This modeling program analyzes the covariance matrix among the variables to arrive at a system of simultaneous linear equations that allows the dependent variable (number of crashes) to be expressed in terms of the structural relationships among the independent variables. An important advantage of LISREL over approaches such as multiple regression is that it allows one to evaluate whether each independent variable has a direct versus indirect effect on the dependent variable. The details of the LISREL model development were described elsewhere (Ball et al., 1993). The best fitting model is pictured in Fig. 11.1. The only variables that had direct effects on the number of crashes incurred during the previous 5 years were the size of the UFOV® and to a lesser

TABLE 11.2
Correlations Among the Protocol Variables and Number of Prior Crashes

	CS	*CD*	*DG*	*NG*	*CVF*	*PVF*	*MS*	*UFOV®*	*CRH*	*PRH*	*OM*	*Prior Crashes*
Visual Acuity (VA)	-.73	-.35	.15	.19	.48	.44	.18	.41	.62	.61	.46	.22
Contr Sensitivity (CS)		.36	-.11	-.23	-.58	-.53	-.21	-.47	-.66	-.66	-.49	-.24
Color Discr (CD)			-.02	-.04	-.24	-.19	-.10	-.18	-.31	-.35	-.27	-.10
Day Glare (DG)				.06	.13	.13	.09	.08	.08	.02	-.02	.12
Night Glare (NG)					.14	.17	.16	.28	.23	.19	.26	.15
Central VF (CVF)						.84	.29	.46	.52	.50	.38	.26
Periph VF (PVF)							.32	.47	.46	.46	.30	.24
Mental Status (MS)								.48	.22	.21	.19	.37
UFOV®									.42	.39	.27	.50
Cent Ret Health (CRH)										.76	.80	.22
Periph Ret Health (PRH)											.65	.19
Ocular Media (OM)												.15

Note: Critical $r = 0.12$, $df = 294$, p .05, two-tailed.

TABLE 11.3
Correlations Among Variables Used in the LISREL
Model for Predicting Prior Crashes

	Central Vision	*Peripheral Vision*	*Mental Status*	*UFOV®*	*Prior Crashes*
Eye Health	-.67	.50	.24	.40	.23
Central Vision		-.57	-.20	-.47	-.24
Peripheral Vision			.29	.48	.26
Mental Status				.48	.34
UFOV®					.52

Note: Critical $r = 0.12$, $df = 294$, p .05, two-tailed.

extent, mental status. The measures of central and peripheral vision and eye health were related to crashes; however, their effects on the number of crashes were indirect and mediated by the size of the useful field of view. Although the overall model accounted for 74% of the variance in the sample data, it was also of interest to determine the R^2 associated with crash prediction alone. Only two variables, UFOV® and mental status, had direct effects on crash frequency, jointly accounting for 28% of the crash variance. Alternative models were evaluated, but none were superior to the model in Fig. 11.1 in that they did not improve the percentage of crash variance accounted for. For example, when the LISREL model was respecified so that central and peripheral vision were forced to have direct effects on crash frequency (in addition to their indirect effect through UFOV®), there was no increase in R^2. The main role of central and peripheral vision in the model is their significant direct effect on the size of UFOV®; together they accounted for 30% of the UFOV® variance. Not surprisingly, visual attentional skills like those used in the UFOV® task crucially depend on the integrity of information entering the visual sensory channel. In other respecifications of the model, we entirely removed UFOV®. Because central and peripheral vision were correlated with UFOV®, perhaps UFOV® provided redundant information to the model. However, with UFOV® omitted, the visual variables (central vision, peripheral vision, and eye health) jointly accounted for only 5% of the crash variance, and with the introduction of mental status to the model, R^2 only increased to 16%. Therefore, the model presented in Figure 11.1, which includes UFOV® and accounts for 28% of the crash variance, clearly maximizes the prediction of crash frequency during the prior 5-year period.

In summary, vision is a necessary but not sufficient predictor of crash frequency. Eye health and visual function do not contribute any unique variance to crash frequency in addition to their indirect effect through UFOV®. Mental status also had a significant direct effect on UFOV®, and a statistically significant direct effect on crash frequency. However, the effect of mental status on crash frequency was primarily indirect, because removal of its direct effect in the LISREL model only slightly reduced the amount of crash frequency variance accounted for (from 28% to 27%). These

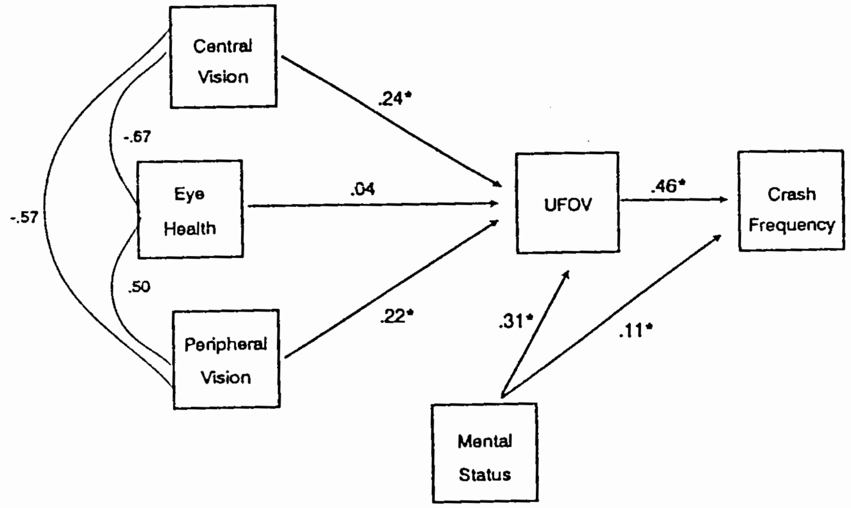

FIG. 11.1. LISREL model for predicting the number of crashes incurred over 5-year period prior to the test date (from Ball et al., 1993). The solid arrows represent the hypothesized direct effects, and each is labeled with a standardized path coefficient. Significant direct effects are indicated with an asterisk. Curvilinear lines on the left side of Fig. 11.1 indicate that central vision, peripheral vision, and eye health are intercorrelated, and the *r* labels each curve. UFOV® and mental status were the only variables that had direct effects on crash frequency. The overall LISREL model accounted for 74% of the variance in the data, and 28% of the crash variance. Other models were considered (see text), but the model portrayed here maximizes the prediction of number of prior crashes.

results supported our hypothesis that UFOV® is a mediating variable between crash frequency on the one hand, and eye health, visual function, and mental status on the other.

Another way to look at this data is to determine how well the main independent variables identify older drivers who were crash-involved in the prior 5 years versus those older drivers who were crash-free. Recall that most of the independent variables were performance-based tests evaluating various aspects of the visual processing system. For the purpose of generating an ROC curve for each independent variable, the definition of good performance on each variable was varied. Then, for this set of definitions, the probability of a hit was plotted against the probability of a false alarm. A false alarm was defined as a driver who performed poorly on the independent variable (e.g., poor acuity) but who nevertheless had no crashes on record. Figure 11.2 displays these ROC curves. Values on the diagonal indicate an equal probability of hits and false alarms, that is, an inability to classify drivers appropriately. Greater distance between an ROC curve and the diagonal corresponds to higher sensitivity in correctly identifying drivers at risk for crashes. Note that the UFOV® test is clearly superior to acuity, contrast sensitivity, peripheral field sensitivity, and mental status in identifying older drivers with a history of at least one crash in the previous 5 years.

Figure 11.3 illustrates that the average number of crashes increases with increasing severity of UFOV® reduction. Given the UFOV® test's superior predictability as illustrated in the ROC analysis, it is useful to consider its utility as a "diagnostic" test using a 2 × 2 contingency table, perhaps a more typical way to look at the issue from a clinical standpoint. The reader is referred to Table 11.4. In this context, *sensitivity* refers to the probability that an older driver with a greater than 40% reduction in UFOV® has one or more crashes during the prior 5 years. *Specificity* refers to the probability that an older driver with no crashes on record in the prior 5 years has a UFOV® reduction 40% or less. The UFOV® test had both high sensitivity (89%) and high specificity (81%) in classifying older drivers as crash involved. This level of predictability is unprecedented in the research literature on crash-risk in older drivers.

Furthermore, the information in Fig. 11.3 was also used to calculate an odds ratio, indicating that individuals with UFOV® reduction greater than

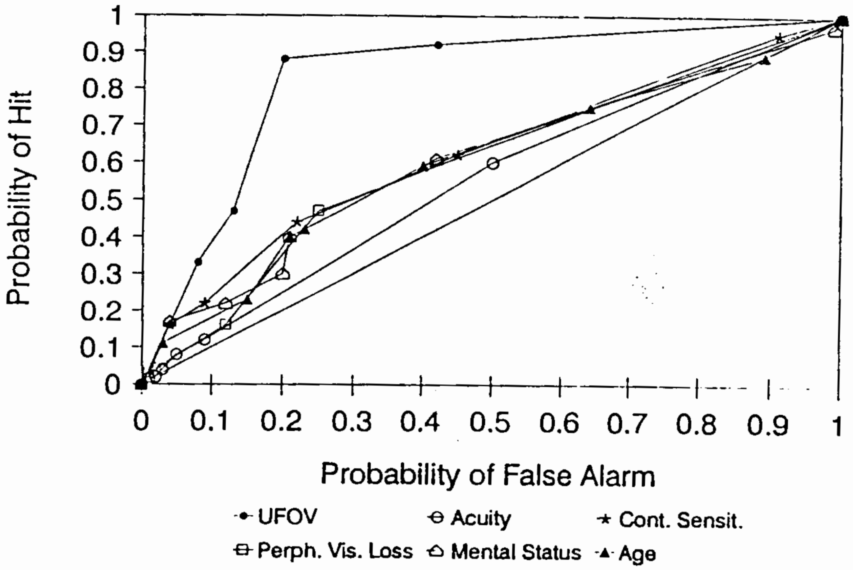

FIG. 11.2. ROC curves (probability of hits plotted against probability of false alarms) for major independent variables. These curves provide information about the ability of each independent variable to identify drivers who have a history of crash problems. The d' values for each of the ROC curve are: acuity (d' = 0.24), contrast sensitivity (d'= 0.67), peripheral field sensitivity (d' = 0.60), mental status (d' = 0.50), UFOV® (d' = 2.27), age (d' = 0.58). It is clear that UFOV® is superior to all other variables in identifying older drivers with a history of crash problems.

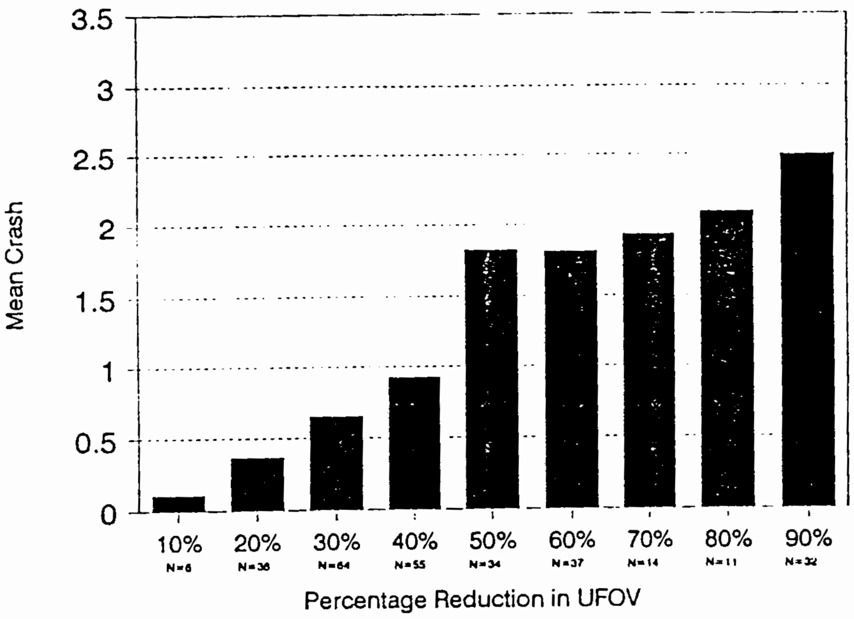

FIG. 11.3. Mean crash frequency as a function of UFOV® reduction for drivers with "good" mental status versus those with "poor" mental status. For the purposes of our analysis, good mental status is defined as a MOMSSE composite score of < 9, and poor mental status as a score > 9. Note that the relationship between crash frequency and UFOV® reduction is very similar within each mental status subgroup. Our analysis indicates that although UFOV® reduction is correlated with poor mental status, the two are not identical constructs. An older subject can have decreased mental status, yet have a normal UFOV®.

TABLE 11.4
Number of Subjects in Each UFOV and Crash Category in the Retrospective Study

	Prior Crash Category	
UFOV® Category	*≥ 1 Crashes*	*0 Crashes*
UFOV® reduction 40%	142	25
UFOV® reduction plain 40%	18	109
Sensitivity = 89%		
Specificity = 81%		

40% were six times more likely to be at least partially responsible for a crash than those with reduction of 40% or less. Of the 25 false-positive predictions, 19 were subjects who reported that they avoided driving in general, avoided driving alone, or avoided left-hand turns, which thus minimized their driving exposure. In fact, if we exclude those individuals who specified on the driving habits questionnaire that they avoided these particular aspects of driving, the correlation between UFOV® and crash frequency increased from $r = .52$ to $r = .62$. Although avoidance is a somewhat difficult construct to measure, it appears that some older drivers are effectively compensating for visual or attentional decline and that some valid measure of exposure or avoidance behavior would be an appropriate addition to a predictive model of crash frequency.

Figure 11.4 illustrates how restrictions in the UFOV® may increase the probability of crashes. Panel A displays the average size of the "attentional window" for those individuals with little to no restriction of the UFOV® (< 10% as shown in Fig. 11.3). Panel B displays this window for those individuals with approximately 40% decline. Panel C displays this window for those individuals with approximately 80% reduction. Finally, the most extreme case of UFOV® restriction is illustrated in Panel D (90% reduction). The areas depicted in this figure do not represent the size of the visual field, but are scaled to represent relative reductions in the size of the UFOV® for different groups of individuals.

Another question that arises is whether UFOV® reduction is predictive of only certain categories of at-fault crashes (e.g. failure to notice a traffic signal, merging), or whether the prediction applies to many crash types. In order to evaluate this question, 364 at-fault crashes incurred by our sample were classified into six types: failure to notice a traffic control device (n = 35), failure to notice another vehicle (n = 174), merging (n = 51), hitting the rear of another vehicle (n = 54), backing up into another vehicle or object (n = 26), other (n = 24). The correlation between UFOV® and crash frequency was similarly high for each crash type (r = .45 to .48), and the slight reduction in the strength of these correlation coefficients (compared to the analysis on all crash types) was due to decreased sample size for each type of crash, and to a lower total accident frequency for a given subject. An alternative breakdown of crashes into intersection (n = 220) and nonintersection crashes (n = 144) also revealed that the UFOV® was a good predictor of both types (r = .41 for nonintersection, and r = .49 for intersection accidents). These analyses imply that the UFOV® task assesses some critical visual attentional factor common to many types of at-fault crashes.

Thus far, the discussion has been directed at the retrospective study in which the relationship between visual–cognitive factors and crashes previous to our test date was examined. The more crucial question might be whether or not visual and cognitive abilities can predict which older drivers are at risk for future crashes. In our prospective study (Owsley, 1994), the number of future crashes for each subject was defined as the total number of at-fault crashes incurred by that subject between the 1990 test date and October 1993, approximately a 3-year period. Our approach to data analysis

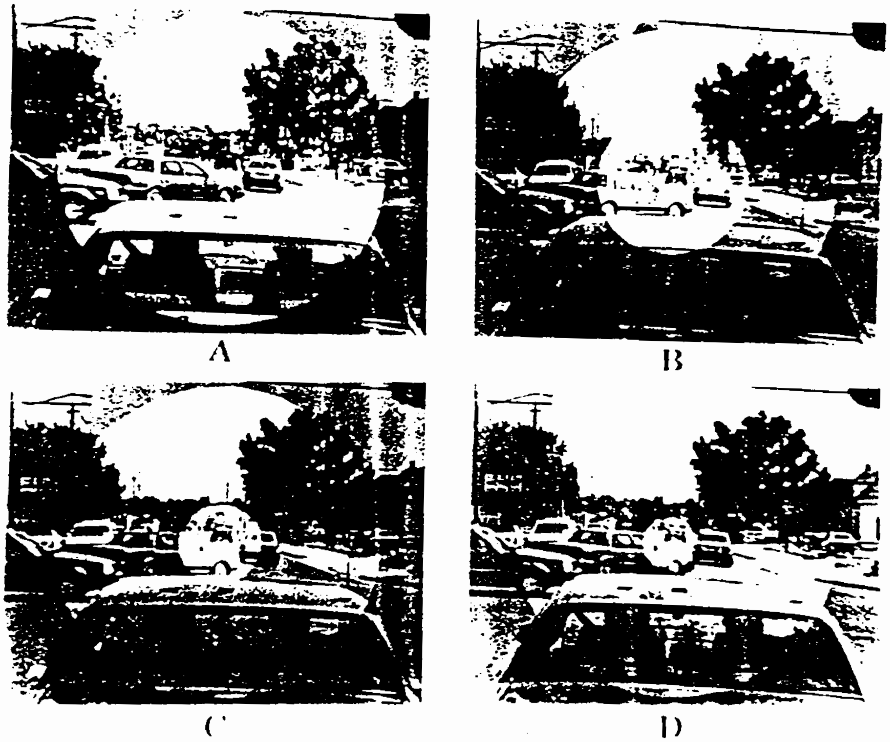

FIG. 11.4. An illustration of how restrictions in the UFOV® may increase the probability of crashes. Panel A displays the average size of the attentional window for those individuals with no restriction of the UFOV. Panel B displays this window for those individuals who have experienced a significant decline in the speed of visual information processing. Panel C displays this window for those individuals who have experienced both a slowing and an extreme sensitivity to distraction. Finally, the most extreme cases of UFOV® restriction is illustrated in Panel D for those individuals who have experienced slowing, sensitivity to distraction, and the inability to divide their attention between central and peripheral tasks. Note that the areas depicted do not represent the size of the visual field, but are scaled to represent relative reductions in the size of the UFOV® for different groups of individuals.

was similar to that used for the retrospective study (Ball et al., 1993). We wanted to determine whether or not the LISREL model developed on the basis of our retrospective data (see Fig. 11.1) was also applicable to the prediction of future crashes.

Before proceeding with the data analysis, however, it was important to take into consideration those subjects who stopped driving or died during the 3-year prospective period. If a subject was not driving during this time period, then they could not incur vehicle crashes, that is, their crash risk would be zero by definition. Thirty-nine subjects stopped driving and 32 subjects died during the first 6 months of the prospective period, leaving a sample of 223 older drivers, which served as the basis of the prospective data analysis. Table 11.5 lists the correlation matrix among the main independent variables to be used in model development and the number of future crashes. Also included in Table 11.5 are the correlations between number of at-fault prior crashes and the other variables. The rationale for including this variable is that the number of previous crashes is typically a good predictor of the number of future crashes, as is well-known in the automobile insurance industry. Thus, we thought it important to include prior crashes as a variable in the attempt to predict future crashes.

Looking at the last column of Table 11.5, the pattern of correlations among the visual and cognitive variables and the number of future crashes is similar to that from the retrospective study (see Table 11.3). More specifically, the strongest correlate of future crashes is UFOV® with $r = .46$. Central vision, peripheral vision, and mental status were also significantly correlated with future crashes; however, the strength of these relationships was weaker than that between UFOV® and future crashes. The relationship between eye health status and future crashes was not significant, unlike the retrospective study analysis on prior crashes. The strength of the correlation coefficients was generally lower in the prospective study (Table 11.5) compared to the retrospective study (Table 11.3). Two factors that may be contributing to this trend are that crash data were averaged over a shorter period in the prospective study (3 years) than in the retrospective study (5 years), and subjects who dropped out of the sample (because they died or stopped driving) tended to be those with serious visual or cognitive impairment. Both of these factors could reduce the magnitude of correlations. The number of prior crashes was significantly correlated with the number of future crashes ($r = .40$), but was not as strong as the relationship between UFOV® and future crashes ($r = .46$).

Using the covariance matrix of the independent variables and future crash data, we evaluated how well the original LISREL model (see Fig. 11.1), which optimized the prediction of prior crashes, predicted future crashes. Figure 11.5 displays the model from Figure 11.1, but this time the dependent

TABLE 11.5
Correlations Among Variables Used in the LISREL Model for Predicting Future Crashes

	Central Vision	*Peripheral Vision*	*Mental Status*	*UFOV®*	*Prior Crashes*
Eye health	-.60	.47	.16	.34	.10
Central vision		.41	.09	.30	.15
Peripheral vision			.26	.44	.21
Mental status				.43	.16
UFOV					.46

Note: Critical $r = .13$, $df = 223$, p .05, two-tailed.

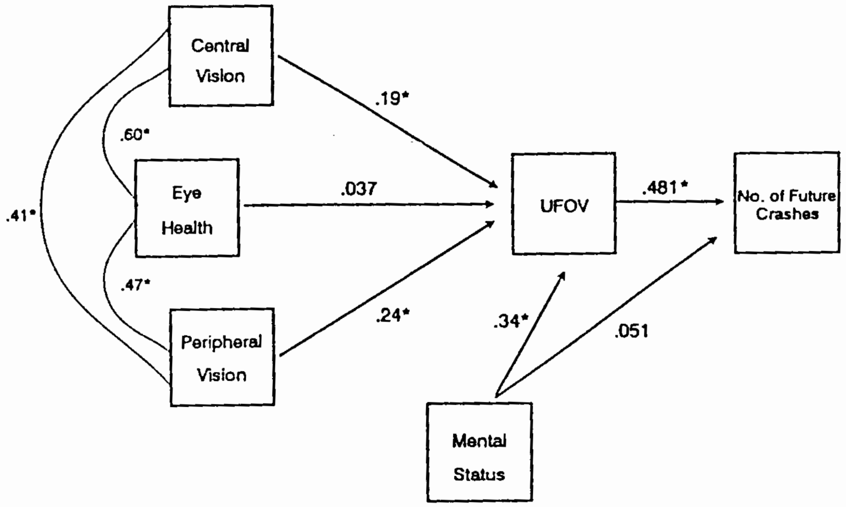

FIG. 11.5. LISREL model for predicting the number of future crashes incurred over the next 3 years after the test date. This model maximized the prediction of future crashes. The overall LISREL model accounted for 56% of the variance in the data, and 22% of the crash variance. Note that the general structure of the model is identical to that in Fig. 11.1, where the independent variable was the number of prior crashes. UFOV® (but not mental status) was the only variable that had a direct effect on the number of future crashes.

variable is the number of future crashes and the standardized path coefficients and other labels are based on the prospective data set. Unlike the retrospective model, only one variable, UFOV®, but not mental status, has a significant direct effect on the number of future crashes. This model accounts for 22% of the crash variance. Other alternative models were considered in order to determine if the model pictured in Figure 11.5 is actually the best fitting model. Because central vision and peripheral vision were both correlated with UFOV®, we considered the possibility that UFOV® was providing redundant information in the model, given that central and peripheral vision were already entered. If UFOV® and mental status are omitted, then the percentage of crash variance accounted for is 4.6%. This is drastically less than the 22% of the variance accounted for when UFOV® is in the model. In another respecification of the model, we included the number of prior crashes as an independent variable, as illustrated in Fig. 11.6, as Table 11.5 indicated that it was correlated with the number of future crashes. It was included in the same position in the model as in the retrospective model (to the right of UFOV®, see Fig. 11.1). This model accounted for 21% of the crash variance. This was not an improvement over the percentage of variance accounted for by the model in Fig. 11.5 (22%), which did not include prior crashes. Thus, information about prior crashes, although significantly correlated with future crashes, does not appear to provide critical information to the model not already provided by the visual and cognitive variables.

The sensitivity and specificity of the UFOV® test were computed in the same way as discussed earlier, in terms of its ability to identify older drivers at risk for one or more crashes over the next 3 years. Table 11.6 presents the 2 × 2 table, analogous to Table 11.4, but this time for future crashes. The sensitivity and the specificity of the UFOV® test are still relatively high (94% and 65%, respectively). The information in Table 11.6 was used to compute an odds ratio, which indicated that older drivers with greater than 40% reduction in UFOV® were 16 times more likely to incur one or more crashes than were those with no or minimal UFOV® reduction. Individuals with UFOV® reduction greater than 40% (top line of Table 11.6) were heavily represented in both the crash-involved and crash-free categories. This result might be due to the fact that individuals with severe UFOV® reduction (> 40%) were more likely to drop out of the study during the prospective period than were those with no or minimal reduction (≥40%). Specifically, 37% of the > 40% reduction category dropped out of the study, compared to only 8% of the ≤40% UFOV® reduction category. These dropouts were either due to death or to stopping driving. This association between UFOV® reduction and death or mobility restriction is interesting in and of itself.

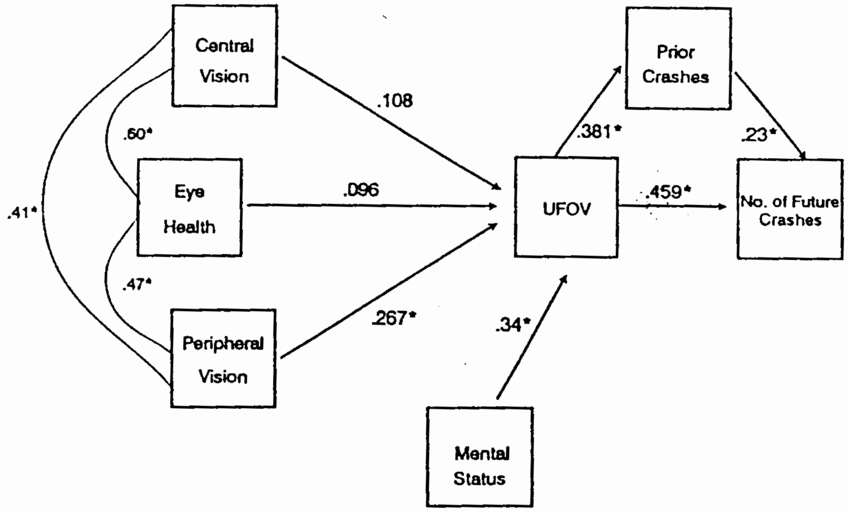

FIG. 11.6. LISREL model for predicting the number of future crashes incurred over the next 3 years after the test date, but in this model, the number of prior crashes is also included as an independent variable in the model. This model accounted for 21% of the crash variance, less variance than in the future crash model—which did not include prior crashes (see Fig. 11.5). Thus, the inclusion of information about the number of prior crashes did not improve Fig. 11.5.

TABLE 11.6
Number of Subjects in Each UFOV
and Crash Category in the Prospective Study

UFOV® Category	Future Crash Category	
	1 Crashes	0 Crashes
UFOV® Reduction 40%	44	62
UFOV® Reduction plain 40%	3	114
Sensitivity = 94%		
Specificity = 65%		

Discussion

This program of research suggests that older drivers in poor eye health, with visual sensory impairment, cognitive impairment, and/or visual attentional deficits are at greater risk for crashes than are those without these problems. The UFOV test, which is a measure of visual attention skills and visual processing speed, was more useful, compared to other visual–cognitive measures, in identifying older drivers who are likely to have one or more crashes. It had a relatively high sensitivity and specificity in identifying crash-involved drivers.

Older drivers with a severe restriction in the spatial area over which they could rapidly use visual information were six times more likely to have incurred one or more crashes in the previous 5-year period than were those with minimal or no restriction. There are several types of mechanisms that could potentially underlie a restriction in the size of the useful field of view in older adults. Earlier research demonstrated that many older adults have deficits in selective attention and divided attention (Parasuraman & Nestor, 1991; Plude & Hoyer, 1986), as well as a slowing in the rate of visual information processing (Hoyer & Plude, 1982). These types of deficits could contribute to a narrowing of the perceptual window. Another potential cause of UFOV® constrictions is visual sensory impairment, such as severe loss in central or peripheral vision; an observer cannot attend to a visual event that is not adequately registered. Visual sensory and attentional deficits in older adults can occur separately or together. For example, we previously showed that useful field of view shrinkage can occur even in older adults with excellent visual field sensitivity (Ball, Owsley, & Beard, 1990). In fact, 41% of our subjects in the present study having a UFOV® reduction greater than 40% had an average loss of visual field sensitivity of less than 2.5 dB. Furthermore, 43% of our subjects with acuity better than 20/20 had a UFOV® reduction of greater than 40%. Thus although visual status is related to the size of the UFOV®, good visual status alone is not a sufficient condition for a normal UFOV®. Because the UFOV® test relies on both visual sensory and cognitive skills, it provides a more global measure of visual functional status than either sensory or cognitive tests alone, thus improving its sensitivity and specificity in identifying older drivers at risk for crashes. We are currently examining these visual and cognitive mechanisms in order to sort out their relative conributions to UFOV® restrictions, as well as their interactions.

This research has several implications. It suggests that policies that restrict driving privileges based solely on age or on common stereotypes of age-related declines in vision and cognition are scientifically unfounded, as others also argued (Drachman, 1988). Our data also imply that current visual screening techniques, such as tests of acuity and peripheral vision as used at driver licensing sites, are not adequate in identifying which elderly drivers are likely to be involved in crashes. Screening tests of acuity and peripheral vision administered at licensing offices may have other benefits for the older adult population, such as screening out those with profound vision loss and designating those in need of referral for eye care. But our analysis indicates they do not successfully identify elderly drivers who have a recent history of crash involvement, thus posing a safety risk to themselves and other road users. We identified a composite measure of visual attention and visual processing speed highly predictive of crash problems in the elderly. With the identification of this or similar tests, this study points to a way in which the suitability of licensure in the older driver can be based on objective, performance-based criteria.

ATTENTIONAL TRAINING AND OTHER INTERVENTIONS

In general, medical diagnoses and sensory tests are inadequate for prediction of everyday abilities, or for competency in industrial or military settings. There is a need, therefore, for functional measures, such as the UFOV®, which are predictive of job or task performance. In addition, there is a need to explore ways in which performance can be improved. It is likely that some older adults will have to be restricted from driving because of serious and irreversible deterioration in skills crucial to driving. However, it may be the case that many older adults with driving problems can improve their driving skills through treatment of ocular conditions impairing visual function (e.g., cataract, glaucoma) or through training or educational programs. We previously showed that a reduction in UFOV® size in some older adults can be at least partially reversed through a training program (Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball, Roenker, & Bruni, 1990). This training targeted the individual's specific attentional deficit(s) (e.g., processing speed or the ability to divide attention between two targets in either an uncluttered or cluttered visual field). Training progressed by gradually decreasing presentation time in order to increase processing speed and, in the case of multiple targets, successively increasing the eccenticity of peripheral targets. The training required only a modest investment in time, and the resulting field expansion was maintained 1 year after completion of the program.

The intriguing question remaining is, given that UFOV® shrinkage is associated with increased crash frequency, would expansions in UFOV® size through a laboratory training program lead to improved driving performance and decreased crashes? Our study also indicated that some older adults, who are at risk for crashes because they have serious visual impairment, modify their driving behavior by avoiding exposure to challenging driving situations (e.g., driving alone, turning left across traffi, driving at night). This self-regulation of driving behavior was associated with a lower crash frequency. Therefore, if older adults were better educated about their visual information processing problems including visual attentional deficits, some might voluntarily impose restrictions on their driving behavior that could lower their crash risk. Research to evaluate these potential interventions should be given high priority, given society's need to enhance the mobility and personal independence of older adults without sacrificing safety concerns.

Given these statements, a logical step in the research is to evaluate potential interventions for reducing crash risk. Our model in Figs. 11.1 or 11.5 suggests there are at least two ways in which one could intervene to lower crash risk—to improve visual sensory function, or to expand the size of the useful field of view. We are examining these two ways of intervening in our ongoing research. First, patients who are candidates for cataract surgery will be evaluated with respect to visual and cognitive abilities before and after surgery and intraocular lens insertion in terms of how this ophthalmic intervention reduces crash risk and expands driving habits. Cataract surgery is the most common surgical procedure covered by Medicare in the elderly population, accounting for 12% of the entire Medicare budget (Stark, Sommer & Smith, 1989), and is also a highly successful intervention. Studies reported that 90% of patients achieve at least 20/40 acuity or better following surgery (Straatsma, Foos, Horwitz, Gardner, & Petit, 1985). This is a common and effective way that vision is improved in the elderly, and is thus an ideal scenario for evaluating to what extent improvement in visual sensory function reduces crash risk and improves other aspects of mobility.

For our second intervention, which is currently under evaluation, there is some preliminary evidence that expansion of the UFOV® improves driving performance. Mature drivers (55+ years, $N = 317$) were screened on acuity, contrast sensitivity, and UFOV®. From this pool, 87 individuals were identified for potential inclusion in a training study (primarily based on the extent of UFOV® reduction), and 68 agreed to participate. Thirty-three of these subjects completed a UFOV® training program, 24 completed a simulator training program, and 11 served as controls. Subjects in the UFOV® training group received individualized training until a UFOV® size of less than 30% loss was achieved. Subjects in the simulator training group received 3 hours of training in a Doron Driving Simulator and 1 additional hour in an open road demonstration of the skills discussed while in the simulator. Control subjects received no training. All subjects were assessed pre- and posttraining on (a) the size of the UFOV®, (b) simple and complex RT as well as the detection of threatening driving situations in a Doron

Driving Simulator, and (c) a detailed evaluation with a driving instructor during an on-the-road driving test.

The results of UFOV® training were successful in that those in the UFOV® training group showed a significant decrease in UFOV® loss. UFOV® size did not change significantly during the training phase for those in the simulator or control groups. Both simple RT measures and the probability of detecting a threatening event did not differ between the three groups initially, and was not altered by training. Performance in the complex RT task, however, did reveal a significant improvement for the UFOV® training group only. In this task, subjects were required to scan a display covering an area of 8′ × 10′ and containing three to six targets. Unpredictably, one of the targets would change and the subject was required to respond to the change. Given a car moving at 55 miles per hour, subjects in the UFOV® training group responded by stopping or maneuvering their vehicle 26 feet earlier following training relative to their pretest measure. This corresponds to a 14% improvement in stopping time.

Several measures were evaluated from the open road driving test: (a) a global rating of driving skill by an experienced driving instructor, (b) a global rating by two back seat evaluators, (c) six composite scores generated from 455 behaviorally anchored specific driving maneuvers, and (d) the number of hazardous maneuvers during the drive as determined by the driving instructor. For all subjects, regardless of group, there was a significant improvement in global ratings of their driving skills during the testing period as rated by both the experienced driving instructor and the back seat evaluators. All six composites generated from the 455 items also showed significant improvement from pre- to posttraining regardless of group. The number of hazardous maneuvers during the drive showed a different pattern, however. For this measure, the number of hazardous maneuvers was significantly reduced for only the UFOV® training group (by 50%). The number of hazardous maneuvers did not differ for the simulator and control groups pre- and posttraining.

Thus, study data demonstrate that UFOV® training transfers to driving tasks, such as reduced stopping time to an unexpected perceptual event, and to a reduction in the number of dangerous maneuvers in an on-the-road driving evaluation. Although the occurrence of hazardous maneuvers is relatively infrequent while driving, a 50% reduction in such maneuvers has potential safety benefits.

Other types of interventions must also be considered. Older drivers with visual impairment were more likely to avoid difficult driving situations than were those without these deficits (Ball et al., 1993). That is, some older drivers may self-regulate their driving (i.e., exercise certain self-imposed limitations if they became aware of their visual deficits). Thus, a mechanism for educating older drivers about how their visual processing problems impact their driving ability under challenging driving situations may minimize crash risk. These types of interventions underwent some preliminary evaluations (Janke, 1994), but a clear-cut answer as to the utility of this type of intervention is not yet available.

APPLICATIONS FOR ATTENTION ASSESSMENT–TRAINING

As stated earlier, the ability to pay attention is a functional ability we cannot do without, and yet this ability is something most adults take for granted. Everyone experiences diminished attentional function at some time due to fatigue, stress, illness, or alcohol consumption. However, it is only when this ability is lost, such as following traumatic brain injury, stroke, dementia, or age-related decline, that the full range of everyday activities affected by attentional function become apparent. At the other end of the continuum, occupations that require above-average attentional skills are becoming more prevalent in industry and the military as society continues to become more technical. Thus, the applications for new technology to evaluate and train attentional function include not only older drivers, but also older pilots, older workers, and younger individuals who must meet the requirements for exceptional performance. Our research showed that although attentional function can be regained in some individuals following traumatic brain injury, this type of rehabilitation is both time consuming and costly. Thus the benefits of using new technology for prevention of injury on the road or in the workplace could significantly reduce the cost of health care in the future.

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