Baseline Differences in Driving Frequency as a Predictor of Cognitive Decline

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BASELINE DIFFERENCES IN DRIVING FREQUENCY AS A PREDICTOR OF COGNITIVE DECLINE

A Thesis
Submitted to the Graduate Faculty of the Louisiana State University Agricultural and Mechanical College in partial fulfilment of the requirements for the degree of Master of Arts in The Department of Psychology

by
Luke R. Miller
B.S., Drexel University, 2020
August 2022
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ABSTRACT

Driving is a complex task heavily dependent on cognitive functions which can decline with age including executive functions and processing speed. Although driving cessation as a predictor of cognitive changes has been studied, driving frequency is understudied in the literature. Thus, the objective of the current study is to evaluate the predictive utility of driving frequency at baseline toward objective cognitive decline beyond other factors associated with cognitive decline (e.g., depression, general functional mobility). The sample included a subset of 1,426 older adults (M age = 77.6, SD = 7.1) from the Rush University Memory and Aging Project. Participants completed batteries of questionnaires and neuropsychological tests at baseline and yearly follow-ups (M = 6.8, SD = 4.9). Linear mixed effects models were estimated to examine the incremental predictive utility of daily driving frequency at baseline on cognitive decline across multiple cognitive domains beyond mobility, depression, and demographics. Less daily driving frequency was independently associated with worse objective cognitive functioning globally and in all domains except for episodic memory. The interaction between driving frequency and follow-up year was associated with objective cognitive functioning globally and in all domains such that less driving was associated with greater rates of decline. Our findings extend prior research linking driving cessation to greater levels of cognitive decline. Future research should explore changes in driving frequency (or other driving habits) over time to better understand the relationship between functional and cognitive decline.
INTRODUCTION

Normal Aging and Cognitive Decline

The developmental trajectory of cognitive functioning, the mental ability to think, learn, and manipulate information, varies across specific domains (e.g., memory, attention, executive functioning, visuospatial functioning, language) (Drag & Bieliauskas, 2010; Marcotte et al., 2010; Tucker-Drob et al., 2019). One differentiating factor in terms of cognitive trajectories relates to the distinction between fluid and crystallized abilities (Cattell, 1963; Horn, J. L. 1965). Fluid abilities entail cognitive domains associated with increased effort in processing, which include episodic memory, complex attention, executive function, visuospatial abilities, and processing speed (Cattell, 1963; Horn, J. L. 1965; Drag & Bieliauskas, 2010; Marcotte et al., 2010; Tucker-Drob et al., 2019). Crystallized abilities include the application of acquired knowledge, procedural knowledge, and verbal abilities (Drag & Bieliauskas, 2010; Marcotte et al., 2010; Tucker-Drob et al., 2019). Though both crystallized and fluid abilities normally increase throughout childhood and into early adulthood, widespread evidence suggests fluid abilities peak in early adulthood and begin to decline while crystallized abilities continue to increase and peak later into adulthood (Drag & Bieliauskas, 2010; Tucker-Drob et al., 2019). Although this distinction is useful in describing major trends, research has also shown that there is variability in cognitive change observed across specific abilities within cognitive domains (Drag & Bieliauskas, 2010; Tucker-Drob et al., 2019).

In terms of attention and executive functioning (i.e., goal-directed behavior, organization, regulation), greater complexity is associated with increased cognitive decline (Drag & Bieliauskas, 2010; Kirova et al., 2015; Tucker-Drob et al., 2019). For example, tasks assessing working memory, inhibitory control, and shifting show decline in performance with age (Drag &
Bieliauskas, 2010; Kirova et al., 2015; Tucker-Drob et al., 2019) that is not observed on tasks of simple attention (Harada et al., 2013; Tucker-Drob et al., 2019). This distinction has also been reported in terms of daily living tasks as those involving working memory (e.g., calculating a tip for a restaurant bill) show greater decline with age than those relying only on short-term memory (e.g., recalling a phone number heard seconds ago) (Drag & Bieliauskas, 2010; Tucker-Drob et al., 2019). Given the role of executive functioning in coordinating other cognitive functions, age-related decline in executive functioning can also have an influence on task performance for other cognitive domains (Drag & Bieliauskas, 2010).

In terms of memory, domains most susceptible to normal decline are often heavily rooted in self-initiation and frontal lobe function (Drag & Bieliauskas, 2010; Tucker-Drob et al., 2019). In other words, types of memory that require the recollection of specific details or context surrounding an event (e.g., episodic, autobiographical, prospective, source) are dependent on cognitive resources and strategies necessary for encoding (creating detailed memories) and retrieval stages involved in memory functioning (Drag & Bieliauskas, 2010; Tucker-Drob et al., 2019). Thus, memory requiring less frontally mediated effort such as implicit (e.g., procedural), emotionally linked (e.g., flashbulb), and semantic memory (e.g. trivial knowledge) are less sensitive to decline (Drag & Bieliauskas, 2010; Tucker-Drob et al., 2019). In other words, older adults with normal cognitive decline may easily retain the ability to play piano, vocabulary, and details surrounding events such as 9/11, while having more difficulty recalling specific circumstances in which they met someone or when to take a specific medication (Drag & Bieliauskas, 2010; Tucker-Drob et al., 2019).

In line with other crystallized abilities, many tasks involving language do not show significant declines with age and some aspects of language (e.g., vocabulary) increase
throughout adulthood (Drag & Bieliauskas, 2010; Harada et al., 2013). Although many older adults complain of word finding difficulties, rather than a decline in language ability, it is believed that this issue is likely attributed to deficits in word retrieval related to issues with accessing lexical information (Drag & Bieliauskas, 2010; Schwartz & Metcalfe, 2011). Thus, it is hypothesized that decline in this domain may be better explained by memory abilities rather than a particular deficit in language given that cognitively normal older adults do not exhibit issues in linguistic rules rooted in semantic knowledge (Drag & Bieliauskas, 2010; Schwartz & Metcalfe, 2011). In other words, neither sentence formulation or comprehension of word meaning are sensitive to normal cognitive decline (Drag & Bieliauskas, 2010). Moreover, other deficits related to language that are sensitive to normal aging may be better explained by frontal, executive functions (Drag & Bieliauskas, 2010). For example, compared to younger adults, evidence suggests older adults exhibit greater tendencies to go off-topic during normal conversation (Drag & Bieliauskas, 2010). However, this tendency is likely better explained by normal decline in inhibitory control leading to difficulties filtering out irrelevant information (Drag & Bieliauskas, 2010).

In terms of visuospatial ability, declines across a number of different tasks have been observed (Drag & Bieliauskas, 2010; Cohen et al., 2019). Performance across visuospatial tasks such as in clock drawing tasks and those in the Wechsler Adult Intelligence Scale (WAIS) often show significantly worse performance in older adults compared to younger adults suggesting that normal decline is linked to worse visuoconstruction, planning, orientation, visuospatial attention, visuospatial memory, figure copying, and visual processing speed (Drag & Bieliauskas, 2010). Similar to other cognitive domains, age-related changes on these tasks may be influenced by executive functioning (Drag & Bieliauskas, 2010). Additionally, the relatively strong
relationships connecting worse visuospatial abilities to normal decline compared to other
cognitive domains (e.g., verbal abilities) may be attributed to greater complexity typically
associated with tasks assessing the visuospatial cognitive domain (Drag & Bieliauskas, 2010;
Cohen et al., 2019).

Predictors of Cognitive Decline

Evidence suggests that multiple factors including physical health, mental health, social,
and cognitive reserve are associated with worse cognitive functioning over time. For example, in
terms of physical health, robust evidence has shown that worse cardiovascular health (e.g.,
obesity, cardiovascular disease, high blood pressure, diabetes, high cholesterol), and less
physical activity (e.g., muscle strength, frequency of exercise) are linked to greater cognitive
decline (Tzourio et al., 1999; Rusinek et al., 2003; Verdelho et al., 2008; Sturman et al., 2005;
Bherer et al., 2013; Harrison et al., 2014; Davidson et al., 2014). In terms of mental health,
depression has shown links to greater cognitive decline; however, greater anxiety and lower
sleep quality and sense of purpose have shown links to decline but remain understudied (Butters
et al., 2000; Sinoff & Werner, 2003; Chodosh et al., 2007; Donovan et al., 2017; Brailean et al.,
2019; Rafnsson et al., 2020; Kuiper et al., 2020; Nøbes et al., 2009; Kim et al., 2019; Phyoe et al.,
2021). Robust research on social factors such as social activity (e.g., network size, frequency of
contact) suggest less activity is related to greater cognitive decline (James et al., 2011a; James et
al., 2011b; Bourassa et al., 2017; Pugh et al., 2021). Despite limited research on cognitive
reserve and decline, evidence suggests less cognitive activity and lower educational attainment
are associated with greater decline (Wilson et al., 2012b; Wilson et al., 2013; Marioni et al.,
2014).
Although research often focuses on predictors of cognitive decline in normal aging, another important question pertains to which factors explain variability in cognitive decline trajectories among same-aged peers (Tucker-Drob et al., 2019). It has been hypothesized that this variability is often attributed to the accumulation of factors that impact decline (Wilson et al., 2005a; Tucker-Drob et al., 2019). In other words, higher rates of normal decline may be attributed to the presence of a greater number of risk factors (e.g., worse physical and mental health) as well as their severity (Wilson et al., 2005a; Tucker-Drob et al., 2019). These same risk factors have also been studied as predictors of pathological cognitive decline (e.g., development of mild cognitive impairment and dementia) (Wilson et al., 2005a; Tucker-Drob et al., 2019). Specifically, studies have shown that multiple risk factors predict subsets of older adults who convert from a normal aging trajectory to trajectory associated with disease (e.g., Alzheimer’s disease, vascular dementia) (Wilson et al., 2005a; Tucker-Drob et al., 2019).

**Overview of Dementia**

By 2030, the U.S. population aged 65 years or older is expected to surpass 72 million people and will account for over 20% of the total population (U.S. Census Bureau, 2011). As a result, diseases that increase in prevalence with age (e.g., dementia) are expected to rise alongside the increasingly older population (CDC, 2020; Cao et al., 2020). Dementia, a severe neurodegenerative condition, is categorized into different subtypes based upon the cause of the condition (Cao et al., 2020). The two most prevalent subtypes, which account for about 80% of dementia cases total, are Alzheimer’s disease (AD) and vascular dementia (VaD) (Cao et al., 2020).
Diagnosis of dementia, or major neurocognitive disorder, according to the Diagnostic and Statistical Manual of Mental Disorders - 5th Edition (DSM-5) requires a significant decline in at least one cognitive domain, which leads to problems with independence in everyday functioning (American Psychiatric Association, 2013). For AD, objective cognitive decline in learning or memory and everyday functioning must be present whereas VaD is associated with declines in executive functions and complex forms of attention (including processing speed) attributed to a stroke or another cardiovascular condition (American Psychiatric Association, 2013; Karantzoulis & Galvin, 2011). However, domains of cognitive decline experienced by those with VaD may vary due to comorbidity and location of stroke, if applicable (Karantzoulis & Galvin, 2011). VaD is often associated with greater impairment in physical and motor skills, which is likely the reason VaD is often associated with greater earlier impairment in everyday functioning in terms of basic activities of daily living (ADLs) than AD (Gure et al., 2010). In terms of instrumental activities of daily living (IADLs) results have been mixed with some studies finding no differences in everyday functioning between AD and VaD (Gure et al., 2010).

Widespread evidence suggests older adults may still exhibit subtle, yet significant declines in cognitive abilities while not meeting the necessary criteria of impaired everyday functioning for dementia diagnosis, which has often been referred to as mild cognitive impairment (MCI) (Karantzoulis & Galvin, 2011). In terms of DSM-5 diagnostic criteria, this intermediate stage of cognitive decline is characterized as a mild neurocognitive disorder where cognitive deficits are not as severe as those in dementia diagnosis, but still show greater levels of cognitive impairment than those with normal cognitive decline (Ganguli, 2013). As opposed to the loss of functional dependence related to cognitive domains required for dementia diagnosis, the DSM-5 describes those with a mild NCD (i.e., MCI) as remaining functionally independent,
but requiring greater effort or use of compensatory strategies in tasks of everyday functioning (Ganguli, 2013). Though not a diagnostic category according to the DSM-5, research often seeks to conceptualize milder, pre-clinical phases of dementia even earlier than MCI in order to understand who is at greater risk for future pathological decline and to implement early intervention (Karantzoulis & Galvin, 2011; Barnett, Lewis, Blackwell, & Taylor, 2014). Early intervention particularly with the management of modifiable risk factors (e.g., cardiovascular conditions, physical activity) may reduce the risk for dementia (Baumgart et al., 2015).

Moreover, providing knowledge of greater risk for dementia ahead of time has shown to help affected individuals and their families prepare for cognitive and functional difficulties likely to arrive further down the road (Robinson, Tang, & Taylor, 2015; Lissek & Suchan, 2021).

However, defining factors of preclinical phases are widely debated. For example, some argue that subjective cognitive complaints (SCCs) (i.e., perceived deficits in cognitive functioning) are important indicators of preclinical phases as they are often present before observable decline in cognitive and functional abilities (Karantzoulis & Galvin, 2011; Gulpers et al., 2016). However, others question the utility of SCCs as markers of pathological aging given that individuals may not be able to differentiate normal versus impaired cognition; especially in memory (Reese, Cherry, & Copeland, 2000).

**Everyday Functioning**

Everyday functioning entails accomplishing a number of important tasks necessary for survival and making the most out of the human experience (Baltes & Lang, 1997; Perez et al., 2008; Miller et al., 2016). This includes carrying out numerous tasks varying in both complexity and in specific physical and cognitive demands of the body and brain (Baltes & Lang, 1997;
Miller et al., 2016). Though cognition plays a role in every task an individual partakes in, it may be more or less taxed in some activities of everyday functioning (Baltes & Lang, 1997; Miller et al., 2016). For instance, tasks such as bathing are generally not cognitively challenging for most individuals, but may require relatively more complex physical flexibility and reaching movements of the extremities (Bedard et al., 2001; den Ouden, et al 2013; Miller et al., 2016). In other tasks, demands may be less physical and placed more on specific domains of higher-order cognition (Perez et al., 2008; Miller et al., 2016). For example, if an individual is to remember to take medication at a future time, this task primarily depends on prospective memory skills in encoding, retrieval of memory, and awareness of time (Sheppard et al., 2020). However, some tasks may require complex functioning across multiple domains of cognitive and physical abilities (Anstey et al., 2005; Perez et al., 2008; Miller et al., 2016). For example, tasks such as driving often require higher levels of executive functions (e.g., working memory, inhibitory control, switching), attention (e.g., divided, sustained), processing speed, visuospatial abilities, and physical abilities (e.g., grip/muscle strength, motor speed, flexibility, neck rotation) operating simultaneously in order for an individual to drive safely in everyday life (Anstey et al., 2005, Miller et al., 2016).

**Early Changes in Everyday Functioning**

Evidence suggests that functional decline often follows changes in cognitive functioning; therefore, changes in functioning may depend on trajectories of cognitive decline (Marcotte et al., 2010). Given that cognitive domains rooted in more frontal, executive functioning abilities are affected earlier in the process of cognitive decline, everyday functioning tasks associated with executive function and memory (e.g., episodic, prospective) such as medication
management and calculating tip on a restaurant bill may be indicative of earlier functional decline than other tasks (Perez et al., 2008; Marcotte et al., 2010; Farias et al., 2017). However, given that semantic memory is much more resistant to normal decline, everyday functioning tasks reliant on semantic memory are not expected to decline with age (e.g., identifying where one is or identifying the use of important objects such as eating utensils) (Forde & Humphreys, 2000; Marcotte et al., 2010; Taler et al., 2020). Thus, even slight changes in everyday functioning in this area may be indicative of early pathological decline in cognition (Marcotte et al., 2010).

Although, as noted, research has typically focused on cognitive changes preceding changes in functioning, some research has examined the reverse and has shown that functional decline may be a sensitive predictor of or precede observable changes in cognitive decline. One longitudinal study found that reported greater early limitations in everyday functioning was significantly associated with conversion from normal cognitive ability to MCI (Farias et al., 2017). Moreover, other findings comparing the trajectories of subjective functional limitations and objective cognitive decline across tests of reasoning, memory, and processing speed found that declines in functioning preceded cognition (Tomaszewski Farias et al., 2018). Evidence also suggests that everyday functioning may be an important discriminating factor in situations where it is difficult to differentiate pathological from normal cognitive aging (Tomaszewski Farias et al., 2018). For example, subtle declines in episodic memory may be characteristic of either normal or pathological aging, so impaired everyday functioning in this area has been used to identify individuals with pathological changes (Marcotte et al., 2010). Moreover, difficulty with cognitive complex everyday tasks that place greater demand on higher-order, frontal cognitive
abilities may be particularly indicative early of age-related decline as executive functions are known to decline early in the aging process (Perez et al., 2008; Tucker-Drob et al., 2019).

**Driving and Aging**

Driving is known as a complex task requiring high levels of cognitive and physical functioning (Edward et al., 2008). Driving is also known to be an important component of healthy aging as it has been associated with greater independence, quality of life, and other aspects of mental and cognitive health (Sanford et al., 2019; Panchana et al., 2017). Given that domains associated with fluid reasoning (e.g., attention, processing speed, executive functions, memory, visual perception) are subject to decline in normal aging, evidence suggests healthy older adults are likely to experience changes in driving abilities broadly (Harada et al., 2013; Depestele et al., 2020). For instance, compared to younger adults, evidence suggests cognitively normal older adults show greater inconsistencies in lane maintenance and speed adaptation while driving and that older adults often drove significantly slower (Depestele et al., 2020). Evidence also suggests that older adults may exhibit heightened levels of risky driving and potentially crash at high rates comparable to those experienced in younger adults per total miles driven (McGwin Jr. & Brown, 1999; Lucidi et al., 2014). Some studies have shown that those with milder pathological cognitive decline (such as those with MCI) exhibit worse performance on reaction times, headway management, managing cell phone distractions than those who are cognitively normal while driving (Kawano et al., 2012; Beratis et al., 2017; Mosti et al., 2019). Although individuals with milder pathological decline often do not demonstrate impaired objective driving performance compared to those with normal cognitive decline, some evidence suggests those with MCI may require more effort to accomplish the same tasks (e.g., lane
maintenance and navigating left turns) (Wadley et al., 2009; Mosti et al., 2019). However, the
generalizability of findings on the effects of mild pathological decline on driving are greatly
limited due to small sample sizes. Compared to those with normal and milder pathological
cognitive declines, evidence suggest those with dementia show significantly impaired driving
performance across various metrics such as reaction time, number of road departures, turning
events, subtle (less serious) unsafe driving errors, serious unsafe driving errors, total number of
driving errors, and overall slower driving (Frittelli et al., 2009; Hird et al., 2016; Chee et al.,
2017). Moreover, those with dementia are more likely to fail on-road tests than those who are
cognitively normal (Chee et al., 2017). Some studies investigating motor vehicle crashes in
dementia (including state-recorded data) have found that those with dementia are at a
significantly greater crash risk than those who are cognitively normal (Chee et al., 2017). Other
studies on dementia and crashes found no significant differences between those with and without
dementia; however, these results were likely limited as those with potentially very mild dementia
were included (Chee et al., 2017).

Although some work has linked mobility more broadly to cognition (e.g., life space, the
extent of one’s movement throughout their environment) (James et al., 2011c; Edwards et al.,
2009; Ball & Owsley, 1991), driving may also be a more robust predictor variable as it is more
specific to one’s physical and cognitive abilities and is less likely to be influenced by other
variables independent of an individual’s functioning (e.g., another person arranges transportation
or drives instead). Driving cessation - the decision to stop driving - has been linked to higher
rates of cognitive decline (Choi et al., 2014). Given that driving is more heavily dependent on
higher order cognitive abilities than other everyday activities such as hygiene, shopping, and
medication management, this factor may be particularly poised to be an early predictor of
cognitive decline (Miller et al., 2016; Pérès et al., 2008). Moreover, driving cessation may also be a robust, early predictor of objective cognitive decline given it has shown strong links with depression (a strong predictor of decline) and that it may be a precipitating factor of depression (Marottoli et al., 1997; Fonda et al., 2001; Ragland et al., 2005).

The current study aims to replicate and extend prior research findings connecting driving cessation to greater rates of objective cognitive decline by investigating other driving habits (i.e., daily driving frequency) in relation to changes in cognitive functioning over time in older adults (Choi et al., 2014). Specifically, the current analysis aims to extend prior research via measuring cognitive functioning in a more comprehensive manner (including specific domains) using in-person administered batteries of neuropsychological assessments while accounting for depression, life space, and demographic variables associated with cognition. It was hypothesized that greater driving frequency (i.e., number of days typically driven per week at baseline) would predict reduced rates of objective cognitive decline globally and in specific domains.
METHODS

Participants

The current study included a subset of data from a larger longitudinal dataset collected via the Rush University Memory and Aging Project (MAP), an ongoing cohort study since 1997 examining healthy middle-aged and older adults at baseline in relation to trajectories of cognitive and functional decline, risk of dementia, and other factors (Bennett et al., 2012). MAP included those with no known diagnosis of dementia and who were able to sign an Anatomical Gift Act at baseline (Bennett et al., 2005). Participants were recruited from retirement communities and subsidized housing in facilities in eastern Illinois and throughout the Chicago metropolitan area (Bennett et al., 2005). In the current study, 1,426 individuals over the age of 50 who were licensed to drive, had driven in the past year, and completed a self-reported item on daily driving frequency at baseline were included. Participants completed average of 6.8 follow-up sessions (SD = 4.9).

Measures

Driving Frequency. Each participant completed a measure of self-reported daily driving frequency as per Shah et al. (2013). Individuals indicated how many days per week they typically drove via endorsing one of four options: (1) 6 or 7 days, (2) 3 to 5 days, (3) 1 to 2 days, (4) less than once. Thus, larger scores indicated less driving frequency. This variable was only assessed at baseline. Less daily driving frequency is associated with greater age (Bauer et al., 2003), and is linked to worse health in older adults (e.g., less social participation, activity involvement, physical activity) whereas those who drive more exhibit greater functioning in factors such as vision and lower extremity use (Pristavec, 2018; Abe et al., 2018).
Life space. A modified Life Space Questionnaire (LSQ) was included to assess the extent to which individuals move spatially throughout their environment (Barnes et al., 2007). At baseline and each follow-up visit, participants indicated via “yes” or “no” the extent of their movement within 6 specific zones in the past week including (1) other rooms within your house or apartment, (2) immediately outside areas (e.g., patio, deck, garage, or hallway), (3) areas outside the house or apartment (e.g., a driveway, parking lot, yard, or courtyard), (4) within the neighborhood (5) immediately outside the neighborhood, (6) outside of the neighborhood, and (7) places outside of community/town. Life space scores were be calculated by summing scores of each item (yes = 1, no = 0) then reverse coding, so that larger scores indicate greater life space or movement. Evidence suggests the modified LSQ has good construct validity as it was derived from a measure of life space that was related to other scales of mobility and physical functioning, and that it has strong test retest reliability (kappa coefficient = .80) (Stalvey et al., 1999). Discriminant validity has also been demonstrated between the modified LSQ and ADLs and iADLs (Barnes et al., 2007). Life space was included in the analyses given its association with greater cognitive decline in older adults (James et al., 2011c).

Depression. A modified, 10-item Center for Epidemiologic Studies Depression scale (CES-D) was used to measure the number of depression symptoms experienced (Kohout et al., 1993). Specifically, participants responded “yes” or “no” individually to a list of depression symptoms (e.g., “I felt lonely,” “I felt depressed,” “I enjoyed life,” “I felt sad”) as whether they experienced each symptom much of the time in the last week. In terms of reliability, the CES-D was found to have both good internal consistency (Cronbach α = .92) and test retest reliability (r = .70) in older adults (Andresen et al., 1994; Mohebbi et al., 2018). Evidence also suggests the
10-item CES-D has high criterion validity (e.g., 84% specificity, 97% sensitivity) in relation to older adults with major depressive disorder (Irwin et al., 1999).

**Neuropsychological Assessments.** Scores from neuropsychological tests were included to measure objective cognitive function in multiple domains consistent with a factor structure supported by prior research (Wilson et al., 2005a). Episodic memory was measured via tasks including immediate and delayed recall trials from both Logical Memory (Story A) (Wechsler, 1987) and East Boston Story tests (Albert et al., 1991; Wilson et al., 2002), Word List, Word List Memory, Word List Recognition, and Word List Recall (Morris et al., 1989). Semantic memory was measured via tasks including Verbal Fluency (Morris et al., 1989; Wilson et al., 2002), Boston Naming Test (15-item) (Morris et al., 1989), word reading test (15-item) (Wilson et al., 2002). Measures of processing speed included Symbol Digit Modalities Test (SDMT) (Smith, 1982), Number Comparison (Ekstrom et al., 1976; Wilson et al., 2002), Stroop word reading and color naming (Trenerry et al., 1989). Assessments of working memory included digit Span (forward, backward, and ordering) (Wechsler 1987; Cooper & Sagar 1993; Wilson et al, 2002). Measures of perceptual orientation consisted of Judgement of Line Orientation - 15 item (JOLO) and Standard Progressive Matrices (Benton et al., 1994; Raven et al., 1992). Each cognitive domain included neuropsychological assessments that are sensitive to age-related changes in cognitive functioning (Choi et al., 2014b; Souchay et al., 2000; Andel et al., 2003; Emmerson et al., 1989; Wilson & Bennett, 2005). Several of these measures (or measures similar in design) have shown adequate to high test-retest reliability in one meta-analysis (e.g., digit span $r = .79$) (Calamia et al., 2013). Averaged z-scores were used in analysis for each cognitive domain assessed (Wilson et al., 2005a). Global cognitive ability was calculated via the average of all tests (Wilson et al., 2005a).
Procedure

Individuals enrolled in MAP took part in responding to a series of questionnaires including demographics (e.g., age, race, ethnicity, education, socioeconomic status, etc.), lifestyle factors, psychopathology symptoms (e.g., depression), substance use, medical and psychiatric history, functional ability, and others as well as a comprehensive battery of neuropsychological assessments at baseline and at annual follow-ups (Bennett et al., 2005). Research personnel conducted all study sessions at the participants’ homes to avoid exclusively recruiting “healthy volunteers” (Bennett et al., 2005).

Analyses

Separate mixed effects models (i.e., for global cognition and each cognitive domain) were be used to examine the incremental predictive utility of driving frequency on cognitive decline. Within these models, daily driving frequency and other variables previously shown to be associated with cognition (i.e., life space, depressive symptoms, sex, race, ethnicity, level of education, socioeconomic status (SES) were included as fixed effects predictors of cognition along with time (i.e., follow-up year) and the interaction of driving frequency with time. The measure of SES used in prior research by Wilson and colleagues (2005b) included averaged ratings of two items assessing where they rank their standing to be in terms of education, money, and occupation compared to those in their community and the rest of the United States. A random intercept for participant and random slope for time were used to capture variability in baseline performance and rates of cognitive decline. The interaction of time by daily driving
frequency was used to evaluate whether the effect of time on cognitive functioning depends on
daily driving frequency. Based on prior research, it was hypothesized that less driving would
predict greater rates of cognitive decline both globally and in multiple cognitive domains
associated with driving (e.g., processing speed). For analysis, racial background was coded into a
binary variable (i.e., White or Non-White) given that low numbers of participants were reported
from specific non-white groups.
RESULTS

See Table 1 for the demographics of the sample. Six multilevel mixed-effects models revealed less daily driving frequency was associated with worse cognitive functioning globally and in domains of working memory, perceptual orientation, semantic memory, and processing speed while accounting for depression, life space, and demographics (i.e., sex, race, ethnicity, years of education, socioeconomic status) (See Table 2). Daily driving frequency was not independently associated with worse episodic memory functioning. For all six models, the interaction term of driving by follow-up year was significant, which indicated that less driving frequency predicted greater rates of cognitive decline over time globally and across those domains (For example, See Figure 1). There were no concerns with variance inflation, and the association between driving frequency and cognition did not depend on variability in rates of decline.

Table 1. Demographic Profile of Older Adult Sample (N = 1426)

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Mean (SD) / %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
<td>77.6 (7.1)</td>
</tr>
<tr>
<td>Age Range</td>
<td>53-98</td>
</tr>
<tr>
<td>Female</td>
<td>71.2%</td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
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<tr>
<td>Non-Hispanic</td>
<td>95.7%</td>
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<tr>
<td>Race</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>93.9%</td>
</tr>
<tr>
<td>Non-White</td>
<td>6.1%</td>
</tr>
<tr>
<td>Years of Education</td>
<td></td>
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<td>&lt;12</td>
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<tr>
<td>12</td>
<td>17.1%</td>
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<td>13</td>
<td>7.6%</td>
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<tr>
<td>14</td>
<td>11.1%</td>
</tr>
<tr>
<td>&gt;14</td>
<td>60.5%</td>
</tr>
</tbody>
</table>

Note: SD = standard deviation
Table 2. Linear Mixed Effects Models of Driving Frequency and Time Predicting Cognitive Functioning

<table>
<thead>
<tr>
<th>Objective Cognitive Functioning Domains</th>
<th>Global Cognition</th>
<th>Episodic Memory</th>
<th>Semantic Memory</th>
<th>Working Memory</th>
<th>Perceptual Orientation</th>
<th>Processing Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving Frequency</td>
<td>-0.06***</td>
<td>-0.03</td>
<td>-0.04*</td>
<td>-0.06*</td>
<td>-0.05*</td>
<td>-0.10***</td>
</tr>
<tr>
<td>Driving Frequency x Time</td>
<td>-0.01***</td>
<td>-0.01***</td>
<td>-0.01***</td>
<td>-0.01*</td>
<td>-0.01**</td>
<td>-0.01***</td>
</tr>
<tr>
<td>Time</td>
<td>-0.03***</td>
<td>-0.01</td>
<td>-0.02**</td>
<td>-0.02***</td>
<td>-0.01</td>
<td>-0.06***</td>
</tr>
<tr>
<td>Depression</td>
<td>-0.01***</td>
<td>-0.01***</td>
<td>-0.01*</td>
<td>-0.004</td>
<td>-0.01**</td>
<td>-0.02***</td>
</tr>
<tr>
<td>Life Space</td>
<td>0.04***</td>
<td>0.05***</td>
<td>-0.04***</td>
<td>0.03***</td>
<td>0.04***</td>
<td>0.05***</td>
</tr>
<tr>
<td>Sex</td>
<td>-0.23***</td>
<td>-0.38***</td>
<td>-0.27***</td>
<td>-0.09</td>
<td>0.19***</td>
<td>-0.26***</td>
</tr>
<tr>
<td>Non-White Racial Background</td>
<td>-0.35***</td>
<td>-0.15</td>
<td>-0.54***</td>
<td>-0.28**</td>
<td>-0.50***</td>
<td>-0.36***</td>
</tr>
<tr>
<td>Non-Hispanic Ethnicity</td>
<td>0.16</td>
<td>0.08</td>
<td>0.29*</td>
<td>0.34*</td>
<td>0.31*</td>
<td>0.18</td>
</tr>
<tr>
<td>Years of Education</td>
<td>0.04***</td>
<td>0.03***</td>
<td>0.05***</td>
<td>0.04***</td>
<td>0.06***</td>
<td>0.04***</td>
</tr>
<tr>
<td>Socioeconomic Status</td>
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<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01, *** p < .001

Note: Unstandardized beta weights for each predictor are reported below each predicted cognitive domain. Driving Frequency = daily driving frequency at baseline, Time = follow-up year. Beta weights were not reported for specific non-white groups (e.g., Asian, Native American, Pacific Islander) due to low numbers included in the current sample.
Figure 1. Daily Driving Frequency by Follow-Up Year Predicting Global Cognitive Functioning

Note: Daily Driving Frequency = number of days typically driven per week at baseline, Follow-Up Year = year of follow-up assessment
DISCUSSION

The current study aimed to replicate and extend prior research findings connecting driving habits to greater rates of objective cognitive decline by investigating other driving habits (i.e., daily driving frequency) in relation to changes in cognitive functioning over time in older adults while accounting for other variables linked to cognitive decline such as depression, mobility (i.e., life space), and demographic variables. Consistent with prior research suggesting that driving taxes a wide variety of cognitive abilities (Edward et al., 2008), the current study found that driving was also associated with cognitive functioning globally and across specific domains. Our findings that less driving frequency alone as a predictor was associated with worse cognitive functioning in specific domains of working memory, processing speed, and perceptual orientation are consistent with prior research suggesting that fluid abilities (i.e., attention, executive functioning, visuospatial skills) are heavily involved in the task (Harada et al., 2013; Depestele et al., 2020). Prior research has normal declines in processing speed and executive function/complex attention to issues with driving performance in lane maintenance, speed adaptation and control, and higher crash rates (Depestele et al., 2020). In those with MCI and mild AD, prior research has found that worse driving performance was related to greater issues with global cognitive functioning, attention, executive functioning, and visuospatial abilities (Hird et al., 2016).

A wide variety of factors including physical (e.g., extremity functioning, grip strength, balance), cognitive, and mental health (e.g., depression, lower well-being) have been linked to changes in driving in older adults (Fonda et al., 2001; Moon & Park, 2020; Hwang & Hong, 2018; Anstey et al., 2006; Sims et al., 2007). In terms of cognitive functioning, worse executive functioning whether attributed to pathological (i.e., MCI, dementia) or normal decline has been
linked to driving cessation and restriction (i.e., avoidance of challenging driving conditions) (Shimada et al., 2015; Kurzthaler et al., 2017; Edwards, Delahunt, & Mahncke, 2009; Connors et al., 2018; Pyun et al., 2018; Connors et al., 2017). Although research on driving and cognition has largely focused on neuropsychological measures as predictors of driving performance, it is likely that changes in driving performance may precede detectable changes in cognition on neuropsychological measures. Research has shown that subtle changes in higher-level everyday functional abilities (e.g., managing finances) can precede cognitive decline on neuropsychological measures (Tomaszewski Farias et al., 2018; Gold, 2012). Though driving is also an important task that requires higher levels of everyday functioning, to our knowledge, only one study (Choi, Lohman, & Mezuk, 2014a) has investigated driving habits as a predictor of objective cognitive decline. Our findings extend those from Choi and colleagues (2014a) that connect driving cessation to greater rates of global cognitive decline over time by demonstrating that daily driving frequency was associated cognitive decline globally and across specific domains (i.e., working memory, processing speed, perceptual orientation, episodic memory, semantic memory). Building off of Choi and colleagues’ study that included a cognitive screener administered over telephone (Telephone Interview for Cognitive Status (TICS); Brandt, Spencer, & Folstein, 2008), our study included data from an extensive battery of tests administered in-person composed of commonly used measures and the typical domains assessed in neuropsychological evaluations and research (Bennett et al., 2005; Larrabee, 2014; Rabin, Paolillo, & Barr, 2016).

The current study adds to the literature as it provides further evidence to suggest driving habits predict cognitive decline. As opposed to larger changes in driving such as cessation, our results suggest cognitive functioning and declines in cognition may be influenced by more subtle
variations in driving such as daily driving frequency (Edwards, Delahunt, & Mahncke, 2009). Moreover, given that it has been found to precede cessation (Edwards, Delahunt, & Mahncke, 2009), daily driving frequency may be an earlier indicator of decline. Future research should seek to investigate the effect of changes in driving habits and behavior (within-subjects variability) on cognitive functioning overtime. Surprisingly, there is no known research examining whether driving cessation predicts incidence of MCI or dementia diagnoses.

Our findings also add to broader literatures that connect reported worse mobility (e.g., life space, driving cessation), subjective mental health (e.g., depression, anxiety, loneliness, less social activity), and less access to resources (i.e., socioeconomic status (SES), level of education) to greater rates of cognitive decline over time (James et al., 2011a; James et al., 2011c; Donovan et al., 2017, Butters et al., 2000: James et al., 2011b; Marioni et al., 2014). When accounting for some of these factors (i.e., depression, life space, SES, years of education), driving frequency still had a significant effect on cognitive decline across all domains over time. Notably, there may be some benefits to measuring driving habits given they can be assessed quickly and in a straightforward manner (e.g., Were you ever licensed to drive? When did you stop driving? How many days do you typically drive per week?). Given these advantages and the unique associations observed with cognitive decline, driving habits may be particularly poised for use in future research; especially longitudinal studies with greatly limited time and space for questionnaire items. Consistent with research attempting to minimize risk of cognitive decline by improving risk factors (e.g., low physical and cognitive activity, depression, anxiety), future research may benefit from examining whether improving driving abilities and frequency might reduce levels of cognitive decline.
It is important to note the limitations of the current study. Despite the benefits of measuring constructs via minimal numbers of items, the current study only included one for daily driving frequency in the current analysis, which may increase risk for measurement error. Moreover, daily driving frequency was also only measured at baseline. Given that no known studies on driving habits as predictors of cognitive decline measure this construct at follow-up intervals, future research assessing changes in these variables in relation to changes in cognitive ability over time may also be useful. Although participants were asked to describe their typical daily driving frequency, their interpretation of this item in relation to the time of year (e.g., summer vs. winter) they completed it may have influenced their response (Myers, Trang, & Crizzle, 2011). Although the current study adjusted for race, ethnicity, and SES, our sample had low variability in these parameters, which limit the generalizability of our findings to other populations. The current study was also limited in that it did not distinguish between normal (expected, natural levels of cognitive decline) and pathological decline. Although individuals consented to the study were initially not found to have MCI or dementia, some individuals included in this analysis were diagnosed with these conditions at a later time (Bennett et al., 2012). Future research should work to examine the differential effects driving habits may have on normal and pathological levels of aging as this may provide useful information for detection and intervention of these conditions.
References


Vita

Luke Richard Miller was born in Pittsburgh, Pennsylvania and received his Bachelor of Sciences in psychology from Drexel University in Philadelphia, Pennsylvania. He worked as a research assistant in multiple labs examining the effects of mental health on driving behavior and the predictors (e.g., motivation, sleep) of neuropsychological rehabilitation outcomes in those with traumatic brain injury. He is currently a graduate student in his second year under the supervision of Dr. Matthew R. Calamia. Luke’s current research explores the utility of virtual reality (e.g., driving simulation) and measuring positive neuropsychological factors (positive mood, resilience, psychological flexibility) in a neuropsychological rehabilitation context. He plans to receive his Masters in August 2022.