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Scholarly Review

Driving Performance in Older Adults: Current Measures, Findings, and Implications for Roadway Safety

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Abstract

Background and Objectives: Over 10,000 people a day turn 65 in the United States. For many older adults, driving represents an essential component of independence and is one of the most important factors in overall mobility. Recent survey studies in older adults suggest that up to 60% of older adult drivers with mild cognitive impairment, and up to 30% with dementia, continue to drive. The purpose of this review is to provide a comprehensive and detailed resource on the topics of cognition and driving for clinicians, researchers, and policymakers working on efforts related to older adult drivers.
Research Design and Methods: Publications on PubMed and Medline and discussions with experts working in geriatrics, technology, driving policy, psychology, and diverse aspects of driving performance were utilized to inform the current review.
Results: Research indicates that there is a complex and inverse correlation between multiple cognitive measures, driving performance, and risky driving behaviors. The fragmented nature of available peer-reviewed literature, and a reliance on correlative data, do not currently allow for the identification of the temporal and reciprocal nature of the interplay between cognition and driving endpoints.
Discussion and Implications: There are currently no widely accepted definitions, conceptual models, or uniform set of analyses for conducting geriatric research that is focused on driving. Establishing conventions for conducting research that harmonizes the fields of geriatrics, cognition, and driving research is critical for the development of the evidence base that will inform clinical practice and road safety policy.

Translational Significance: The purpose of this review is to identify the challenges in developing comprehensive guidance for clinicians, researchers, and policymakers to advance a research agenda on aging and driving. There is a pressing need to advance our understanding of the associations between cognitive change, dementia, and road safety for both geriatric care and population health. This review outlines federal and state policies related to driving regulations for older adults, details the current tools and assessments employed in the evaluation of cognition and driving, and summarizes established knowledge and what remains unknown in terms of driving and cognitive function.

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Keywords: Aging, Cognitive function, Dementia, Mobility, Risky driving

Driving and Cognitive Function

The advent of widespread access to personal motor vehicles was one of the most transformative events in the development of a modern and industrialized society. Both directly and indirectly, this new technology sets in motion innumerable changes in daily life for all citizens worldwide. Transportation is a social determinant of health (Dannenberg & Sener, 2015) and for those who can afford them, personal vehicles facilitate increased access to economic opportunities as well as essential services such as health care. It should not be surprising that retaining the ability to drive—and therefore the independence and mobility afforded by the personal vehicle—becomes an even more valuable asset for older adults. For the majority of older adults in the United States, the loss of the ability to drive, whether voluntary or involuntary, results in decreased independence and increased difficulty in maintaining access to valued resources and social support. Because driving is a routine activity that allows older adults to maintain independence but also places themselves and others at risk, there is a pressing need to improve our understanding of the impacts of aging and age-related diseases toward driving performance.

Driving is a complex task that requires learned skills and the coordination of complex cognitive and physical tasks (Simons-Morton & Ehsani, 2016). Difficulties with this complexity manifest in the elevated crash risk among the youngest and oldest drivers. When teenagers first start driving, their crash risk is high (Williams, 2003), primarily due to inexperience. Graduated driver licensing policies for teenage drivers scaffold the risks facing novice drivers by phasing in their exposure to increasingly demanding environments and diverse driving conditions. However, partly due to the heterogeneity of the older adult population, there is no clear policy equivalent for older drivers that could reduce older drivers' crash risk.

Among older drivers, fatal crash rates per traveled mile increase noticeably starting at age 70–74 and are highest among drivers 85 and older (McGwin & Brown, 1999). Our current understanding is that the increased fatal crash risk among older drivers is largely due to their increased susceptibility to injury, particularly chest injuries, and medical complications, rather than an increased tendency to get into crashes (Cicchino, 2015). An emerging body of evidence is examining the link between multiple aspects of aging and common age-related diseases and driving performance (Aksan et al., 2012, 2015; Carr & O'Neill, 2015). While changes in cognition and physical mobility are normal aspects of healthy aging, the reductions in age-related driving performance are most pronounced in those experiencing a clinically atypical degree of cognitive decline, such as those with mild cognitive impairment (MCI) or Alzheimer's disease and related dementia (ADRD; Anstey et al., 2017; Barco et al., 2015; Carr, 2000; Lundberg et al., 1997).

Nearly five million adults in the United States have ADRD (Alzheimer's Association Facts and Figures, 2021), and this number is anticipated to increase to 15 million in the next 30 years, yet little is known about the relationship between the development of ADRD and driving ability. Identification and remediation of driving performance in older adults could improve roadway safety. Optimally, efforts to develop standards for driving performance for older adults should leverage both established and novel methods for assessing cognition, and real-world driving behavior, and place special emphasis on identifying drivers experiencing accelerated impairments in driving abilities. Elucidating the relationship between each of these various aspects and determining their impact on driving behavior is a much-needed area of research, as emerging data will inform and guide about how best to preserve the independence for older adults and ensure safety for all who share the road.

Cognition is critical, but not alone, in affecting the driving performance in individuals with MCI or ADRD. For example, the majority of individuals with MCI or ADRD have at least one additional chronic condition that is known to potentially impair driving performance (diabetes, arthritis, glaucoma, etc.; Alzheimer's Association Facts and Figures, 2021). Additionally, the majority of individuals with MCI and ADRD are known to take five or more medications daily (Alzheimer's Association Facts and Figures, 2021), with many medications having the potential to negatively affect driving ability in older adults. Health complications related to medication use in older adults are significant enough to warrant the development and maintenance of the *Beers Criteria*—a list of medications deemed as potentially inappropriate in this age group that prescribers should carefully evaluate in terms of their risk to benefit ratio (Charles & Eaton, 2020). Lastly, physical and neurological changes (neuropathy, decreased range of neck motion, vision issues, etc.) have high occurrence within older adults and impair driving performance. Any attempt at examining the interactions between driving performance and overall cognitive function in older persons will require measuring and accounting for each of these variables within well-characterized normal, MCI, and ADRD participants. At a minimum, these data are needed to account for their potential role as moderators of driving performance. Moreover, and perhaps even more importantly, it is essential for future research to develop a simplified infrastructure for *accurately* capturing and incorporating analyses of these medication and physical factors in driving performance of older adult drivers.

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Individuals with neurocognitive compromise, even those with MCI, are at heightened crash risk relative to their healthy counterparts (Reger et al., 2004). Compared to healthy individuals, those with cognitive impairment perform more poorly on on-road evaluations and driving simulator tasks (Man-Son-Hing et al., 2007) and are as much as 3 times more likely to be in a crash (Tuokko, Beattie et al., 1995; Tuokko, Tallman et al., 1995). Older adults with cognitive impairment are also more likely to receive driving-cessation-related recommendations from health care providers (e.g., physicians, neuropsychologists) than are other clinical groups (e.g., patients with traumatic brain injury or psychiatric diagnoses; Bernstein et al., 2019, 2020; Betz et al., 2013, 2016). While numerous studies have linked cognitive function to driving safely in the older adult population, meta-analyses and review articles suggest that these associations vary widely from study to study (Hird et al., 2016; Reger et al., 2004). The effects of cognitive performance on driving safety in this population appear to partially depend on whether a control group is used, as most effects (with the exception of visuospatial abilities and mental status) disappear when studies without control groups are included in meta-analyses (Reger et al., 2004). This may reflect the fact that tests that are sensitive to the presence of cognitive impairment may not necessarily be sensitive to the severity of cognitive impairment, which affects the ability to detect associations between the level of cognitive performance and real-world functioning (Larrabee, 2014).

Cognitive Changes During Aging, MCI, and ADRD

The older adult population in the United States increases by approximately 10,000 individuals each day. Those in the 85 and older age group comprise the fastest growing segment of the U.S. population (Alzheimer's Association Facts and Figures, 2021). Although the majority of people in this cohort are cognitively normal, nearly one in seven currently has some form of dementia, with ADRD accounting for more than 60% of incident dementia. The transition from normal cognitive status to what is recognized as a form of clinical dementia is nonlinear and heterogeneous in presentation, resembling a continuum that current measures struggle to quantify.

A common precursor to ADRD is MCI, a preclinical state of cognitive dysfunction characterized by significant impairment in at least one cognitive domain (e.g., memory, executive function, language) in the absence of significant impairment in work or social life (Roberts & Knopman, 2013; Tangalos & Petersen, 2018). Amnestic MCI, and multidomain MCI where memory is impaired, are both associated with a 10-fold increase risk for future development of ADRD. Almost one third of MCI diagnoses are believed not to progress to dementia (Barco et al., 2015), further highlighting the heterogeneity of MCI. Individuals with MCI report slower responses to items in their peripheral view while driving and exhibit more difficulty with divided attention tasks (Cera et al., 2019; Vardaki et al., 2019).

A diagnosis of ADRD requires a significant decline in cognitive function involving one or more specific cognitive domains (e.g., memory, language, attention, or executive functioning) that interferes with independence in everyday activities (McKhann et al., 2011). The linkage between driving performance and the functional cognitive level within an individual will depend on how the unique mosaic (fingerprint) of cognitive disturbances present within the individual. Identifying these disturbances and the interplay with driving performance invites a review of existing and surfacing measures for assessing global and domain-specific cognitive abilities.

Traditional Neuropsychological Testing

As noted earlier, the stages of normal cognition, MCI, and dementia exist on a continuum. Traditional methods for classifying cognitive status typically employ neuropsychological testing and rigid diagnostic criteria to assign individuals to a specific cognitive status. This traditional in-clinic, test-based approach employs the use of pencil-and-paper assessments, but emerging methods of assessments to quantify the level of cognitive function globally as well as in specific cognitive domains are growing in use, such as natural language processing and computer-based assessments, which are described in detail below.

As individuals age, age-associated changes in cognitive functioning are expected (Greiner et al.,1996; Harada et al., 2013), and certain cognitive domains are especially prone to age-related decrements. These areas include divided attention and switching of attention (De Ribaupierre & Ludwig, 2003; McDowd & Craik, 1988; McDowd, 1997), long-term episodic memory (McDonough et al., 2020), working memory (Andrés et al., 2004; Hasher et al. 1991), and processing speed (Salthouse, 2000; Salthouse & Meinz, 1995). A number of studies have examined the utility of specific executive functioning and visuospatial performance measures in predicting driving outcomes (Silva et al., 2009). For example, the Neuropsychological Assessment Battery (NAB) has shown promise in predicting driving outcomes and on-road performance (Brown et al., 2005); in particular, the NAB Driving Scenes subtest may accurately categorize safe from unsafe older drivers (Brown et al., 2005). Other tests including the Trail-Making Test Part A, Trail-Making Test Part B, and the NAB Mazes subtest have also shown value in predicting driving-related outcomes (Niewoehner et al., 2012; Radford et al., 2004). To make determinations regarding driving safety, neuropsychologists usually employ a comprehensive battery approach in order to appreciate cognitive strengths and weaknesses across cognitive domains (Szlyk et al., 2002). These tests are seldom used in isolation due to their limited ecological validity and their inability to assess the full range of abilities necessary for safe driving.

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Several of these cognitive domains are considered essential for driving safety. In particular, divided attention has been repeatedly linked to a greater risk of crashing and has been shown to be a strong predictor of driving performance (Bherer et al., 2005; Parasuraman & Nestor, 1993). A smaller literature hints that other cognitive domains, including delayed visual and auditory memory (Hu et al., 1998; McKnight & McKnight, 1999), inhibitory control (Daigneault et al., 2002; Stutts et al.,1998), and processing speed (Marie Dit Asse et al., 2014), may also be associated with poor driving outcomes. While less sensitive to more subtle decrements to cognition, measures of mental status including the Montreal Cognitive Assessment and the Mini-Mental State Examination may also be useful in predicting crash risk in older adulthood (Owsley et al., 1991, 1998; Stutts et al., 1998).

Despite the popularity of pen-and-paper assessments of cognition in research focused on driving performance and risky driving behavior (Mathias & Lucas, 2009), they have obvious practical limitations. The most consequential among these is that older adults do not typically undergo routine neuropsychological assessment without prompt. Notably, medical assessment of cognition in a clinical setting may not occur until there is a remarkable functional deficit, at which point the risky driving behaviors are likely to have already manifested. Additionally, many neuropsychological measures were developed to identify cognitive impairment in the context of brain damage and not to predict specific aspects of everyday functioning such as real-world driving performance (Snigdha et al., 2013). Lastly, in-clinic measures require travel to the clinic, which may be difficult to arrange for older adults residing in areas with limited transportation options and few qualified providers.

Dual-Task Walking

Recent studies have identified that in-clinic measures that combine physical tasks with cognitive challenges may be particularly useful in understanding the progression between normal aging, MCI, and dementia (Bruce-Keller et al., 2012; Montero-Odasso et al., 2019; Parihar et al., 2013). Perhaps more importantly, some of these in-clinic measures such as dual-task walking (DTW) appear to be capable of predicting the development of cognitive impairment and dementia prior to their detection with traditional in-clinic neuropsychological tests and structured clinical interviews (Åhman et al., 2020; Verghese et al., 2019). While the experimental setting can vary, DTW consists of a short segment of observed and timed walking under nondistracted and distracted conditions. Under distracted conditions, the individual is asked to sequentially subtract, spell a word backward, or conduct some other cognitive challenge while walking. There is a very limited amount of clinical research on the links between DTW and driving, although numerous studies have identified strong links between impaired DTW and falls (MacAulay et al., 2015; Zukowski et al., 2021), which is particularly relevant given the long-established positive correlation between falls and vehicle crashes/accidents (Scott et al., 2017).

Natural Language Processing Technologies

Researchers have continually aspired to utilize machine learning technology, such as natural language processing, to assist in the early detection of cognitive decline (Petti et al., 2020). It has been demonstrated that analyzing lexical and phonological features of speech can discriminate between cognitively normal adults, those with MCI, and ADRD (Festa et al., 2010). It should be noted that technology to understand the role of neural networks in the characterization of speech and discourse analysis is still in the early stages of development, although the promise of passive natural language processing as a novel measure to assess cognitive status in clinical and nonclinical settings is among the most exciting developments in the analysis of cognition (Duncan et al., 2016).

Computer-Based Cognitive Assessments

Computer and web-based neuropsychological assessments are providing a new level of flexibility in terms of where and how the evaluation of cognitive function occurs. Benefitting from their similarity to pen-and-paper measures, computer evaluations are easily constructed and validated and can be efficiently adapted for remote administration (Calamia et al., 2021; Galusha-Glasscock et al., 2016; Morrison et al., 2015). Remote cognitive batteries do not benefit from the adaptability of in-person assessment with a psychometrist, but they have numerous benefits including increased precision in administration and scoring (e.g., accurate measurement of reaction times; Parsons et al., 2018). Given the ubiquity of personal computers and internet access, remote assessments are also conveniently deployable and cost-efficient. These platforms also have the potential to deliver via telemedicine modalities the kind of evaluation and care that some older persons would otherwise not be able to access.

Driving Behavior, Driving Performance, and Naturalistic Driving Measures

Driving Behavior and Habits Questionnaires

Two of the most commonly utilized paper-based assessments focused on driving are the Driving Behavior Questionnaire and Driving Habits Questionnaire (Owsley et al., 1999; Reason et al., 1990). These questionnaires utilize a self-report format to gain insight as to the perceptions of the driver in terms of their driving ability and the frequency with which they partake in specific risky driving behaviors. Because each of these, and related, questionnaires focus on elucidating the current behaviors and habits of the driver,

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they can be particularly useful in providing ecological context for measures of cognition and/or driving performance. In the context of dementia, which can be associated with problems with insight, informant ratings (e.g., from a spouse) may be more informative than a patient's own self-report (Iverson et al., 2010).

Computer-Based Driving Assessments

Computerized driving assessments can be used to provide an in-depth assessment of multiple aspects of driving performance and driving safety. These tasks have demonstrated utility in the prediction of driving safety, although further investigation is needed to assess whether they are more sensitive or provide additional information above and beyond traditional paper-and-pencil measures (Myers et al., 2000; Whelihan et al., 2005). For this reason, computerized measures are generally used in combination with, not instead of, paper-and-pencil batteries (Spark et al., 2015). Of these computerized measures, the Useful Field of View (UFOV) task is the most often used and has been shown to predict driving performance and outcomes in both clinical and nonclinical populations (Edwards et al., 2006; Myers et al., 2000). The UFOV, which taps aspects of visual attention, has been shown to predict older adults' on-road driving evaluation performance and road crashes, and other measures of impaired driving (Edwards et al., 2006; Myers et al., 2000). The Hazard Perception Task, a personal computer-based measure of visual search, has been less extensively used in clinical settings but nonetheless represents another option when assessing driving safety in older adults (Lacherez et al., 2014; McKenna & Horswill, 2006). Older adults who take longer periods of time to perceive hazards on this measure are more likely to be involved in an on-road crash (Anstey et al., 2012). Hazard perception latencies and UFOV have been shown to account for separate variance in older adults' crash involvement (Anstey et al., 2012).

Virtual Reality

Virtual reality (VR) driving simulators have emerged as a tool to replicate standardized, on-road evaluations without risk to the driver when challenging conditions are introduced. These environmental simulations allow for complete control over stimuli presented, making it possible to administer the same performance measures, without deviation, to an infinite number of drivers. In addition to assessing how one responds to simple and challenging driving tasks, capturing the driving behaviors in question, VR simulations have also been shown to successfully and *simultaneously* measure various neurocognitive abilities that are typically measured in-clinic (Parsons et al., 2008). A concurrent benefit is their superior ecological validity, because driving questionnaires and traditional neuropsychological tests are unable to recreate a high-fidelity, interactive copy of the real world, no matter how good their predictive validity may be (Parsons & Barnett, 2017). Despite their expanding utility, a significant limitation of using VR simulations to measure cognition and driving behavior is the relatively high cost to construct them. Even if one ignores the hurdle of cost, there are still too few standardized roadway models available, and these models are unable to capture all on-road driving conditions. Virtual reality simulations position themselves as highly valuable measures for understanding both cognition and ecologically realistic driving behavior. Their ability to introduce and control for a variety of driving conditions without risk to the driver, including those that are extremely challenging, makes them unique in the extent of environmental control among all forms of assessment. The replicable administration of the same task enables a 1:1 comparison of drivers with discrepant cognitive abilities. In addition to its ability to detect cognitive changes indicative of impairment, VR has been used in cognitive remediation for patients having suffered adverse cerebrovascular events (Maresca et al., 2019; Parsons & Barnett, 2017). Driving questionnaires and traditional neuropsychological tests are unable to recreate a high-fidelity, interactive copy of the real world, and while these measures have good predictive validity (Parsons et al., 2018), VR may present superior ecological validity.

On-Road Evaluations

On-road evaluations with a certified driving evaluator are used to identify and remediate poor driving behavior in aspiring license-holders, usually in combination with a vision exam and written test. Once granted, however, licenses in most U.S. jurisdictions can be renewed without additional performance monitoring for decades—barring a precipitating event (e.g., crash, physician reporting concern). The only ability routinely assessed prior to license renewal is eyesight, and even this precaution is not universal among all 50 states and the District of Columbia (Tefft, 2014). Many states do require in-person renewal after a certain age, and the District of Columbia requires written medical clearance, but Illinois stands alone in its requirement for adults aged 75 and older to actually pass an on-road test to renew (Rock, 1998).

These on-road driving assessments are useful measures of driving performance because they examine drivers in a standardized setting, and the presentation of specific driving circumstances (sufficient to monitor risky driving) is well controlled. Primary drawbacks to on-road assessments include the driver stress induced by formal observation, the motivation for "best performance" (as opposed to relaxed, real-world driving behavior exhibited once alone on the road), and the inability to test in nonoptimal conditions without risking the safety of the driver and evaluator (Bhalla et al., 2007; Dickerson et al., 2013).

The long-standing expectation that new drivers will pass an on-road evaluation is not a subject of contention, but attempts to apply this expectation to older drivers have

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been met with intense scrutiny. While Illinois is currently the only state that requires an on-road evaluation prompted by age, New Hampshire *previously* required an on-road test every 5 years for drivers aged 75 and older, and this law was repealed in 2011. One legislator asserted it was a form of baseless age discrimination, claiming there was no evidence supporting improved roadway safety. A 2013 study by the National Highway Traffic Safety Administration systematically reviewed license renewal policies for drivers aged 65 and older in all states. The study also examined crash data from Illinois and New Hampshire (those available prior to the repeal of the on-road requirement). The analysis found that stricter renewal requirements, including the on-road test, *did* show an association with reduced motor vehicle collisions (MVCs) per licensed driver (Thomas et al., 2013). This could be due to purging inactive drivers from the registry, but the in-person renewal requirement has consistently proved to have the largest impact on reducing MVCs and traffic fatalities among older drivers (Grabowski et al., 2004). Lack of direct evidence to support mandatory on-road testing for older adults should not be used to entirely discount the idea of age-based triggers for *any* kind of driving assessment. Brief, on-road tests do not account for changes in driving ability between license renewals, and they incorporate no instruments to measure cognition, which is a known factor in determining driving performance in unfavorable conditions. Ultimately, the value in observing driving performance under controlled, yet real, roadway conditions cannot be ignored, if only because it offers the chance for immediate remediation of any identified deficits. This is not, however, a proposal for a repetition of common education courses for younger drivers (i.e., Driver's Ed). Engagement in risky driving among older drivers is not due to inexperience, but rather physical and cognitive changes, requiring a different approach.

Naturalistic Driving Studies

A naturalistic driving study (NDS) involves the prospective collection of continuous high-resolution behavioral data (e.g., using video, GPS, accelerometers) in a cohort of drivers without experimental manipulation for an extended period of time (Ehsani, 2021). NDS enables the observation of driving behavior in the real world and allows for long-term monitoring of subtle changes. Additionally, NDS typically includes the collection of the occurrence of crashes or near-crashes, the occurrence of risky driving behaviors in the form of elevated gravitational-force (g-force) events, trip duration, trip time of day, weather during the trip, and road type(s) during the trip.

These data can be captured and analyzed to differentiate between driving behaviors in relation to a particular roadway and those unique to a particular driver (Freidlin et al., 2018) and have already been implemented in younger and older drivers with success (Ehsani et al., 2020; Li et al., 2017). NDS data are less likely to be subjective when compared to in-person driving assessments and do not require the extensive programming required for driving simulators and VR assessments.

Naturalistic driving (ND) data are typically coupled with survey data collected at baseline and specific follow-up time points with the study participants. Questionnaires can include demographic and vehicle information—for example, sex, race/ethnicity, educational attainment, household income, marital status, employment status, vehicle ownership, and vehicle safety features. Participants can also provide responses on validated scales that assess psychological characteristics previously associated with driving behavior. The combination of these two approaches offers a powerful approach to situate self-reported behaviors alongside observational data.

Smartphone-based NDS have the additional qualities of scalability and affordability. By making use of widely possessed technology, smartphone-based NDS can be used in cross-sectional and longitudinal analyses in order to understand both within-driver changes and between-driver differences. Emerging measures such as the Driving Space developed by Bayat et al. offer a glimpse of what smartphone-based NDS could capture for older adults (Bayat et al., 2021). These include the number of trips, the total traveled distance, the driving radius, number of night trips, and the number of unique destinations. These measures could be captured in a longitudinal cohort of drivers and changes in the driving space could be quantified over time.

Examples of risky driving behaviors that can be monitored using ND tools include speeding, elevated g-force event rates resulting from rapid acceleration, hard braking, or striking a curb. Cell phone use can also be observed. In addition, specific risky driving behaviors commonly associated with MCI and ADRD can be observed. These include lane changes, turns, intersection management, and inappropriate sudden braking (Aksan et al., 2012; Anstey et al., 2018; Lincoln et al., 2006). Recent NDSs with older drivers, such as the Longitudinal Research on Aging Drivers study, have identified the potential for NDS to identify driving behaviors associated with MCI and ADRD (Di et al., 2021).

While the ND approach has a number of advantages, one weakness intrinsic to ND is the inability to standardize exposure. Other limitations include the possibility of altering driver behavior due to the "Hawthorne effect" that leads to improvements in behavior simply as a result of being observed. The limited research on this topic suggests that research participants' awareness of ND instrumentation is short-lived and is not associated with risky driving outcomes (Ehsani et al., 2017). The computational and statistical challenges in dealing with the large data sets of driving behavior are also formidable and require appropriate resource allocation (Bennett et al., 2016; Simons-Morton, 2017). Nevertheless, the advantages of NDS outweigh the limitations and direct observation

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of real-world driving over a prolonged period should be considered in any attempt to assess driving performance in older adults.

Establishing Uniform Assessments of Driving Performance

Identifying efficient and relevant measures/correlates for quantifying meaningful change in driving across the age spectrum is a critical and urgent need for researchers, clinicians, and policymakers alike. It is clear that a large number of validated and technologically advanced tools are currently available and continuing to emerge, providing ample opportunity for the creation of uniform data sets for researchers, clinicians, and policymakers. However, there are currently no widely accepted definitions, conceptual models, or uniform set of analyses for conducting geriatric research that is focused on driving (Carr & Ott, 2010). The lack of an established uniform assessment battery for researchers focused on driving, particularly the driving by older drivers, has resulted in a largely fragmented literature consisting of isolated driving measures being conducted in individual cohorts or sample of drivers. Stakeholders are forced to extrapolate the data from these often indirectly related studies to design and interpret their own research or policy interest. A rapid and significant increase in the efficiency and impact of driving research could be achieved by establishing a uniform driver data set that collects a consistent set of endpoints in the following categories for every study: demographics, medication history, health history, cognitive function, self-reported driving behaviors, driving performance, and record of recent driving. Decisions around which components and methodologies are used for the collection of demographics, medication history, and health history are much less difficult than the decisions regarding the types of cognition, driving behavior, and recent driving data to be collected. Logistical, operational, financial, and participant burden constraints will likely result in a tiered approach for identifying the optimal data set to be collected in the research study based on existing constraints.

It is certain that the uniform set of variables would need to establish a minimum criterion to be included in all research studies including driving as a primary or secondary outcome and to provide guidance for the endpoints and measures to be used in more specialized research settings including longitudinal, population-based, or randomized controlled trials. This approach for establishing uniform data sets in MCI and AD research as part of the Alzheimer's Disease Research Centers (ADRCs) efforts significantly and rapidly advanced research studies at both ADRC and non-ADRC sites by allowing more direct comparison of data and outcomes between studies and facilitating the ease and pace of collaboration. A secondary benefit for the establishment of some uniformity in data collection is the likelihood that much-needed evidence-based guidance for physicians and policymakers can be achieved in a more rapid and efficient manner. Consistent data collected across multiple studies, as opposed to a piecemeal approach collecting data from fragmented components of different studies, are critical for the development of the evidence base that will inform clinical practice and road safety policy. The Model Systems Knowledge Translation Center (MSKTC) is an example of an NIH-funded project that could serve as a model for the cognition and driving; related data outlined in this review. The MSKTC is successful in coordinating the collection and dispersion of uniform and credible data related to spinal cord injury, traumatic brain injury, and burn injury to multiple stakeholder groups.

Policy Adoption and Social Implications

The lack of uniform methods for assessing performance and cognition among older drivers has deprived clinicians and policymakers of data to inform their decision making regarding requirements for driver licensing and renewal, as well as implementation of potential driving restrictions (Carr & Ott, 2010). In the interim, stark discrepancies remain among state renewal requirements, with some not having any age-specific policies at all. Among those that use renewal practices to surveil older drivers, many of the restrictions placed on older drivers as a result have proven ineffective (Bell et al., 2015).

Most of the safeguards that have been implemented involve in-person renewals and assessment of physical fitness (e.g., eyesight exams, hearing tests, medical clearance). In the United States and elsewhere, in-person renewal requirements *have* proven beneficial, largely because they frequently (but not always) require an eyesight examination. Interestingly, only limited evidence is available regarding the effectiveness of requiring medical clearance or mandating physicians to report concerns about potential patient driving performance, when measured in terms of reduced crash rates or hospitalizations (Agimi et al., 2018a, b). One reason why such mandates have not proven effective could be conflict avoidance by the physician, the patient, or the patient's caregiver(s). If a physician has reason to suspect that the patient is at risk for impaired driving, but the patient is adamantly opposed to voluntary driving cessation, referring the patient for mandatory assessment based on suspicion alone could prove damaging to the physician–patient relationship, and it is not a guarantee that the patient will have driving privileges revoked (Gupta, 2007). This also requires a breach of physician–patient confidentiality, raising considerable ethical implications for physicians. As a result of a referral, mutual trust may be broken and the patient may no longer seek care. Similarly, if the patient's caregiver believes that he or she should cease driving but the patient disagrees, asking the physician to make this determination based on professional opinion creates additional questions about authority and responsibility.

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For some medical conditions (e.g., severely impaired eyesight, epilepsy, substance addiction, diagnosed ADRD, and self-reported dementia), state laws are clear about mandatory reporting and subsequent driving cessation, offering well-defined, actionable criteria. With regard to mild-to-moderate cognitive impairment, however, it is sometimes difficult to determine at which degree of decline the driver becomes unsafe to remain on the road. One study involving primary care physicians in Canada found that many do not feel confident in determining at which stage on the dementia continuum it is necessary to refer drivers for evaluation (Berger et al., 2000).

In the absence of universal criteria and expertise in performing comprehensive driving assessments, physicians are potentially forced to choose between acting in the public interest and continuing to provide quality care and support to their patients. Aggressive reporting could result in unnecessary barriers to mobility. A better understanding of the specific stages of functional decline and their corresponding driving risk is necessary in order to inform physicians about when to report. Existing methods for high-risk driver identification generally aim to remove them from the road, therefore denying them the opportunity for risk remediation. While some impediments to safe driving cannot be overcome, many of the factors associated with risky driving and crash risk can be addressed using methods previously discussed (Payyanadan et al., 2017; Walshe et al., 2021). If older drivers were proactively screened using a combination of naturalistic observation and cognitive assessment, those identified as exhibiting driving behaviors that place them at an elevated risk of crashes could be referred for further evaluation.

Once identified and referred, high-risk drivers could undergo a driving assessment and receive early intervention through the use of safety technologies, such as driver monitoring and feedback. These approaches have been used effectively in other populations including teenagers and professional drivers (Simons-Morton et al., 2013). While total elimination of risky driving behaviors and restoration of baseline cognition are unlikely, moderate restrictions can be implemented (such as maximum allowed travel distance from home, hours of the day, etc.) based on ongoing driving performance rather than of revoking driving privileges outright. Given that MCI and other neurocognitive disorders are often progressive, more frequent license renewals and ongoing driver evaluation using driver monitoring could be warranted in these drivers. This approach would foster bidirectional validation between traditional cognitive assessments and real-world driving performance and avoid the perilous tendency to rely on too few measures when making clinical determinations.

Assuming all hurdles to development presented here could be overcome, achieving widespread adoption of uniform assessment criteria is a policy challenge. In the United States, states are responsible for issuing permits and driver's licenses. This autonomy manifests in a high degree of heterogeneity in licensing renewal policies. Developing guidance documents and model programs can help align state practices, particularly if these are developed through a consensus process engaging state licensing officials. In addition, federal highway safety grant programs provide an opportunity to incentivize states to make desired changes by allocating extra funds to states that comply with certain criteria.

Setting these challenges aside, any measure of driving performance that has the potential to withhold driving privileges invokes serious social, economic, and health consequences (Kochtitzky et al., 2011). Meta-analyses and longitudinal studies have shown that driving cessation often precipitates a decline in physical and mental health (Chihuri et al., 2016) and that the rate of overall health decline often accelerates as a result, when controlling for other factors (Edwards et al., 2009). The lessened social engagement that follows such driving restrictions is not necessarily mitigated by access to public transit, particularly in economically disadvantaged populations (Mezuk & Rebok, 2008). Diminished mobility also leads to a reduction in spending, negatively affecting local economies (Kim & Richardson, 2006).

Every effort should be made to help older drivers remain on the road as long as they safely can. Approaches using classroom-based, simulator-based, and on-road driving training have had some success in reducing risky driving behaviors among older adults with and without cognitive impairment (Anstey et al., 2018; Shimada et al., 2019). However, these approaches are likely not scalable to reach an ever-growing older adult population. Low-cost and accessible interventions that reduce driving while assisting older adults to maintain mobility and the associated health benefits are needed. New and emerging forms of mobility such as ridesharing and autonomous shuttles show promise for helping older adults remain functionally independent. A recent study in which older adults were provided with 3 months of access to rideshare found that 90% of participants reported increases in quality of life and 80% indicated they intended to keep using rideshare services. Simultaneously, policy discussion should prioritize ways in which alternate transportation can be provided in cases where driving privileges must be revoked.

Summary and Conclusions

It is well established that older adult drivers, especially those with MCI or ADRD, are at higher risk for at-fault roadway collisions. Studies have examined their engagement in risky driving behaviors, but few have incorporated thorough neuropsychological testing, controlled for comorbid health problems, and validated clinical observations with a naturalistic component. The methods presented in this review demonstrate that there is a need and opportunity to advance the field by adopting a common set of terminology and establishing conventions for conducting research or aging and driving.

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Understanding the causal interactions between driving behaviors and cognitive change, and ultimately identifying the specific driving behaviors that demarcate the transitions between normal aging, MCI, and ADRD, will require the integration of well-defined clinical and driver monitoring data. The majority of the metrics that will be required for the next generation of cognition-driving research will have to establish defined equivalents/measures in the clinical setting, laboratory setting, on-road testing conditions, as well as naturalistic driving conditions in order to isolate the tools that are most efficient. These technologies are still in the process of maturation, however, and extensive research is necessary before an evidence base could be used to inform policy.

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Conflict of Interest

None declared.

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