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Visual/Cognitive Correlates of Vehicle Accidents in Older Drivers

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Older drivers have more accidents per miles driven than any other age group and tend to have significant impairments in their visual function, which could interfere with driving. Previous research has largely failed to document a link between vision and driving in the elderly. We have taken a comprehensive approach by examining how accident frequency in older drivers relates to the visual/cognitive system at a number of levels: ophthalmological disease, visual function, visual attention, and cognitive function. The best predictor of accident frequency as recorded by the state was a model incorporating measures of early visual attention and mental status, which together accounted for 20% of the variance, a much stronger model than in earlier studies. Those older drivers with a visual attentional disorder or with poor scores on a mental status test had 3–4 times more accidents (of any type) and 15 times more intersection accidents than those without these problems.

Investigations of the relationship between visual functioning and driving performance in older adults have high priority, because there has been a steady increase in both the number of licensed drivers over age 65 and the average number of miles driven by this group (National Highway Traffic Safety Administration [NHTSA], 1989a; Transportation Research Board, 1988). Older drivers have more traffic convictions and accidents and incur more fatalities per miles driven than any other adult age group. Furthermore, given that the automobile has become the dominant mode of travel in our society, these statistics underscore the need for research on aging and driving performance (NHTSA, 1988, 1989b; Federal Highway Administration, 1989).

Because driving is a highly visual task, it is important to note that many older adults tend to have significant deficits in visual function (see Owsley & Sloane, 1990). Yet, despite intuitions that older adults' impaired vision should be related to an increased risk for accidents, research to date has failed to establish a strong link between vision and driving in elderly persons. For example, several large sample studies (Henderson & Burg, 1974; Hills & Burg, 1977; Shinar, 1977) have found statistically significant correlations between accidents and various vision tests (e.g., static acuity, dynamic acuity, and disability glare), but these correlations are so low (accounting for less than 5% of the variance) that they are insignificant from the practical standpoint of identifying older adults who are at risk for accidents.

In another widely cited, large-sample study, Hofstetter (1976) reported that the percentage of drivers with poor acuity who reported three or more accidents was approximately double the percentage of drivers with good acuity who reported three or more accidents. However, this analysis did not apply the same acuity criterion in each age group for determining the quartile cut-offs for poor and good acuity. In this way of parsing up the data, poor acuity in the young group (who were reported to average 20/20 vision) may be better than good acuity in the old group (who were reported to average 20/60). If poor acuity is the basis for accidents, then the same acuity criterion should hold across all age groups. In addition, because no other potential predictors were evaluated in this study, and the number of individuals who had three or more accidents in each age group was not given, it is impossible to determine whether the role of acuity is in fact stronger than that obtained in the other studies.

A study by Johnson and Keltner (1986) has had some success in linking vision and accident frequency. They reported in a large sample study that the small subset of drivers with severe visual field loss in both eyes (196 drivers out of the 10,000 studied) had accident and conviction rates twice those in the general population. Because these drivers were primarily older adults,

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this study illustrates a relationship between impaired visual function and driving in elderly persons. However, no study to date has established a link between driving and the more subtle types of visual field loss due to normal aging. Thus it still remains to be determined if there are any visual variables that have a strong and widespread relationship with driving performance in older adults.

Limitations of Accident Prediction

The question then is why previous research has failed to document a firm link between vision and driving performance in older adults. One possible reason is the use of vehicle accidents as the dependent measure for driving behavior. An accident is a rather uncommon occurrence when one considers the many miles we drive each year, and thus the researcher has the statistical burden of trying to predict an improbable event. In addition, accidents are caused not only by factors intrinsic to the driver such as vision but can also be caused by extrinsic factors such as weather conditions. Thus, it is not very surprising that visual sensory status by itself has not been found to be a powerful predictor of vehicle accidents.

However, despite these problems, accidents have proven to be a popular dependent measure in driving research. There are at least two ways to index the frequency with which accidents occur. In many studies, the drivers are simply asked how many accidents they have had in a given period of time (e.g., Hofstetter, 1976; Shinar, 1977). This self-report measure of accident frequency, although easy data to collect, can be problematic because the validity of this information can vary widely when it is compared with a second index of accident frequency provided through the state records. For example, Sloane, Ball, Owsley, Roenker, and Bruni (1990) found that those older drivers with the highest number of recorded accidents on the State record are largely men who tend to underreport accident involvement on a driving habits questionnaire.

A second measure of accident frequency commonly used in previous research is the number of accidents reported by law enforcement agencies and then recorded on the state computer (e.g., Burg, 1967, 1968; Henderson & Burg, 1974; Johnson & Keltner, 1986). It is clear that there are some positive features to using state-recorded accidents. State-recorded accidents have the advantage of being more objective than self-reported accidents in that they are not affected by the subjective biases and memory failures of the research subject. In addition, accident records are maintained by the state in a standardized format on computer for all licensed drivers. These data include information about the number of accidents as well as the details surrounding each accident itself (e.g., time of day, roadway and weather conditions, location, and specific circumstances). Demographic information is also available on each driver (e.g., birthdate, sex, and municipality). Therefore, state-recorded accident records are a potentially rich source of information, which may assist in identifying risk factors for poor driving in the elderly. An additional reason for using accident data is that this information is used by government agencies (e.g., state and federal legislative bodies and agencies concerned with licensing and transportation) to formulate public policy, and by insurance companies to set rates.

There are a few drawbacks to using state-recorded accidents, although these seem comparatively minor. The number of state-recorded accidents does not include accidents in which neither driver involved in the accident chooses to call the police to the scene. In addition, even though an accident is reported to the police, there is always the slight chance that the actual accident report may be misfiled and thus it would never be added to the State data base.

It might be argued that researchers would be more successful in predicting driving performance if they used a dependent measure that reflected *actual* driving behavior (e.g., performance on a closed-road course or driving simulator) rather than measuring a *consequence* of poor driving, namely, accident occurrences. Although this might be true, it is important to keep in mind that one important goal of research on the elderly driver is to minimize crash involvement. Thus, if these performance measures (e.g., performance in a simulator or road test) were to be used for determining who was at risk for accident involvement, they would eventually have to be validated against accident frequency. In addition, the ability to predict and eventually reduce accident frequency in the elderly could have dramatic social and financial implications in our society. Thus, there is a strong argument for using accident frequency as the dependent measure in research on the older driver.

Another possible reason why earlier studies have failed to document a strong link between vision and driving in the elderly population is because of the choice of independent measures, that is, tests for evaluating vision. Sensory tests, such as visual acuity, contrast sensitivity, and visual field sensitivity, although quite appropriate for the clinical assessment of vision loss, do not presently reflect the visual complexity of the driving task. The visual demands of driving are quite intricate; the driving task involves a visually cluttered array, both primary and secondary visual tasks, and simultaneous use of central and peripheral vision. In addition, the driver is usually uncertain as to when and where an important visual event may occur. Visual sensory tests do not typically incorporate these stimulus features but instead seek to minimize perceptual/cognitive influences to obtain a purely sensory measure. This approach is appropriate for the clinical management of eye disease but is inadequate by itself when applied to understanding visual performance in a complex task, such as driving.

Modeling Visual/Cognitive Correlates of Accident Frequency

In building and testing a theoretical model predictive of accident frequency in the older driver, the approach we have taken is to assess the quality of information at various levels in the visual/cognitive information-processing system. By use of the term *levels*, we do not imply that we think these components are necessarily sequential or independent; rather, we use the term to denote our interest in approaching the problem from various perspectives.

The first level in the visual information-processing system that must be considered is the ophthalmological level, at which structural and physiological changes in the eye and visual pathway due to disease can seriously impair visual function and thus lead to driving problems. For example, there has been some evidence that individuals with retinitis pigmentosa are at risk for poor driving performance and increased accidents

(Fishman, Anderson, Stinson, & Haque, 1981; Szlyk, Fishman, Mater, & Alexander, 1990). However, it is doubtful that the presence versus absence of ocular disease alone could provide sufficient information to determine accident risk. First, the functional impairment associated with a given diagnosis is quite variable. Two individuals can have similar structural alterations in the visual system due to disease yet have drastically different visual functional capabilities. In addition, different patients can adopt different coping or adaptation strategies for dealing with ocular disease, leading one individual to have better functional capabilities than the other. Therefore, it is necessary to include another level in our model, that of direct assessment of functional vision (e.g., acuity, contrast sensitivity, and visual field sensitivity). The encoding of visual information is a crucial stage in understanding the driving task. As mentioned earlier, there is already evidence that at least one functional variable, severe binocular field loss, is related to increased accident frequency (Johnson & Keltner, 1986).

Because driving is a complex visual/cognitive task, it is unlikely that the assessment of eye health and visual function alone would be sufficient to predict accident frequency. Eye health and visual function variables measure the quality of visual information available to the driver. Even if the incoming visual information is not degraded, different drivers may attend to different aspects of the scene as well as interpret the visual information in different ways. Thus, any model that attempts to predict accidents on the basis of visual input must include measures of information-processing skills. One such skill is visual attention. Several years ago a few studies suggested a link between attentional skills and accident frequency (e.g., Barrett, Mihal, Panek, Sterns, & Alexander, 1977; Kahneman, Ben-Ishai, & Lotan, 1973; Mihal & Barrett, 1976), but this line of research was never further developed.

Visual attention can be assessed either at a preattentive (parallel) processing level, or at an attentive (serial) processing level. Attention is most commonly measured by using a visual search paradigm (see Ball, Roenker, & Bruni, 1990). Because of our interest in driving, we are particularly interested in visual attention at the preattentive level because this earliest stage of attention is used to quickly capture and direct one's attention to highly salient visual events (such as the approach of vehicles in peripheral vision). A task that assesses this preattentive process is based on the concept of the useful field of view (UFOV). The UFOV refers to the visual field extent needed for a specific visual task (Sanders, 1970). The size of the UFOV is very different from visual field size as determined by clinical perimetry and is typically smaller than the area of visual sensitivity (Ball, Owsley & Beard, 1990). The UFOV is measured binocularly and can require detection, localization, or identification of suprathreshold targets in complex visual scenes (Verriest et al., 1983, 1985).

Earlier research has shown that the size of the UFOV varies across individuals and situations. For example, the size of the UFOV is reduced when a secondary central task is added (Ball, Beard, Roenker, Miller, & Griggs, 1988; Leibowitz & Appelle, 1969); when the target is embedded in distractors (Ball et al., 1988; Drury & Clement, 1978; Scialfa, Kline, & Lyman, 1987); when the similarity between the target and distractor is increased (Bergen & Julesz, 1983; Engel, 1977; Treisman & Gelade, 1980); and when stimulus duration is decreased (Ball, Roenker, & Bruni, 1990). Furthermore, the impact of these variables is generally much greater for older adults (Ball et al., 1988, Ball, Roenker, & Bruni, 1990; Scialfa et al., 1987; Sekuler & Ball, 1986). Our previous work has focused on understanding the bases for restricted UFOV in some older individuals. Rather than a single cause for restricted UFOV, we found that at least three mechanisms are required to account for older adults' UFOV restriction, as follows: reduced speed of visual information processing, inability to ignore distractors, and inability to divide attention (Ball, Roenker, & Bruni, 1990; Ball, Roenker, & Bruni, 1991) and that the prevalence of each of these problems increases with age such that a given individual may experience none, one, or more than one of these problems in later life.

Furthermore, our earlier research also indicated that those older adults with UFOV shrinkage reported more problems in their everyday activities, especially tasks using peripheral vision (Ball, Owsley, & Beard, 1990). Older adults in this study had normal visual field sensitivity as measured by clinical perimetry, implying that their UFOV restrictions and reported problems in peripheral vision were not due to impaired visual sensitivity throughout the field. Thus, our earlier work implies that a test of the useful field of view may be quite helpful in understanding older adults' problems in routine visual activities.

There is an obvious dependence of tests of visual attention (e.g., the UFOV) on the quality of visual information being processed by the visual sensory system; that is, although the UFOV task is not a sensory test, it makes use of information coming through the visual sensory channel and thus depends on the integrity of this information. For example, if a person has severe binocular field loss, this individual would probably have an impaired UFOV, not necessarily because of an attentional deficit but because the quality of the sensory information was poor. On the other hand, visual sensory field loss is not a necessary condition for a constricted UFOV. A person can have a normal visual field yet have a constricted UFOV, as pointed out earlier.

Another level of analysis to be evaluated in building a model to predict accident involvement in the elderly population is cognitive function. Cognitive functioning would seem to be an appropriate factor to include in understanding driving behavior because driving, as all navigation tasks, depends heavily on working memory and problem-solving skills. Furthermore, there is preliminary evidence that cognitive impairment in elderly persons due to dementing disease is associated with increased driving problems (Coyne, Feins, Powell, & Joslin, 1990; Friedland et al., 1988; Kaszniak, Nussbaum, & Allender, 1990; Lucas-Blaustein, Filipp, Dungan, & Tune, 1988). For these reasons, it seems worthwhile to include an assessment of cognitive status in a model of accident prediction.

In summary, it is clear that a comprehensive approach to studying the older driver must include assessment at a number of different levels in the visual information-processing system, as follows: health status of the visual system, visual sensory function, visual attentional skills, and cognitive skills. Given the integrated nature of such a system, it is not surprising that previous attempts at predicting driving difficulty have largely failed; earlier studies have typically examined only one level of analysis within the system. Previous studies on sensory variables have largely ignored higher order perceptual or cognitive components, whereas studies focusing on mental status and cognitive variables have largely ignored sensory components. The comprehensive approach taken here allows one to determine the effects of all these variables singularly and in combination as they interact within the same individual (see also Ball & Owsley, in press, for discussion of these issues).

Method

Subjects

Subjects were recruited from the Primary Care Clinic of the School of Optometry at the University of Alabama at Birmingham. There were a total of 53 participants (26 men and 27 women; mean age = 70 years, range = 57–83 years). Each participant had a valid driver's license in the State of Alabama and drove at least 1,000 miles per year. All subjects were living independently in the community. Written informed consent was obtained from each subject prior to participation in the study.

Test Protocol

There were four categories of tests; each is described later and listed in the Appendix. All subjects participated in all segments of the protocol. Except for the eye health exam and the questionnaire, the order of testing was counterbalanced across subjects. The entire protocol, not including the eye health exam, lasted between 2 and 3 hrs per subject and was completed in one session, with rest periods between each separate test.

Eye health. All subjects received a detailed eye health examination within 12 months before their participation in this study. This examination included direct and indirect ophthalmoscopy, biomicroscopy (slit lamp exam), applanation tonometry, complete refraction with measurement of best-corrected acuity, and an assessment of external eye health. On the basis of these clinical judgments as well as standard functional assessments performed by the clinician (e.g., acuity; Amsler grid), ratings were assigned with respect to what extent clinical changes in the eye would be expected to cause a functional problem in each of the following three broad categories: central vision, peripheral vision, and ocular media problem. Ratings were assigned (0 = *no estimated functional problem*, 1 = *a moderate problem*, and 2 = *a serious problem*) without knowledge of how the subject performed in the rest of the protocol. In addition, each subject was assigned to one of the following primary diagnostic categories: normal eye health, cataract, age-related macular degeneration (AMD), diabetic retinopathy, glaucoma, or other. The ratings and the assignments into a diagnostic category took into consideration the health of both eyes because clinically observed ocular changes were largely bilateral.

Visual function tests. For most tests of visual function, we administered the tests binocularly while subjects wore their own optical correction (i.e., they wore the glasses or contact lenses they wore in their normal everyday life). Because we were interested in their everyday visual performance, we did not optically correct anyone's vision beyond what they were already using. However, if a test of visual function specifically called for a near-correction in the standard instructions for administering the test (e.g., Pelli-Robson contrast sensitivity or Humphrey visual field), we followed these instructions.

1. *Visual acuity:* The Bailey-Lovie Chart (see Ferris, Kassoff, Bresnick, & Bailey, 1982) was used to measure distance acuity for letters. Letter acuity was expressed in terms of log minimum angle resolvable (logmar). The mean luminance of the chart was 100 cd/m^2. Viewing distance was 4.2 m (14 ft). Two features of this chart make it ideal for research purposes: Letter size decreases from line to line in 0.1 logarithmic steps, and the same number of letters are on each line (see Ferris et al., 1982).

2. *Contrast sensitivity:* The Pelli-Robson Contrast Sensitivity Chart (see Pelli, Robson, & Wilkins, 1988) was used to measure contrast sensitivity. This chart measures how much contrast a person requires to see letters subtending about 2.8 degrees of visual angle. Contrast decreases in 0.15 log unit steps each half line. The mean luminance of the chart was 100 cd/m^2. Viewing distance was 1 m. Subjects wore a +0.75 D correction over their own correction, as recommended in the directions which accompany the chart. Performance on the Pelli-Robson chart is related to peak sensitivity on the contrast sensitivity function (Pelli et al., 1988). The chart has excellent test–retest reliability, even for older adults (Elliott, Sanderson, & Conkey, 1990).

3. *Disability glare:* The MCT 8000 (Vistech Consultants, Inc.) was used to measure the degree to which glare impairs letter acuity. Letter acuity was measured under both day conditions (219 cd/m^2) and night-driving conditions (22 cd/m^2). A measure of disability glare was generated for both luminance conditions by computing the difference between letter acuity (logmar) under conditions of glare versus no glare. The veiling luminance (glare source) was 119 cd/m^2.

4. *Stereopsis:* The following three clinical tests of stereopsis were administered to each subject: the Randot, the TNO, and the Frisby (see Simons, 1981). All three tests provide a measure of stereoacuity. The Randot uses polarizing glasses and provides an estimate of stereoacuity ranging from 20 to 500 seconds of arc. The Randot's test targets have monocular contour information that could facilitate the identification of the disparate target and hence could contaminate the estimate of stereoacuity. This is not the case with the TNO test, which uses random dot stereograms presented to the observer using the anaglyph technique. The stereoacuity range covered by Plates 5 to 7 of the TNO is 15–480 seconds of arc. The Frisby test, which does not require special viewing glasses, provides a range of 15–600 seconds of arc in much finer steps than the TNO, because in the Frisby the plates of different thickness can be presented over a range of viewing distances (30–80 cm). In all tests, subjects who showed no stereopsis were assigned a maximum value of 600 seconds of arc.

5. *Color discrimination:* The Farnsworth Dichotomous Test Panel D15 was designed to test gross confusions in color discrimination. It consists of 15 color caps that the subject must arrange in a color sequence. The test is reliable (Higgins & Knoblauch, 1977), and its administration is brief. We used an enlarged D15, which uses caps identical in color to those used in the standard test but the caps are enlarged by a 2.5 relative size magnification factor (Ehrnst & Georgeson, 1983). We have previously found that the enlarged D15 facilitates color vision assessment in visually impaired patients and that older adults tend to prefer the larger cap size when performing the task (Sloane, Kuyk, Owsley, Ernst, & Nowakowski, 1989). In this study, the D15 was scored by using the traditional scoring procedure (Farnsworth, 1947).

6. *Visual field sensitivity:* The Humphrey Visual Field Analyzer (Allergan Humphrey), a computerized perimeter, was used to measure visual field loss in each eye separately. We used the screening program for the central 60°, with the "quantify defects" option, which measures the depth or degree of sensitivity loss at 120 locations in the visual field. In our application of this program, we used a pre-set initialization value of 34 dB (both central and peripheral), which serves as a baseline or normal visual field against which performance is measured. Our choice of 34 dB as the pre-set value was based on the normal visual field sensitivity for adults in their 50s who are in good eye health (see Brenton & Phelps, 1986). This program yields a map of the visual field for each eye that illustrates locations of sensitivity loss in terms of dB. From each map, we computed the average depth of defect for both the central 30° and the peripheral 30° (area from 30°–60°).

7. *Useful field of view:* The UFOV was assessed under varying stimulus conditions to yield measures for each of the three potential mechanisms underlying restriction of the field. The method was very similar to that described in detail previously (Ball et al., 1988; Ball, Roenker, & Bruni, 1991). For all three subtests (described later), subjects viewed a large screen (60° × 60°) binocularly from a distance of

28.5 cm. It was unnecessary to optically correct subjects for the test distance because our earlier work clearly demonstrated that performance in this task is unaffected by the large degree of blur in a presbyopic subject viewing a near target (Sekuler & Ball, 1986).

Each trial consisted of a sequence of four successive displays. The first display consisted of a bright outline box to direct the subject's fixation. After 1 s the stimulus display appeared for some variable duration (between 12.5 and 250 ms). The central task portion of the stimulus display consisted of a schematic diagram of a two-lane road that either contained a schematic truck and a schematic car, two trucks, two cars, one truck and a blank lane, one car and a blank lane, or two blank lanes. (Our pilot work indicated that it did not matter what specific target was used, as long as the targets were sufficiently discriminable). The subject's task was to indicate whether what was contained in the two lanes was the same or was different. The peripheral localization portion of the stimulus display, when presented, consisted of a target (a stop sign) that would appear unpredictably, but equally often, at any one of 24 different locations (along one of eight meridians at one of three eccentricities: 10°, 20°, or 30°). This target was sometimes embedded in 47 distractor stimuli (boxes) and sometimes presented in isolation. The third display consisted of spatially random masking noise and was presented for 1 s to erase any residual afterimage on the computer screen. The fourth display consisted of a radial pattern with eight spokes corresponding to the eight meridians on which the target could appear. This display remained until the subject made a radial localization judgment by indicating on which spoke they believed the peripheral target had been presented.

Measures of UFOV performance were obtained for three subtests. These subtests are designed to examine the basis or cause of a given subject's restricted UFOV. Our earlier work has indicated that there are generally three different mechanisms underlying a restricted UFOV, as follows: slowing of information processing, impaired ability to divide attention, and impaired ability to ignore visual distractors (Ball, Roenker, & Bruni, 1991). A given individual can have UFOV shrinkage due to any one or a combination of these mechanisms, and the effects are additive. Thus, we administered three subtests that were designed to quickly evaluate the presence of each of the three problems. In Subtest 1, subjects had to perform the central task *only*, and a measure of stimulus-processing speed was derived by varying duration (between 12.5 and 250 ms). In Subtest 2, a measure of divided attention was obtained by requiring subjects to perform both the central and peripheral tasks concurrently without a cluttered visual field and comparing the time required for this task with the results of Subtest 1. In Subtest 3, a measure of distractibility was obtained by having subjects perform both tasks concurrently with distractors in the field and comparing their performance with the results of Subtest 2. To develop a criterion for UFOV prediction we then grouped individuals into two groups (those who failed all three subtests vs. the remaining subjects, i.e., those who passed at least one subtest). This categorical classification was adopted because of time limitations in performing the test. Failure on Subtest 1 was indicated by an inability to make the same-difference judgment correctly 75% of the time within the duration limit of 250 ms. Failure on Subtests 2 and 3 was indicated by the inability to perform the central task and concurrently localize the peripheral target (either with or without distractors) beyond the minimum field size of 5° at the maximum duration (250 ms). If an individual performed clearly better than this minimum value, that individual was scored as passing the subtest and time was not taken to quantify the field size beyond this point. Those individuals who failed thus represented a group of individuals with distractor, slowing, and divided attention problems and therefore were characterized by the most severe restriction of the UFOV. Our previous work has demonstrated that all three subtests of the useful field of view have good test–retest reliability ($r = .93–.97$) in older adults (Ball, Owsley, Beard, Roenker, & Ball, 1989).

Mental status test. To obtain a measure of mental status, the Mattis Organic Mental Status Syndrome Examination (MOMSSE) was administered to each subject (Mattis, 1976). We chose this test because it provides a relatively rapid measure of cognitive functioning and was specifically designed for use with older adults. The MOMSSE provides more detailed information than the Mini-Mental State exam (Folstein, Folstein, & McHugh, 1975) but is less time-consuming than the Dementia Rating Scale exam (Mattis, 1976). The MOMSSE test evaluates the following 14 categories of cognitive function: information, abstraction, digit span, orientation, verbal memory, visual memory, speech, naming, comprehension, sentence repetition, writing, reading, drawing, and block design. We scored each subtest from 0 (*normal*) to 2 (*impaired*). An overall composite score of mental status is obtained by adding the subtest scores. Composite scores range from 0 to 28 (0 = *excellent mental status*, 28 = *severe dementia*).

Questionnaire. The Driving Habits Questionnaire (Sloane et al., 1990) was administered to each subject. Two measures derived from this questionnaire were relevant to this study. They included self-reported accident frequency during the previous 5-year period and a composite measure of driving avoidance that allowed a determination of whether any of our visual/cognitive measures were significantly related to self-imposed restrictions in driving (e.g., cutting back on how often one drives; not driving at night or at peak-traffic times). This questionnaire was filled out before any other testing.

Driving data. Driving record information was obtained on all subjects from the Alabama Department of Public Safety, the state agency that manages matters related to licensing drivers in the State of Alabama. The data obtained included the total number of vehicle accidents for the previous 5-year period and the total number of convictions for violation of traffic laws. None of the subjects in our sample had alcohol- or drug-related traffic citations or accident involvements. In addition, we obtained the accident reports for all our subjects who were accident-involved during the 5-year period. These reports provided detailed information about the circumstances surrounding each accident.

Results

Definition of the Dependent Variable

Before describing our results further, our primary dependent variable—accidents—must be defined. Because we obtained both state-recorded accidents during the previous 5-year period for all subjects and self-reported police accidents, we first compared these two types of accident data. In Alabama, police are required to submit written accident reports to the State each time they go to the scene of an accident. Therefore, theoretically speaking, state-recorded accidents and self-reported police accidents should be perfectly related. However, we found that the number of accidents on the state record (hereafter called state-recorded accidents) was not related to the self-reported number of accidents where the police were at the scene ($r = 0.11$), as indicated by the Driving Habits Questionnaire (hereafter called self-report police accidents).

There are a number of possible reasons for this lack of relationship. One likely explanation is suggested by the pattern of our data. In general we found that the people who have state-recorded accidents are not reporting those accidents. For example, of the 18 individuals who had one or more state-recorded accidents, only 6 of them had self-reports that accurately reflected the number on the state record. The other 12 individuals who had state-recorded accidents (this included all those with multiple accidents) reported no accidents at all. As a result, there is a poor relationship between state-recorded accidents and self-reported accidents in which the police were called to the scene in this sample ($r = 0.11$). Thus in our study, rather than using the potentially misleading self-reported accident data, we used state-recorded accidents as our dependent variable in all other analyses.

Another issue to be addressed regarding the accident dependent measure is that many earlier studies have used accident *rate* as a dependent measure. Rate is typically calculated in either of two ways: by dividing the number of accidents in a given time period by the self-reported miles the person drove during that time, or by dividing the number of accidents by the estimated mileage for a person of that particular age group, usually taken from a government study on self-reported mileage per year as a function of age. In previous studies, the self-report information on mileage has typically been based on one global question, such as "how many miles do you drive per year?" However, we have found that responses to this type of question did not logically relate to responses to similar questions about mileage, such as "how many miles do you drive per week," or "how many days a week do you drive." Specifically, we found that the correlations among questions designed to generate a yearly mileage estimate ranged from 0.22 to 0.68 (Pearson's r). For example, one individual reported that she drove over 30,000 miles per year, yet drove only 3 days per week with an average distance of 5 miles for each trip.

Therefore, we have used the state-recorded accident data, uncorrected for self-reported mileage as our dependent variable. Because our study only involved older drivers, we also rejected using the other type of correction for mileage driven, which is based on the average mileage for a driver of a given age as described in government reports (Williams & Carsten, 1989). Older drivers in our sample's age range drive the same or similar average miles per year, as estimated in these government reports; thus, the rate correction would simply consist of dividing accident frequency for all subjects by a constant.

Correlations Among Variables

Before describing how the variables in our study relate to accident data, we will first characterize the range of performance found in our sample with respect to various visual sensory tests and the mental status test. Figure 1 is a series of scatter plots illustrating the wide variability in our data for some of the visual sensory and mental status measures in our protocol. Note the high interindividual variability on these measures, a typical finding in gerontological research. The regression line in each graph indicates the best fitting line relating age and visual function for each test. These graphs illustrate that there is a tendency for visual function to decline with age. However, given the theoretical assumption that age is a surrogate for changes in the underlying processes evaluated in this model (which may or may not decline on an individual basis), and given that there is an extremely low zero-order correlation between accidents and age in this sample, we chose not to evaluate it as a predictor of accidents.

To evaluate the interrelationships among the various measures of eye health, visual and cognitive function, self-reported driving difficulties, and number of accidents, we first computed Pearson correlation coefficients between all the variables in the protocol (see Table 1). The values above the diagonal in Table 1 portray the relationships among these variables as well as with the number of accidents and the number of traffic citations. Regarding the eye health diagnoses, cataract is the only diagnostic category listed because the other disease categories were insufficiently represented for the purposes of analysis.

As expected, the various eye health ratings (media, central vision, and peripheral vision problems) were highly intercorrelated with each other and with the diagnostic category of cataract. In addition, the eye health ratings and the diagnosis of cataract were related to many of the visual function variables. It is interesting that all of the eye health variables except the peripheral vision rating were significantly related to the composite score from the Driving Habits Questionnaire dealing with avoidance of challenging driving situations (e.g., driving at night; driving on high-traffic roads). In other words, serious problems in central vision or ocular media, as well as a diagnosis of cataract, were associated with subjects avoiding difficult driving situations. However, the driving avoidance composite score was not related to accident frequency or to the number of citations on the state record. In addition, none of the eye health ratings or a diagnosis of cataract were related to number of accidents or citations.

In a similar manner, tests of visual function are intercorrelated, as expected. The UFOV was related to both measures of peripheral vision (central and peripheral sensitivity loss) and to night acuity. Only the mental status total score, the UFOV, and the measure of day disability glare were significantly related to state-recorded accidents, and the UFOV was the only variable related to traffic citations. We should note at this point that the relationship of day disability glare to accidents ($r = .25$) was carried entirely by the extreme value of one individual who experienced a severe day glare problem. When this individual's score was removed from the analysis, the resulting correlation approached zero. As a result, the association between day disability glare and the number of accidents was considered to be spurious.

Model Development

A central question in the model development stage of this research is whether incorporating eye health, visual function, UFOV, and mental status could predict number of accidents in our sample. Figure 2 illustrates interrelationships among variables at various levels of analysis, from eye health status to overall cognitive function. The first level in our model was eye health status, and included ratings of the media, central vision, and peripheral vision problems, and whether or not subjects had a primary diagnosis of cataract. (As mentioned earlier, the other diagnostic categories did not occur in our sample with sufficient frequency to allow us to stratify our data along these diagnostic conditions.) The second level was visual function, which included all the vision function (except UFOV) tests listed in the Appendix. A multiple correlation was computed between the four eye health variables and each of the visual function variables. These multiple correlations were averaged, $R = .53$, $F(3, 47) = 2.86$, $p < .0001$, to measure the strength of the relationship between these two variable sets (Lambert, Wildt, & Durand, 1988). The relationships between eye health and all other variables in the model (UFOV, mental status, and

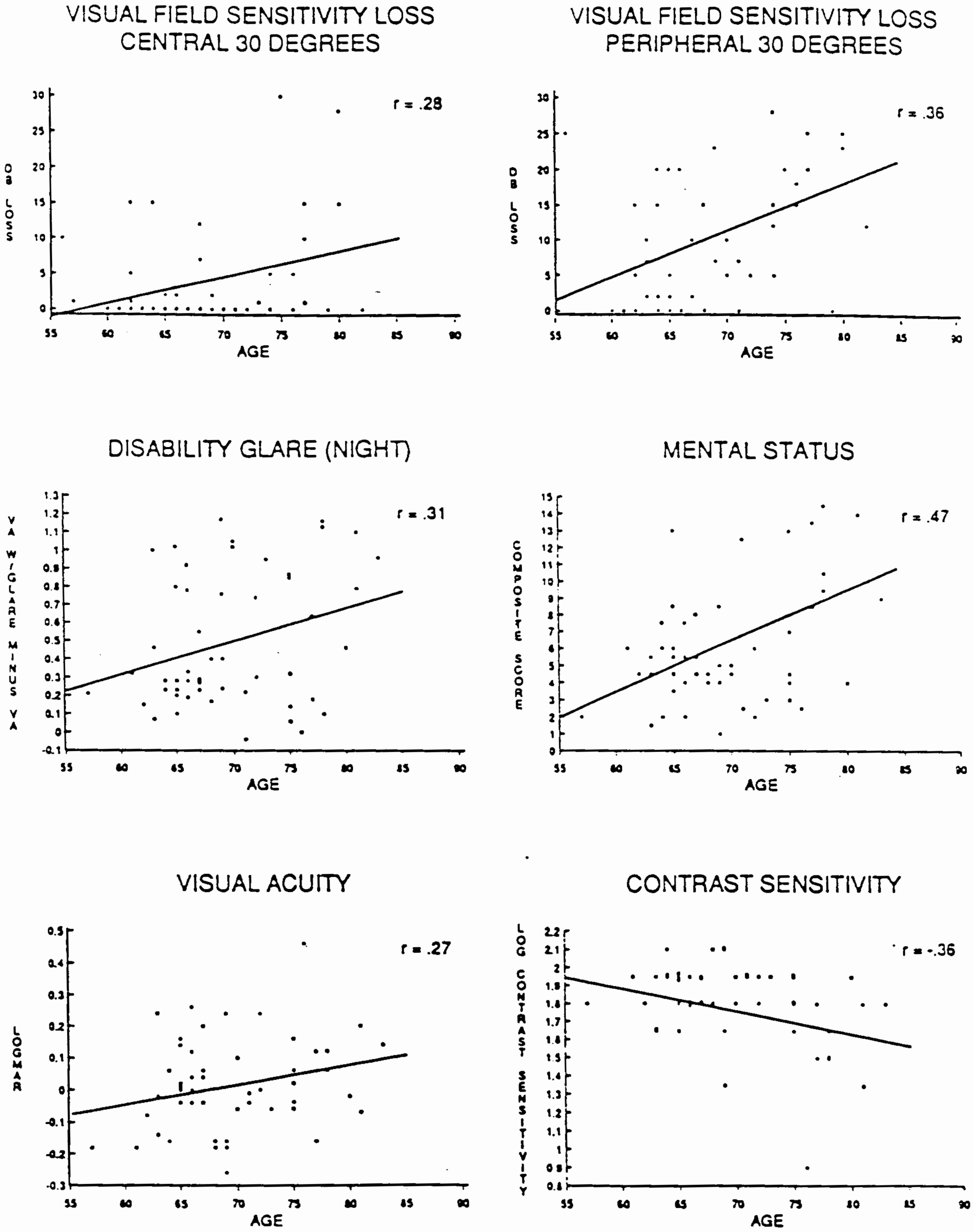

Figure 1. Scatter plots relating various measures of visual function and mental status to age. (VA = visual acuity; W/GLARE = with glare; LOGMAR = log minimum angle resolvable.)

accidents) were not significant, indicating that eye health alone is not linked to accidents in this sample. Regressing UFOV on all visual function variables resulted in a significant prediction, $R = .59$, $F(9, 42) = 3.86$, $p < .004$. However, regressing mental status or accidents on these variables did not produce a significant prediction, indicating that visual function is also not significantly linked to accidents in this sample. Note that the multiple correlation relating visual function to mental status was quite high, $R = .52$, $F(9, 42) = 1.72$, $p > .05$) but not significant, due to the large degree of residual variance.

Finally, there were significant zero-order correlations between UFOV and accident frequency ($r = .36$, $p < .004$) and between mental status (total MOMSSE score) and accidents ($r = .34$, $p < .02$). UFOV and mental status were also significantly related to each other ($r = .32$, $p < .05$). Because those individuals with extreme scores on the MOMSSE had great difficulty performing the UFOV task, a line is indicated from the MOMSSE to the UFOV. These two variables jointly predicted accident frequency, $R^2 = 0.20$, $F(2, 49) = 6.01$, $p < .005$. Figure 3 illustrates only the significant pathways of our model, as a means of summarizing our results.

To illustrate how the number of accidents related to the UFOV, we compared those who passed the UFOV ($n = 27$) with those who failed ($n = 26$). Individuals who failed the test experienced 4.2 times more accidents on the average than those who passed. For the composite mental status score, individuals with the high MOMSSE scores ($n = 8$) experienced 3.5 times more accidents on the average than those with MOMSSE scores less than 10 ($n = 45$).

Intersection Analysis

On the basis of detailed accident reports, accidents were categorized into the following five types: improper backing up, improper stopping, loss of control, failure to merge, and intersection problems. We first noted that most of the accidents in the sample (67%) were intersection accidents. These accidents were primarily due to failure of the driver to yield the right of way or to notice another vehicle in the intersection, as attributed by the police officer at the scene. Figure 3 illustrates the pathways of the model that specifically relate to the frequency of intersection accidents. Both the UFOV and MOMSSE were better predictors of intersection accidents than overall accidents ($rs = .46$ and $.41$, respectively). Jointly, these two measures predicted 29% of the variance in intersection accidents, $R = .54$, $F(2, 49) = 9.8$, $p < .001$. Subjects with MOMSSE scores over 10 ($n = 8$) had a total of nine intersection accidents, and those with scores under 10 ($n = 39$) had only seven intersection accidents between them. Thus, on the basis of the number of subjects in each group, those individuals with higher MOMSSE scores had 6.3 times more intersection accidents than those individuals with lower scores.

With respect to the UFOV, those subjects who failed were responsible for all but one of the intersection accidents. In this case, those individuals who failed the UFOV ($n = 26$) had 15.6 times more intersection accidents on average than those who passed. Intersections are situations where peripheral visual field or awareness of peripheral vehicles or obstacles is crucial. Thus, this would be the type of accident one would expect to relate to a test of visual attention such as the UFOV. The five

Table 1
Pearson Correlations Among Protocol Measures, Accidents, and Citations

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Age	—	.24*	.32*	−.14	.45*	.27*	.27*	−.40*	.06	.25*	.12	.31*	.28*	.40*	.47*	.60*	.08	.08	.19
2. Ocular media rating		—	.65*	.30*	.86*	.50*	.19	−.19	.13	.20	.03	.27*	−.10	.14	.09	.01	.03	.13	.32*
3. Central vision rating			—	.39*	.69*	.69*	.42	−.60*	.44*	.35*	.27*	.33*	.35*	.35*	.21	.12	.12	.03	.27*
4. Peripheral vision rating				—	−.40*	.15	.32	−.19	−.19	.20	−.20	−.10	.26*	.25*	.09	.10	.18	−.10	.18
5. Cataract					—	.62*	.47	−.40*	.35*	.13	.04	.13	.21	.44*	.28*	.11	.14	.00	.38*
6. Visual acuity						—	.54*	−.60*	.34*	.30*	.11	.22	.23*	.14	.04	.08	.00	−.10	.08
7. Night acuity							—	−.60*	.37*	.46*	.10	−.10	.53*	.32*	.23*	.27*	.12	.14	.19
8. Contrast sensitivity								—	−.50*	−.30*	−.20	−.10	−.70	−.50*	−.30*	.29	−.10	−.10	−.10
9. Stereoacuity									—	−.17	.02	.02	.65*	.34*	.21	.11	.13	−.10	.10
10. Color vision										—	−.10	−.10	.24*	.13	.20	−.20	.15	.09	.02
11. Day glare											—	.12	.27*	.21	.29*	.06	.25*	−.20	.05
12. Night glare												—	−.10	.11	.08	.04	−.10	−.10	.09
13. Visual field, central 30°													—	.57*	.40*	.33*	.13	−.20	.17
14. Visual field, peripheral 30°														—	.39*	.47*	.12	−.20	.21
15. Mental status															—	.32*	.34*	.03	.18
16. Useful field of view																—	.36*	.25*	.10
17. Accidents																	—	.34*	.12
18. Citations																		—	−.10
19. Drive avoidance																			—

* $p < .05$.

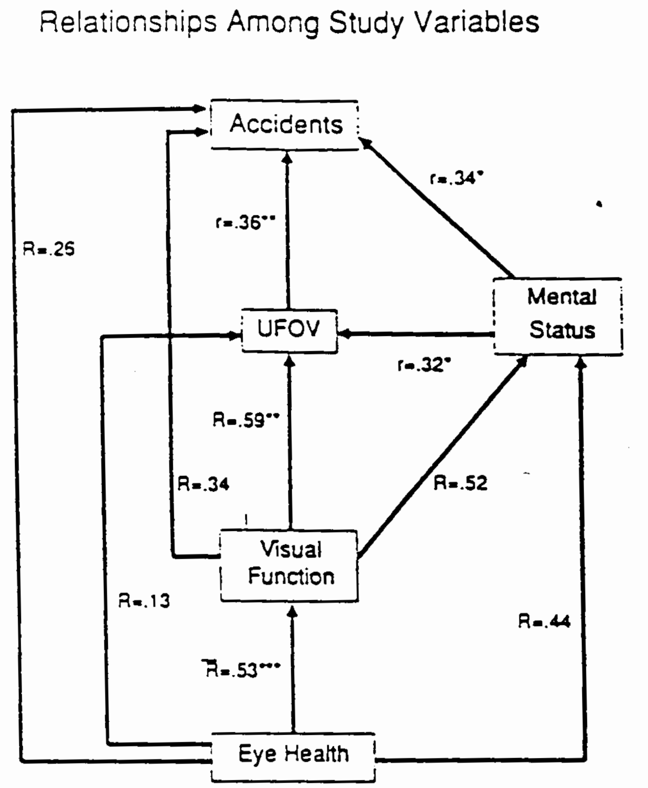

Figure 2. Interrelationships among variables at different levels of analysis. (*p < .05. **p < .01. p < .001. UFOV = useful field of view)

individuals who passed the UFOV and who also had accidents on record tended to be involved in other types of accidents. Three of the five were hit by another vehicle from behind while they were stopped, one lost control of his car on wet pavement, and one backed up into another car. The other types of accidents occurring in our sample (improper backing up, improper stopping, loss of control, failure to merge) did not occur with sufficient frequency for us to explore with any validity how these accident types relate to performance on our functional tests.

Table 2 illustrates the ability of both the MOMSSE and UFOV measures to predict intersection accidents. With respect to the MOMSSE, 34 individuals were predicted to have no accidents. Although 25 of these in fact had no accidents on record, 9 of them did have one or more accidents, and thus 9 individuals were misclassified in the sense that they were not identified by the test. On the other hand, 19 individuals were predicted to have one or more accidents. Of this group, 11 had no accidents on record and thus were misclassified in the sense that they were having fewer accidents than would be predicted by the mental status exam. Eight individuals who were predicted to be accident-involved had accidents on record, although 5 of these had fewer accidents than predicted by the MOMSSE.

The UFOV predictions were somewhat better. On the basis of this test, only one individual who had an intersection accident was not predicted. Eleven individuals were predicted to have intersection accidents and in fact had one or more accidents. Six of these individuals experienced more than one intersection accident. There were, however, 14 individuals who were predicted to have intersection accidents and did not. These false alarms could be due to a number of reasons, which will be discussed later.

Discussion

The strongest predictor of vehicle accidents in our study was a measure of visual attention (i.e., size of the useful field of view), followed by mental status. Taken together, these variables accounted for 20% of the accident variance in general, and 29% of the intersection accident variance. Although eye health and visual sensory variables contributed to UFOV performance, they were in themselves unrelated to accidents. Thus, this model provided a much stronger prediction of driving accidents than models reported in earlier studies on vision and driving, which have been largely limited to visual sensory tests as the independent variables. In these previous studies, less than 5% of the accident variance was accounted for by visual sensory tests; some of the correlations in this earlier work did reach statistical significance, but this significance was only achieved with a huge sample size (e.g., over 10,000 subjects). Thus, our model incorporating a measure of attention and mental status, even though it is based on a smaller sample, is a clear improvement over the previous work.

Our results imply that tests of the useful field of view and of mental status evaluate crucial aspects of visual/cognitive information processing necessary for handling the complexity of the driving task. The useful field of view test provides a measure of

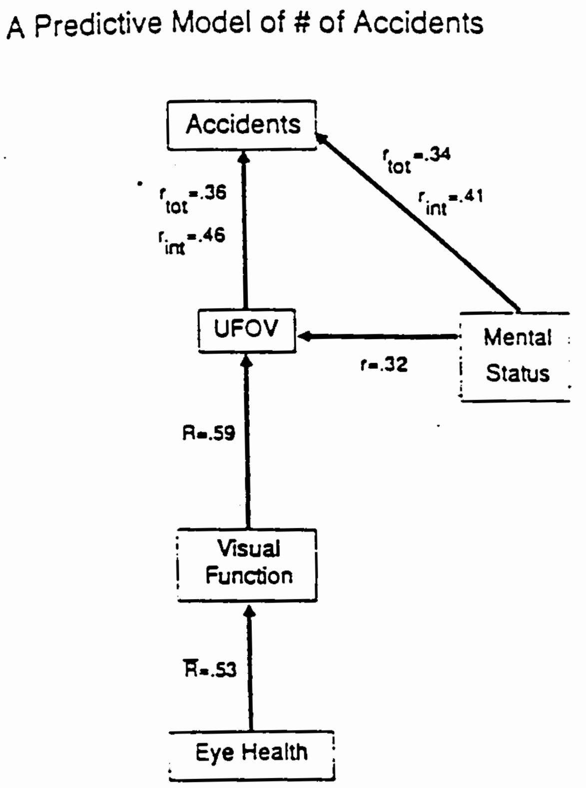

Figure 3. Regression model illustrating significant predictors of accident frequency in our sample of older drivers. (tot = total; int = intersection; UFOV = useful field of view)

Table 2
Intersection Accidents Predicted by MOMSSE and UFOV

Prediction	Accidents	
	On record = 0	On record > 0
MOMSSE		
Accidents = 0	25 correct rejections	9 misses
Accidents > 0	11 false alarms; 5 underpredictions	3 hits
Useful field of view		
Accidents = 0	26 correct rejections	1 miss
Accidents > 0	14 false alarms	11 hits

Note. MOMSSE = Mattis Organic Mental Status Syndrome Examination; UFOV = useful field of view.

efficiency at the earliest stage of attention, at which visual stimuli quickly capture and direct one's attention to highly salient visual events. This ability is critical during driving and is particularly important when approaching an intersection, where visual attention must quickly direct attention to events in the periphery. In fact, 95% of the intersection accidents in our sample were incurred by subjects who failed the UFOV test, and all individuals with multiple accidents in our sample failed the UFOV.

Mental status was also related to accidents, with those subjects having poor mental status incurring about three times more accidents than those with good mental status. This finding is consistent with earlier research linking accidents and cognitive impairment in elderly persons (Coyne et al., 1990; Friedland et al., 1988; Lucas-Blaustein et al., 1988). Although our sample did not include large numbers of individuals with serious dementia, our data imply that there is a significant cognitive component to safe driving, that not only involves the attentional system but also memory and information-processing skills.

Although we found that the visual sensory tests included in our protocol were unrelated to accident frequency, we do not wish to give the impression that visual sensory status is irrelevant for safe driving. Tests of visual attention, such as the useful field of view, are obviously dependent on the quality of visual information being processed by the visual system as illustrated in the model. As pointed out earlier, the correlation between visual field sensitivity loss and the UFOV ($r = 0.48$) was the primary contributor to the relationship between visual function and UFOV. Even though the relationships between visual field sensitivity loss and accidents were not significant given our sample size, we found that those drivers with poor visual fields had approximately twice as many accidents as those with normal visual field sensitivity, consistent with Johnson and Keltner's work (1986). However, it is also important to point out that, although good visual status is related to the useful field of view, good visual status alone is not a sufficient condition for a normal useful field of view: Approximately 50% of our subjects had good visual function yet failed the UFOV test. It was for this reason that the UFOV test was a better predictor of accidents than visual status alone.

It is obvious that there must be some minimum level of visual status required to perform the driving task adequately. It could be that most of our patients met those minimum requirements and, as a result, relationships between sensory status and accidents were attenuated because of restriction of range on these variables as well. A study currently underway in our lab will better evaluate the relationship between the full range of visual function and driving, because our new sample includes a broader range of visual sensory capabilities, especially those individuals with more serious vision loss.

Another point is that vehicle accidents are multiply caused. It would be naive to think that visual information-processing variables alone would account for all the variance in our accident measure. Previous research has suggested that other medical variables such as cardiovascular disease, musculoskeletal disorders, and medications contribute to accidents in elderly individuals (NHTSA, 1989b). Given this wide array of possible causes, it is noteworthy that we were able to account for as much variance in our accident measure as we did.

It should be mentioned that we have found that both mental status and UFOV predict driving problems in approximately 26% of individuals who actually have no accidents on the state record. There are several potential reasons for this finding. First, recall that those individuals with significant eye health problems (in particular, cataracts or severe visual field loss) reported more frequent avoidance of challenging driving situations (e.g., driving during rush hour traffic) than those who did not have these ocular health problems (see Table 1). These eye conditions themselves were not associated with a higher accident rate, but this may be partly due to the fact that these individuals were aware of their visual deficits due to their eye health problems and therefore voluntarily restricted their driving activity. Thus, in response to knowing they have serious eye health problems, some individuals may stop driving altogether, some may limit the miles that they drive, and still others may restrict their driving to certain times of day. Therefore, it is possible that simply informing an older driver with a significant visual attention deficit (as assessed by the UFOV task) that they have such a problem might in itself contribute to his or her avoidance of especially difficult driving situations and possibly reduce accidents.

With respect to accidents as the dependent variable, we have found that self-reported measures do not agree with state records. Consider why these older drivers are not reporting state-recorded accidents correctly. For example, why did several individuals overreport the number of accidents where police came to the scene? The following possibilities come to mind: (a) The police reports on these accidents were never entered on computer because of human error in doing the paperwork; (b) the accidents occurred outside the state of Alabama and thus were not reported to the Alabama Department of Public Safety; or (c) these subjects have a memory problem or have trouble reconstructing events during the previous 5-year period. Although we did not have any data to support the first two options, we examined the third possibility by comparing the mental status scores of our overreporters with those whose self-reports match the state records. Such an analysis indicates that those individuals who overreported their police-involved accidents did not differ significantly from the veridical reporters on either the total score or the memory subtests of the exam ($t < 1$, $p > .05$). Because memory or mental status scores were not different for these two groups, it may very well be that these individuals were reporting their accidents correctly, and one or both of the first two explanations account for the discrepancy.

With respect to those individuals who underreported the number of accidents on the state record, the possibility that they were not functioning as well cognitively is an even stronger possibility given the relationship of mental status and accident rate. However, in this case as well, the mental status scores of the underreporters did not differ significantly from those of the accurate reporters ($t < 1$, $p > .05$). Given that the tendency to correctly report accidents relates to the driver's accident involvement as defined by the state record, it could be that these older drivers with accident involvement were embarrassed by it and thus preferred not to formally admit their accident problems. This possibility seems quite likely, given that these individuals not only did not report accidents where police were called to the scene but also did not report any additional accidents where the police were not involved (Sloane et al., 1990). The net effect, however, given differential reporting based on the number of accidents on state record, is to invalidate the use of self-reported accidents as a measure of accident involvement in our study. Given consistent responding across accident groups, it would be possible to obtain some true measure of accident involvement by correcting state records with additional self-reported accidents. However, it is impossible to do so under the present circumstances because the additional accidents (where police were not called to the scene) of the drivers with greater numbers of accidents on record may have occurred at a higher rate as well. Finally, note that when we used self-reported accident frequency as the dependent variable in preliminary analyses of the data, we found many significant relationships between our independent variables (see Table 1) and accident frequency. This thereby supports our contention that the choice of dependent variable can substantially sway the results of studies on the relationship between visual function and vehicle accidents. Given that there still exists some controversy about the validity of self-report accident data (e.g., McGuire, 1973; Smith, 1976), we will continue to address this issue in our ongoing work on the older driver.

This study has established a link between visual attention abilities and accidents in older drivers and further indicates that a measure of mental status strengthens this relationship. These relationships were identified in our data set, despite the fact that certain features of our design were less than optimal for detecting statistically significant relationships among the variables. First, in selecting our sample, we had no control over the number of individuals with or without accidents recruited into our study because these individuals were recruited through an eye clinic. Over half of our subjects did not have any state-recorded accidents. This creates a restriction of range problem in a regression model, which tends to reduce the strength of any relationships that may exist. We are currently carrying out a large sample investigation that improves on the design of this study by balancing the number of individuals in both the low and high accident categories and extending the range of accidents to much higher frequencies.

In a similar vein, we were unable to evaluate the roles of several variables in this study because of the low number of individuals either experiencing extreme values on those measures or with particular diagnoses, as mentioned earlier. For example, the number of individuals with extreme scores on the mental status test was limited to only eight individuals, and these scores did not cover the full range of the test. In a similar way, we did not have enough individuals in many of the eye health diagnostic categories (e.g., glaucoma, AMD) to permit an evaluation of specific diseases. In the ongoing study described earlier, we have extended the age range of the sample to include individuals in their 80s and 90s, who are much more likely to have the more serious visual and mental deficits that can occur in old age.

In summary, our study has established a significant link between a measure of visual attention—the size of the useful field of view—and vehicle accidents in the older driver. Our model incorporating a measure of the useful field of view is strengthened by a measure of mental status but is not enhanced by measures of visual sensory function. In addition, our study has demonstrated that self-reported accident frequency by older drivers is not an accurate measure of their actual accident frequency and, therefore, the use of this dependent measure in earlier studies may have led to erroneous conclusions about vision and driving relationships.

References

Ball, K., Beard, B., Roenker, D., Miller, R., & Griggs, D. (1988). Age and visual search: Expanding the useful field of view. *Journal of the Optical Society of America A, 5*, 2210–2219.

Ball, K., & Owsley, C. (in press). Identifying correlates of accident involvement for the older driver. *Human Factors.*

Ball, K., Owsley, C., & Beard, B. (1990). Clinical visual perimetry underestimates peripheral field problems in older adults. *Clinical Vision Sciences, 5*, 113–125.

Ball, K., Owsley, C., Beard, B., Roenker, D., & Ball, D. (1989). Age and functional vision as related to everyday performance. *Investigative Ophthalmology & Visual Science* [Supplement], *30*, 408.

Ball, K., Roenker, D., & Bruni, J. (1991). *Mechanisms for reduced visual attention in older adults.* Manuscript submitted for publication.

Ball, K., Roenker, D. L., & Bruni, J. R. (1990). Developmental changes in attention and visual search throughout adulthood. In J. Enns (Ed.), *Advances in Psychology, 69*, 489–508.

Barrett, G. V., Mihal, W. L., Panek, P. E., Sterns, H. L., & Alexander, R. A. (1977). Information-processing skills predictive of accident involvement for younger and older commercial drivers. *Industrial Gerontology, 4*, 173–182.

Bergen, J., & Julesz, B. (1983). Parallel versus serial processing in rapid pattern discrimination. *Nature, 303*, 696–698.

Brenton, R. S., & Phelps, C. D. (1986). The normal visual field on the Humphrey Field Analyzer. *Ophthalmologica, 193*, 56–74.

Burg, A. (1967). *The relationship between test scores and driving record:*

General findings (Report NO. 67-24). Los Angeles: Department of Engineering, University of California.

Burg, A. (1968). *Vision test scores and driving record: Additional findings* (Report No. 68-27). Los Angeles: Department of Engineering, University of California.

Coyne, A. C., Feins, L. C., Powell, A. L., & Joslin, B. L. (1990, March). *The relationship between driving and dementia.* Poster presented at the 1990 Cognitive Aging Conference, Atlanta, GA.

Drury, C., & Clement, M. (1978). The effect of area, density, and number of background characters in visual search. *Human Factors, 20,* 597–602.

Ehrnst, S., & Georgeson, J. (1983). Jumbo Farnsworth D-15. *Rehabilitative Optometry, 1,* 15.

Elliott, D. B., Sanderson, K., & Conkey, A. (1990). The reliability of the Pelli-Robson contrast sensitivity chart. *Ophthalmic and Physiological Optics, 10,* 21–24.

Engel, F. (1977). Visual conspicuity, visual search, and fixation tendencies of the eye. *Vision Research, 17,* 91–97.

Farnsworth, D. (1947). *The Farnsworth Dichotomous test for color blindness. Panel D-15 Manual.* New York: The Psychological Corporation.

Federal Highway Administration. (1989). *The Federal Highway Administration's Action Plan for Older Persons.* Washington, DC: U.S. Department of Transportation.

Ferris, F. L., III, Kassoff, A., Bresnick, G. H., & Bailey, I. (1982). New visual acuity charts for clinical research. *American Journal of Ophthalmology, 94,* 91–96.

Fishman, G. A., Anderson, R. J., Stinson, L., & Haque, A. (1981). Driving performance of retinitis pigmentosa patients. *British Journal of Ophthalmology, 65,* 122–126.

Folstein, M. F., Folstein, S. W., & McHugh, P. R. (1975). "Mini-mental State", a practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189–198.

Friedland, R. P., Koss, E., Kumar, A., Gaine, S., Metzler, D., Haxby, J. V., & Moore, A. (1988). Motor vehicle crashes in dementia of the Alzheimer type. *Annals of Neurology, 24,* 782–786.

Henderson, R., & Burg, A. (1974). *Vision and audition in driving* (Tech. Rep. No. TM[L]-5297/000/00). Washington, DC: Dept. of Transportation.

Higgins, K. E., & Knoblauch, K. (1977). Validity of Pinckers 100-hue version of the Panel D-15. *American Journal of Optometry and Physiological Optics, 54,* 165–170.

Hills, B. L., & Burg, A. (1977). *A re-analysis of California driver vision data: General findings* (Report 768). Crowthorne, England: Transport and Road Research Laboratory.

Hofstetter, H. W. (1976). Visual acuity and highway accidents. *Journal of the American Optometric Association, 47,* 887–893.

Johnson, C., & Keltner, J. (1986). Incidence of visual field loss in 20,000 eyes and its relationship to driving performance. *Archives of Ophthalmology, 101,* 371–375.

Kahneman, D., Ben-Ishai, R., & Lotan, M. (1973). Relation of a test of attention to road accidents. *Journal of Applied Psychology, 58,* 113–115.

Kaszniak, A. W., Nussbaum, P., Allender, J. (1990, August). *Driving in elderly patients with dementia or depression.* Paper presented at the 98th Annual Convention of the American Psychological Association, Boston, MA.

Lambert, Z. V., Wildt, A. R., & Durand, R. M. (1988). Redundancy Analysis: An alternative to canonical correlation and multivariate multiple regression in exploring interset associations. *Psychological Bulletin, 104,* 282–289.

Leibowitz, H., & Appelle, S. (1969). The effect of a central task on luminance thresholds for peripherally presented stimuli. *Human Factors, 11,* 387–392.

Lucas-Blaustein, M. J., Filipp, L., Dungan, C., & Tune, L. (1988). Driving in patients with dementia. *Journal of the American Geriatrics Society, 36,* 1087–1091.

Mattis, S. (1976). Mental status examination for organic mental syndrome in the elderly patient. In L. Bella & T. B. Karasu (Eds.), *Geriatric Psychiatry (Second Edition).* New York: Oxford University Press.

McGuire, F. L. (1973). The nature of bias in official accident and violation records. *Journal of Applied Psychology, 57,* 300–305.

Mihal, W. L., & Barrett, G. V. (1976). Individual differences in perceptual information processing and their relation to automobile accident involvement. *Journal of Applied Psychology, 61,* 229–233.

National Highway Traffic Safety Administration. (1988). *The National Highway Traffic Safety Administration's traffic safety plan for older persons* (Report No. DOT HS 807 316). Washington, DC: U.S. Department of Transportation.

National Highway Traffic Safety Administration. (1989a). *Older drivers. The age factor in traffic safety* (Report No. DOT HS 807 402). Washington, DC: U.S. Department of Transportation.

National Highway Traffic Safety Administration. (1989b). *Conference on Research and Development Needed to Improve Safety and Mobility of Older Drivers* (Report No. DOT HS 807 554). Washington, DC: U.S. Department of Transportation.

Owsley, C., & Sloane, M. E. (1990). Vision and aging. In F. Boller & J. Grafman (Eds). *Handbook of Neuropsychology. Volume 4* (pp. 229–249). The Netherlands: Elsevier.

Pelli, D. G., Robson, J. G., & Wilkins, A. J. (1988). The design of a new letter chart for measuring contrast sensitivity. *Clinical Vision Sciences, 2,* 187–199.

Sanders, A. F. (1970). Some aspects of the selective process in the functional field of view. *Ergonomics, 13,* 101–117.

Scialfa, C. T., Kline, D. W., & Lyman, B. J. (1987). Age differences in target identification as a function of retinal location and noise level: an examination of the useful field of view. *Psychology and Aging, 2,* 14–19.

Sekuler, R., & Ball, K. (1986). Visual localization: Age and practice. *Journal of the Optical Society of America A, 3,* 864–867.

Shinar, D. (1977). *Driver visual limitations: Diagnosis and treatment* (Contract DOT-HS-5-1275). Washington, DC: Department of Transportation.

Simons, K. (1981). A comparison of the Frisby, Random-Dot E, TNO, and Randot Circles Stereotests in screening and office use. *Archives of Ophthalmology, 99,* 446–452.

Sloane, M. E., Ball, K., Owsley, C., Roenker, D. L., & Bruni, J. R. (1990). [The Driving Habits Questionnaire: An evaluation of the validity of self-reported driving habits]. Unpublished raw data.

Sloane, M. E., Kuyk, T., Owsley, C., & Ernst, S., & Nowakowski, R. (1989). The effects of relative size magnification of Farnsworth D15 Color Chips on color vision assessment in low vision patients. *Noninvasive Assessment of the Visual System. 1989 Technical Digest Series* (Vol. 7, pp. 140–143). Washington, DC: Optical Society of America.

Smith, D. I. (1976). Official driver records and self-reports as sources of accident and conviction data for research purposes. *Accident Analysis and Prevention, 8,* 207–211.

Szlyk, J. P., Fishman, G. A., Mater, S., & Alexander, K. R. (1990). Visual field screening for driving in retinitis pigmentosa patients. *Investigative Ophthalmology and Visual Science, 31*(Suppl.), 416.

Transportation Research Board. (1988). *Transportation in an aging society* (Vol. 1). Washington, DC: National Research Council.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12,* 97–136.

Verriest, G., Barca, L., Dubois-Poulsen, A., Houtmans, M., Inditsky, B., Johnson, C., Overington, I., Ronchi, L., & Villani, S. (1983). The occupational visual field. I: Theoretical aspects. The normal functional visual field. In G. Verriest (Ed.), *5th International Visual Field Symposium* (pp. 165–185). Junk, The Netherlands: Kluwer Academic Publishers.

Verriest, G., Barca, L., Calbria, E., Crick, R., Enoch, J., Esterman, B., Friedmann, A., Hill, A., Ikeda, M., Johnson, C., Overington, I., Ronchi, L., Saida, S., Serra, A., Villani, S., Weale, R., Wolbarsht, M., & Zingirian, M. (1985). The occupational visual field: II. Practical aspects: The functional visual field in abnormal conditions and its relationship to visual ergonomics, visual impairment and job fitness. In G. Verriest (Ed.), *6th International Visual Field Symposium* (pp. 281–326). Junk, The Netherlands: Kluwer Academic Publishers.

Williams, A. F., & Carsten, O. (1989). Driver age and crash involvement. *American Journal of Public Health Briefs, 79*, 326–327.