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Research Article

Neuropsychological Correlates of Changes in Driving Behavior Among Clinically Healthy Older Adults

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Abstract

Objectives: To determine the extent to which cognitive domain scores moderate change in driving behavior in cognitively healthy older adults using naturalistic (Global Positioning System-based) driving outcomes and to compare against self-reported outcomes using an established driving questionnaire.

Methods: We analyzed longitudinal naturalistic driving behavior from a sample (N = 161, 45% female, mean age = 74.7 years, mean education = 16.5 years) of cognitively healthy, nondemented older adults. Composite driving variables were formed that indexed "driving space" and "driving performance." All participants completed a baseline comprehensive cognitive assessment that measured multiple domains as well as an annual self-reported driving outcomes questionnaire.

Results: Across an average of 24 months of naturalistic driving, our results showed that attentional control, broadly defined as the ability to focus on relevant aspects of the environment and ignore distracting or competing information as measured behaviorally with tasks such as the Stroop color naming test, moderated change in driving space scores over time. Specifically, individuals with lower attentional control scores drove fewer trips per month, drove less at night, visited fewer unique locations, and drove in smaller spaces than those with higher attentional control scores. No cognitive domain predicted driving performance such as hard braking or sudden acceleration.

Discussion: Attentional control is a key moderator of change over time in driving space but not driving performance in older adults. We speculate on mechanisms that may relate attentional control ability to modifications of driving behaviors.

Keywords: Attentional control, Naturalistic driving, Self-regulation

Driving is a complex, functional behavior that relies on multiple sensory, motor, and cognitive processes. Moreover, the ability to drive is a crucial aspect of maintaining independent living and mobility within the community as one ages (Dickerson et al., 2019). However, older adult drivers are also at a higher risk of being involved in a fatal crash compared to younger adults (Cox & Cicchino, 2021), and for a variety of reasons, they may ultimately retire from driving due to health issues or other personal circumstances (Campbell et al., 1993; O'Neill et al., 2000). Although driving cessation removes the risk of vehicle crashes and fatalities, a number of negative social and health-related consequences (e.g., depression, isolation) may result (Edwards et al., 2009; Qin et al., 2020). Rather than ceasing to drive all together, some individuals may modify or regulate (either by choice or by external demands such as diminished cognitive capacity due to disease) their driving behavior, such as combining multiple trips into a single outing or avoiding driving at night (Naumann et al., 2011), to maintain some level of independence while avoiding high-risk driving situations. Nevertheless, a sizable portion of the older adult population report that they do not restrict or self-regulate their driving behaviors (Baldock et al., 2006; Gwyther & Holland, 2012; Molnar et al., 2013) and it is therefore critically important to identify factors that are associated with appropriate modifications of driving behavior among older drivers.

One possible factor that is associated with self-regulation of driving behavior is cognitive functioning. Longitudinal trajectories of cognitive ability are quite heterogeneous among older adults (Goh et al., 2012; Lindenberger, 2014), possibly due to the presence of presymptomatic neurodegenerative disease in a substantial portion of older adult samples (Harrington et al., 2021). Driving performance has been linked to visual processing, attention, and, occasionally, episodic memory (see Anstey et al., 2005; Mathias & Lucas, 2009 for reviews and meta-analysis); it is reasonable to assume that an older adult who has specific concerns regarding their cognitive health may be more likely to limit (self-regulate) their driving behavior to minimize risky driving situations. Indeed, a number of studies have found a relationship between attention or processing speed (most frequently the Useful Field of View [UFoV] test), and driving self-regulation measured via self-report (e.g., O'Connor et al., 2012; Okonkwo et al., 2008; Rapoport et al., 2013; Ross et al., 2009; Vance et al., 2006).

It is important to note that metrics of driving performance can be collected in a variety of ways, such as standardized road tests, driving simulators, or responses from self-report questionnaires. Although road tests and simulators provide an assessment of driving ability under very tightly controlled conditions, simulator fidelity and validity vary and likely do not reflect "real-world" driving habits or scenarios (Wynne et al., 2019). Moreover, driving simulators and road tests do not measure driving habits or self-regulation, which can be indexed with variables such as the number of trips taken over a certain time interval or the time of day at which an individual typically chooses to drive. Similarly, responses to self-reported items are susceptible to biases and further assume participants can accurately estimate their engagement with specific driving behaviors. Indeed, studies have shown that while older adult participants are relatively accurate at estimating some driving behaviors, they are relatively poor at estimating others (Blanchard et al., 2010; Molnar et al., 2018; Paire-Ficout et al., 2021).

Naturalistic driving assessments that utilize mobile sensors to track numerous driving outcomes from a driver's personal vehicle are commonly used (Babulal et al., 2019; Freed et al., 2021; Roe et al., 2019; Singh & Kathuria, 2021) and can overcome some of the limitations associated with traditional driving evaluations in research. Specific advantages include measuring individuals in their natural driving environments, the ability to measure behavior over shorter (days to weeks) and longer (months to years) timescales, and the elimination of concerns such as performance biases (e.g., rater subjectivity, Hawthorne effect) that may arise from self-report questionnaires. Several studies have capitalized on the advantages afforded by naturalistic driving assessments to understand how cognitive abilities are associated with driving performance. Broadly speaking, measures of attention and executive functioning/processing speed have been shown to correlate with risk of crashes (Antin et al., 2017; Huisingh et al., 2017), speeding events unadjusted for distance driven (Chevalier, Coxon, Rogers, et al., 2016), and lane change errors (Munro et al., 2010). Furthermore, a global cognitive composite that included measures of attention and executive function was related to differences in accelerating, braking, and steering behaviors (Merickel et al., 2019).

The goals of this study were twofold. First, we aimed to assess the association of cognitive ability to changes in naturalistic driving behavior across an average of 24 months of follow-up. We extend prior studies using naturalistic driving data with older adults in several important ways. First, the majority of past research has focused on adverse driving events (e.g., incidence of crashes or crash risk) and we also examine aspects of individuals' driving space (e.g., number of trips taken each month and number of locations visited) as a marker of driving self-regulation. Second, earlier studies have either been cross-sectional in nature (Chevalier, Coxon, Chevalier, et al., 2016; Munro et al., 2010), or a longitudinal study where time trends were not considered (i.e., driving events were averaged across the entire study period; Antin et al., 2017; Bayat et al., 2021; Chevalier, Coxon, Rogers, et al., 2016; Huisingh et al., 2017; Merickel et al., 2019). In the present study, we use multilevel modeling techniques to examine how baseline cognitive abilities predict monthly *change* in driving outcomes over a period of approximately 2 years.

The second primary goal of this study was to examine the influence of cognitive abilities on *self-reported* driving outcomes over a similar period as the naturalistic data. As reviewed above, we anticipated that measures of attentional control, the ability to direct attention toward important aspects of the environment and ignore distracting information, or processing speed, the relative speed at which mental operations are completed, would predict reductions in key behaviors in naturalistic driving and these moderations would be larger in naturalistic driving than in self-reported outcomes.

Method

Participants

Participants were recruited from ongoing longitudinal studies of memory and aging at the Knight Alzheimer Disease Research Center (ADRC) at Washington University in St. Louis. To be included in the present analysis, participants were required to have a cognitive and clinical assessment within 1 year of their enrollment in our longitudinal driving study, self-report driving at least once per week, be rated as cognitively normal (Clinical Dementia Rating [CDR] of 0, indicating no evidence of clinical, functional, or cognitive impairment) at that assessment, be at least 65 years of age, and have at least 12 months of driving data available. A total of 161 participants met these criteria (see Table 1 for a summary of the demographics of our cohort). In line with our previous studies, participants were 74.7 years of age on average, highly educated (mean years of education = 16.5, *SD* = 2.4), predominantly White (82% White, 17% Black/African American, and 1% more than one race), consisted roughly equally of men and women (45% female), and had average scores (mean = 25.9, *SD* = 2.6, range = 19–30) on the Montreal Cognitive Assessment within a similar range as published normative data (Nasreddine et al., 2005; Rossetti et al., 2011). The mean length of naturalistic driving data available on our participants was approximately 24 months (range = 12 months to 39 months). To ensure length of follow-up was not disproportionately unbalanced, we binned individuals into 6-month categories and tabulated the frequencies of occurrence. A total of 44 participants had between 12 and 18 months of follow-up, 53 had between 18 and 24 months, 38 had between 24 and 30 months, 7 participants had between 30 and 36 months, and 19 participants had more than 36 months of follow-up available. For the Driving Habits Questionnaire (DHQ), the average length of follow-up was 3.5 years (*SD* = 2.3, min = 0 years [i.e., 1 DHQ assessment only], max = 7.8 years).

Table 1. Demographics of the Cohort (*N* = 161) at the Baseline Assessment

Variable	Mean (*SD*)
Age	74.7 (5.0)
Education	16.5 (2.4)
N Females (%)	72 (45%)
N Race (%)	
Black/African American	28 (17%)
White	132 (82%)
More than one race	1 (1%)
Montreal Cognitive Assessment	25.9 (2.6)
Months of driving data	23.5 (7.5)

Based on inclusion/exclusion criteria, the current sample of participants is a subset of older adults who have enrolled in the Driving Real-World In-Vehicle Evaluation System (DRIVES) study. The DRIVES study is a prospective, longitudinal naturalistic driving study from our research group that was designed to investigate how naturalistic driving outcomes might serve as a marker of early-stage or preclinical Alzheimer disease (Babulal et al., 2019; Bayat et al., 2021; Roe et al., 2019). These prior studies have largely focused on whether naturalistic driving outcomes differ between individuals who are at high risk versus low risk of developing Alzheimer disease in the future. While many participants that form the current sample would have been included in prior analyses, the current study is the first to use this well-characterized sample to investigate how individual differences in important cognitive outcomes predict driving behavior.

Clinical/Cognitive Assessment

All participants at the Knight ADRC are administered comprehensive clinical and cognitive assessments annually. A trained clinician rates the participant for presence and severity of dementia symptoms using the CDR (Morris, 1993). The cognitive battery consists of multiple tests to measure critical cognitive domains, and includes the following assessments: Craft Story 21 Immediate and Delayed Recall (Craft et al., 1996) and the free recall test from the Free and Cued Selective Reminding test (Grober et al., 1988) to measure *episodic memory*; accuracy from the incongruent condition of a computerized variant of the Stroop color naming task (Stroop, 1935), accuracy on a computerized variant of the Simon task (Simon, 1969), and accuracy on the mixed block condition of a Consonant/Vowel versus Odd/Even task switching (Huff et al., 2015) to measure *attentional control*; Trail making Parts A and B (Armitage, 1945) and Digit Symbol Substitution from the Weschler Adult Intelligence Scale—Revised (WAIS-R; Wechsler, 1981) to measure *processing speed* (see Author Note 1); and Number Span Forward and Backward and Letter–Number Sequencing from the Weschler Memory Scale—III (Wechsler, 1997) to measure *working memory* ability. Each cognitive test was *z*-scored to the baseline cognitive assessment, defined as the cognitive assessment nearest a participant's enrollment into the driving study, and averaged to form a composite domain score.

Driving Data Collection and Outcomes

A commercial off-the-shelf datalogger was installed in the participants' vehicle (Azuga G2 Tracking device), which allows driving metrics to be continuously collected for a given "trip," defined as ignition start to ignition off, which are date- and time-stamped. Naturalistic driving data collected include vehicle speed, location (latitude and longitude), and adverse driving events such as hard braking or sudden acceleration (>8 mph/s of acceleration or deceleration). Based on prior research from our group using the DRIVES study (Bayat et al., 2021), we defined the following outcomes: total number of trips, radius of gyration, average distance traveled, number of night trips taken, number of days driven, number of unique locations visited, proportion of trips with overspeeding, proportion of trips with hard braking, and proportion of trips with sudden acceleration. We examined these naturalistic driving variables in the context of two behavioral categories, "driving space" and "driving performance" (see Table 2 for a description of how each variable was calculated). Driving data were tabulated for each full month of the study and were *z*-scored to the baseline (i.e., the first full month of driving) mean and standard deviation and averaged together to form a "driving space" composite and a "driving performance" composite.

In addition to the naturalistic driving assessment, all participants completed the DHQ (Owsley et al., 1999) annually. The DHQ consists of self-reported questions regarding driving behavior over the previous year and scores can be aggregated to reflect specific outcomes. For the purposes of the present study, we analyzed the following variables: total miles driven, number of trips taken, driving space, dependency (the extent to which a person relies on someone else to drive them around), number of unique destinations driven to, and reported difficulty driving. Given changes in driving behavior associated with coronavirus disease 2019 lockdowns and restrictions (Roe et al., 2021), we only analyzed data that were obtained prior to March 2020. For the DHQ analyses, we included anyone who met our criteria for inclusion in the naturalistic driving analyses. Specifically, anyone who had DHQ data available AND had at least 12 months of naturalistic driving information was included. As some participants completed DHQ assessments prior to enrolling in the naturalistic driving study, the interval of follow-up does not perfectly overlap. Moreover, because the DHQ is given annually, some participants only completed a single DHQ (25 participants in the current sample). We considered it most important to analyze as much DHQ data as possible, and on the same participants as who were analyzed for the naturalistic driving outcomes, as opposed to strictly matching the time intervals of follow-up across DHQ and naturalistic driving which would limit and imbalance the sample sizes across analyses. To ensure that participants with only a single DHQ were not biasing the results, we reran all analyses with the 25 individuals removed and the results were unchanged.

Statistical Analysis

All analyses were conducted using the lme4 (Bates et al., 2014) package in the R statistical computing environment. We report effects as a mean estimate with a 95% confidence interval. We conducted two sets of analyses. In the first set, we predicted each driving composite, in separate models, from the following fixed-effects terms: age at baseline, years of education, gender, time in the driving study (quantified in months and hereafter referred to as "time"). This was done to quantify the amount of change observed in driving outcomes in the entire cohort. We then added the baseline score in a cognitive domain and the cognition by time interaction. Random intercepts and random slopes of time were included in all models, unless the model did not

Table 2. Definitions of Each Driving Variable and the Method of Calculation

Outcome	Calculation	Mean[a]	*SD*[a]
Driving space			
Total # trips	Number of trips recorded (ignition start to stop) in each month	115.4	56.7
Radius of gyration[b]	Typical distance a person tends to travel (see González et al., 2008)	209.9	624.9
Distance traveled[b]	Average distance (km) per trip in each month	7.0	5.0
Number of night trips	Number of monthly trips started after the sun has set	62.9	43.1
Number of days traveled	Number of days in the month that a trip was taken	23.4	6.1
Number of unique locations	Number of unique GPS coordinates visited in each month	40.8	21.9
Driving performance			
Overspeeding proportion[c]	Proportion of monthly trips that speed was registered at 6 miles per hour above the speed limit	0.09	0.11
Hard braking propotion[c]	Proportion of monthly trips where deacceleration rate exceeded 8 miles per hour in 1 s per mile	0.09	0.08
Sudden acceleration proportion[c]	Proportion of monthly trips acceleration rate exceeded 8 miles per hour in 1 s per mile	0.05	0.09

Notes: DRIVES = Driving Real-World In-Vehicle Evaluation System; GPS = Global Positioning System. Reported mean and *SD* were calculated at the first full month of participation in the DRIVES study.

[a]Were calculated at the baseline assessment, that is, the first full month enrolled in the DRIVES study.

[b]These variables are summarized in the raw metric but were not normally distributed and were log-transformed prior to analysis.

[c]These variables are summarized in the raw metric but were arcsine square root-transformed prior to analysis.

converge, in which case the random slope was removed. Each cognitive domain was analyzed in a separate model. If a cognition by driving interaction was statistically significant, we conducted follow-up analyses of each component of the composite to isolate specific effects. We then repeated these analyses using outcomes from the DHQ as the dependent variables rather than the naturalistic driving outcomes. We focus exclusively on the cognition by time interaction to determine how cognition moderates outcomes of interest. Complete model summaries can be found in the Supplementary Materials. We conducted a total of 32 statistical comparisons (four cognitive composites by two driving composites and six different outcomes on the DHQ); thus, we set a relatively conservative significance criterion at 0.05/32 = 0.002, based on a Bonferroni correction. We report any comparison that was lower than a nominal p-value of .05, to aid in future hypothesis generation; however, only comparisons that exceed the 0.002 threshold will be interpreted.

Results

Naturalistic Driving Space Composite

Without considering cognitive variables, change over time in driving space was not significant ($\beta = -0.004$, CI = −0.008, 0.0002, $p = .066$). However, change over time in driving space was significantly moderated only by the attentional control composite ($\beta = 0.011$, CI = 0.005, 0.016, $p < .001$), after controlling for participant age, gender, and education level. As shown in Figure 1, individuals who were relatively low on attentional control decreased significantly more over time on the driving space composite relative to individuals with higher attentional control. No other cognitive domain significantly moderated change in driving space. Follow-up analyses on the individual components of the driving space composite revealed that attentional control moderated change over time in the number of trips taken per month ($\beta = 0.59$, CI = 0.36, 0.82, $p < .001$), unique locations visited ($\beta = 0.17$, CI = 0.09, 0.24, $p < .001$), number of night trips ($\beta = 0.42$, CI = 0.25, 0.59, $p < .001$), radius of gyration ($\beta = 0.01$, CI = 0.005, 0.02, $p = .001$), distance traveled per month ($\beta = 0.004$, CI = 0.000, 0.008, $p = .03$), and number of days driven ($\beta = 0.08$, CI = 0.04, 0.11, $p < .001$), again after controlling for the effects of age, gender, and education, although the distance traveled analysis did not exceed our Bonferroni-adjusted threshold. These effects are plotted in Figure 2, and as shown, individuals with relatively low attentional control decrease over time their number of trips per month, visit fewer unique locations, take fewer night trips, drive in smaller space, travel less distance, and drive fewer days of the month, compared to participants higher on attentional control. In the absence of a significant interaction on the composite score, individual components of the driving space composite in relation to other cognitive domains were not examined.

Naturalistic Driving, Driving Performance Composite

Change over time in driving performance was significant ($\beta = -0.004$, CI = −0.007, −0.001, $p = .003$), indicating that the proportion of trips with an adverse driving event (i.e., an occurrence of rapid acceleration, hard braking, or overspeeding) decreased over time in the study. However, change over time in this composite was not significantly moderated by any cognitive domain (details provided in the Supplementary Materials).

Driving Habits Questionnaire

Based on this self-report questionnaire, all participants reported driving in a smaller space ($\beta = -0.07$, CI = −0.10, −0.03, $p < .001$), driving to fewer places ($\beta = -0.07$, CI = −0.14, −0.01, $p = .03$), and increasing difficulty driving

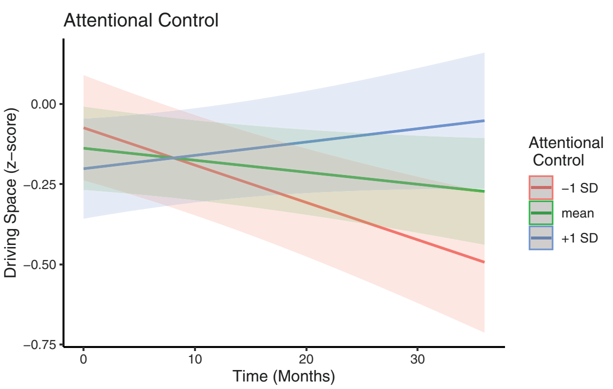

Figure 1. Moderating effect of attentional control on the driving space composite ($p < 0.001$). Trend lines are estimated at the mean attention score and 1 *SD* above and below the mean. A decrease in the driving space composite indicates a reduction in driving activities (e.g., driving fewer trips per month). Full color version is available within the online issue.

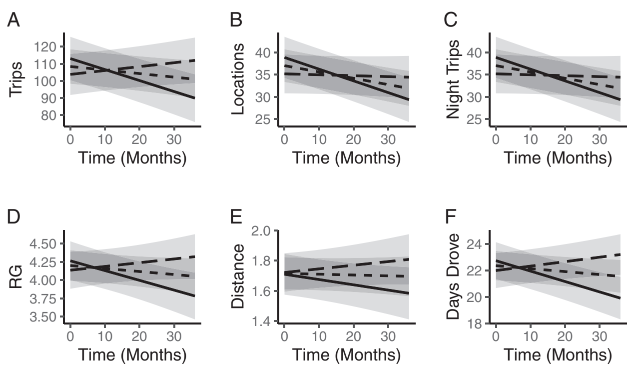

Figure 2. Moderating effect of attentional control on specific components of the driving space composite. Trend lines are plotted at 1 *SD* below the mean (solid line), the mean attention score (short dashed line) and 1 *SD* above the mean (long dashed line). All outcomes are plotted in the original metric except the radius of gyration and distance traveled which were both log-transformed.

over time (β = −0.009, CI = −0.02, 0.000, *p* = .03), although the latter two effects did not exceed our adjusted statistical threshold. Episodic memory ability moderated rates of change in total number of miles driven per week over the preceding year (β = 13.50, CI = 5.96, 21.03, *p* < .001). This effect is illustrated in Figure 3, and as shown, individuals with lower episodic memory ability report driving fewer miles per week over the course of the study. Processing speed moderated rates of change in reported driving difficulty (β = 0.02, CI = 0.003, 0.03, *p* = .02), working memory ability moderated rates of change in the number of places driven (β = −0.09, CI = −0.18, −0.009, *p* = .03), and attentional control moderated the number of miles driven (β = 11.76, CI = 0.87, 22.65, *p* = .03), but these latter three interactions did not exceed our Bonferroni-adjusted threshold. No other effects were significant.

Discussion

Declining physical or cognitive health may necessitate a complete cessation of driving activities for some older drivers. Driving cessation is unfortunately accompanied by adverse health-related and social outcomes (Edwards et al., 2009). Thus, rather than a complete elimination of driving, some older adults simply adapt (either by conscious choice or in response to diminishing cognitive ability) their driving behavior to not only maximize independent driving, but to also avoid negative consequences such as injury or fatal crashes. The primary aim of this study was to determine which, if any, cognitive factors were associated with changes over time in driving behavior, indexed either by naturalistic driving outcomes or self-report on an established driving behaviors questionnaire.

In our study, episodic memory, working memory, and processing speed did not significantly moderate any naturalistic driving outcome that indexed either driving space or performance. In contrast, attentional control was significantly associated with reductions on multiple critical

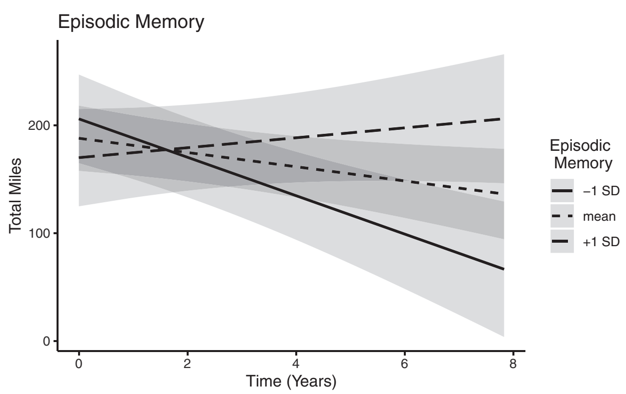

Figure 3. Moderating effect of episodic memory on self-reported weekly miles driven on the Driving Habits Questionnaire. Trend lines are plotted at 1 *SD* below the memory mean, at the mean memory score, and 1 *SD* above the mean.

driving space variables, including number of trips taken per month, number of night trips taken, and the typical radius a person drives in, after statistically controlling for participant age, education, and gender. This finding is in line with previous studies that have shown an association between attention tests (e.g., the UFoV) and driving self-regulation (O'Connor et al., 2012; Okonkwo et al., 2008; Rapoport et al., 2013; Ross et al., 2009; Vance et al., 2006). Again, attentional control was not associated with measures of driving performance including the proportion of trips with adverse events such as hard braking, sudden acceleration, or overspeeding.

Attentional control, broadly defined as the ability to focus on relevant aspects of the environment and ignore distracting or competing information and measured in the current study using the Stroop color naming test, the Simon task, and a task-switching paradigm, is clearly highly involved in everyday driving as shown by correlations between driving scores and visual attention scores (Mathias & Lucas, 2009; Richardson & Marottoli, 2003). Our work and that of others have shown that attentional control abilities decline in healthy aging (Aschenbrenner & Balota, 2015; Bugg et al., 2007), and that failures in attentional control are relatively common and noticeable at least by younger adults, as indexed by self-reported mind-wandering or "task-unrelated thoughts" (Unsworth et al., 2012). Although reports of mind-wandering surprisingly tend to decrease in healthy aging (Jackson & Balota, 2012), it is possible older adults with relatively lower attentional control abilities may notice their diminished capacity and regulate their driving as needed, for example, by traveling to fewer unique destinations. It is important to note that attentional control was not related to change in adverse events such as hard braking. Thus, it is not the case that individuals with lower attentional control scores are having more "near-misses" in terms of crashes (e.g., needed to brake quickly) and that is driving modifications in other aspects of driving behavior.

Declines in processing speed (measured in our study using the Trail Making tests and Digit Symbol Substitution from the WAIS-R) are perhaps the most widely reported effect in cognitive aging and are postulated to contribute to deficits in a variety of other cognitive domains (Salthouse, 1996). Given that typical neuropsychological tasks are administered under time constraints (e.g., words in a memory test are read at a fixed speed, fluency tests give a time limit to produce responses, etc.), the basic idea is that older individuals simply have less time to process and integrate individual stimuli and this produces deficits on any given task. In a real-world driving situation, reduced speed of processing would afford less time to respond to rapidly changing events (e.g., a car changing lanes, traffic light turning red, etc.). In our sample, processing speed was not associated with reductions in driving space or driving performance over time, even after age was removed as a covariate from the statistical models. Although a nonsignificant effect is surprising given that studies have suggested Trail Making and UFoV to be the best predictors of passing or failing an on-road driving test (Carr et al., 2011; Classen et al., 2013), it is consistent with earlier work using naturalistic driving studies and Trail Making (a component of our processing speed composite). Specifically, many naturalistic driving studies have generally not found significant relationships between the Trail Making tests and driving outcomes after adjusting for additional variables (e.g., Antin et al., 2017; Chevalier, Coxon, Rogers, et al., 2016; Munro et al., 2010). However, studies have shown that laboratory-based measures of speed (e.g., our composite score in the present study) do not necessarily map very well onto "real-world" speed measures (Lin et al., 2013). Future studies may consider using a more ecologically valid measure of visual processing speed, such as the UFoV task which has shown significant relationships with driving outcomes in many studies.

Previous studies using naturalistic driving outcomes have revealed a relationship between cognitive ability and driving performance (e.g., Merickel et al., 2019) and an important extension of our study was to examine time trends regarding these outcomes. Clearly, there are no reductions in adverse events associated with baseline cognitive ability in any domain. This finding fits with studies that have shown a minimal relationship between self-regulation and driving space with driving performance. For example, Owsley et al. (2004) conducted a randomized control trial in which older adults were assigned received an educational safe-driving intervention or to a "usual care" placebo group. Their results indicated that the intervention increased self-regulation, but this increase had no impact on overall driving safety. Other studies have similarly suggested a minimal relationship between driving ability and self-regulation (Baldock et al., 2006; Ross et al., 2009). There are several reasons why attentional control might not be expected to relate to adverse driving events. First, attentional control may only moderate self regulation, and as Owsley et al. have shown, self-regulation is not related to decreased incidence of adverse events. Alternatively, it is possible that attentional control was not related to adverse outcomes precisely because those same individuals restricted their driving to the lowest risk situations.

Interestingly, cognition did not consistently predict change on DHQ-reported outcomes with the sole exception of episodic memory moderating rates of change in miles driven. Given that memory did not correspond to miles driven as derived from naturalistic data, it is reasonable to assume that individuals with poorer memory are simply less able to accurately report their driving history. The relative lack of effects on the DHQ may be due to individuals' difficulty in accurately reporting driving outcomes in the preceding year. Indeed, in our earlier work, we showed that DHQ and naturalistic driving outcomes are only modestly correlated (Babulal et al., 2019), further emphasizing the benefit of naturalistic driving methodologies in capturing accurate driving habits as they occur over time.

The forgoing discussion assumes a direct link between cognitive ability and driving self-regulation. That is, individuals are consciously aware of a change in their cognitive function and regulate driving according. However, many older adults are not accurate in their estimation of their cognitive ability (Paire-Ficout et al., 2021) and tend to increase driving self-regulation when provided explicit feedback on their cognitive performance (Ackerman et al., 2016). Thus, it is possible that the participant themself is noticing cognitive difficulties and, consciously or unconsciously, adjusting their driving behavior accordingly, but also equally likely that someone else, perhaps a family member, becomes worried about the participant's cognitive health and suggests they restrict where and how frequently the participant should drive (Ang et al., 2020). Alternatively, the link between cognition and self-regulation may be indirect, via an intermediary mechanism such as driving comfort or anxiety (Meng & Siren, 2012; Molnar et al., 2018). That is, lower-functioning participants may become less comfortable driving in high-risk driving situations and regulate their driving accordingly based on comfort. Future studies could seek to disentangle these mechanisms by obtaining measures of driving comfort and anxiety in addition to robust cognitive measures.

There were many strengths to this study including a large, well-characterized, cognitively healthy older adult sample that had been followed for approximately 2 years on average and had received a comprehensive cognitive assessment battery. Despite these strengths a few limitations need to be mentioned. First, our sample of older adults was highly educated and predominantly White, so our results may not generalize to the larger population of older adult drivers. Second, although the association between attentional control and driving behavior is clear and robust, the exact mechanism underlying changes in driving behavior is unclear. Future studies could design questionnaires or other outcomes to directly test these possible mechanisms. Similarly, because we focused on cognitively healthy, high-functioning older adults over a relatively short time span, the practical effect sizes in our study were rather small. For example, attentional control explained ~1% of the variance in change over time in the driving space composite, and participants who were 1 *SD* below the mean on attentional control take less than 1 fewer trips per month than a participant with average attentional control (six fewer trips per month after 1 year). There are clearly a number of additional variables that will be important to consider in future research (e.g., degree of social support, rural vs urban residence, etc.), in addition to baseline cognitive function. Finally, we examined only cross-sectional performance in cognitive function and thus we cannot determine if the low performers are already in a state of cognitive decline. Future studies with longer cognitive follow-up can explicitly test whether reductions in cognitive performance covary with changes in driving behaviors.

Conclusion

We have shown that individual differences in primarily attentional control predict modifications in driving behavior over time. This effect was limited to the typical space a participant drives in and did not influence rates of change in adverse driving events. Given our sample was cognitively healthy at baseline, it is possible that multidomain impairment (e.g., deficits in attentional control AND memory) is required before adverse events become apparent. Naturalistic driving performance may also serve as a sensitive functional indicator of cognitive ability.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* online.

Author Note

1. We chose to classify this domain as "processing speed" as two of the three tests were listed as "processing speed" based on recommendations from the Alzheimer's Disease Centers Clinical Task Force (Weintraub et al., 2009); however, it is quite likely there are also "executive function" contributions to scores on this composite.

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Conflict of Interest

JC Morris is funded by NIH grants # P30 AG066444; P01AG003991; P01AG026276; U19 AG032438; and U19 AG024904. Neither Dr. Morris nor his family owns stock or has equity interest (outside of mutual funds or other externally directed accounts) in any pharmaceutical or biotechnology company. All other authors have no conflicts to report.

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Data Availability

Data used in the manuscript can be obtained by qualified researchers by submitting a request to the following website: https://knightadrc.wustl.edu/professionals-clinicians/request-center-resources/submit-a-request/. This study was not preregistered.

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