Longitudinal Predictors of Driving Cessation
Among Older Adults From the ACTIVE Clinical Trial

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We examined the physical, visual, health, and cognitive abilities of 1,656 older adults as prospective predictors of self-reported driving cessation over a 5-year period. We examined the time to driving cessation across 5 years after we controlled for days driven per week at baseline and any cognitive intervention participation. Older age, congestive heart failure, and poorer physical performance (according to the Turn 360 Test) were statistically significant risk factors for driving cessation. Slower speed of processing (according to the Digit Symbol Substitution and Useful Field of View tests) was a significant risk factor even after we took baseline driving, age, health, vision, and physical performance into consideration. Implications are that assessments of cognitive speed of processing can provide valuable information about the subsequent risk of driving cessation.

Key Words: Driving cessation— Speed of processing—Cognition—Older driver—Vision.

FEW could argue with the statement that mobility is essential to healthy aging. An important index of mobility in our society is driving. Because most older adults in the United States primarily rely upon the personal automobile for maintaining mobility (Jette & Branch, 1992), the impact of driving cessation for older Americans may be detrimental. Driving restrictions, driving cessation in particular, threaten older adults’ independence and lead to adverse consequences such as decreased activity, increased dependency, and increased depression, even when alternative transportation is available (Fonda, Wallace, & Herzog, 2001; Marottoli et al., 1997, 2000). Furthermore, even after adjustments for health, researchers have found that older adults who cease driving are at higher risk of entry into long-term-care facilities (Freeman, Gange, Munoz, & West, 2006).

Even so, to our knowledge there are only a few longitudinal studies of driving cessation (Anstey, Windsor, Luszcz, & Andrews, 2006; Jette & Branch, 1992; Marottoli et al., 1993). Only Anstey and colleagues examined the role of cognitive performance in driving cessation. Our purpose in this study was to prospectively evaluate and compare demographic variables, vision, physical performance, health conditions, and cognitive performance as predictors of driving cessation among a contemporary cohort of older drivers in the United States.

Driving-Cessation Risk Factors

Several demographic factors have been associated with an increased likelihood of driving cessation. For example, older age, less education, and lower income have been cross-sectionally and longitudinally identified as risk factors for driving cessation and decreased driving exposure (Campbell, Bush, & Hale, 1993; Dellinger, Sehgal, Sleet, & Barrett-Connor, 2001; Jette & Branch, 1992; Marottoli et al., 1993; O’Neill, Bruce, Kirby, & Lawlor, 2000). Female gender may also be a risk factor (Jette & Branch), although such findings are not consistent in the literature (Dellinger et al.; Hakamies-Blomqvist & Siren, 2003).

It is commonly assumed that individuals stop driving as a result of their health or physical condition, and cross-sectional research has confirmed this association. For example, individuals who have ceased driving have a higher number of medical conditions and poorer self-ratings of health (Campbell et al., 1993; Forrest, Bunker, Songer, Coben, & Cauley, 1997; Hakamies-Blomqvist & Siren, 2003; Jette & Branch, 1992; Marottoli et al., 1993). Studies have indicated that individuals who have ceased driving are more likely to report physical performance difficulties (Campbell et al.; Jette & Branch; Marottoli et al.). In a longitudinal investigation, Anstey and colleagues (2006) found that self-rated health and cognitive function were better predictors of driving cessation than were either reported medical conditions or physical performance.

Another widely held belief is that vision problems primarily lead to driving cessation among older adults. Accordingly, several studies have found a cross-sectional association (Ragland, Satariano, & MacLeod, 2004) as well as a longitudinal association (Freeman, Munoz, Turano, & West, 2005; Marottoli et al., 1993) between vision and driving cessation. Interestingly, West and colleagues (2003) found that older individuals self-restricted their driving as a result of vision problems, but they did not regulate their driving for cognitive impairment as measured by visual attention.

Of primary interest to us in this study were the following questions: What specific cognitive performance domains predict driving cessation? How does the predictor of cognitive...
Driving cessation. — We used the Mobility Questionnaire (Ball et al., 1998; Owsley, Stalvey, Wells, & Sloane, 1999; Stalvey, Owsley, Sloane, & Ball, 1999) to ascertain whether or not the participant was a current driver, which was defined as someone who has driven a car within the past 12 months and who could drive a car today if necessary.

Depression. — The short form of the Center for Epidemiologic Studies–Depression scale (Radloff, 1977) is a self-administered instrument of 12 questions assessing the frequency of depressive symptoms, such as loneliness and restlessness, experienced over the past week. Participants are instructed to rate the frequency with which they have experienced that symptom during the past week. Higher scores reflect more depressive symptoms.

Health and physical functioning. — Participants indicated whether a doctor or nurse had ever told them that they had the following: osteoporosis; asthma, chronic bronchitis, or emphysema; cataracts; glaucoma; macular degeneration; diabetic retinopathy or diabetic eye disease; angina or chest pain that was due to heart disease; congestive heart failure; stroke, ministroke, or transient ischemic attack; hypertension or high blood pressure; or high cholesterol.

We also used the SF-36 Questionnaire to assess health and physical functioning (Ware & Sherbourne, 1992). We used three of the eight subscales in our analyses: physical functioning, physical role, and general health. We chose these subscales to best represent the domains of physical functioning and general ratings of health, which have been implicated by prior research as predictors of cessation. Each subscale ranges from 0 to 100, with higher scores reflecting better health and function.

We assessed balance by using the Turn 360 Test (Steinhagen-Thiessen & Borchelt, 1999). Researchers asked participants to stand and turn in one complete circle. We counted the number of steps required to make one complete turn, with fewer steps indicating better balance. We used the average number of steps taken across both attempts in our analyses.

Vision. — We used a standard early treatment of diabetic retinopathy study, or ETDRS, chart to measure far visual acuity. We assigned scores from 0 to 90 on the basis of how many letters were correctly discriminated (a score of 0 is equivalent to a Snellen score of 20/125; a score of 90 is equivalent to a Snellen score of 20/16).

Cognition. — Cognitive measures included the domains of speed of processing, reasoning, and memory. We assessed mental status with the Mini-Mental State Examination (MMSE), which has been used to screen for dementia (Folstein, Folstein, & McHugh, 1975). Scores on the MMSE measure range from 0 to 30, with higher scores representing better cognitive function. We included only those individuals with a score of 23 or better in our study.

We assessed cognitive speed of visual processing by using the PC, touch, four-subtest version of the UFOV Test, or Useful Field of View Test, with standard procedures (Edwards, Vance et al., 2005). This test includes four progressively more difficult subtests in which the display-duration threshold value for 75% correct performance is measured by means of a double-staircase method varying between 16.67 and 500 ms.

We also used the Digit Symbol Substitution test from the revised Wechsler Adult Intelligence Scale to assess speed of processing (Wechsler, 1987). A key of nine symbols, each associated with a number between 1 and 9, is presented. For 90 seconds, participants fill in a grid of empty squares by pairing the number appearing above each square with its associated symbol from the key. In our analyses, we used the number of correct substitutions made.

Memory measures included the Hopkins Verbal Learning Test (HVLT; Brandt, 1991), the Rey Auditory Verbal Learning test (AVLT), and the Rivermead Behavioral Memory test. The HVLT involves a list of 12 words from four semantically
related groups that are read by the tester. After the tester reads the words, he or she immediately asks the participants to recall as many words as possible. Three recall trials are given, after which the tester asks the participants to identify words from the original list from among both semantically related and unrelated words. This recognition trial is scored by use of a discrimination index, which is created by subtracting the number of false positives from the number of true positives. We used the discrimination index in our analyses.

In the AVLT (Jobe et al., 2001; Rey, 1941), participants listen to and attempt to remember 15 words read from an audiotape. They have up to 3 minutes to write down as many of the words as possible. A tester then replays the list and instructs the participants to again write down as many words as possible. This process is repeated five times; we used the total number of correct words in our analyses.

We assessed prose memory by using the Stories subtest of the Rivermead Behavioral Memory test (Wilson, Cockburn, & Baddeley, 1985). Participants are read a short story and asked to write down as much of the story as possible within 2 minutes. Scores range from 0 to 21, with higher scores indicating better performance.

We included three measures of inductive reasoning. The Letter Series task assesses participants’ abilities to determine patterns among series of 10 to 15 letters (Thurstone & Thurstone, 1949). After practice, participants are presented with a row of letters that exhibit a distinct pattern. They must then determine which letter would come next in the pattern from a list of five possible answers. Participants are given up to 6 minutes to answer 30 items. Higher total scores indicate better performance.

The Word Series task (Gonda & Schaie, 1985) is similar to the Letter Series task and assesses participants’ abilities to decipher a distinctive pattern among a series of words. After practice, participants are presented with 30 series of words, ranging from 10 to 15 words per series. They are given 6 minutes to decipher the patterns and choose the correct answer from five given possibilities. Higher scores indicate better performance.

For the Letter Sets task, participants are presented with 15 rows of five sets of letters (four letters within each set; see Ekstrom, French, Harman, and Derman, 1976). After practice, participants are instructed to choose the set of letters within each row that does not fit the same pattern as the others. Higher scores indicate better performance.

### Procedure

A primary objective of the ACTIVE study protocol was to examine driving outcomes in relation to cognitive training (Jobe et al., 2001). Procedures of the ACTIVE study are detailed elsewhere (Ball et al., 2002; Jobe et al.). At the baseline visits ($N = 2,802$), researchers assessed vision, hearing, and mental status, and they administered the Mobility Questionnaire. The baseline visits also included a more extensive battery of cognitive performance tests (speed of processing, memory, and reasoning) and physical performance tests, as well as extensive health and medication questionnaires. Researchers randomized the participants to receive either memory, reasoning, or speed of processing training or to participate in a no-contact control condition. The researchers conducted these analyses in order to examine predictors of driving cessation; thus they statistically controlled for participation in cognitive training before they evaluated the risk factors. This covariate was coded as participation in one or more training sessions of any type in comparison with no training participation.

### Statistical Analyses

On the basis of the literature reviewed, we selected variables from the ACTIVE data set from the four domains potentially impacting driving cessation, that is, demographics, physical performance and health, vision, and cognition, for inclusion in our analyses. We used Cox regression analyses to assess the probability that an individual would cease driving across a 5-year period as a function of the predictors (after we controlled for baseline driving and training participation). The resulting hazard ratios represent the risk for cessation associated with an increase of 1 SD in the predictor, all other explanatory variables remaining constant. Hazard ratios smaller than 1 indicate a protective effect against cessation associated with an increase in the predictor, whereas those greater than 1 indicate greater risk for cessation associated with an increase in the predictor (or as compared with the reference group for categorical predictors). Persons who were still driving at the 5-year follow-up assessment were right-censored, in terms of the timing of the event. For persons who did not remain drivers, we used the point at which driving ceased in terms of months after baseline to time the event. We first selected possible demographic, physical, health, visual, and cognitive predictor variables on the basis of significant correlation to time to cessation. Next, to identify the strongest independent predictors of time to driving cessation within each domain, we explored four separate models including predictors from each domain of interest. We subsequently included significant predictors from each of these domains in a final model.

### RESULTS

In order to reduce the number of predictor variables in the regression models, we first examined Spearman correlations among time to cease driving and demographic, vision, health, and cognitive variables. These analyses indicated that, with regard to demographic variables, being of younger age, being married, not living alone, and being of male gender were associated with longer times to driving cessation ($ps < .05$; see Table 1). With regard to sensory abilities and eye disease, having better visual acuity and not having glaucoma or macular degeneration were associated with longer times to driving cessation ($ps < .05$). When considering physical performance and health conditions, we found that no report of stroke or congestive heart failure, better self-ratings of health, higher SF-36 rating of physical function, and better Turn 360 Test performance were associated with longer times to driving cessation ($ps < .05$). Better cognitive performance as indicated by performance on the UFOV, Digit Symbol Substitution, Letter Sets, Letter Series, Word Series, HVLT, AVLT, and Rivermead Behavioral Memory tests was also associated with longer time to driving cessation ($ps < .05$). Thus, we chose these demographic, visual, health, physical, and cognitive variables for inclusion in our Cox regression analyses. Education; the presence of depression, cataracts, diabetic retinopathy, heart disease, or hypertension; MMSE score; and Road Sign Test performance were not correlated to time to driving cessation, so we did not explore them further.
We converted continuous data to z-scores and we conducted four Cox regression models by using the enter method, such that all variables were entered into the model simultaneously, to first identify significant predictors of time to driving cessation within each domain of (a) demographic indicators, (b) sensory measures, (c) health and physical functioning variables, and (d) cognitive performance (after we controlled for baseline driving and intervention participation). We first adjusted all models for baseline days driven per week and participation in training. For all models, driving fewer days per week at baseline was a significant risk factor for driving cessation (p < .001). Results of these four models are presented in Table 2.

Only older age was identified as a significant demographic risk factor for driving cessation across 5 years. On one hand, better visual acuity at baseline was protective against driving cessation, as was physical functioning per the SF-36. On the other hand, self-report of congestive heart failure indicated an increased risk for driving cessation. Those participants who performed more poorly on the Turn 360 Test were at greater risk for driving cessation. With regard to cognitive performance, individuals with poor UFOV performance were at greater risk for driving cessation, whereas those with better Digit Symbol Substitution or AVLT performance were less likely to cease driving over time.

We used the results of these regression analyses to examine risk for driving cessation in a final multivariate model simultaneously examining significant demographic, health, physical function, vision, and cognitive risk factors. We examined time to driving cessation at 5 years after we controlled for days driven per week at baseline and any type of intervention participation. We used the enter method. We entered age on the second step; we entered visual acuity, report of congestive heart failure, and physical functioning (Turn 360, SF-36 physical functioning) on the third step; and we entered cognitive speed of processing (UFOV, Digit Symbol Substitution) and memory (AVLT) on the final step. Results of the final model are presented in Table 3. Analyses indicated that, after we controlled for days driven per week at baseline as well as training participation, significant risk factors for driving cessation included older age (hazard ratio or HR = 1.09), congestive heart failure (HR = 1.83), and poor balance as indicated by the Turn 360 Test (HR = 1.23). Better baseline rating of physical functioning (SF-36) was protective against driving cessation (HR = 0.78). Even after considering age, vision, and health, we found that cognitive speed of processing emerged as a significant indicator of risk for driving cessation. Individuals with poor UFOV performance were at greater risk for driving cessation (HR = 1.18), whereas those with better Digit Symbol Substitution performance were less likely to cease driving over the 5-year period (HR = 0.80).

### Discussion

In the present study we examined risk factors for driving cessation over a 5-year period among older adults. After considering baseline driving and controlling for participation in
Table 2. Cox Regression Models Examining Risk Factors for Driving Cessation

<table>
<thead>
<tr>
<th>Model</th>
<th>HR</th>
<th>95% CI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Demographics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marital status (reference)</td>
<td>1.56</td>
<td>0.97–2.49</td>
<td>.063</td>
</tr>
<tr>
<td>Living arrangements (reference)</td>
<td>1.21</td>
<td>0.80–1.82</td>
<td>.356</td>
</tr>
<tr>
<td>Gender (male reference)</td>
<td>0.94</td>
<td>0.64–1.39</td>
<td>.785</td>
</tr>
<tr>
<td>2. Physical Function and Health</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-rated health</td>
<td>1.12</td>
<td>0.95–1.31</td>
<td>.165</td>
</tr>
<tr>
<td>SF-36 physical functioning</td>
<td>0.756</td>
<td>0.64–0.88</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Turn 360 Test</td>
<td>1.45</td>
<td>1.30–1.61</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>CHF</td>
<td>1.93</td>
<td>1.14–3.27</td>
<td>.014</td>
</tr>
<tr>
<td>Stroke</td>
<td>0.96</td>
<td>0.59–1.57</td>
<td>.883</td>
</tr>
<tr>
<td>3. Vision</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual acuity</td>
<td>0.69</td>
<td>0.61–0.78</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Glaucoma</td>
<td>1.47</td>
<td>0.98–2.19</td>
<td>.060</td>
</tr>
<tr>
<td>Macular degeneration</td>
<td>1.46</td>
<td>0.91–2.36</td>
<td>.120</td>
</tr>
<tr>
<td>4. Cognition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVLT</td>
<td>0.83</td>
<td>0.69–0.99</td>
<td>.046</td>
</tr>
<tr>
<td>HVLT</td>
<td>0.94</td>
<td>0.79–1.13</td>
<td>.548</td>
</tr>
<tr>
<td>Rivermead</td>
<td>0.90</td>
<td>0.78–1.03</td>
<td>.152</td>
</tr>
<tr>
<td>UFOV Test</td>
<td>1.50</td>
<td>1.28–1.75</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>DSS Test</td>
<td>0.81</td>
<td>0.67–0.98</td>
<td>.031</td>
</tr>
<tr>
<td>Letter series</td>
<td>0.92</td>
<td>0.69–1.24</td>
<td>.620</td>
</tr>
<tr>
<td>Letter sets</td>
<td>1.00</td>
<td>0.82–1.22</td>
<td>.991</td>
</tr>
<tr>
<td>Word series</td>
<td>1.09</td>
<td>0.81–1.45</td>
<td>.556</td>
</tr>
</tbody>
</table>

Notes: HR = hazard ratio; 95% CI = 95% confidence interval; CHF = congestive heart failure; AVLT = Auditory Verbal Learning Test; HVLT = Hopkins Verbal Learning Test; Rivermead = Rivermead Behavioral Memory Test; UFOV = Useful Field of View; DSS = Digit Symbol Substitution.

Models are adjusted for baseline driving and intervention participation (one or more training session of any kind vs none).

For the Turn 360 and UFOV tests, smaller scores reflect better performance.

Table 3. Final Multivariate Model of Risk Factors for Driving Cessation

<table>
<thead>
<tr>
<th>Variable</th>
<th>HR</th>
<th>95% CI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training participation</td>
<td>1.108</td>
<td>0.740–1.399</td>
<td>.914</td>
</tr>
<tr>
<td>Days driven per week at baseline</td>
<td>0.731</td>
<td>0.680–0.787</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Age</td>
<td>1.088</td>
<td>1.056–1.122</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>SF-36 physical functioning</td>
<td>0.777</td>
<td>0.674–0.895</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Turn 360 Test</td>
<td>1.230</td>
<td>1.102–1.372</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>1.827</td>
<td>1.083–3.083</td>
<td>.024</td>
</tr>
<tr>
<td>Visual acuity</td>
<td>0.910</td>
<td>0.791–1.046</td>
<td>.184</td>
</tr>
<tr>
<td>AVLT</td>
<td>0.911</td>
<td>0.777–1.068</td>
<td>.251</td>
</tr>
<tr>
<td>UFOV Test</td>
<td>1.178</td>
<td>1.00–1.389</td>
<td>.050</td>
</tr>
<tr>
<td>DSS Test</td>
<td>0.798</td>
<td>0.667–0.954</td>
<td>.013</td>
</tr>
</tbody>
</table>

Notes: HR = hazard ratio; 95% CI = 95% confidence interval; AVLT = Auditory Verbal Learning Test; UFOV = Useful Field of View; DSS = Digit Symbol Substitution.

For the Turn 360 and UFOV tests, smaller scores reflect better performance.

After we considered baseline driving. Several cross-sectional studies have indicated that women are more likely than men to cease driving (e.g., Vance et al., 2006). Overall, prior research and these results indicate that although older women from contemporary cohorts drive less at baseline, they may not be more likely to cease driving across time. However, we must be cautious about overinterpreting the conflicting cross-sectional and longitudinal research, as both designs contain specific methodological biases that may make direct evaluation of cross-sectional as compared with longitudinal predictors difficult (Anstey, 2002; Hofer, Sliwinski, & Flaherty, 2002).

There has been some debate concerning whether older adults with cognitive impairment self-regulate their driving, and thereby remain safe (Man-Son-Hing, Marshall, Molnar, & Wilson, 2007), or continue to drive despite impairments (Freund & Szinovacz, 2002; West et al., 2003), possibly as a result of lack of awareness (Owsley, Ball et al., 1998). These results indicate that, over time, older individuals may self-regulate their driving when they experience reduced speed of processing. However, this may not be the case when severe cognitive decline impairs judgment, as in dementia. This concept deserves further investigation, as the relationship between cognitive impairment and regulation of driving may not be linear. Although older adults and their loved ones may notice impairments in visual function and physical performance, declines in cognitive speed of processing may be less noticeable (Baldock, Mathias, McLean, & Berndt, 2006; Owsley, Ball et al.). Thus, it is even more important for researchers to include performance-based cognitive along with physical assessments when they are evaluating older adults.

The performance-based measures in this study associated with driving cessation have several benefits. Benefits of using the Turn 360 task is that it requires no equipment and can be used to quickly and easily assess balance in any setting. The Digit Symbol Substitution test is relatively inexpensive, does not require the use of technology, and can be administered in just a few minutes. Benefits of the UFOV Test include that performance is related to several indices of driving (Clay et al., 2005), such as prospective crash risk (Ball et al., 2006; Owsley, Ball et al., 1998), injurious crash risk (Owsley, McGwin, & Ball, 1998), simulated driving (i.e., Hoffman, McDowd, Atchley, & Dubinsky, 2005), and on-road driving performance (i.e., Roenker, Cissell, Ball, Wadley, & Edwards, 2003).
Considering that performance on UFOV Subtest 2 alone is indicative of crash risk (Ball et al.), post hoc analyses confirmed that UFOV Subtest 2, which can be administered in 5 to 8 minutes, alone is indicative of driving cessation risk (HR = 1.00, p < .001).

Considering the cognitive and physical predictors of driving cessation identified in these analyses, we find that interventions that enhance speed of processing (Edwards, Wadley, Vance, Roenker, & Ball, 2005; Roenker et al., 2003; Willis et al., 2006) or that improve balance, such as Tai Chi (Li et al., 2005; Motivala, Sollers, Thayer, & Irwin, 2006; Wolf et al., 2003), may be implemented for the purpose of delaying or avoiding driving cessation.

There are a few limitations to the current analyses. First, the ACTIVE sample is not population based and at baseline represented a healthy group of older adults who were intact in terms of cognitive, sensory, and functional abilities. Similar analyses in a more impaired sample may yield differing results. Second, many of the health and physical measures included in our analyses, which were not significant risk factors for driving cessation, relied upon self-report. Physical and health conditions may be more informative of driving cessation risk when assessed differently. Some measures of executive function, most commonly the Trail Making Test, have been associated with driving outcomes, but they were not included here. Further research should evaluate the role of executive functioning in driving cessation.

Further research is necessary to clarify the longitudinal relationships among health and driving status. Although many studies have highlighted the negative outcomes associated with driving cessation (i.e., Freeman et al., 2006; Marottoli et al., 1997, 2000), it is not certain, although possible, that ceasing driving in and of itself leads to further physical, health, and cognitive declines.

The present results confirm that reduced cognitive speed of processing is associated with an increased risk for driving cessation. Assessment of cognitive speed of processing is quick, reliable, and correlated with older adults’ abilities to perform a variety of instrumental activities of daily living (i.e., Owsley & McGwin Jr., 2004; Owsley et al., 1999; Riolo, 2003; Sims, McGwin, Pulley, & Roseman, 2001; Stalvey et al., 1999; Staplin, Gish, & Wagner, 2003). Assessments of cognitive functioning and physical performance should be considered when one is examining older adults’ risk for functional impairments.

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REFERENCES


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