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Exploring Predictors of Older Adults' Performance on a Novel Driving Simulator Task

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EXPLORING PREDICTORS OF OLDER ADULTS' PERFORMANCE ON A NOVEL DRIVING SIMULATOR TASK

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ABSTRACT

On a per-mile driven basis, older adults are at increased risk of being involved in an automobile accident. The development and implementation of driving assessment tools is necessary to inform decisions about driving reduction and cessation. Driving simulators are one method of assessing driving performance and safety, however many simulators are cost-prohibitive for most researchers and clinicians. Additionally, while driving performance has been previously explored with respect to clinical populations (e.g., Alzheimer's Disease), less work has evaluated this topic in a cognitively healthy sample. The present study sought to determine whether a novel, cost-effective driving simulator (Assetto Corsa (AC)) might be useful in the evaluation of driving performance in a sample of cognitively healthy older adults. A total of 53 participants completed a battery of paper-and-pencil and computerized cognitive performance measures and self-reports regarding their driving safety and behaviors, and a subset of participants (n = 35) completed the driving simulator task. Hierarchical regressions revealed that paper-and-pencil measures of simple attention and executive functioning and a computerized measure of processing speed were associated with aspects of driving simulator performance. Pearson correlation coefficients revealed that lower self-rated driving was associated with slower completion of the simulator task, and decrements in several cognitive domains were associated with greater self-reported difficulty driving in various conditions, greater aberrant driving behaviors, and higher likelihood of having legal difficulties as a result of driving (e.g., traffic tickets). Implications for future work are discussed.

INTRODUCTION

Older Adulthood and Driving in the United States

An estimated 10,000 individuals turn age 65 in the United States each day, making the older adult population the fastest growing age demographic in the country (Cohn & Taylor, 2010). By 2050, the number of Americans age 65 or older will outnumber those ages 18 or younger for the first time in history (Vespa, Armstrong, & Medina, 2018). Given this tremendous growth in numbers, it is unsurprising that recent research has increasingly focused on activities that maintain older adults' sense of independence, such as driving (Anton et al., 2015; Harvey, Chastin, & Skelton, 2015). Older adults represent the fastest growing segment of drivers in the country, with the number of drivers over age 65 expected to double in size from 2005 to 2025 (Stutts & Martell, 1992). This trend may partially be explained by older adults remaining active drivers longer than previous generations (Lyman, Ferguson, Braver, & Williams, 2002).

Driving is one of the most fundamental components of daily living for older adults (Adler & Rottunda, 2006) and is central to most Americans' sense of autonomy (Burkhardt, 1999; Ragland, Satariano, & MacLeod, 2005). The average American drives approximately 13,000 miles each year, and automobiles are the most popular means of transportation in the country (World Health Organization, 2015). Despite this, driving poses a serious threat to the safety of other drivers and road-users, as approximately 1.2 million individuals die and 50 million are injured due to automobile collisions on a yearly basis (Organization, 2015). A variety of influences including vehicle malfunction and environmental variables are thought to have an effect on driving safety; however, driver error is thought to have the strongest ties to risk of motor vehicle collision (Nelligan, 2003).

Older adulthood is one factor that contributes to dangerous driving (i.e., at high risk of being in crashes, driving in a manner that risks the well-being of other road-users). On a per-mile driven basis, older adults are more likely than other age groups to be involved in an accident (Dellinger, Langlois, & Li, 2002; Keall & Frith, 2004; Massie, Campbell, & Williams, 1995; Ryan, Legge, & Rosman, 1998). Older adults are disproportionately represented in the number of Americans killed on the road, accounting for 18% of all accidents (World Health Organization, 2015). When involved in accidents, older adults are also more likely than younger adults to die or be seriously injured (Evans, 1988; Lyman et al., 2002; Williams & Shabanova, 2003). As a result, exploration of the factors that are associated with driving safety in this population is a significant public health concern. Psychologists, neurologists and occupational therapists are but a few parties tasked with helping to accurately determine when an older adult may wish to consider driving cessation, although states differ in whether these determinations must be reported to the relevant authorities (e.g., the Department for Motor Vehicles) (Berger, Rosner, Kark, Bennett, & York, 2000).

Age-Related Normative Changes and Driving

Normal, age-associated changes in variety of areas of functioning may have a negative effect on older individuals' driving abilities. These changes include declines in cognitive capacities, sensory deficiencies and physical decrements that frequently accompany older age.

Cognitive Changes and Driving

Older adulthood is marked by normal age-associated changes in cognitive functioning (Greiner, Snowdon, & Schmitt, 1996; Secker, Hill, Villeneau, & Parkman, 2003) and certain cognitive domains are especially prone to age-related decrements. Divided attention and switching of attention have exhibited reductions in older adulthood, although other aspects of attention (e.g., sustained attention) appear largely unaffected (De Ribaupierre & Ludwig, 2003; McDowd & Craik, 1988; Verhaeghen & Cerella, 2002). Episodic long-term memory has been shown to decline in older adulthood (Craik & Jennings, 1992), and older adults especially exhibit difficulty recalling whether something actually occurred or was merely thought about (what is termed "reality monitoring") (Johnson, Hashtroudi, & Lindsay, 1993). Some work by Salthouse and others suggests that much of the variance in declines in long-term memory may be attributed to slowed processing speed (Salthouse, 1994; Salthouse, 1995; Salthouse & Meinz, 1995). Still others suggest that reductions in inhibitory control may help explain age-related declines in cognitive functioning, especially working memory (Hasher, Stoltzfus, Zacks, & Rypma, 1991; Hasher & Zacks, 1988; May, Hasher, & Kane, 1999). Broadly speaking, changes in aspects of attention, long-term and working memory, processing speed and inhibition are common in normal, healthy aging (Glisky, 2007).

Many of the cognitive domains affected in normal aging are the same ones necessary for safe driving. This is especially true with regard to visual and divided attention, which previous reviews and meta-analyses have shown to be associated with greater risk of driving accident and driving performance (e.g., on-road evaluations, driving simulator tasks) (Clay et al., 2005; McDowd & Shaw, 2000). In comparison, a relatively small but extant body of work indicates that other domains may be linked to higher accident risk. Individual studies suggest that poor delayed visual and auditory memory (Hu, Trumble, Foley, Eberhard, & Wallace, 1998; McKnight & McKnight, 1999), inhibitory control (Daigneault, Joly, & Frigon, 2002; Stutts, Stewart, & Martell, 1998) and processing speed (Lafont et al., 2010) may be linked to worse driving outcomes among older adults. In addition, a significant body of literature indicates that older adults with lower overall mental status are at increased accident risk (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Odenheimer et al., 1994; Owsley, Ball, Sloane, Roenker, & Bruni, 1991; Stutts et al., 1998). Thus, measures that reliably assess these cognitive capacities may prove useful in helping to predict driving ability among older adults. The utility of these measures is vital given that clinicians are more likely to give individuals of greater age recommendations related to reducing or ceasing driving (Lyman et al., 2002; Ryan et al., 1998).

Sensory/Physical Changes and Driving

Sensory and physical functioning have also been cited as common causes of driving difficulties in older adulthood (Anstey, Wood, Lord, & Walker, 2005), however results remain inconclusive. Visual acuity frequently declines as part of the normal aging process (Gittings & Fozard, 1986; Spear, 1993), and some have indicated that visual deficits accompanying older adulthood may be related to increased self-reported crash risk (Ivers, Mitchell, & Cumming, 1999) as well as state-recorded crashes (Owsley, Stalvey, Wells, Sloane, & McGwin, 2001; Sims, McGwin Jr, Allman, Ball, & Owsley, 2000). However, others have failed to identify such a relationship and suggest that visual acuity tests used in isolation are insufficient for predicting a task as complex as driving within older adult populations (Owsley, Ball, et al., 1998; Owsley, McGwin Jr, & Ball, 1998; Wood & Higgins, 1999). Hearing loss, another symptom typical as one ages (Wallhagen, Strawbridge, Cohen, & Kaplan, 1997), remains an additional point of disagreement, with one group finding an effect of self-reported hearing loss in the right ear on crash risk, and another finding no effect for either ear (Sims et al., 2000; Sims, Owsley, Allman, Ball, & Smoot, 1998). Part of the reason for conflicts in findings may stem from the fact that impaired sensory abilities appear to have a greater impact on driving safety in high-demand driving conditions, and this effect is particularly pronounced in older adults (Brabyn, Schneck, Lott, & HaegerstrÖM-Portnoy, 2005; Freeman, Munoz, Turano, & West, 2006; Konstantopoulos, Chapman, & Crundall, 2010).

A variety of health conditions especially prevalent in older adulthood have also been linked to crash risk in these individuals, including heart disease, stroke, arthritis and greater drop in orthostatic systolic blood pressure (Margolis et al., 2002; McGwin Jr, Sims, Pulley, & Roseman, 2000). Older adults also exhibit greater difficulties in neck movement and rotation, and poor neck rotation has been found to more than double the risk of crash (Marottoli et al., 1998; Netzer & Payne, 1993); however, other physical conditions that might be presumed to result in poorer driving (e.g., trunk rotation, grip strength) as well as disability status have not demonstrated effects (Anstey et al., 2005). It has been hypothesized that such lack of effects are the result of these individuals' voluntary driving cessation rather than accidents, as well as little regard among studies for possible compensation strategies that individuals may utilize (Anstey et al., 2005).

Clinically Significant Cognitive Impairment in Older Drivers

Given the established relationship between cognitive functioning and driving safety in cognitively healthy older adults (Anstey et al., 2005), it is of little surprise that individuals with neurocognitive disorders are at especially heightened risk of engaging in unsafe driving behaviors (Reger et al., 2004). This is true both with regard to older adults with mild or early-stage dementia, as well as with more severe cases (Duchek et al., 2003; Lundberg et al., 1997). In comparison to their cognitively healthy counterparts, cognitively impaired older adults routinely demonstrate poorer driving ability on on-road and driving simulator evaluations (Man‑Son‑Hing, Marshall, Molnar, & Wilson, 2007) and are between two and a half to three times more likely to be in an accident (Cooper, Tallman, Tuokko, & Beattie, 1993; Tomioka et al., 2009). A growing body of literature further indicates that in comparison to both cognitively healthy older adults as well as other clinical samples (e.g., traumatic brain injury, psychiatric diagnoses), physicians and neuropsychologists are especially likely to give driving-related recommendations to older adults with cognitive impairment (Betz, Jones, Petroff, & Schwartz, 2013; Iverson et al., 2010; Meth, Bernstein, Calamia, & Tranel, 2019; Molnar, Byszewski, Marshall, & Man-Son-Hing, 2005; Ryan et al., 1998). Both cognitively impaired older adults and their caregivers report that the former's decreased capacity to safely navigate driving situations may be "frustrating" and caregivers are a frequent referral source for neuropsychological assessments designed to evaluate driving safety as well as on-road evaluations (Carr & Ott, 2010).

A wealth of literature exists regarding the relationship between cognitive performance and driving safety in cognitively impaired older adults; however, a meta-analysis by Reger and colleagues (2004) suggests that these associations vary from study to study depending on whether a control group (i.e., a cognitively healthy group) was included (Reger et al., 2004). When studies in the meta-analysis included solely those studies without a control group, visuospatial skills and mental status were strongly associated with driving measures. However, when the meta-analysis included studies both with and without control groups, driving measures were moderately correlated with cognition across all cognitive domains examined. A more recent review and meta-analysis by Hird and colleagues (2016) indicated that while cognitive impairment severity was broadly related to driving outcomes in those with Alzheimer's disease or mild cognitive impairment, disagreement persists as to the specific domains most closely tied to driving outcomes (Hird, Egeto, Fischer, Naglie, & Schweizer, 2016).

Similar to the literature as it pertains to sensory abilities, part of this disagreement may be due to the circumstances under which driving tasks are completed. For example, visual attention has been shown to be a particularly strong predictor of tendency to avoid various driving situations (e.g., poor weather conditions) but not nighttime driving (Okonkwo, Crowe, Wadley, & Ball, 2008). Visual attention has also been tied to crucial driving behaviors that some, but not all, driving tasks assess (e.g., interaction with other drivers or pedestrians) (Richardson & Marottoli, 2003).

Driving Assessment Methods with Older Adults

On-Road Evaluations

Given the impact that an individual's impaired driving may have on the safety of other drivers and road users, a variety of methodologies have been developed in both research and clinical contexts in order to assess aspects of driving safety. Of these methodologies, on-road driving evaluations represent the “gold standard” methodology (Kay, Bundy, Clemson, Cheal, & Glendenning, 2012). When assessing driving fitness, the majority of clinicians report employing on-road evaluations irrespective of the results of any other measures administered (Korner-Bitensky, Bitensky, Sofer, Man-Son-Hing, & Gelinas, 2006), and on-road evaluations have been found to be especially useful when neuropsychological test findings are ambiguous (Schanke & Sundet, 2000). However, it is worth noting that most clinicians use a nonstandardized on-road assessment procedure (i.e., ability to complete a standard driving route), as opposed to those that have been more supported in the literature (i.e., an established scoring system) (Korner-Bitensky et al., 2006). On-road evaluations are also typically expensive, requiring a trained professional, an actual vehicle and other resources depending on the nature of the task (e.g., closed course). Additionally, on-road evaluations by definition may put the safety of the participant and the evaluator at risk if the participant’s driving ability is sufficiently impaired. Despite this, other clinical tools designed to assess driving are frequently compared to on-road evaluations to determine their relative utility (Kay et al., 2012; Myers, Ball, Kalina, Roth, & Goode, 2000).

Paper-and-Pencil Cognitive Tasks

Neuropsychologists usually employ a comprehensive battery approach when using paper-and-pencil measures to make determinations as to driving safety, whereby cognitive strengths and weaknesses across domains are denoted (Szlyk, Myers, Zhang, Wetzel, & Shapiro, 2002). Such information may be useful given that work utilizing a full battery of paper-and-pencil tests has found differential relationships between various aspects of cognition with facets of driving performance, although specific associations between domains and driving variables differ depending on the cognitive and driving measures used and the patient's cognitive disease status (Fox, Bowden, Bashford, & Smith, 1997; Rebok, Keyl, Bylsma, Blaustein, & Tune, 1994).

Although administration of a comprehensive battery is standard practice when conducting driving safety evaluations, several studies have examined the utility of specific measures of executive functioning and visuospatial abilities in predicting driving outcome variables (Silva, Laks, & Engelhardt, 2009). For example, the Neuropsychological Assessment Battery (NAB) has shown evidence in favor of its use in predicting driving outcomes and on-road performance (Brown et al., 2005); in particular, the NAB Driving Scenes subtest has been shown to accurately classify safe from unsafe older drivers (Brown et al., 2005), and the NAB Trail-Making Test Part A and the Mazes Test have also demonstrated promise in their predicting outcomes of on-road driving tests (Asimakopulos et al., 2012; Niewoehner et al., 2012). Similar results have been found for the Trail-Making Test Part B (Lezak, Howieson, Loring, & Fischer, 2004).

Despite their documented utility, paper-and-pencil neuropsychological measures are not typically used in isolation when making driving safety decisions. This is likely due to their limited ecological validity and the fact that these tests fail to capture the full range of complex, multiple-step tasks that are characteristic of driving (Schultheis & Mourant, 2001).

Computerized Cognitive Tasks

In comparison to paper-and-pencil measures, which assess a broad array of cognitive domains that may be related to driving safety and performance, computerized cognitive tasks offer a more in-depth approach to assessing a more limited set of driving safety and performance facets. These tasks have demonstrated ability to predict driving performance, although more work is necessary to determine whether they are more sensitive than traditional paper-and-pencil measures (Myers et al., 2000; Whelihan, DiCarlo, & Paul, 2005), and are generally recommended for use in combination with comprehensive neuropsychological batteries, not in their place (Wood, Horswill, Lacherez, & Anstey, 2013). The Useful Field of Vision (UFOV) task is perhaps the most frequently used of these, having been implemented in a multitude of studies predicting driving performance and outcomes in clinical and non-clinical populations (Ball, 1997; Clay et al., 2005; Goode et al., 1998; McGwin Jr, Chapman, & Owsley, 2000). The UFOV is a visual attention measure that assesses the capacity to detect and identify targets presented across a wide visual field. The UFOV has been shown to predict the capacity of older adults to safely drive a car, as exhibited both through individuals' performance on driving simulators and their actual crash frequency (Ball, 1997; Clay et al., 2005; Goode et al., 1998; McGwin Jr, Chapman, et al., 2000). Results of UFOV administration have also been shown to predict performance on on-road driving evaluations (Myers et al., 2000). The UFOV has further demonstrated a high level of sensitivity (86.3%) and specificity (84.3%) in the prediction of previous on-road crashes among older drivers (Goode et al., 1998). A meta-analysis collapsing across a number of different driving outcomes showed that the UFOV had a large association with impaired driving (Cohen's d=0.945) (Clay et al., 2005). Overall, with the exception of on-road evaluations, the UFOV represents one of the most frequently relied-on tools when making determinations regarding driving safety.

Another computerized cognitive task that has proven useful in predicting crashes is the Hazard Perception Task. This personal computer-based measure assesses a driver's capacity to actively visually search the road in front of them on a screen for potential hazards that must be avoided (Darby, Murray, & Raeside, 2009; McKenna & Horswill, 1999; Wells, Tong, Sexton, Grayson, & Jones, 2008). The Hazard Perception Task has been utilized in several populations considered to be at risk for motorvehicle accident, including traumatic brain injury (Preece, Horswill, & Geffen, 2010), impaired sleep (S. S. Smith, Horswill, Chambers, & Wetton, 2009), and cognitively healthy older adults (Horswill, Anstey, Hatherly, & Wood, 2010; Horswill et al., 2008). Among older adults, time necessary to perceive hazards on this measure has been linked to crash involvement (Horswill et al., 2010). It has also been noted that while hazard perception response times increase with age, this slowing of response times may be attributable to contrast sensitivity and useful field of view (Horswill et al., 2008). Moreover, hazard perception latencies and UFOV have been shown to account for separate variance in older adults' crash involvement (Horswill et al., 2010). Similar tasks have been developed to help train novice drivers to detect potential hazards in the driving environment (e.g., the Risk Awareness and Perception Training program) (Pradhan, Fisher, & Pollatsek, 2006).

Although computerized tasks assess abilities that are thought to be necessary for safe driving, concerns exist regarding the lack of interaction between participants and the device as well as their unsophisticated graphics (Schultheis & Mourant, 2001). As a result, the generalizability of these measures remains an issue. Similar to paper-and-pencil tasks, computerized measures also typically assess specific abilities and do not evaluate more complex behaviors that are characteristic of driving (Schultheis & Mourant, 2001).

Self-Report Measures

Several self-report measures have been developed to assist in the evaluation of various aspects of driving (Lajunen, Parker, & Summala, 2004; Ulleberg & Rundmo, 2003). In comparison to on-road evaluations and cognitive tests (both pencil-and-paper and computerized), self-report measures are relatively inexpensive and many are free to obtain and administer. Self-reports also require little training to administer and many have been adapted for online completion (Berdoulat, Vavassori, & Sastre, 2013; Bernstein & Calamia, 2018; Lajunen et al., 2004; Shi, Bai, Ying, & Atchley, 2010). Self-reports assess a range of aspects of driving behaviors, such as aggressive driving practices (Houston, Harris, & Norman, 2003), avoidance of various driving situations (Baldock, Mathias, McLean, & Berndt, 2006; Wong, Smith, & Sullivan, 2015), behavioral reactions to perceived threats or reckless driving from others drivers (Wiesenthal, Hennessy, & Gibson, 2000), prosocial driving practices (Harris et al., 2014) and general dangerous driving methods (Dula, Adams, Miesner, & Leonard, 2010; Dula & Ballard, 2003). Self-reports also assess more internal aspects of driving including negative emotions and thoughts experienced while driving (Blanchard, Barton, & Malta, 2000; Deffenbacher, Oetting, & Lynch, 1994). A recent factor analysis determined that many of the most frequently used driving self-report measures map onto a four-factor structure that includes reckless driving behaviors, negative driving-related emotions, aggressive driving behaviors in response to perceived transgressions on the part of other drivers, and perceived aggressive driving behaviors from others (Bernstein & Calamia, 2019). Such results indicate that while countless self-report measures have been created, they may be conceptualized as clustering into a few distinct categories, and investigators are encouraged to select measures that are most appropriate to answer their research questions. However, it is worth noting that this factor analysis was conducted in a college student sample and results may not generalize to the older adult population.

Self-reports have proven useful in the assessment of older adults' driving practices and safety. A previous meta-analysis indicates that subscales from the Driving Behavior Questionnaire (DBQ), a measure of aberrant driving behaviors and the most widely-used driving self-report measure, are positively correlated with self-reported accidents ($r = .10$ to $r = .13$); however, their associations with state-recorded driving accidents are weaker ($r = .03$ to $r = .05$) (De Winter & Dodou, 2010). Within the older adult population, the DBQ has largely been used to characterize individuals' driving behaviors (Scialfa, Ference, Boone, Tay, & Hudson, 2010) or examine associations with personality characteristics (Owsley, McGwin Jr, & McNeal, 2003), while its associations with actual driving performance and outcome measures have received limited attention. Parker and colleagues found that older adults with greater scores on the Errors or Lapses subscales may be over three times more likely to be involved in an accident (Parker, McDonald, Rabbitt, & Sutcliffe, 2000). Other work suggests that higher DBQ scores are related ($r = .25$) to poorer performance on aspects of a simulated driving task (Schwebel et al., 2007). Notably, although studies have used similar versions of the DBQ across studies, some have scored it in contrasting ways from the most widely used method (e.g., separating the Violations factor into two subscales) (Parker et al., 2000).

Other questionnaires have assessed aspects of older adults' driving experiences and tendencies that may be especially prevalent in this age demographic, such as their avoidance of specific driving conditions (e.g., the Driving Habits Questionnaire, or DHQ) (Ball, 1997; Vance et al., 2006), the ease with which they avoid difficult driving situations (Baldock et al., 2006) and anxiety experienced while driving (Taylor, Alpass, Stephens, & Towers, 2010). These facets of driving have been specifically explored given their associations with driving cessation (Taylor et al., 2010; Vance et al., 2006). These self-report measures have yielded mixed associations with other driving variables, and may vary as a function of the method of driving assessment they are compared to; for example, whereas one study group did not find overall associations between driving situational avoidance and simulated driving performance (Baldock et al., 2006), another group utilizing the same self-report measure (i.e., DHQ) did so with regard to state-recorded crashes (Owsley, Ball, et al., 1998).

Despite their strengths, self-report measures are generally limited by their inherent subjectivity, as individuals may convey their driving ability in an overly positive manner for a number of reasons. Individuals may overrate their abilities due to their desire to appear more competent to observers (Paulhus, 1984). However, prior work has indicated that, at least in the case of the DBQ, the effects of social desirability on participants' responses are relatively low (Lajunen, Corry, Summala, & Hartley, 1997; Lajunen et al., 2004). Greater work is necessary to explore whether this is true of other driving self-report measures. Another explanation for the self report-performance discrepancy suggests that some individuals lack insight into the extent of their driving difficulties (Freund, Colgrove, Burke, & McLeod, 2005; Lajunen et al., 1997). This may pose a significant limitation for using self-reports to guide driving assessment of older adults, as those with the poorest insight into their driving abilities have been found to pose the greatest danger to themselves and others on the road (Horswill, Anstey, Hatherly, Wood, & Pachana, 2011; Meng & Siren, 2012; Wood et al., 2013).

Driving Simulators

Driving simulators represent another means of assessing driving safety, and combine many of the strengths of on-road evaluations, cognitive tasks and self-report measures. Given their ability to immerse the participant in "real-world" driving scenarios, driving simulators are considered to have higher face validity in comparison to self-report measures and cognitive tests, and offer a more objective approach to evaluation. As a result, simulators are less vulnerable to the limitations of most subjective measures, which traditionally have included participants having poor insight or memory regarding the nature of their driving-related impairments (Schultheis & Rizzo, 2001). Simulators are also by definition immune to the biases that frequently cause individuals to attempt to convey themselves over positively on self-reports (Schultheis & Rizzo, 2001). Additionally, while on-road evaluations are considered the most accurate means of assessing driving capacity, simulators provide a safe means of testing driving performance and allow drivers to take actions that may be dangerous on the road (Allen, Stein, Aponso, Rosenthal, & Hogue, 1990; Ivancic IV & Hesketh, 2000). Driving simulators also both require less time and training to administer (Schultheis & Rizzo, 2001). Moreover, many simulators allow the researcher to control aspects of the driving experience, including interactions with other drivers and roadway conditions (Allen et al., 1990; Lee & Lee, 2005). Older adults and physicians generally have positive impressions about the clinical utility of driving simulators and have voiced an interest in continued understanding of simulator applications to real-world driving outcomes (Crisler et al., 2012).

Driving simulators have demonstrated utility in the assessment of cognitively healthy older adults' driving performance (Fraser, Hawken, & Warnes, 1994; Lee, Lee, Cameron, & Li-Tsang, 2003). Poorer performance in driving simulators has been shown to increase older adults' risk of committing being in an accident (odds ratios .39 to .83) and committing traffic violations (incident rate ratios .77 to 1.16) (Lee & Lee, 2005; Lee et al., 2003), and to be highly correlated with on-road test performance (e.g., r = .7 to .8) (Freund, Gravenstein, Ferris, & Shaheen, 2002). Additionally, driving simulators have been used to predict older adults' distractedness and lapses in attention while driving, which have been linked to unsafe driving behaviors (Brouwer, Waterink, Van Wolffelaar, & Rothengatter, 1991; Lee et al., 2003). Older adults' performance in simulators has also been shown to be predicted by other attributes known to impact driving safety in individuals of all ages, including anger, conscientiousness and sensation-seeking (r = .21 to r = .37) (Schwebel, Severson, Ball, & Rizzo, 2006). Some preliminary literature further suggests that driving simulator training may actually improve older adults' on-road performance, hinting at its utility as both an assessment and therapeutic instrument (Casutt, Theill, Martin, Keller, & Jäncke, 2014). Simulators have also been useful in the evaluation of driving capacity in mild cognitive impairment and Alzheimer's Disease patients (Frittelli et al., 2009; Rizzo, Reinach, McGehee, & Dawson, 1997).

Although simulators are a popular choice for assessing driving safety and have produced valuable information about driving performance-related variables in both healthy and clinical populations, many are exceedingly expensive to build (i.e., in the millions of dollars) as well as to administer on a per-participant basis. As a result, much of the driving simulator literature is attributable to only the small handful of research groups and institutions that can manage such exorbitant costs. These simulators offer high fidelity, complex motion platforms and tremendous control responsiveness, however most researchers cannot afford to implement them or administer them to participants.

Personal Computer-Based Simulators

With recent improvements in personal computer (PC) technology, PC-based simulators have been increasingly used for research purposes (Allen et al., 1990; Findley & Fabrizio, 1989; Gibbons, Mullen, Weaver, Reguly, & Bédard, 2014; Hassan & Gausemeier, 2013; W.-S. Lee, Kim, & Cho, 1998). Some have highlighted the value of these PC-based simulators in assessing unsafe driving patterns that put older adults at risk for traffic violations and crashes (Lee & Lee, 2005; Lee et al., 2003). For example, Belanger, Ganon and Yamin (2010) noted that challenging events that require multiple synchronized reactions leads to higher rates of crashes in older adults in comparison to younger adults (Bélanger, Gagnon, & Yamin, 2010). Researchers have even begun to develop models for predicting adverse traffic events based on performance in these simulators. Lee (2008) found that a logarithmic regression taking into account working memory, decision making under time pressure, confidence in one's driving ability at high speed, and compliance with traffic regulations successfully predicted crash risk (Lee, 2008).

While the PC-based simulators described above are less expensive than those discussed previously, they may still be more than most investigators are willing or able to pay; a PC-based simulator constructed at Finland's University of Oulu designed to be of "low cost" is approximately $28,000 to purchase (Koskela, Nurkkala, Kalermo, & Järvilehto, 2011), while the popular STISIM Driving Simulator models typically cost in excess of $20,000 to $30,000 (Bélanger et al., 2010; Lee & Lee, 2005; Lee et al., 2003; Lee, 2008). Lee (2008) notes that the more sophisticated the components of the simulator (i.e., the video image generator, the projection system, the motion system and the sound system), the more expensive the simulator (Lee, 2008)

Current Study

Despite a considerable literature on cognitive predictors of driving outcomes and performance in those with clinically significant cognitive impairment, less work has explored these predictors in cognitively healthy older adults. When research has examined this population, cognition is typically assessed globally rather than at an individual domain level (Ball et al., 1993; Odenheimer et al., 1994; Owsley et al., 1991; Sims et al., 1998; Stutts et al., 1998), or only one particular domain (e.g., attention) is assessed (Clay et al., 2005; McDowd & Shaw, 2000; Park et al., 2011). When these domains are explored, they are traditionally assessed via a limited set of measures (e.g., Trail-Making Test, Symbol-Digit Modalities Test). Other measures that have been purported to have greater ecological validity (e.g., NAB Map-Reading, NAB Mazes, and NAB Driving Scenes), by contrast, have been less explored in their associations with simulated driving performance. As such, the present study assessed relationships between a variety of paper-and-pencil cognitive measures and driving simulator performance. Such work is necessary in order to better ascertain which specific cognitive measures may accurately predict simulated driving performance, which would have implications for neuropsychological clinical practice when assisting in making driving safety determinations.

Additionally, although a variety of self-report measures have been developed to characterize driving behaviors, thoughts and styles, prior work has rarely explored associations between self-report measures and driving simulator performance. What limited work does exist in this area is mixed, and studies have only utilized a single driving self-report measure when making these determinations (Baldock et al., 2006; Schwebel et al., 2007). Given the conflicting literature, the present study evaluated multiple facets of self-reported driving, in particular by exploring both aberrant driving behaviors as well as situational driving avoidance. These aspects of self-reported driving have been shown to change in late life (Ball et al., 1993; De Winter & Dodou, 2010; Vance et al., 2006). Thus, an exploration of whether these changes in self-reported driving translate to poorer performance is warranted.

The current study also sought to examine the utility of a novel driving simulator in the assessment of older adults' driving capacities. Although driving simulators provide numerous advantages over other methods of driving assessment, one drawback is that they are expensive to both purchase and operate (Bélanger et al., 2010; Koskela et al., 2011; Lee & Lee, 2005; Lee et al., 2003; Lee, 2008; W.-S. Lee et al., 1998). This limits the number of investigators and research groups who may administer driving simulator tasks and prevents greater proliferation of driving-related knowledge. As such, the simulator utilized in this study was chosen due to its relative inexpensiveness balanced with state-of-the-art graphics and realism. As such, the study serves as a proof-of-concept for future work utilizing this simulator.

Given the above, the specific research questions that will be examined are:

(1) Do paper-and-pencil measures designed to have greater ecological validity add incremental variance beyond demographics and traditional measures in predicting performance on a measure of simulated driving?

(2) Does computerized cognitive testing (i.e., UFOV) add incremental variance beyond demographics and paper-and-pencil cognitive measures in predicting performance on a measure of simulated driving?

(3) Is self-reported driving (i.e., aberrant driving behaviors and avoidance of specific driving situations) associated with simulated performance on a measure of simulated driving?

(4) Are paper-and-pencil and computerized cognitive measures associated with self-reported driving?

Hypotheses

Hypotheses for each of the research questions is presented below:

(1) Given that the NAB Map-Reading and Driving Scenes were designed to have higher ecological validity than prior paper-and-pencil measures, it is expected that these subtests will account for additional variance in driving simulator variables above and beyond demographic factors and the Trail-Making Test and Symbol-Digit Modalities Test. Additionally, given preliminary work indicative of its utility in predicting driving performance in older adult samples, it is expected that the NAB Mazes subtest will also account for additional variance in driving simulator variables above and beyond demographics, the Trail-Making Test and the Symbol-Digit Modalities Test.

(2) Given literature suggestive of its strong relationship to simulated driving performance in older adult samples, it is expected that the UFOV will account for additional variance in driving simulator variables above and beyond demographics and paper-and-pencil measures.

(3) Given the very limited literature regarding associations between cognitively healthy older adults' self-reported driving ability and simulated driving performance, no hypotheses regarding these relationships were proposed.

(4) Given the very limited literature regarding associations between cognitively healthy older adults' self-reported driving ability and measures of cognitive performance, no hypotheses regarding these relationships were proposed.

METHODS

Participants & Procedure

This study was approved by the Louisiana State University (LSU) Institutional Review Board. Participants were primarily recruited from the Louisiana Aging Brain Study (LaBrainS), a longitudinal study of cognitive aging run by the Institute for Dementia Research and Prevention at the Pennington Biomedical Research Center (Bernstein, Calamia, & Keller, 2018; Brouillette et al., 2013; Calamia, Bernstein, & Keller, 2016; Calamia et al., 2018; MacAulay, Brouillette, Foil, Bruce-Keller, & Keller, 2014). Participants were also recruited via flyers at community events (e.g., local aging research conferences, continuing education classes) and public places (e.g., coffee shops). Participants were compensated $25 for their time. Inclusionary criteria included that participants be native English speakers, over the age of 55, and cognitively healthy at the time of the study appointment (i.e., score of 24 or above on the Mini-Mental Status Exam (MMSE). A power analysis completed using G*Power indicated that a sample of 103 participants would be needed to have 80% power to determine whether a predictor of a medium effect size would add to the R^2 of hierarchical regression models using a statistical significance of $p < .05$.

A total of 53 participants were recruited for the present study. Of these, 35 (66.0%) completed all study measures including at least two laps on the driving simulator. The remaining 18 participants (34%) completed all study measures except the driving simulator task. While these individuals attempted to complete the simulator task, they experienced simulator sickness prior to completing two laps, and thus their participation on the simulator was discontinued.

Participants were a mean of 72.2 years of age (*SD* = 8.1) and had a mean of 16.7 years of education (*SD* = 2.2). A total of 73.6% of the sample was female and 96.0% were Hispanic or Latino. Most participants (96.0%) were Caucasian, while the remainder (4.0%) was African-American. Participants obtained a mean score of 28.9 on the MMSE (*SD* = 1.2), indicating that the sample was broadly cognitively intact. They obtained a mean score of 1.22 (*SD* = 1.88) on the GDS, indicating minimal depression.

Data collection was completed during a single two-hour session for each participant. Study investigators or trained undergraduate research assistants administered all measures to participants. Study sessions commenced with informed consent, followed by completion of the measures described below.

Measures

Driving Simulator

A custom-built, personal computer-based racing simulator was used to measure simulated driving performance (see Figure 1). The simulator program was Assetto Corsa (AC) by Kunos Simulazioni, which features a realistic driving model, easy data access, and high-fidelity graphics. AC is also priced much lower than other simulators ($2,368) (Bugeja, Spina, & Buhagiar, 2017). The simulator used in this study was built in a manner consistent with that of a prior group using AC (Stowe, 2016), and included an Intel Core i5-4690 processor, a Samsung 850 EVO solid state drive, 16GB of memory, and an nVidio GeForce GTX970 4GB SC Gaming graphics card. The simulator ran on Microsoft Windows 7 Pro 64x. The simulator had a 40-inch class LED 1080p HDTV, with a Thrustmaster T500RS steering wheel and pedals (i.e., a throttle pedal and a brake pedal). A STEAM account was used to run AC. MoTec i2 Standard software was used to collect data.

Figure 1. Assetto Corsa Driving Simulator

Prior to completing the driving task, participants were introduced to the simulator controls. Participants then completed one lap on a practice AC course, Monza 1966 Junior course, which is relatively flat in terrain, has a well-defined, paved road and had no other cars on the road. This course was unmodified and available by default via AC. Driving aids (e.g., racing line, traction control) and tire wear and tear were disabled. Consistent with that of a prior group utilizing AC for clinical research (Stowe, 2016), participants were instructed to complete the course driving at a fast pace but one they felt comfortable at and in which they maintained full control of the vehicle.

The test simulator task began following completion of the practice lap and once the participant affirmed that they were comfortable with the driving simulator. The test task involved completion of two laps on the AC course Black Cat County, which is a mountainous and winding route. This course was chosen given its challenging turns and emphasis on maintaining vehicle control and speed. These course attributes would assumedly result in higher cognitive demand, which would allow for significant variability in performance among participants. This course was also chosen in order to be consistent with protocols developed by a prior research group when using AC as a clinical research tool (Stowe, 2016). Similar to the practice AC course, Black Cat County has well-defined, paved roads and was completed without any other cars on the road. Information regarding specific simulator variables measured is included in Table 1. Given that participants were instructed to complete the course as quickly as possible, time served as the primary outcome measure of driving performance quality. Other simulator variables were not in and of themselves considered to represent driving performance quality but rather aspects of driving style (e.g., a “lead foot” profile or tendency to frequently utilize the throttle and brake pedals) (Wakita et al., 2006).

Table 1. Driving Simulator Variables

Variable	**Unit**	**Data Collected**	**Description**
Time	Seconds	Lap 1, Lap 2, Combined	Elapsed time since the simulator task began
Tires Off Track	Number of tires	Average	Number of tires located off course road
Throttle Pressure	Percent	Average, Max	Percent of total possible pressure applied to throttle pedal
Brake Pressure	Percent	Average, Max	Percent of total possible pressure applied to brake pedal

All tables were previously published as John PK Bernstein, Matthew Calamia, Alyssa N De Vito, Katie E Cherry, & Jeffrey N Keller, “Multimethod Assessment of Driving in Older Adults Using a Novel Driving Simulator”, *Applied Neuropsychology: Adult* (2020): 1-10. Reprinted by permission of Taylor & Francis Group.

Cognitive Performance Measures

Participants completed a battery of cognitive measures that encompassed a range of cognitive domains. Some of these measures were derived from the Neuropsychological Assessment Battery (NAB), whereas the rest were standalone measures.

Mini Mental State Examination (MMSE). The MMSE is a screener measure of global cognitive functioning (Folstein, 1975). The MMSE has demonstrated adequate internal consistency and test-retest reliability in previous work (.80 to .95) (Tombaugh & McIntyre, 1992).

NAB Driving Scenes. NAB Driving Scenes is a complex visual task assessing visual working memory and attention and visual scanning. In this task, the participant is first presented with drawing of a driving scene as viewed from behind a steering wheel, and then shown a second scene and asked to determine what features were not present in the first scene. Four additional scenes are given (White & Stern, 2003). NAB subtests included in the present study demonstrate adequate to high internal consistency (.70 to .90) (White & Stern, 2003) although test-retest reliability is lower (.59 to .69).

NAB Map Reading. NAB Map Reading is a complex measure of visuospatial ability, including visual scanning and orientation. In this task, the participant answers oral and written questions about a city map that has a compass rose and mileage legend (White & Stern, 2003).

NAB Mazes. NAB Mazes is an executive functioning task assessing inhibition and planning. In this task, the participant completes seven timed paper-and-pencil mazes of increasing difficulty (White & Stern, 2003).

Trail-Making Test (A & B). This is a measure of visual attention and task switching. In Part A of this task, the participant connects a set of circles (numbered 1-25) in numerical order as quickly as possible. In Part B, the circles are labeled with either numbers (1-13) or letters (A-L), and the participant connects them in an ordered, alternating pattern (i.e. 1, A, 2, B, etc.) (Reitan, 1955). Both Trails A and B demonstrate adequate to high test-retest reliability (.79 to .89) (Dikmen et al., 1999).

Symbol Digit Modalities Test (SDMT). The SDMT is s a widely used measure of processing speed. In this task, the participant uses a key matching numbers to figures to complete a grid in which figures are present, but the corresponding numbers are missing (Smith, 1982). The SDMT has high test-retest reliability (.80) (Smith, 1991).

Uniform Field of Vision Task (UFOV). The UFOV is a computerized measure with three subtests assessing processing speed, selective attention, and divided attention. In this task, participants are asked to identify the type of object or location of an object following very brief presentations of visual stimuli across a wide field of view (Owsley et al., 1991). The UFOV has high test-retest reliability (Edwards, Vance, Wadley, Cissell, Roenker & Ball, 2005).

Self-Report Measures

Participants completed an online survey using Qualtrics software during the study appointment (www.qualtrics.com). The survey included several measures assessing self-reported driving behaviors and history. These measures are traditionally administered via pencil-and-paper. Modified versions of all questionnaires were used in this study to allow for online completion. Other measures not included in the proposed analyses were also administered as part of this study.

Driving Behavior Questionnaire (DBQ). Participants completed the shortened 24-item version of the DBQ as a measure of aberrant driving behaviors (Reason, Manstead, Stradling, Baxter, & Campbell, 1990). The DBQ includes three subscales: Lapses in Attention (i.e., unintentional behaviors that do not risk the safety of other road-users, e.g., misreading signs), Errors (i.e., unintentional behaviors that could risk the safety of other drivers, e.g., getting into wrong lane when approaching intersections) and Violations (i.e., deliberately breaking rules of safe driving that may could risk the safety of other drivers, e.g., getting involved in unofficial 'races' with other drivers). Respondents report the frequency with which they engage in these behaviors on a scale of 1 (Never) to 6 (Nearly All The Time). The DBQ has adequate test-retest reliability across subscales (.50 to .76) (Ozkan, Lajunen & Summala, 2006).

Driving Habits Questionnaire (DHQ). The survey included items from the DHQ, which is a measure of self-reported exposure to driving, dependence on other drivers, avoidance of driving, places driven and recent history of crashes and citations (Ball et al., 1998). The current study utilized solely those items related to crashes and citations within the past year. Specifically, respondents report the number of occurrences, on a scale of 0 to 5 or more, with which they have been involved in: (1) any crashes for which they were the driver, irrespective of fault; (2) any crashes for which the police were called to the scene; (3) any times pulled over by the police, irrespective of whether a ticket was received; and (4) any traffic tickets received (other than parking tickets). Participants also report the number of accidents in the past year they've been involved in when they were the driver, number of accidents when police were called to the scene, number of times pulled over by the police, and how many times they received a traffic ticket (e.g., speeding tickets, tickets for running a red light). Following data collection, these responses to each item were dichotomized (e.g., history/no history of crashes within the previous year) given the high number of participants reporting no crashes or citations. Participants also rate how safe a driver they believed they are in comparison to other drivers their age, on a five-point scale from 1 (Far Less Safe Than Others) to 5 (Far More Safe Than Others). The DHQ has good test-retest reliability and adequate to high internal consistency (.52 to .96) (Song, Chun & Chung, 2015).

Fitness to Drive Screening Measure (FD). The FD is a 54-item paper-and-pencil measure of self or informant-reported difficulties driving in various traffic and weather conditions. Respondents report the difficulty with which they drive in these conditions on a scale of 1 (Very Difficult) to 4 (Not Difficult) (Classen et al., 2013; Winter et al., 2011). The FD has demonstrated high internal consistency (.97) (Classen, Velozo, Winter, Bedard & Wang, 2015).

Geriatric Depression Scale (GDS). The GDS is a 30-item paper-and-pencil measure of self-reported depressive symptoms. Respondents report whether or not they have experienced each symptom in the past week (i.e., Yes/No) (Yesavage et al., 1982). The GDS has high internal consistency (.94) and good test-retest reliability (.85) (Yesavage et al., 1982).

Analyses

To address question and hypothesis 1, multiple hierarchical regressions were used to examine relative contributions of each cognitive measure to individual driving simulator variables. Traditional paper-and-pencil measures (i.e., Trail-Making Test, SDMT) and demographic variables were entered in step 1 of regressions to control for their effects, and newer measures (i.e., NAB Driving Scenes, Map Reading and Mazes) were entered in Step 2 to determine whether additional variability in each driving simulator variable is accounted for. Each regression included one of the simulator variables as the outcome measure.

To evaluate question and hypothesis 2, multiple hierarchical regressions were used to examine relative contributions of paper-and-pencil cognitive measures and a computerized cognitive measure to individual driving simulator variables. All paper-and-pencil cognitive measures (i.e., both traditional and newer measures) as well as demographic variables were entered in step 1 of regressions to control for their effects, and UFOV measures were entered in step 2 to determine whether additional variability in each driving simulator variable was accounted for. Each regression included one of the simulator variables as the outcome measure.

To address question 3, Pearson correlation coefficients were used to examine associations between continuously measured self-report measures and simulator performance variables. Point-biserial correlation coefficients were used to examine associations between simulator performance variables and dichotomously measured self-report variables (i.e., DHQ objective driving variables).

To explore question 4, Pearson correlation coefficients were used to examine associations between continuously measured cognitive variables and self-report measures. Point-biserial correlation coefficients were used to examine associations between cognitive variables and dichotomously measured self-report variables.

RESULTS

Differences Between Participants Who Did and Did Not Complete Simulator Task

Relative to participants who completed the simulator measure (*M* = 0.98, *SD* = 1.42), those who did not complete the simulator measure (*M* = 2.33, *SD* = 2.16) endorsed a greater number of depression-related symptoms (t (48) = 2.01, $p = .05$). Participants who did not complete the simulator measure (*M* = 73.00, *SD* = 16.09) also reported greater difficulty driving in various conditions than those who did complete the simulator measure (*M* = 93.17, *SD* = 23.41, $t(48) = -1.98$, $p = .06$). No other differences between groups were observed for any self-report measures (all $p > .05$). No differences were observed for any demographic variables (i.e., age, sex, education, race, ethnicity) or cognitive performance measures (all $p > .05$).

Question & Hypothesis 1

Results of the multiple regression analyses with demographics and paper-and-pencil cognitive measures as predictors of driving simulator performance may be found in Table 2. Step 1 variables (i.e., demographics and traditional paper-and-pencil cognitive measures) predicted average number of wheels off the track (adjusted $R^2 = .31$, $F(6, 29) = 3.64$, $p < .01$). Inspection of individual step 1 predictor variables revealed that poorer simple attention and executive functioning (i.e., longer times taken to complete Trails A ($\beta = .46$, $t(35) = 2.87$, $p < .01$) and Trails B ($\beta = 2.90$, $t(35) = 2.90$, $p < .01$)) were both associated with greater average number of tires off the track). Step 1 variables did not predict any other simulator outcome measures (all $p > .05$). The addition of newer paper-and-pencil measures (i.e., NAB measures) in step 2 did not increase the model's capacity to predict any simulator outcome measures (all $p > .05$).

Table 2. Effect of Demographics and Paper-and-Pencil Cognitive Measures on Driving Simulator Variables

Outcome Variable	Model	R Square	Adjusted R Square	R Square Change	F Change	Sig. F Change
Lap 1 Time	1	.10	-.09	.10	.55	.77
	2	.22	-.06	.11	1.26	.31
Lap 2 Time	1	.07	-.17	.07	.30	.93
	2	.13	-.26	.06	.47	.71
Combined Time	1	.07	-.17	.07	.30	.93
	2	.16	-.22	.09	.70	.56
Tires Off Track (Average)	1*	.43	.31	.43	3.64	.01
	2	.44	.25	.01	.20	.90
Throttle Pressure (Average)	1	.08	-.11	.08	.45	.84
	2	.25	-.01	.17	1.94	.15
Throttle Pressure (Max)	1	.15	-.03	.15	.85	.54
	2	.25	-.01	.10	1.20	.33
Brake Pressure (Average)	1	.10	-.09	.10	.51	.80
	2	.20	-.08	.11	1.16	.34
Brake Pressure (Max)	1	.14	-.04	.14	.76	.61
	2	.14	-.15	.01	.08	.98

Note. Model 1 includes demographic variables (i.e., age, sex, education) and traditional paper-and-pencil cognitive performance measures (i.e., Trails A and B, SDMT). Model 2 includes Model 1 measures as well as newer paper-and-pencil cognitive performance measures (i.e., NAB Map-Reading, Driving Scenes, Mazes).
*p < .01

Question & Hypothesis 2

Results of the multiple regression analyses with demographics, paper-and-pencil cognitive measures and computerized cognitive measures as predictors of driving simulator performance may be found in Table 3. Step 2 variables (i.e., UFOV measures) predicted average brake pressure above and beyond all variables included in step 1 (demographics, traditional paper-and-pencil cognitive measures, NAB measures) (adjusted $R^2 = .25$, $F(6, 29) = 4.68$, $p < .05$). Inspection of individual step 2 predictor variables revealed that poorer processing speed (i.e., longer threshold latencies on UFOV subtest 1) predicted greater average brake pressure ($\beta = .60$, $t(35) = 2.53$, $p < .05$). Step 2 variables did not predict any other simulator outcome measures after taking into account step 1 variables (all $p > .05$).

Table 3. Effect of Demographics, Paper-and-Pencil Cognitive Measures and Computerized Cognitive Measures on Driving Simulator Variables

Outcome Variable	Model	R Square	Adjusted R Square	R Square Change	F Change	Sig. F Change
Lap 1 Time	1	.15	-.28	.15	.35	.95
	2	.28	-.30	.13	.92	.45
Lap 2 Time	1	.11	-.50	.11	.19	.99
	2	.16	-.85	.05	.19	.90
Combined Time	1	.13	-.47	.13	.22	.99
	2	.22	-.73	.09	.36	.78
Tires Off Track (Average)	1	.42	.12	.42	1.42	.25
	2	.46	.03	.05	.42	.74
Throttle Pressure (Average)	1	.30	-.05	.30	.86	.58
	2	.35	-.17	.05	.40	.75
Throttle Pressure (Max)	1	.40	.10	.40	1.32	.29
	2	.44	-.01	.04	.35	.79
Brake Pressure (Average)	1	.20	-.20	.20	.49	.86
	2*	.59	.25	.39	4.68	.02
Brake Pressure (Max)	1	.14	-.29	.14	.33	.95
	2	.40	-.09	.25	2.10	.14

Note. Model 1 includes demographic variables (i.e., age, sex, education), traditional paper-and-pencil cognitive performance measures (i.e., Trails A and B, SDMT) and newer paper-and-pencil cognitive performance measures (i.e., NAB Map-Reading, Driving Scenes, Mazes). Model 2 includes Model 1 measures as well as computerized cognitive performance measures (i.e., UFOV).
* $p < .05$

Question 3

Correlation matrices including self-report and simulator measures may be found in Table 4. Slower lap 2 times and slower combined lap 1 and 2 times were associated with lower self-ratings of driving safety in comparison to other drivers ($r(33) = -.54$, $p < .01$ and $r(33) = -.53$, $p < .01$, respectively). Higher average throttle pressure was associated with higher self-ratings of driving safety in comparison to other drivers ($r(33) = .55$, $p < .01$). No other significant correlations between self-report and simulator measures were found (all $p > .05$).

Table 4. Correlations Among Driving Self-Report Measures and Driving Simulator Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. FD	-																
2. DBQ Lapses	.30	-															
3. DBQ Errors	.14	.56**	-														
4. DBQ Violations	.37*	.56**	.59**	-													
5. Self-Rating	.33	.25	.49**	.52**	-												
6. Accidents Past Year	-.20	.13	.23	.24	.10	-											
7. Accidents Past Year, Police Called	-.07	.05	.32	.37**	.38*	.68**	-										
8. Times Past Year Pulled Over By Police	.18	-.02	.41*	.-.06	.05	-.07	-.05	-									
9. Times Past Year Received Traffic Ticket	.18	-.02	.41*	-.06	.05	-.07	-.05	1.00**	-								
10. Lap 1 Time	-.25	-.04	-.10	.02	-.35	.27	-.14	-.06	-.06	-							
11. Lap 2 Time	-.23	-.11	-.18	-.07	-.54**	.27	-.14	-.08	-.08	.78**	-						
12. Combined Time	-.26	-.11	-.17	-.04	-.53**	.28	-.16	-.09	-.09	.95**	.94**	-					
13. Tires Off Track (Average)	.02	-.06	-.17	.16	-.041	.06	-.23	-.18	-.18	.13	-.02	.03	-				
14. Throttle Pressure (Average)	.27	-.04	.08	.07	.55**	-.15	.18	.05	.05	-.77**	-.84**	-.85**	.15	-			
15. Throttle Pressure (Max)	.34	-.18	-.11	-.12	.29	-.16	.14	.14	.14	-.46**	-.58**	-.61**	.13	.51**	-		
16. Brake Pressure (Average)	.10	-.30	-.05	-.16	.36	-.06	.20	.31	.31	-.45**	-.61**	-.57**	-.07	.61**	.42**	-	
17. Brake Pressure (Max)	-.03	-.06	-.09	-.17	-.10	.17	.03	.14	.14	-.33*	-.36**	-.31	.04	.40**	.15	.57**	-

Note. FD = Fitness to Drive Screening Measure; DBQ = Driving Behavior Questionnaire
*p < .05 **p < .01

Question 4

Correlation matrices including cognitive performance and self-report measures may be found in Table 5. Poorer processing speed (i.e., worse performance on the SDMT) was associated with higher self-reported difficulty driving in various conditions ($r(51) = .41$, $p < .05$). Poorer simple attention (i.e., worse performance on Trails A) was associated with greater self-reported frequency of unintentional driving errors that may endanger other drivers and greater likelihood of having been behind the wheel when involved in an accident in the past year ($r(51) = .45$, $p < .05$ and $r_{pb}(51) = .38$, $p < .05$, respectively). Poorer visuospatial abilities (i.e., worse performance on NAB Map-Reading) were associated with greater self-reported frequency of unintentional driving errors that may endanger other drivers ($r(51) = -.39$, $p < .05$).

Poorer visuospatial abilities were also associated with higher likelihood of having been pulled over by police and higher likelihood of receiving a traffic ticket in the past year (both $r_{pb}(51) = -.36$, $p < .01$). Poorer divided attention (i.e., longer threshold latencies on UFOV subtest 2) was associated with greater likelihood of having been behind the wheel when involved in an accident in the past year ($r_{pb}(51) = .51$, $p < .01$). Poorer selective attention (i.e., longer threshold latencies on UFOV subtest 3) was associated with greater likelihood of being pulled over by police and receiving a traffic ticket in the past year (both $r_{pb}(51) = .57$, $p < .01$). No other significant correlations between cognitive performance and self-report measures were found (all $p > .05$).

Table 5. Correlations Among Cognitive Performance and Driving Self-Report Measures

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. FD	-																	
2. DBQ Lapses	.30	-																
3. DBQ Errors	.14	.56**	-															
4. DBQ Violations	.37*	.56**	.59**	-														
5. Self-Rating	.33	.25	.49**	.52**	-													
6. Accidents Past Year	-.20	.13	.23	.24	.10	-												
7. Accidents Past Year, Police Called	-.07	.05	.32	.37**	.38*	.68**	-											
8. Times Past Year Pulled Over By Police	.18	-.02	.41*	.-.06	.05	-.07	-.05	-										
9. Times Past Year Received Traffic Ticket	.18	-.02	.41*	-.06	.05	-.07	-.05	1.00**	-									
10. Trails A	.05	.35	.45*	.28	.25	.38*	.25	.31	.31	-								
11. Trails B	-.16	.14	.00	.13	-.15	.00	-.15	-.07	-.07	.40**	-							
12. SDMT	.41*	-.10	-.23	-.08	.04	-.04	.15	-.20	-.20	-.47**	-.44**	-						
13. NAB Map Reading	-.13	-.22	-.39*	-.25	-.01	-.03	.07	-.36**	-.36*	-.39**	-.31*	.26	-					
14. NAB Driving Scenes	.18	.11	-.25	-.02	-.25	.07	.01	-.18	-.18	-.25	.19	.18	.17	-				
15. NAB Mazes	.19	-.15	-.30	-.01	.04	.10	.08	-.25	-.25	-.41**	-.30*	.43**	.35*	.31*	-			
16. UFOV Test 1	.30	.33	.26	.21	.05	-.07	.06	.08	.08	.27	.15	-.14	-.23	-.24	-.22	-		
17. UFOV Test 2	-.10	.00	-.05	-.17	-.16	.51**	.02	.06	.06	.33*	.08	-.17	.05	.05	-.24	.08	-	
18. UFOV Test 3	-.17	-.04	.31	-.19	-.29	.18	.11	.57**	.57**	.38*	.13	-.37*	-.12	-.01	-.43**	.37*	.45**	-

Note. FD = Fitness to Drive Screening Measure; DBQ = Driving Behavior Questionnaire; SDMT = Symbol-Digit Modalities Test; NAB = Neuropsychological Assessment Battery; UFOV = Useful Field of Vision
*p < .05 ** p < .01

DISCUSSION

As the number of older drivers on the roads continues to increase, so do concerns regarding their driving safety. Clinicians tasked with evaluating older adults' driving safety report positive views of driving simulator technologies as a means of driving evaluation in this population (Crisler et al., 2012). However, while simulators present with a number of benefits over on-road evaluations (e.g., safety, control of the driving environment), self-reports (e.g., objectivity), and cognitive tests (e.g., ecological validity), exorbitant purchasing and operation costs have limited the use of simulators in clinical and research settings. The present study sought to determine whether a novel, cost-effective driving simulator measure might be useful in the assessment of driving-related abilities in a cognitively healthy older adult sample.

Associations Between Demographics and Driving Simulator Variables

Age was unassociated with any driving simulator variables, a finding at odds with prior older adult literature suggestive of a negative relationship between this variable and simulated driving performance (Brouwer et al., 1991; Lee et al., 2003) and in spite of a large age range within the sample. Other demographic variables (i.e., sex, education) were also not found to predict simulator variables. These results are in conflict with a limited literature indicating that males drive at higher speeds and put greater pressure on the acceleration pedal (Hagen, 1975). These findings have not been replicated in other simulator studies as more recent work in this area has relied exclusively on self-report (Lourens, Vissers, & Jessurun, 1999; Shinar, Schechtman, & Compton, 2001). Similarly, education has not been explored in depth as a predictor of on-road or simulated driving performance. Although self-report studies suggest those with greater education differ in some respects from those with less education (e.g., higher rates of seatbelt use, lower adherence to speed limits), these facets of driving are not assessed in the simulator utilized by the present study (Lourens et al., 1999; Shinar et al., 2001). Lack of observed associations between simulator variables and demographics may also be partially attributable to the homogeneity of the sample with regard to sex (73.6% female) and education (mean of 16.7 years (*SD* = 2.2)). With greater male representation and educational diversity, it is possible that these variables would have emerged as significant predictors of simulator variables.

Paper-and-Pencil Tests of Cognition and Driving Simulator Variables

Poorer performance on traditional measures of both simple attention (i.e., Trails A) and executive function (i.e., Trails B) was associated with a greater average number of tires off the track. These results are broadly consistent with a multitude of literature suggesting that these measures are useful when screening for driving safety in older adults, including on-road performance (Asimakopulos et al., 2012; Lezak et al., 2004; Niewoehner et al., 2012) and state-recorded, at-fault crashes (Ball et al., 2006; Goode et al., 1998). Richardson and Marottoli (2003) have similarly noted that both visual attention (measured via the number cancellation task) and executive functioning (Trails B) are associated with older adults' driving performance, with the former demonstrating an especially pertinent role in many important driving maneuvers (Richardson & Marottoli, 2003).

In contrast, performance on a traditional measure of processing speed (SDMT) was not associated with any driving performance variables, a finding at odds with prior work (Schultheis et al., 2010; Stolwyk, Charlton, Triggs, Iansek, & Bradshaw, 2006).

However, these studies have largely recruited from clinical populations in which impaired processing speed is common (i.e., multiple sclerosis, Parkinson's Disease). In their study of a cognitively healthy sample, Richardson and Marottoli (2003) found no association between SDMT scores and on-road driving performance after controlling for visual acuity (Richardson & Marottoli, 2003). Furthermore, while others have noted that interventions to improve processing speed may result in delayed driving cessation, a potential indicator of driving safety (Edwards, Delahunt, & Mahncke, 2009; Roenker, Cissell, Ball, Wadley, & Edwards, 2003), the individuals recruited for these studies had low baseline processing speed (i.e., poor UFOV scores). As the present study sample was composed largely of individuals who performed well on the UFOV and had no history of significant neurological disorders, ceiling effects may have prevented a similar relationship from being observed.

At odds with hypotheses, newer paper-and-pencil measures of cognition (i.e., NAB measures) did not demonstrate increased predictive utility above and beyond traditional measures. This is surprising given that these measures both were designed to increase the ecological validity of neuropsychological assessment, as well as have shown promise in predicting on-road performance previously (Brown et al., 2005; Niewoehner et al., 2012). These results may hint at the importance of cognitive performance in predicting driving safety, independent of the assumed ecological validity of the cognitive measures used. Niewoehener and colleagues (2012) and Brown and colleagues (2005) also recruited samples at least partially comprised of those with cognitive or visual impairment; this greater variability in cognitive ability likely translated to increased variability in driving safety among participants as well, and thus resulted in the observed cognition-driving relationships.

Associations Between Computerized Measures of Cognition and Driving Simulator Variables

After first entering demographic and paper-and-pencil cognitive measures, the addition of all three UFOV subtests into regression models resulted in a significant increase in prediction of brake pressure. This increase was attributed to UFOV subtest 1, which is comprised of a simple stimulus identification task and taps basic processing speed. This finding is somewhat surprising, as a measure of processing speed is already included in step 1 (i.e., SDMT) and thus potentially accounting for some of the variance in brake pressure that otherwise would be attributable to UFOV subtest 1. However, inspection of correlations between UFOV subtest 1 and SDMT scores reveal no association between the two (r = -.14), which is consistent with that reported by Edwards and colleagues (2006) regarding the same UFOV subtest and a measure similar to the SDMT (i.e., WAIS-R Digit Symbol Substitution) (r = -.27) (Edwards et al., 2006). Thus, while the two measures are both purported to assess processing speed, they may tap different aspects of the domain. In particular, the SDMT but not the UFOV subtest 1 requires intact speeded motor movements. As a result, the former may be considered to assess both processing speed and motor speed, while the latter may be considered solely a measure of processing speed. Given the lack of associations between the SDMT and simulator variables discussed earlier, this pattern of findings suggests that measures that purely tap processing speed, and not also motor functioning, may be useful in predicting aspects of simulated driving in cognitively healthy older adults.

By comparison to findings regarding UFOV subtest 1, neither subtest 2 nor 3 was significantly predictive of any simulator variables. This pattern of results indicates that while poorer processing speed is associated with increased brake pressure, higher-level abilities assessed via the UFOV (i.e., divided and selective attention) are not after taking into account the demographic and cognitive variables included in step 1. These results are at odds with expectations, particularly concerning UFOV subtest 2; of the three UFOV subtests, subtest 2 has been shown to be the best predictor of at-fault crash involvement (Ball et al., 2006).

In general, relatively few cognitive measures were found to be associated with driving simulator variables. This was true both for newer measures for which there is little prior investigation of their associations with simulated driving performance (i.e., the NAB measures), but also for measures that have been frequently linked to on-road and simulated driving performance (i.e., Trails A and B, SDMT, UFOV). It is worth noting, however, that even relationships between most of these tests and driving performance vary from study to study (with the possible exception of UFOV) and are generally modest in strength (Mathias & Lucas, 2009). This is true even within an individual research group; for example, whereas Anderson and colleagues (2005) denoted significant associations between both Trails A and B with a composite measure of driving performance, Dawson and colleagues (2010) (a group comprised largely of the same team of investigators) did not identify these relationships (Anderson, Rizzo, Shi, Uc, & Dawson, 2005; Dawson, Uc, Anderson, Johnson, & Rizzo, 2010). One noticeable difference between Anderson (2005) and Dawson (2010) is that whereas the former employed a simulator, the latter employed an on-road evaluation. The discrepancy in findings between these studies highlights that associations between cognitive measures and driving performance may depend partially on the driving performance measure chosen.

Moreover, investigators must consider their results in light of how their driving measure differs from others. In the case of the present study, whereas other simulators typically involve frequent stopping maneuvers and adjustments for objects in the environment (e.g., pedestrians, stop signs, traffic lights, speed limit signs) (Lee & Lee, 2005; Schultheis & Rizzo, 2001; Schwebel et al., 2007), AC courses do not include these, as they are closed speedways. The presence of other drivers on the road, which an individual relies on to establish a safe driving speed and in a way serve as obstacles that a driver must navigate around safely (Broughton, Switzer, & Scott, 2007), was also absent from the AC course used. In-car technologies that may distract a driver (e.g., radio, global positioning system (GPS) navigation) are not included in AC vehicles (Brown & Laurier, 2012; Horberry, Anderson, Regan, Triggs, & Brown, 2006). These facets of the driving experience have been shown to increase demand on a variety of cognitive abilities in older adults as well as more broadly when completing on-road evaluations or driving simulator tasks (Mäntylä, Karlsson, & Marklund, 2009; Patten, Kircher, Östlund, Nilsson, & Svenson, 2006; Son et al., 2011; Wood, Chaparro, & Hickson, 2009). As such, it is possible that the absence of these attributes may have reduced the overall cognitive demands of the task, resulting in limited observed associations between simulator variables and cognitive performance. Future studies should take this information into consideration when determining whether the AC is appropriate for their research goals.

Associations Between Self-Report Measures and Driving Simulator Variables

In general, participants who drove more slowly during the simulator task rated themselves as being worse drivers relative to others of similar age. This was true with regard to longer times taken to complete both the second lap of the course and cumulative time across the two laps. Self-reported driving safety is often a poor predictor of older adults' on-road performance, and some have even found that those who report even being just slightly better drivers than others their age are in fact more likely to be unsafe (Freund et al., 2005; Marottoli et al., 1998). Findings from the present study are at odds with this literature. As participants were instructed to drive as quickly as possible, slower driving was equated with poorer performance, and thus results suggested that self-reported driving safety was actually an accurate indicator of performance.

Associations Between Self-Report Measures and Cognitive Performance

Several lower-level cognitive abilities assessed via paper-and-pencil measures were associated with individual facets of self-reported difficulties driving. Poorer simple attention was associated with greater frequency of self-reported unintentional driving errors and higher self-reported accident risk. Taken in tandem with the effect of simple attention on simulated driving performance reported earlier, these results hint at the fundamental role that simple attention plays in underpinning many of the everyday abilities necessary for safe driving. Although not a predictor in regression analyses, poorer paper-and-pencil-measured processing speed (i.e., SDMT) was associated with greater self-reported difficulty driving in various conditions, further suggesting that the measure may be a useful correlate if not independent predictor of aspects of driving behavior. Given the pertinent role visuospatial abilities play in driving safety both in impaired (Foley et al., 2013; Uc et al., 2007) and cognitively healthy older adult populations (Ball et al., 1993; Owsley et al., 1991), it is unsurprising that this domain was linked to a range of unintentional driving errors and legal repercussions (i.e., being pulled over by police, receiving tickets) associated with driving.

In contrast, higher-order cognitive abilities (e.g., executive functioning) assessed via paper-and-pencil were unrelated to self-reported driving difficulties. Both the traditional and newer paper-and-pencil executive functioning measures utilized in the present study have demonstrated associations with self-reported accident risk and aberrant driving behaviors in previous studies (Asimakopulos et al., 2012; Ball et al., 2006; Niewoehner et al., 2012). Trails B in particular is among the most oft-used neuropsychological instruments when making driving safety determinations (Anstey et al., 2005; Ott et al., 2013; Ott et al., 2003; Roy & Molnar, 2013; Stutts et al., 1998; Vrkljan, Myers, Blanchard, Crizzle, & Marshall, 2015). However, while this past work has frequently identified associations with driving variables in those individuals at heightened risk for being involved in an accident (e.g., based on UFOV scores, a clinical diagnosis or prior accident history), associations in nonclinical samples are more inconsistent (Ott et al., 2013; Ott et al., 2003; Rapoport et al., 2013; Richardson & Marottoli, 2003). This contrast from the present study, which did not specifically target individuals with a clinical diagnosis, may help explain the lack of self-report correlates with executive functioning measures.

UFOV subtests 2 and 3 were correlated with self-report driving measures related to crash risk and legal repercussions due to driving. These findings are consistent with a wealth of literature supportive of the UFOV as a predictor of past and future driving difficulties (Ball et al., 1993; Clay et al., 2005; Owsley et al., 1991). Poorer divided attention, as assessed via UFOV subtest 2, was linked to heightened risk for being involved in an accident. As indicated earlier, this UFOV subtest has been found to be the most accurate indicator of at-fault crash involvement (Ball et al., 2006). Selective attention, as assessed via UFOV subtest 3, was associated with heightened likelihood of being pulled over by police and receiving a ticket. While the UFOV has been used extensively to predict crash risk, less is known about its capacity to predict older adults' non-crash related driving incidents that nonetheless may be an indicator of dangerous driving. As such, the present study is among the first to suggest that UFOV measures may be useful in predicting this aspect of self-reported driving safety.

Limitations

The present study was limited by a relatively small sample size, particularly with regard to the number of individuals who actually completed two laps on the driving simulator measure. A sizable proportion of the sample (33%) was unable to complete the simulator task due to simulator sickness. In comparison to young adults, older adults take longer to adapt to driving simulators and are more prone to simulator sickness (Classen, Bewernitz, & Shechtman, 2011; Kawano et al., 2012; Roenker et al., 2003). Simulator sickness is a frequent cause of study dropout in this population, with prior work often indicating similar or higher dropout rates to the present investigation (Edwards, Creaser, Caird, Lamsdale, & Chisholm, 2003; Kawano et al., 2012; Roenker et al., 2003). Future studies utilizing AC in an older adult sample should plan to recruit a larger number of participants than is necessary for analyses. They may also wish to screen for simulator sickness during recruitment (Kennedy, Lane, Berbaum, & Lilienthal, 1993) and employ techniques that might help reduce simulator sickness, such as providing a two-day delay between initial acclimation to the simulator and the driving session (Domeyer, Cassavaugh, & Backs, 2013).

The exclusion from analyses of participants who did not complete the simulator measure, and trends regarding their differences from those who did complete the measure (i.e., depressive symptoms, self-rating of driving safety) may have resulted in a selection bias and thus findings may not be representative of cognitively healthy older adults more broadly. As greater age has been linked to heightened accident risk on a per-mile driven basis (Dellinger et al., 2002; Keall & Frith, 2004; Massie et al., 1995; Ryan et al., 1998), future work should explore this through the recruitment of a lifespan sample and having participants drive a greater and uniform distance in the simulator. In comparison to the older adult population in the state of Louisiana, the present study sample was also more highly comprised of Caucasians, females, and those with greater educational attainment (AARP, 2017), which may further limit generalizability.

As AC has never been validated against an on-road driving test and lacks several attributes typical of most individuals' everyday driving experiences (e.g, presence of other drivers, stoplights, speed limits), it remains unclear whether performance on AC is indicative of actual driving safety. Future validation work should include an on-road evaluation in order to better determine the clinical and research utility of this simulator.

The present study was exploratory in several respects: it was among the first to utilize the AC simulator in a clinical research context, it recruited an exclusively cognitively healthy sample, it included several cognitive measures not frequently examined in relation to driving performance, and it examined associations among types of variables that, while related to driving safety, have not been extensively evaluated (e.g., cognitive performance and driving self-reports). Given the exploratory nature of the study, it was decided to run analyses without correcting for multiple comparisons, which allowed for several significant associations between measures (particularly with regard to study questions 3 and 4) to be identified. By not making an adjustment for multiple comparisons, this study is subject to an increased likelihood of type 1 error and caution is advised when interpreting results. However, by reporting on these associations, it is hoped that future investigations with larger samples (and thus greater power to detect these relationships) will be conducted. Such work would be able to better determine whether relationships identified in the present study reflect true associations or are due to chance.

APPENDIX A: IRB APPROVAL

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
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irb@lsu.edu | lsu.edu/irb

TO: Matthew Calamia
Psychology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: February 7, 2017

RE: **IRB#** 3831

TITLE: Louisiana Observational Driving Study (LODS)

New Protocol/Modification/Continuation: New Protocol

Review type: Full ____ Expedited _X_ **Review date:** 2/2/2017

Risk Factor: Minimal ___X___ Uncertain ______ Greater Than Minimal_______

Approved_____X_____ **Disapproved**__________

Approval Date: 2/7/2017 **Approval Expiration Date:** 2/6/2018

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 100

LSU Proposal Number (if applicable)**:**

Protocol Matches Scope of Work in Grant proposal: (if applicable)

By: Dennis Landin, Chairman ______________________

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: When emailing more than one recipient, make sure you use bcc.**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

APPENDIX B: COPYRIGHT INFORMATION

Multimethod assessment of driving in older adults using a novel driving simulator

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