Published in final edited form as:
Psychol Aging. 2012 September ; 27(3): 550–559. doi:10.1037/a0026359.

Predictors of Driving Outcomes in Advancing Age

Jamie L. Emerson,
University of Iowa Department of Neurology 200 Hawkins Drive Iowa City, IA 52242 Phone: (319) 356-0808

Amy M. Johnson,
University of Iowa Department of Biostatistics 200 Hawkins Drive Iowa City, IA 52242 Phone: (319) 384-5023

Jeffrey D. Dawson,
University of Iowa Department of Biostatistics 200 Hawkins Drive Iowa City, IA 52242 Phone: (319) 384-5023

Ergun Y. Uc,
1-University of Iowa Department of Neurology 200 Hawkins Drive Iowa City, IA 52242 Phone: (319) 356-8754 2-Neurology Service Veterans Affairs Medical Center Iowa City, IA, USA

Steven W. Anderson, and
University of Iowa Department of Neurology 200 Hawkins Drive Iowa City, IA 52242 Phone: (319) 356-2671 Fax: (319) 384-7199

Matthew Rizzo
University of Iowa Department of Neurology 200 Hawkins Drive Iowa City, IA 52242 Phone: (319) 356-8748 Fax: (319) 384-7199

Jamie L. Emerson: jamie-emerson@uiowa.edu; Amy M. Johnson: amy-m-johnson@uiowa.edu; Jeffrey D. Dawson: jeffrey-dawson@uiowa.edu; Ergun Y. Uc: ergun-uc@uiowa.edu; Steven W. Anderson: steven-anderson@uiowa.edu; Matthew Rizzo: matthew-rizzo@uiowa.edu

Abstract

This study aimed to develop predictive models for real-life driving outcomes in older drivers. Demographics, driving history, on-road driving errors, and performance on visual, motor, and neuropsychological test scores at baseline were assessed in 100 older drivers (ages 65–89 years [72.7]). These variables were used to predict time to driving cessation, first moving violation, or crash. Using Cox proportional hazards regression models, significant individual predictors for driving cessation were greater age and poorer scores on Near Visual Acuity, Contrast Sensitivity, Useful Field of View, Judgment of Line Orientation, Trail Making Test-Part A, Benton Visual Retention Test, Grooved Pegboard, and a composite index of overall cognitive ability. Greater weekly mileage, higher education, and “serious” on-road errors predicted moving violations. Poorer scores from Trail Making Test-Part B or Trail Making Test (B-A) and serious on-road errors predicted crashes. Multivariate models using “off-road” predictors revealed (1) age and

Correspondence to: Matthew Rizzo, matthew-rizzo@uiowa.edu.

Author Contributions: JDD, EYU, SWA, and MR were responsible for study concept and design, with MR being the principal investigator. MR oversaw the enrollment of subjects. AMJ and JDD provided analysis of the data, with all authors helping interpret the results. All authors helped prepare the manuscript, with JLE being the lead author.

Contrast Sensitivity as best predictors for driving cessation; (2) education, weekly mileage, and Auditory Verbal Learning Task-Recall for moving violations; and (3) education, number of crashes over the past year, Auditory Verbal Learning Task-Recall, and Trail Making Test (B-A) for crashes. Diminished visual, motor, and cognitive abilities in older drivers can be easily and noninvasively monitored with standardized off-road tests, and performances on these measures predict involvement in motor vehicle crashes and driving cessation, even in the absence of a neurological disorder.

Keywords

neuropsychological tests; safety errors; driving cessation; instrumented vehicle

Introduction

As the population of older drivers in the United States keeps growing, so does the imperative to address growing issues of older driving safety and mobility (Dellinger, Langlois, & Li, 2002; US Government Accountability Office, 2007). Aging and associated medical disorders impair functional abilities required to drive safely, increasing the risk of driver errors that lead to vehicle crashes (Rizzo, 2011). Those ages 65 years and older are at particular crash risk (Duchek et al., 2003; Fildes et al., 2001; Hills, 1980; Hu et al., , 2000; Shinar & Schieber, 1991) due to cognitive and medical disorders (Rizzo, 2011). The causal pathway often involves a chain of factors or events, some of which can be prevented or controlled (Runyan, 1998).

The relationship between driver behavior and safety errors can be represented by an imaginary iceberg (Heinrich et al., 1980; Maycock, 1997). Tip-of-the-iceberg events are visible driver errors that produce crashes resulting in fatality, serious injury, mild injury, or, most frequently, property damage. Hidden, below-the-waterline events occur more often and range from more innocuous errors, such as failing to check the rear-view mirror on a barren highway, to serious errors, such as choosing to drive while impaired or distracted, leading to failure to brake or steer when needed, and to traffic conflicts, near-crashes, and traffic citations if a trooper is present (Rizzo & Kellison, 2010). Effective interventions can operate before, during, or after a crash occurs, at the levels of driver capacity, vehicle and road design, and public policy (Haddon, 1972).

The goal of this study— identifying combinations of cognitive, health, and demographic variables that predict real world driving outcomes — is critical to support valid state licensing criteria and accurate recommendations by health professionals on whether patients should continue driving. The decision of when to restrict driving or cease driving altogether is of vital importance, considering both the safety risks imposed by impaired drivers and the fact that driving cessation can lead to decreased activity, increased social isolation, depression, and increased caregiver burden (Fonda et al, 2001; Marottoli et al., 1997; Marottoli et al., 2000; Ragland et al, 2005; Windsor & Anstey, 2006).

The functions necessary for safely driving a motor vehicle can be measured using tests of attention, perception, memory, decision-making and other executive functions, emotional state, level of arousal, psychomotor factors, general mobility, and awareness of situation and self (Dawson et al, 2009; Marottoli et al., 1994; Rizzo et al, 2001; Rizzo et al, 1997; Uc et al., 2006; Wickens, 1992).

Perceptual, cognitive, and motor functions have been examined as crash predictors in older drivers (Ball et al, 1993; Cross et al., 2009; Owsley et al., 1998; Sims et al., 1998; Sivak, 1996). The useful field of view (UFOV), a measure of speed of processing for visual attention tasks, discriminated between at-fault crashers and crash-free drivers in retrospective studies (Ball et al., 1993; Sims et al., 1998) and prospectively (Cross et al., 2009; Owsley et al., 1998), as did worse performances on the Motor Free Visual Perception Test and the Trail Making Test Part B, a measure of working memory and visuomotor skills (Ball et al., 2006; Cross et al., 2009). Potential predictors of moving violations include walking less than one block per day, foot abnormalities, poor design copying on the Mini-Mental State Examination (Marottoli et al., 1994), and personality factors, including thrill and adventure seeking, as well as disinhibition (Trimpop & Kirkcaldy, 1997).

Driving cessation among the elderly reportedly depends on multiple factors including advanced age (Anstey et al, 2006; Edwards et al., 2008; Edwards, Bart, O'Connor, & Cissell, 2010; Marottoli et al., 1993), decreased grip strength (Anstey et al., 2006), lower self-rated health (Anstey et al., 2006), congestive heart failure (Edwards et al., 2008), and worse performance on the Turn 360 Test of balance (Edwards et al., 2008). Tests of processing speed (Digit Symbol Substitution: Anstey et al., 2006; Edwards et al., 2008), UFOV (Edwards et al., 2008; Edwards et al., 2010), verbal reasoning (Similarities Test: Anstey et al., 2006), symbol memory (Digit Symbol Substitution Symbol recall: Anstey et al., 2006), picture memory (Picture Naming Test recall: Anstey et al., 2006) may also predict future driving status, as may social factors such as income and employment (Marottoli et al., 1993). Composite measures of overall cognitive function, such as COGSTAT, based on several abovementioned functions of theoretical importance to driving ability, have provided better predictors of driving safety errors than tasks restricted to a single domain (Dawson et al., 2009; Dawson et al, 2010), but they have not yet been used to predict driving cessation.

While substantial research has linked various demographic, physical, and cognitive measures to negative driving outcomes, the best models for identification of at-risk older drivers are still unclear. The goal of this study was to develop predictive models for real-life driving outcomes from participant demographic and driving history characteristics, physical measures, and neuropsychological scores obtained from objective tests. Measures included in the test battery have been predictive in previous research or are theoretically related to driving, which requires visual, motor, and spatial abilities to execute vehicle maneuvers. The three outcomes considered in this study are driving cessation, citations, and crashes. Theoretical arguments exist for how predictors may relate differentially to these three driving outcomes. Some drivers may cease driving because of actual declines in abilities necessary for safe driving, perceived either by themselves or by family members, medical professionals, or licensing authorities. Therefore, we would suspect that driving cessation could be associated with poorer scores on tests of neuropsychological functioning. By contrast, moving violations could potentially be predicted by better scores on neuropsychological tests, as those who have less cognitive decline may be more active, have more confidence, and take more risks, both in terms of increased driving as well as a disregard for traffic laws. For motor vehicle crashes, declines in driving ability could potentially lead to an increase in crashes. On the other hand, those who have a decline in ability may drive less under potentially dangerous conditions, so they may actually have a decrease in crashes.

Methods

Participants

Participants comprised 100 older adult drivers (49 women and 51 men), between 65 and 89 years ($M = 72.68$, $SD = 5.03$), who were recruited from the general community using public service announcements and advertisements posted in the local newspapers, senior centers, and churches. Drivers diagnosed with neurological diseases and certain conditions, including brain tumors, stroke, traumatic brain injury, epilepsy, depression, dementia, sleep disorders, vestibular disorders, and alcohol or substance abuse, were excluded from the study. We also excluded drivers taking any prescription medications that may affect cognition, including stimulants, antihistamines, narcotics, anxiolytics, anticonvulsants, and neuroleptics. Individuals with diseases of the optic nerve, retina, or ocular media were excluded only if they had corrected visual acuity worse than 20/50. We examined all experimental subjects with a comprehensive battery of standardized neuropsychological procedures measuring cognitive, perceptual, and motor functions. From the results of these formalized tests, it was confirmed that none of these subjects met formal criteria for Alzheimer's disease and very few showed any indication of dementia. Specifically, based on the Iowa Screening Battery for Mental Decline, only 3% were classified as having highly probable dementia; however, these were likely false positives, as Eslinger (1985) found a false positive rate of 5.5% when this screening was applied to normal control subjects. Results were generally similar whether we included or excluded these 3 subjects, so we kept them in our study and analysis. The Institutional Review Board at the University of Iowa approved this study, and informed consent was obtained in accordance with institutional and federal guidelines for human subject safety and confidentiality.

Design

All predictor variables, including demographics, driving behavior characteristics, and a battery of visual, motor, and cognitive tests, were collected during the baseline visit. The on-road drive in an instrumented vehicle was also completed during the baseline assessment. Driving outcomes were collected via multiple sources following baseline assessment of each participant. Due to rolling induction, the length of follow-up ranged from 3 to 8 years.

Materials and Procedures

Demographics and Driving Characteristics—Participant age, gender, and years of education were collected from a questionnaire.

Self-reported driving habits and exposure: The University of Alabama at Birmingham Driving Habits Questionnaire (DHQ) assessed several aspects of self-reported driving exposure, driving preferences and habits, and intentional avoidance of risky driving situations. Participants reported average weekly mileage, number of vehicle crashes in the previous year, and the number of times pulled over in the previous year (Sloane, Ball, Owsley, Roenker, & Bruni, 1990). An exposure reduction score was calculated from addition of each "no" response on eight questions asking whether the participant had driven in certain potentially risky driving situations during the last 2 months (e.g. have you driven while it is raining?) (Uc et al., 2011). An intentional avoidance score was computed by adding all "yes" responses to questions asking if the participant specifically avoided a potentially risky driving situation. Participants also gave a rating of the quality of their own driving.

Depression—The Geriatric Depression Scale (GDS) assessed depressive symptoms (Yesavage et al., 1982–1983).

Motor Function Measures

Get-up and go: Starting from a sitting position, participants were asked to stand up, walk a distance of three meters at a comfortable pace, turn around, and return to their seat. Time to completion was measured from the word "Go" until the participant returned to their seat.

Two trials were completed, in most cases, and averaged for analyses (Alexander, 1994; Mathias, Nayak, & Isaacs, 1986; Podsiadlo & Richardson, 1990; Tinetti, 1986).

Functional reach (FR): Participants stood with their right arm parallel to a measuring tape and their feet flat on the ground. From this position, participants leaned forward as far as possible without losing balance or moving their feet. Functional reach distance was measured, in inches, as the arm's length subtracted from the maximal forward reach distance (Alexander, 1994; Duncan et al., 1990).

Grooved pegboard test (Pegs): Participants inserted pegs into 25 pegboard holes oriented in different directions, as quickly as possible. Time taken to completion for the right hand and left hand, each done separately, was averaged for analyses (Heaton et al., 1991).

Basic Vision and Visual Perception Measures—Participants completed all vision assessments with any corrective glasses or lenses normally worn while driving.

Near visual acuity (NVA): Number acuity was assessed using the Rosenbaum Pocket Vision Screener held 14 inches from the eyes, and a LogMAR score was calculated (Ferris, Kassoff et al., 1982).

Far visual acuity (FVA): Letter acuity was measured using the ETDRS (Early Treatment Diabetic Retinopathy Study) wall chart at a distance of 13 feet, and a LogMAR score was calculated (Ferris et al., 1982).

Contrast sensitivity (CS): The Pelli-Robson wall chart was used to assess OU (*oculus uterque;* Latin, "both eyes") spatial contrast sensitivity at a distance of 10 feet (Pelli et al., 1988). These scores may range from 0 to 2.25, in increments of 0.15.

Judgment of line orientation (JLO): Participants were shown lines whose spatial orientation varied within 180 degrees, and were required to visually match the position of these target lines to correspondingly oriented lines in an array of lines in a reference diagram (Strauss et al., 2006). We used the number correct out of 30 trials, giving us were integers between 0 and 30.

Structure from motion (SFM): Participants identified three-dimensional shapes of cubes, spheres, or no shape from different percentages of rotating dots presented on a computer screen (Rizzo et al., 1997; Rizzo et al., 1995). These are generally positive scores, with lower values being better.

Useful field of view (UFOV): UFOV loss was measured using the personal computer touch screen version of UFOV (Edwards et al., 2005). A total UFOV score was calculated from addition of the four UFOV subtests measuring processing speed, divided attention, and selective attention. UFOV scores on each subtest represent the threshold in milliseconds at which the individual correctly responds to 75% of the trials (Ball & Owsley, 1992).

Visual Cognition and Executive Function Measures

WAIS–III Block Design (Blocks): Participants constructed designs shown on cards using a set of blocks. Constructions were scored based on accuracy and speed of performance and totaled (Wechsler, 1981).

Complex figure test-copy (CFT-Copy): Participants were instructed to copy a complex geometric figure and accuracy of construction was assessed (Stern et al., 1994).

Complex figure test-recall (CFT-Recall): Thirty minutes after participants finished CFT-Copy, they were asked to draw the figure from memory. Accuracy of construction was assessed (Stern et al., 1994). Both CFT-Copy and CFT-Recall provided scores between 0 and 36.

Benton visual retention test (BVRT): Participants viewed pictures with one or more figures for 10 seconds. After 10 seconds, each picture was removed from view and participants drew the picture from memory. Number of errors made in each drawing were assessed and totaled (Sivan, 1992).

Auditory-learning verbal test-recall (AVLT-Recall): Participants were read a list of 15 words and repeated as many words as they could remember on each of five trials. After 30 minutes, participants were asked to recall as many words from the list as possible. Number of words correctly recalled was recorded (Strauss et al., 2006).

Trail making test-part A (TMT A): Participants drew lines to sequentially connect circles numbered 1 to 25, as quickly as possible, without lifting the pencil from the page (Reitan & Davison, 1974). Time to completion was recorded.

Trail making test-part B (TMT B): Participants drew lines to numerically and alphabetically connect alternating circles containing a number or letter, respectively (Reitan & Davison, 1974). Time to completion was recorded. The difference in time to complete Part A and Part B was also used in analyses.

Controlled oral word association (COWA): Participants were given a letter of the alphabet and had 60 seconds to say as many words that begin with that letter as possible. Three trials were completed with different letters. Number of acceptable words on each trial was added together for a total score (Benton & Hamsher, 1978).

COGSTAT: A composite score of several of the above cognitive measures and one visuoperceptual measure (JLO, Blocks, CFT-Copy, CFT-Recall, BVRT, AVLT-Recall, TMT B-A, COWA) was calculated from addition of the eight t-scores as a measure of general cognition (Dawson et al., 2009, 2010; Uc et al., 2009; Uc et al., 2005).

On-road Driving Performance—Participants completed an approximately 45-minute, on-road driving assessment along rural and urban streets in an instrumented vehicle called ARGOS. The specified route incorporated tasks interspersed with baseline segments and was proctored by a trained research assistant, who sat in the front passenger seat throughout the drive. Video of the drive was collected during testing and was reviewed by a certified driving instructor for frequency and type of safety errors committed by each participant. Safety errors were defined and categorized based on the Iowa Department of Transportation (DOT) Drive Test Scoring Standards (September 7, 2005 version), which included 76 error types (e.g., "unsafe passing," "tailgating"). Thirty of these errors were classified by our research team as "serious safety errors" because they would likely result in a "failure" if committed during the Iowa DOT official licensing test (Dawson et al., 2009, 2010). Overall safety errors have been found to have an intra-rater correlation of 95% and an inter-rater correlation of 73% (Dawson et al., 2009). Both overall safety errors and serious safety errors were used in analyses.

Driving Outcomes

Driving Cessation: Participant or family report of driving cessation or continuation was obtained first with follow-up telephone calls conducted 3 to 7 years (mean = 6.6) after baseline assessment. For drivers who were unreachable by telephone call, Iowa DOT driving records, which were requested once per year for a minimum of 4 years following study enrollment, were reviewed for indication of license suspension, revocation, or rescission. If there was no indication of driving cessation after reviewing the DOT records, ARGOS drive dates and the DHQ from longitudinal study visits were reviewed for self-report of driving cessation. Death dates from the Social Security Death Index were used as a final source of driving cessation evidence, if no other information was available. The determination and date of driving cessation or continuation was determined by telephone call (n = 51), driving records (n = 18), ARGOS drive status (n = 14), death date (n = 11), and DHQ (n = 6).

Moving Violations: Moving violations were tracked from yearly requested Iowa DOT driving records. Only citations resulting from driver actions while the vehicle was in motion were included in analyses. Parking and paperwork violations were excluded.

Motor Vehicle Crashes: Motor vehicle crashes were tracked from DHQs administered at annual, longitudinal study visits and from Iowa DOT driving records. Detailed police reports were requested for each crash listed on a participant's driving record that occurred during the study period. Police crash reports were reviewed by two research assistants to determine if the crash should be categorized as "at-fault", "not at-fault", or "not enough information". Crashes that did not have a police report on file were categorized as "no report on file". A third rater was used for discrepancies between the first and second raters. Crashes in which the participant was not the driver were excluded from analyses.

Statistical Analysis—Descriptive statistics (means and standard deviations) for all predictor variables were calculated. Kaplan-Meier estimates and 95% confidence intervals (CIs) were used to assess the likelihood of avoiding the three driving outcomes over time. Cox proportional hazards regression models were used to find individual predictors' CIs of driving outcomes, controlling for age, gender, education, and baseline mileage driven per week. We adjusted for education because it is known to correlate with neuropsychological test performance. As our subjects were generally well educated, those with less education may live in more outlying, less populated locations, which can affect their typical driving environment. In order to facilitate comparisons across predictors, our regression results were reported in terms of a 1-SD difference for each predictor. For crashes and tickets, we modeled the time until the first of each of these events, and drivers were censored at the time of driving cessation, death, or the end of the study (last follow-up time), whichever came first. For driving cessation, we modeled the time until driving ceased (for any reason, including death), and drivers were censored at the end of the study.

We constructed multivariable regression models, considering all neuropsychological variables as potential predictors, except for COGSTAT, TMT B, and TMT A, which were excluded to avoid multicollinearity. We also included the following driving variables as potential predictors: driving rate, driving mode, driving quality, exposure reduction score, intentional avoidance score, days per week driven, suggestion to stop driving, number of accidents, number times pulled over, and overall safety errors. We found several models based on forward and backward stepwise procedures, and chose the final models based on the Akaike Information Criterion (AIC). Care was taken to ensure that the results were not substantially affected by extreme values. Since Cox regression models are rank-based with respect to the outcome, it is outliers of the predictors rather than of the event times that need to be considered. We used "dfbeta" diagnostics to measure the influence that individual data points had on the hazard ratios and test statistics, and we refit our final multivariable models after removing our most influential data points. The results were similar, so we reported only the results which included all possible data.

Results

Table 1 presents the descriptive statistics on demographics and visual, motor, cognitive, and on-road performance. Mean total follow-up time for the drivers was 6.40 years (range: 0.46–9.03). The hazard ratios for driving outcomes for individual predictors, adjusted for age, gender, education, and baseline weekly mileage, are shown in Table 2.

Driving Cessation

Twenty of the 100 (20.0%) older drivers had stopped driving within the follow-up period. Figure 1 shows the probability estimates and confidence intervals for continuing to drive, as a function of time; hence, the cumulative incidence estimates of driving cessation are these probabilities subtracted from the value of 1. For example, cumulative incidence for driving cessation was 4.1% (95% CI: 1.5–10.4%) at 2 years, 10.6% (95% CI: 5.6–19.6%) at 4 years, and 22.1% (95% CI: 14.3–33.5%) at 6 years. Several demographic, visual, motor, and cognitive variables significantly predicted time to driving cessation (Table 2). Specifically, a 5.0 year age increase (e.g., a 1-SD increase, since SD of age is 5.0 in Table 1) corresponded to a hazard ratio of 1.83. For visual measures, a 0.04 (1-SD) NVA increase corresponded to a hazard ratio of 1.44, a 0.15 CS increase corresponded to a hazard ratio of 0.61, a 4.3 increase on JLO corresponded to a hazard ratio of 0.60, and a 209 millisecond UFOV increase corresponded to a hazard ratio of 1.60. Within motor tests, an increase of 18.9 seconds on Pegs corresponded to a hazard ratio of 1.69. Significant measures of cognition included a 2.5 BVRT error increase corresponding to a hazard ratio of 1.75 and a COGSTAT increase of 50 corresponding to a hazard ratio of 0.56. Table 3 shows that the best multivariate model for prediction of driving cessation consisted of age and CS.

There were 15 subjects with at least one predictor with a missing value. Most individual predictors had missing values for three or fewer subjects. When we built our multivariable regression models, we used only complete cases. However, once a model was selected, it was refit to maximize the number of the subjects utilized. For example, the reported multivariate model of driving cessation used 98 of 100 subjects.

Moving Violations

Twenty-seven of the 98 (27.6%) older drivers had been issued a moving violation by follow-up. Cumulative incidence was 10.3% (95% CI: 5.7–18.4%) at 2 years, 16.7% (95% CI: 10.6–25.8%) at 4 years, and 27.5% (95% CI: 19.2–38.4%) at 6 years (graph not shown). Table 2 shows that education, baseline weekly mileage, and serious road safety errors significantly predicted moving violations. A 2.63 year (1-SD) education increase corresponded to a hazard ratio of 1.26, an increase of 193.44 miles driven per week corresponded to a hazard ratio of 1.90, and an increase of 1.67 serious road safety errors corresponded to a hazard ratio of 1.67. When modeled together, education, baseline weekly mileage, and AVLT-Recall best predicted moving violations (Table 3).

Motor Vehicle Crashes

Thirty-four of the 98 (34.7%) older drivers were involved in a crash during the follow-up time period. Cumulative incidence was 16.4% (95% CI: 10.4–25.3%) at 2 years, 28.6% (95% CI: 20.5–38.9%) at 4 years, and 32.4% (95% CI: 23.8–43.0) at 6 years (graph not shown). Of these 34 crashes, 11 were deemed at-fault based on review of the crash report. Since there were no differences in the predictors of overall crashes versus at-fault crashes, only findings from the overall crashes are reported here. Scores on TMT B, TMT (B-A), and serious road safety errors significantly predicted crashes. A 43.73 second (1-SD) increase on TMT B corresponded to a hazard ratio of 1.40, a 36.71 second increase on TMT (B-A) corresponded to a hazard ratio of 1.37, and a 1.67 increase of serious road safety errors corresponded to a hazard ratio of 1.45. Education, number of crashes over the past year, AVLT-Recall, and TMT (B-A) provided the best model for predicting time to a crash, as presented in Table 3.

Discussion

Safe driving depends on a range of functions that decline with advancing age. This study developed multivariable models for predicting real-life driving outcomes (driving cessation, moving violation, or motor vehicle crash) using demographic, visual, motor, and cognitive variables. Results showed that older drivers with diminished visual, motor, and cognitive abilities are more likely to be involved in a motor vehicle crash or stop driving, even in the absence of a neurological disorder.

Driving cessation was best predicted by a multivariate model that included age and CS, with older drivers and those with poor CS more likely to cease driving. CS testing requires only a wall chart, and can provide a time and cost-efficient screening tool in health care and DOT settings (Carr et al., 2010). Edwards et al. (2010) identified age and UFOV (subtest 2) as factors in a predictive model of driving cessation, while our results showed that UFOV (composite score) was a significant individual predictor. Other individual predictors were older age and poorer performance on tests of visual perception (NVA, CS, JLO), visual working memory (BVRT), visuomotor speed (TMT-A), and global cognition (COGSTAT). Our findings are in agreement with other studies that have found risk factors for driving cessation include age (Anstey et al., 2006; Edwards et al., 2008; Edwards et al., 2010; Marottoli et al., 1993), UFOV (Edwards et al., 2008, 2010), and visual memory (Anstey et al., 2006). These tests are theoretically related to driving, which requires visual, motor, and spatial abilities to execute vehicle maneuvers. Overall cognition, measured by COGSTAT, is required to recognize driving situations and make decisions on appropriate actions based on knowledge about rules of the road and past experience. This predictor has also been useful in other studies predicting driving performance from neuropsychological tests (e.g., Dawson et al., 2009; Uc et al., 2011).

Risk for moving violations was best predicted by a multivariate model including education, baseline weekly mileage, and AVLT-Recall. Those with higher education, higher mileage, and better AVLT-Recall scores were more likely to receive moving violations. Greater education and baseline weekly mileage, along with serious road safety errors, were also the individual predictors for this outcome. Drivers with higher weekly mileage showed greater likelihood of moving violations probably because these drivers have more opportunity to be issued a violation. Higher mileage drivers may also be more comfortable on the road and possibly more lax towards driving laws. Overall, this evidence suggests that moving violations may depend more upon driver exposure than general cognitive state or specific impairments.

Risk for crash involvement was best predicted by a multivariate model including education, number of crashes over the past year, AVLT-Recall, and TMT (B-A). Worse scores on TMT B or TMT (B-A) and more serious road safety errors were identified as individual predictors of this outcome. The results support the idea that cognitive processing and set-shifting abilities tested by the TMT are related to collision-avoiding driving abilities (Ball et al., 2006). Previous studies (Cross et al., 2009; Owsley et al., 1998) found that UFOV is related to crashes, but this was not found in the present study and could be due to differences in UFOV test versions and scoring. The crash predictors were identical for both overall crashes and at-fault crashes, suggesting the predictors are capable of identifying not only drivers who cause a crash from unsafe driving but also drivers who are less able to avoid a crash arising from unsafe behaviors by other drivers.

We have found UFOV scores to be predictive of various outcomes in a variety of older driver cohorts, consistent with other research. For example, we found that UFOV impairment is one of the most important predictors of driving cessation in Parkinson's disease (Uc et al., 2011); UFOV total score in the Parkinson's disease cohort (mean ± SD = 880 ± 375 msec vs. 725 ± 209 msec) was significantly higher (i.e., worse) and more variable compared to UFOV scores in the elderly drivers in this study. The lack of significant associations between UFOV loss and moving violation and crash outcomes in the current study might be explained by the normal UFOV scores with relatively narrow variability in our sample of highly-educated, healthy, cognitively preserved elderly drivers.

Driving outcome predictors identified in this research are compatible with those identified in previous studies of driving cessation, tickets, and crashes (Anstey et al., 2006; Ball et al., 2006; Edwards et al., 2008; Edwards et al., 2010; Marottoli et al., 1993), including road tests in an instrumented vehicle (Dawson et al., 2009; 2010). In this vein, increased age and poorer scores on the BVRT, CFT-Copy, TMT A, FR, and COGSTAT were significant predictors of safety errors in drivers with early dementia (Dawson et al., 2009), while greater age and poorer scores on CFT-Copy, CFT-Recall, Blocks, NVA, Pegs, and COGSTAT predicted real-world driving errors in neurologically normal older drivers (Dawson et al., 2010).

A moving violation or a crash may presage driving cessation

In this study 12 drivers had both a moving violation and a crash. Of these five had a crash first, five had a moving violation first, and two drivers had them contemporaneously. Three drivers who received a moving violation also quit driving, but over a year had elapsed since the moving violation, attenuating possible connections between cause and effect. Finally, of the five drivers who crashed and stopped driving, three quit after being in a crash and two did so contemporaneously. Overall, we did not find strong correlations between these outcomes.

The frequency of driving outcomes in this study fits with the epidemiologic record

U.S. Department of Transportation, Federal Highway Administration records disclose 367,137 licensed drivers over age 65 years in Iowa in 2007 (http://www.iowadot.gov/crashanalysis/pdfs/historicaltravelcrashesfatalitiesrates_2001-2009_20100706.pdf), who had 24% (14,400) of statewide total crashes (60,003) that year (http://www.iowadot.gov/mvd/ods/olderdrivers.pdf). This is an approximately 3.9% cumulative incidence crash rate for 1 year. In our cohort, there was a 7.1% (95% CI: 3.4–14.3%) crash rate at 1 year, about 3% higher than found via these Iowa DOT statistics.

Differences in study designs, populations, sample size, predictor test batteries, follow-up time, and methods for collecting and defining driving outcomes make comparisons among existing literature challenging. Yet, the crash rate of 44 older drivers followed by Ott et al. (2008) of 11% at 18 months falls between our cumulative incidence rate at 1 year (7.1%) and 2 years, 16.4% (95% CI: 10.4–25.3%). Lafont et al. (2008) surveyed 986 drivers, 240 (24.3%) of whom had at least one crash in the past 5 years. Our drivers had a crash incidence of 28.6% (95% CI: 20.5–38.9%) at 4 years and 32.4% (95% CI: 23.8–43.0%) at 6 years. Our older driver cohort showed a moving violation incidence rate of 5.1% (95% CI: 2.2–11.8%) at 1 year (0.0075 violations per 1000 miles driven) and 10.3% (95% CI: 5.7–18.4%) at 2 years. In comparison, the 44 older drivers followed by Ott et al. (2008) had zero traffic violations at 18 months and 1.52 violations per 1000 miles driven at 3 years. In the Lafont et al. (2008) survey 21% of drivers over age 65 years stopped driving since they first obtained their license, including 6% in the past 5 years. In this study, cumulative incidence for driving cessation was 10.6% (95% CI: 5.6–19.6%) at 4 years, and 22.1% (95% CI: 14.3–33.5%) at 6 years.

The breadth of our statistical investigations increased the possibility of Type I errors

For example, Table 2 shows the results of 90 statistical tests, four or five of which might be expected to have *P*-values < 0.05, even if none of the factors were truly associated with the outcomes. However, we found 15 significant results, more than triple the number expected by chance alone. Also, while our test battery provided many other measures that we could have considered as predictors (e.g., CFT times, UFOV subtests, AVLT training scores), we focused on variables that we have found useful in other studies, further mitigating against Type I errors.

Continued study of the predictive value of standardized tests and new experimental approaches are essential for determining what types and levels of incapacity may trigger disqualification or restriction of drivers, as age or medical diagnosis alone are often insufficient criteria (Iverson et al., 2010). Critical outcomes such as a moving violation or crash remain difficult to predict because they are rare in a statistical sense and because intervening factors mitigate the effects of driver capability on crash risk. Some unsafe drivers may not yet have had a crash, while others, who perform poorly on laboratory tests, may adopt effective strategies (reduced mileage, avoidance of certain hazards) to mitigate real-world crash risk. Driver self-report of crashes and timing of driving cessation may be inaccurate due to recall bias or error. Licensure rescission dates provide supplementary data, but some drivers continue drive without a license and others retain their license even after quitting driving.

The predictive power and utility of current tools for measuring driver behavior, the factors that influence it, and clinicians' ability to generate fair, accurate, and timely recommendations for driver licensure or driving cessation would be improved by more accurate measures of actual driving exposure. Naturalistic studies of actual driver exposure and errors over extended timeframes, taking advantage of sensor development and a taxonomy of driver error, have the potential to overcome this central problem to advance the research and understanding of older driver safety, mobility, and quality of life.

Acknowledgments

This study was supported by awards AG 17177 and AG 15071 from the National Institute on Aging (NIA), which provided salary support to the authors. The authors would like to thank the entire neuroergonomics research team and all participants in the study.

Sponsor's Role: The only role of the National Institutes of Health and NIA was providing financial support.

References

Alexander NB. Postural control in older adults. Journal of the American Geriatrics Society. 1994; 42:93–108. [PubMed: 8277123]

Anstey KJ, Windsor TD, Luszcz MA, Andrews GR. Predicting driving cessation over 5 years in older adults: Psychological well-being and cognitive competence are stronger predictors than physical health. Journal of the American Geriatrics Society. 2006; 54:121–126. [PubMed: 16420208]

Ball K, Owsley C. The Useful Field of View Test: A new technique for evaluating age-related declines in visual function. Journal of the American Optometric Association. 1992; 64:71–79. [PubMed: 8454831]

Ball K, Owsley C, Sloane ME, Roenker DL, Bruni JR. Visual attention problems as a predictor of vehicle crashes. Investigative Ophthalmology & Visual Science. 1993; 34:3110–3123. [PubMed: 8407219]

Ball KK, Roenker DL, Wadley VG, Edwards JD, Roth DL, McGwin G Jr, et al. Can high-risk older drivers be identified through performance-based measures in a department of motor vehicles setting? Journal of the American Geriatrics Society. 2006; 54:77–84. [PubMed: 16420201]

Benton, AL.; Hamsher, K. Multilingual Aphasia Examination. Iowa City: University of Iowa Hospitals; 1978.

Carr, D.; Schwartberg, J.; Manning, L.; Sempek, K. Physician's guide to assessing and counseling older drivers. 2nd ed.. Washington, DC: NHTSA; 2010.

Cross JM, McGwin G Jr, Rubin GS, Ball KK, West SK, Roenker DL, et al. Visual and medical risk factors for motor vehicle collision involvement among older drivers. The British Journal of Ophthalmology. 2009; 93(3):400–404. [PubMed: 19019937]

Dawson JD, Anderson SW, Uc EY, Dastrup E, Rizzo M. Predictors of driving safety in early Alzheimer disease. Neurology. 2009; 72:521–527. [PubMed: 19204261]

Dawson JD, Uc EY, Anderson SW, Johnson AM, Rizzo M. Neuropsychological predictors of driving errors in older adults. Journal of the American Geriatrics Society. 2010; 58:1090–1096. [PubMed: 20487082]

Dellinger AM, Langlois JA, Li G. Fatal crashes among older drivers: Decomposition of rates into contributing factors. American Journal of Epidemiology. 2002; 155(3):234–241. [PubMed: 11821248]

Duchek JM, Carr DB, Hunt L, Roe CM, Xiong C, Shah K, et al. Longitudinal driving performance in early-stage dementia of the Alzheimer type. Journal of the American Geriatrics Society. 2003; 51:1342–1347. [PubMed: 14511152]

Duncan PW, Weiner DK, Chandler J, Studenski S. Functional reach: A new clinical measure of balance. Journal of Gerontology. 1990; 45:M192–M197. [PubMed: 2229941]

Edwards JD, Bart E, O'Connor ML, Cissell G. Ten years down the road: Predictors of driving cessation. The Gerontologist. 2010; 50(3):393–399. [PubMed: 19726733]

Edwards JD, Ross LA, Ackerman ML, Small BJ, Ball KK, Bradley S, et al. Longitudinal predictors of driving cessation among older adults from the ACTIVE clinical trial. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences. 2008; 63:P6–P12.

Edwards JD, Vance DE, Wadley VG, Cissell GM, Roenker DL, Ball KK. Reliability and validity of useful field of view test scores as administered by personal computer. Journal of Clinical and Experimental Neuropsychology. 2005; 27:529–543. [PubMed: 16019630]

Ferris FL III, Kassoff A, Bresnick GH, Bailey I. New visual acuity charts for clinical research. American Journal of Ophthalmology. 1982; 94:91–96. [PubMed: 7091289]

Fildes, B.; Fitzharris, M.; Charlton, JL.; Pronk, N. Proceedings of the Australian Transport Research Forum. Hobart; 2001. Older driver safety—A challenge for Sweden's 'Vision Zero'.

Fonda SJ, Wallace RB, Herzog AR. Changes in driving patterns and worsening depressive symptoms among older adults. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences. 2001; 56:S343–S351.

Haddon W Jr. A logical framework for categorizing highway safety phenomena and activity. Journal of Trauma. 1972; 12(3):193–207. [PubMed: 5012817]

Heaton, RK.; Grant, I.; Matthews, CG. Comprehensive norms for an expanded Halstead-Reitan battery: Demographic corrections, research findings, and clinical applications. Odessa, FL: Psychological Assessment Resources; 1991.

Heinrich, HW.; Petersen, D.; Roos, N. Industrial accident prevention. New York, NY: McGraw-Hill; 1980.

Hills BL. Vision, visibility and driving. Perception. 1980; 9:183–216. [PubMed: 7375327]

Hu, PS.; Jones, DW.; Reuscher, T.; Schmoyer, RS.; Truett, LF. Projecting fatalities in crashes involving older drivers 2000–2025. Oak Ridge, TN: Oak Ridge National Laboratory; 2000. (Report ORNL-6963)

Iverson DJ, Gronseth GS, Reger MA, Classen S, Dubinsky RM, Rizzo M. Practice parameter update: Evaluation and management of driving risk in dementia. Neurology. 2010; 74:1316–1324. [PubMed: 20385882]

Lafont S, Laumon B, Helmer C, Dartigues JF, Fabrigoule C. Driving cessation and self-reported car crashes in older drivers: the impact of cognitive impairment and dementia in a population-based study. Geriatr Psychiatry Neurol. 2008; 21:171–182.

Marottoli RA, Cooney LM Jr, Wagner R, Doucette J, Tinetti ME. Predictors of automobile crashes and moving violations among elderly drivers. Annals of Internal Medicine. 1994; 121:842–846. [PubMed: 7978696]

Marottoli RA, Mendes de Leon CF, Glass TA, Williams CS, Cooney LM Jr, Berkman LF. Consequences of driving cessation: Decreased out-of-home activity levels. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences. 2000; 55:S334–S340.

Marottoli RA, Mendes de Leon CF, Glass TA, Williams CS, Cooney LM Jr, Berkman LF, et al. Driving cessation and increased depressive symptoms: Prospective evidence from the New Haven EPESE. Established Populations for Epidemiologic Studies of the Elderly. Journal of the American Geriatrics Society. 1997; 45:202–206. [PubMed: 9033520]

Marottoli RA, Ostfeld AM, Merrill SS, Periman GD, Foley DJ, Cooney LM Jr. Driving cessation and changes in mileage driven among elderly individuals. Journal of Gerontology. 1993; 48:S255–S260. [PubMed: 8366274]

Mathias S, Nayak USL, Isaacs B. Balance in elderly patients: The "Get-up and Go Test". Archives of Physical Medicine and Rehabilitation. 1986; 67:387–389. [PubMed: 3487300]

Maycock, G. Accident liability—the human perspective. In: Rothengatter, T.; Carbonell, VE., editors. Traffic and Transport Psychology: Theory and Application. New York: Pergamon; 1997. p. 65-76.

Ott BR, Heindel WC, Papandonatos GD, Festa EK, Davis JD, Daiello LA, Morris JC. A longitudinal study of drivers with Alzheimer disease. Neurology. 2008; 70:1171–1178. [PubMed: 18216302]

Owsley C, Ball K, McGwin G Jr, Sloane ME, Roenker DL, White MF, et al. Visual processing impairment and risk of motor vehicle crash among older adults. Journal of the American Medical Association. 1998; 279:1083–1088. [PubMed: 9546567]

Pelli DG, Robson JG, Wilkins AJ. The design of a new letter chart for measuring contrast sensitivity. Clinical Vision Science. 1988; 2(3):187–199.

Podsiadlo D, Richardson S. The timed 'Up and GO' test: A test of basic functional mobility for frail elderly persons. Journal of the American Geriatrics Society. 1990; 39:142–148. [PubMed: 1991946]

Ragland DR, Satariano WA, MacLeod KE. Driving cessation and increased depressive symptoms. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 2005; 60:399–403.

Reitan, RM.; Davison, LA. Clinical Neuropsychology: Current Status and Applications. New York: Hemisphere; 1974.

Rizzo M. Impaired driving from medical conditions: A 70-year-old man trying to decide if he should continue driving. The Journal of the American Medical Association. 2011; 305(10):1018–1026.

Rizzo, M.; Kellison, IL. The brain on the road. In: Marcotte, TD.; Grant, I., editors. Neuropsychology of everyday functioning. New York: The Guilford Press; 2010. p. 168-208.

Rizzo M, McGehee DV, Dawson JD, Anderson SN. Simulated car crashes at intersections in drivers with Alzheimer disease. Alzheimer Disease and Associated Disorders. 2001; 15(1):10–20. [PubMed: 11236820]

Rizzo M, Nawrot M, Zihl J. Motion and shape perception in cerebral akinetopsia. Brain: A Journal of Neurology. 1995; 118:1105–1128. [PubMed: 7496774]

Rizzo M, Reinach S, McGehee D, Dawson J. Simulated car crashes and crash predictors in drivers with Alzheimer's disease. Archives of Neurology. 1997; 54:545–553. [PubMed: 9152111]

Runyan CW. Using the Haddon matrix: Introducing the third dimension. Injury Prevention. 1998; 4(4): 302–307. [PubMed: 9887425]

Shinar D, Schieber F. Visual requirements for safety and mobility of older drivers. Human Factors. 1991; 33:507–519. [PubMed: 1769671]

Sims RV, Owsley C, Allman RM, Ball K, Smoot TM. A preliminary assessment of the medical and functional factors associated with vehicle crashes by older adults. Journal of the American Geriatrics Society. 1998; 46:556–561. [PubMed: 9588367]

Sivak M. The information that drivers use: Is it indeed 90% visual? Perception. 1996; 25:1081–1089. [PubMed: 8983048]

Sivan, AB. Benton Visual Retention Test. 5th Ed.. San Antonio, TX: The Psychological Corporation; 1992.

Sloane ME, Ball K, Owsley C, Roenker DL, Bruni JR. The Driving Habits Questionnaire: An evaluation of the validity of self-reported driving habits. 1990 Unpublished raw data.

Stern RA, Singer EA, Duke LM, Singer NG, Morey CE, Daughtrey EW, et al. The Boston qualitative scoring system for the Rey-Osterrieth complex figure: Description and interrater reliability. The Clinical Neuropsychologist. 1994; 8:309–322.

Strauss, E.; Sherman, EMS.; Spreen, O. A compendium of neuropsychological tests: Administration, norms, and commentary. 3rd Ed.. New York: Oxford University Press; 2006.

Tinetti ME. Performance-oriented assessment of mobility problems in elderly patients. Journal of the American Geriatric Society. 1986; 34:119–126.

Trimpop R, Kirkcaldy B. Personality predictors of driving accidents. Personality and Individual Differences. 1997; 23:147–152.

Uc EY, Rizzo M, Anderson SW, Shi Q, Dawson JD. Driver identification of landmarks and traffic signs after a stroke. Transportation Research Record: Journal of the Transportation Research Board. 2005; 1922:9–14.

Uc EY, Rizzo M, Anderson SW, Sparks J, Rodnitzky RL, Dawson JD. Driving with distraction in Parkinson’s Disease. Neurology. 2006; 67:1774–1780. [PubMed: 17130409]

Uc EY, Rizzo M, Johnson AM, Dastrup E, Anderson SW, Dawson JD. Road safety in drivers with Parkinson disease. Neurology. 2009; 73:2112–2119. [PubMed: 20018639]

Uc EY, Rizzo M, Johnson AM, Emerson JL, Liu D, Mills ED, et al. Real-life driving outcomes in Parkinson Disease. Neurology. 2011; 76:1894–1902. [PubMed: 21624988]

US Government Accountability Office. Older driver safety: Knowledge sharing should help states prepare for increase in older driver population. Washington, DC: GAO; 2007. http://www.gao.gov/new.items/d07413.pdf

Wechsler, D. WAIS-R Manual. New York, NY: Psychological Corporation; 1981.

Wickens, CD., editor. Engineering, Psychology and Human Performance. 2nd ed.. New York: Harper Collins; 1992. p. 412-444.

Windsor TD, Anstey KJ. Interventions to reduce the adverse psychosocial impact of driving cessation on older adults. Clinical Interventions in Aging. 2006; 1:205–211. [PubMed: 18046872]

Yesavage JA, Brink TL, Rose TL, Lum O, Huang V, Adey M, et al. Development and validation of a Geriatric Depression Screening Scale: A preliminary report. Journal of Psychiatric Research. 1982–1983; 17:37–49.

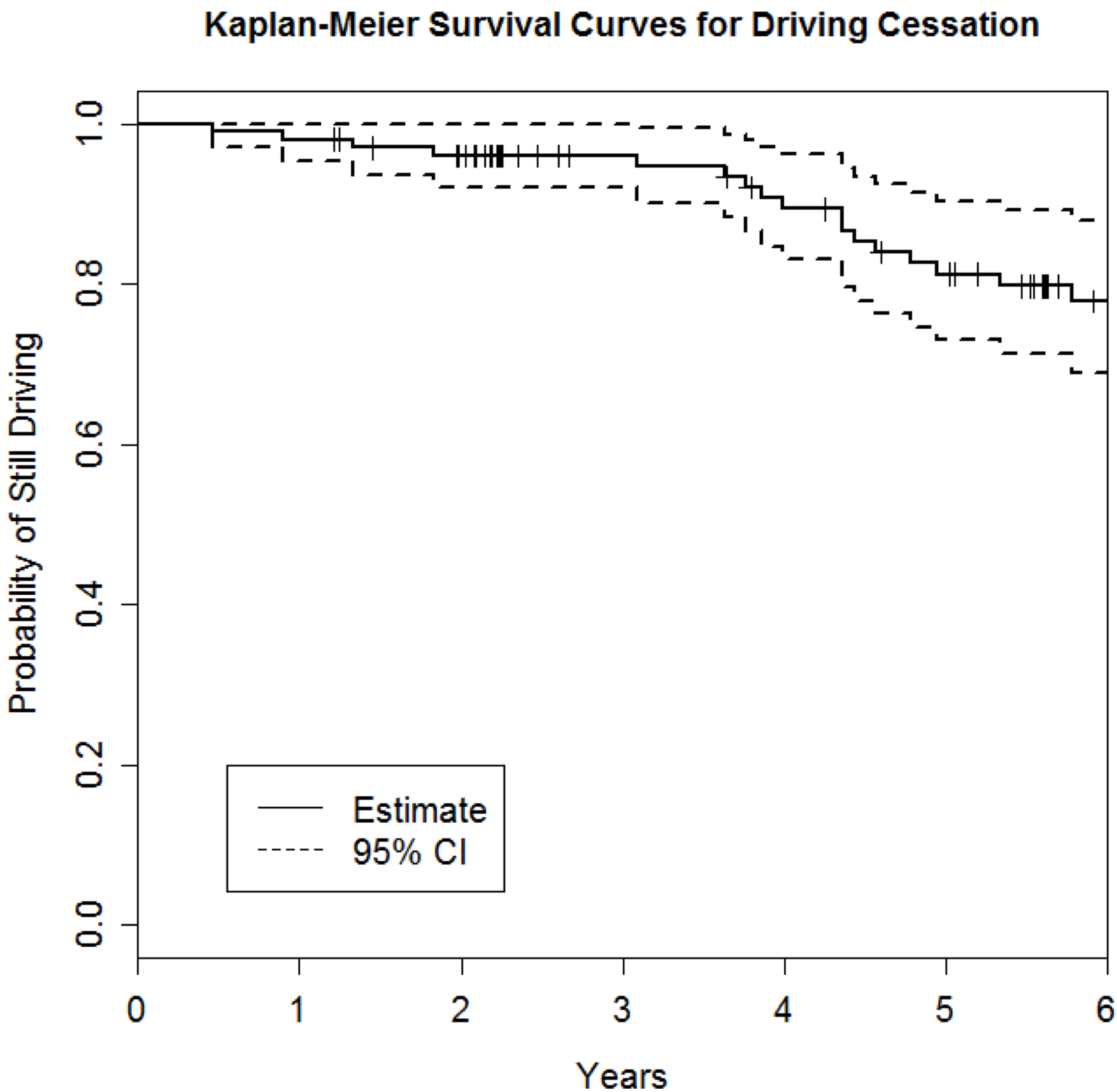

Figure 1.
Kaplan-Meier Survival Curves for Stopped Driving. Kaplan-Meier curves showing the probability of older drivers still driving at 0 to 6 years of follow-up.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Table 1

Mean and Standard Deviation for Driving Outcome Predictor Variables

Predictor variables	N	Mean ± standard deviation	Median	Range
Demographics				
Age	100	72.7 ± 5.0	72.5	65.3–89.0
Education	100	15.6 ± 2.6	16.0	8.0–20.0
Driving characteristics				
Miles per week	100	156 ± 193	100	14–1500
Number of crashes in past 2 yrs	99	0.51 ± 0.72	0.0	0.0–3.0
Number of times pulled over in past 2 yrs	98	0.22 ± 0.58	0.0	0.0–3.0
Exposure reduction score (range 0–8)	99	0.18 ± 0.50	0.0	0.0–3.0
Intentional avoidance score (range 0–8)	99	0.17 ± 0.59	0.0	0.0–3.0
Depression				
GDS	95	3.0 ± 3.6	2.0	0.0–21.0
Motor				
Get-up and Go (≥0 seconds)	93	9.1 ± 2.7	8.7	4.3–19.0
Balance: FR (≥0 inches)	93	12.9 ± 2.5	13.0	6.3–19.5
Pegs (≥0 seconds)	98	93.0 ± 18.9	87.9	62.1–154.8
Basic vision				
NVA (unbounded)	99	0.03 ± 0.04	0.00	0.00–0.20
FVA (unbounded)	98	−0.05 ± 0.11	−0.06	−0.26–0.24
CS (range 0–2.25)	98	1.80 ± 0.15	1.80	1.35–1.95
Visual perception				
Spatial: JLO (range 0–30)	96	25.0 ± 4.3	26.0	13.0–30.0
Motion: SFM (range 5–30)	94	10.3 ± 2.6	10.1	5.0–15.3
Speed of Processing for Visual Attention: UFOV (range 64–2,000)	100	725 ± 209	709	255–1370
Visual cognition				
Construction: Blocks (range 0–68)	96	37.8 ± 9.4	38.5	12.0–56.0
Construction: CFT-Copy (range 0–36)	99	31.7 ± 4.2	33.0	9.5–36.0
Memory: CFT-Recall (range 0–36)	98	15.2 ± 5.2	14.8	4.0–28.0
Memory: BVRT (range 0–24)	97	4.9 ± 2.5	5.0	0.0–13.0
Verbal Memory				
AVLT-Recall (0–15 words)	99	9.3 ± 3.1	9.0	1.0–15.0
Executive function				
Set shifting: TMT A (≥0 seconds)	98	37.5 ± 12.8	34.3	20.2–91.8
Set shifting: TMT B (≥0 seconds)	99	89.1 ± 43.7	74.8	34.0–331.6
Set shifting: TMT (B-A)	98	51.9 ± 36.7	39.9	6.5–271.4
Fluency: COWA (≥0 words)	100	37.2 ± 10.9	38.5	9.0–66.0

Predictor variables	**N**	**Mean ± standard deviation**	**Median**	**Range**
General cognition				
COGSTAT (unbounded)	97	395 ± 50	404	167–476
Road safety errors year 1				
Overall errors	83	35.4 ± 12.9	33.0	12.0–73.0
Serious errors	83	2.07 ± 1.67	2.0	0.0–8.0

Note. GDS = Geriatric Depression Scale; FR = Functional Reach; Pegs = Grooved Pegboard Test; NVA = near visual acuity; FVA = far visual acuity; CS = contrast sensitivity; JLO = Judgment of Line Orientation; SFM = Structure from Motion; UFOV = Useful Field of View; Blocks = WAIS–III Block Design; CFT-Copy = Complex Figure Test-Copy; CFT-Recall = Complex Figure Test-Recall; BVRT = Benton Visual Retention Test; AVLT-Recall = Auditory-Learning Verbal Test-Recall; TMT A = Trail Making Test-Part A; TMT B = Trail Making Test-Part B; COWA = Controlled Oral Word Association.

Table 2

Hazard Ratios for Driving Outcomes for a 1 SD Increase in Visual, Motor, and Cognitive Predictors. All results are adjusted for age, gender, education, and baseline mileage driven per week.

Predictor variables	**Driving cessation (95% CI)**	**Moving violations (95% CI)**	**Crashes (95% CI)**
	n = 100	**n = 98**	**n = 98**
Demographics and mileage (adjustment variables)			
Age	1.83 (1.12–2.99) *	0.93 (0.52–1.65)	1.20 (0.77–1.85)
Gender (male)	1.21 (0.47–3.10)	0.55 (0.24–1.26)	0.86 (0.42–1.76)
Education	0.95 (0.81–1.13)	1.26 (1.07–1.49) †	1.09 (0.95–1.25)
Miles per week (per 100mi)	1.13 (0.99–1.30)	1.44 (1.22–1.71) ‡	1.06 (0.91–1.22)
Driving characteristics			
Number of crashes in past year	1.02 (0.59–1.77)	1.49 (0.95–2.34)	1.06 (0.44–2.55)
Number of times pulled over in past year	0.96 (0.50–1.82)	0.68 (0.29–1.60)	1.05 (0.27–4.07)
Exposure reduction score	0.70 (0.25–1.94)	0.74 (0.31–1.75)	0.50 (0.09–2.81)
Intentional avoidance score	1.16 (0.62–2.17)	0.66 (0.29–1.53)	0.99 (0.36–2.73)
Depression			
GDS	1.41 (0.92–2.16)	0.82 (0.49–1.39)	1.02 (0.69–1.51)
Motor			
Get-up and Go	1.29 (0.88–1.90)	1.01 (0.66–1.53)	1.29 (0.96–1.72)
Balance: FR	0.86 (0.51–1.45)	0.90 (0.57–1.42)	0.83 (0.57–1.19)
Pegs	1.69 (1.03–2.77) *	1.04 (0.65–1.66)	1.24 (0.85–1.79)
Basic vision			
NVA	1.44 (1.01–2.05) *	0.70 (0.42–1.17)	1.17 (0.85–1.59)
FVA	1.01 (0.61–1.68)	0.88 (0.58–1.36)	0.95 (0.64–1.40)
CS	0.61 (0.41–0.91) *	1.03 (0.67–1.59)	1.19 (0.82–1.71)
Visual perception			
Spatial: JLO	0.60 (0.37–1.00) *	1.49 (0.86–2.59)	1.43 (0.94–2.17)
Motion: SFM	1.19 (0.72–1.95)	1.02 (0.68–1.52)	0.88 (0.60–1.29)
Speed of Processing for Visual Attention: UFOV	1.60 (1.03–2.48) *	0.87 (0.54–1.40)	0.96 (0.65–1.42)
Visual cognition			
Construction: Blocks	0.70 (0.38–1.29)	1.09 (0.67–1.78)	1.00 (0.68–1.47)
Construction: CFT-Copy	0.72 (0.48–1.07)	0.95 (0.61–1.46)	1.01 (0.70–1.46)
Memory: CFT-Recall	0.75 (0.48–1.18)	1.14 (0.74–1.77)	0.92 (0.64–1.33)
Memory: BVRT	1.75 (1.13–2.70) *	0.90 (0.59–1.36)	0.92 (0.66–1.29)
Verbal Memory			
AVLT-Recall	0.72 (0.43–1.22)	1.44 (0.91–2.26)	1.25 (0.86–1.81)

Predictor variables	**Driving cessation (95% CI)**	**Moving violations (95% CI)**	**Crashes (95% CI)**
	n = 100	**n = 98**	**n = 98**
Executive function			
Set shifting: TMT (B-A)	1.28 (0.89–1.83)	0.63 (0.34–1.16)	1.37 (1.05–1.80) *
Set shifting: TMT A	1.69 (1.09–2.63) *	0.92 (0.58–1.48)	1.31 (0.92–1.88)
Set shifting: TMT B	1.36 (0.96–1.93)	0.66 (0.37–1.16)	1.40 (1.06–1.84) *
Fluency: COWA	0.76 (0.45–1.26)	1.00 (0.64–1.57)	1.01 (0.68–1.50)
General cognition			
COGSTAT	0.56 (0.37–0.85) †	1.46 (0.82–2.58)	1.06 (0.72–1.56)
Road safety errors year 1			
Overall errors	1.22 (0.71–2.12)	1.13 (0.69–1.85)	1.13 (0.77–1.67)
Serious errors	1.15 (0.69–1.92)	1.67 (1.00–2.78) *	1.45 (1.03–2.05) *

* $P < 0.05$,

† $P < 0.01$,

‡ $P < 0.001$.

Note. GDS = Geriatric Depression Scale; FR = Functional Reach; Pegs = Grooved Pegboard Test; NVA = near visual acuity; FVA = far visual acuity; CS = contrast sensitivity; JLO = Judgment of Line Orientation; SFM = Structure from Motion; UFOV = Useful Field of View; Blocks = WAIS–III Block Design; CFT-Copy = Complex Figure Test-Copy; CFT-Recall = Complex Figure Test-Recall; BVRT = Benton Visual Retention Test; AVLT-Recall = Auditory-Learning Verbal Test-Recall; TMT A = Trail Making Test-Part A; TMT B = Trail Making Test-Part B; COWA = Controlled Oral Word Association.

Table 3

Regression Models Predicting Time to Driving Cessation, Moving Violation, or Crash from Increases in Predictor Variables

Outcome	Variable	Estimate	Standard error	χ^2	Hazard ratios (95% CI)
Driving cessation	Age	0.50	0.27	3.57	1.65 (0.98–2.78)
	CS	−0.43	0.18	5.61	0.65 (0.46–0.93)
Moving violation	Education	0.21	0.09	5.77	1.24 (1.04–1.47)
	Miles per week	0.35	0.08	18.0	1.42 (1.21–1.66)
	AVLT-Recall	0.39	0.22	3.23	1.48 (0.97–2.28)
Crash	Education	0.15	0.08	3.69	1.16 (1.00–1.35)
	# Crashes over the past yr	0.46	0.23	3.84	1.58 (1.00–2.49)
	AVLT-Recall	0.11	0.06	2.70	1.11 (0.98–1.26)
	TMT (B-A)	0.47	0.14	10.81	1.59 (1.21–2.10)

Note. CS = contrast sensitivity; AVLT-Recall = Auditory-Learning Verbal Test-Recall; TMT A = Trail Making Test-Part A; TMT B = Trail Making Test-Part B.