Abstract

Falls, Mood, and Driving Safety in Multiple Sclerosis

Mobility difficulties are a progressive and burdensome consequence of multiple sclerosis (MS) with pervasive effects on functioning. As such, driving retains a critical role in maintaining mobility and functional autonomy in people with MS (pwMS). While cognitive and physical deficits have been established as risk factors for unsafe driving outcomes (e.g., motor vehicle accidents (MVAs) and traffic violations) in pwMS, little is known about the role of falls and psychological symptoms in such outcomes. This study also sought to examine the relationship between falls, psychological symptoms, and self-reported driving characteristics such as MS symptoms interfering with driving ability and restrictive driving practices. Participants included 114 patients at a tertiary care MS Center who had been previously diagnosed with MS by a neurologist. Closed-ended questions about the occurrence of falls within the last year, perceptions about MS symptoms interfering with driving ability, and driving restrictions were presented to all participants; depressive and anxiety symptoms were evaluated by the Patient Health Questionnaire-9 (PHQ-9) and the Hospital Anxiety and Depression Scale – Anxiety subscale (HADS-A), respectively. Driving records were also obtained from the Department of Motor Vehicles (DMV), which noted all traffic violations and MVAs received within the last five years. Results showed that participants without a history of falls had 2.3 times more MVAs within the last five years; however, for traffic violations, MS symptoms hindering driving ability, and driving restrictions, there were no differences between fallers and non-fallers. A higher number of traffic violations received were associated with higher depressive (Wald χ^2 (1) = 17.46, $p < 0.001$) and anxiety (Wald χ^2 (1) = 21.67, $p < 0.001$) symptoms. When adjusting for demographic and disease-related factors, depressive and anxiety symptoms were also associated

with the number of symptoms interfering with driving ability (depression: β= 0.39, *SE* = 0.04; anxiety: β = 0.33, *SE* = 0.04) and the number of driving restrictions (depression: β= 0.35, *SE* = 0.04; anxiety: β = 0.20, *SE* = 0.05). Moreover, there was an interaction effect of age on fall status in relation to violations (Wald χ^2 (1) = 5.86, $p = 0.015$), indicating that older drivers without a history of falls had received a higher number of traffic violations within the last five years. No other significant interaction effects between age and psychological symptoms in relation to DMV outcomes were observed. Exploratory analyses also indicated that more severe fatigue was associated with a higher number of MS symptoms interfering with driving behavior ($r = 0.43$, $p < 0.001$) and a higher number of driving restrictions ($r = 0.35$, $p < 0.001$). A higher number of symptoms hindering driving were also associated with lower extraversion ($r = -0.24$, $p = 0.009$) and higher agreeableness ($r = 0.23$, $p = 0.016$). This is the first study to investigate the relationship between falls, psychological symptoms, driving outcomes, and self-reported driving characteristics in pwMS. Our findings demonstrate a strong association between fall status and MVAs. Psychological symptoms were also strongly associated with traffic violations, MS symptoms impacting driving ability, and driving restrictions. As fall status and psychological symptoms are related to negative driving outcomes, such factors can enhance the identification of pwMS at risk for unsafe driving and, therefore, allow for earlier intervention.

Falls, Mood, and Driving Safety in Multiple Sclerosis

By

Jenna Cohen, M.A.

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The committee for this doctoral dissertation consists of:

Frederick W. Foley, PhD, Chairperson, Ferkauf Graduate School of Psychology

Elizabeth K. Seng, PhD, Ferkauf Graduate School of Psychology

Roee Holtzer, PhD, Ferkauf Graduate School of Psychology

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Dedication

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Chapter I: Introduction

Background/Significance

Multiple Sclerosis Overview

Multiple sclerosis (MS) is a progressive immune-mediated disease of the central nervous system (CNS), affecting nearly one million people living in the United States (Keegan & Noseworthy, 2002; Wallin et al., 2019) and an estimated 2.8 million people worldwide (Walton et al., 2020). MS pathology is characterized by multiple focal lesions of demyelination, accompanied by inflammation and by varying degrees of axonal preservation and loss in the brain and spinal cord (Rensel & Gray, 2016). Often people with MS (pwMS) experience unpredictable episodes of inflammation lasting days to months, leading to worsening symptoms (Czerwińska-Mazur et al., 2019; Hunter, 2016). Symptoms of MS may manifest in visual, motor, sensory, cognitive and psychological domains.

The onset of MS typically occurs in early to middle adulthood, generally between the ages of 20 and 40 (Czerwińska-Mazur et al., 2019; Hunter, 2016). Women are largely affected by MS, with women being three times more likely to develop MS than men (Czerwińska-Mazur et al., 2019; Wallin et al., 2019). Given that the prevalence of MS increases with greater distance from the equator, rates of MS are shown to be higher in North America and in some northern European countries (Czerwińska-Mazur et al., 2019). Research has also indicated that MS is more prevalent in individuals identifying as Caucasian (Amezcua & McCauley, 2020; Briggs & Hill, 2020). Demographic characteristics such as older age at disease onset (>40 years old), the male sex, and ethnic/racial background (African American and Hispanic or Latino/a/x) have been associated with poorer prognoses and more rapid disease progression (Amezcua & McCauley, 2020; Hunter, 2016).

The diagnostic criteria for MS has advanced over time; the current standard, the revised McDonald Criteria, serves as a guide to diagnosing MS and differentiating between types of MS (Thompson et al., 2018). For approximately 85% of individuals, the diagnostic process begins with a single episode of neurological symptoms also known as clinically isolated syndrome (CIS) (Dobson & Giovannoni, 2019; Miller et al., 2005). Nearly half of individuals with CIS will experience a second demyelinating episode within 10 years and therefore receive a diagnosis of relapsing remitting MS (RRMS) (Hou et al., 2018). RRMS is the most common type of MS and is characterized by periods of new or worsening neurological symptoms (relapses) followed by periods of partial or full recovery and relative stability (Hunter, 2016). RRMS is diagnosed based on symptom presentation and objective clinical evidence showing at least one demyelinating lesion (Thompson et al., 2018). Progressive forms of MS, primary progressive MS (PPMS) and secondary progressive MS (SPMS), require at least one year of disease progression and supporting imaging or laboratory evidence for diagnosis (Polman et al., 2011). An estimated five percent of pwMS will present with a progressive disease course at onset, in addition to experiencing episodes of acute relapses; prior to the revisions proposed by the International Advisory Committee on Clinical Trials of MS in 2013, this course of MS was characterized as progressive-relapsing MS (PRMS) but more recently it has been categorized as a form of PPMS (Lublin et al., 2014).

While there is no cure for MS, treatments tend to focus on reducing the number of relapses, slowing disease progression, and managing MS symptoms. Treatments that are used to specifically target MS pathology are known as disease modifying therapies (DMTs). More than 15 DMTs have been approved by the Food and Drug Administration (FDA) for CIS, RRMS, and SPMS with relapses (National Multiple Sclerosis Society, n.d.). DMTs used to treat MS are characteristically either immunosuppressant or immunomodulatory in nature; these types of therapies work to reduce or modulate the immune system response, which in turn suppresses inflammation. Common immunosuppressant DMTs include Gilenya, Tysabri and Ocrevus, while the most prominent immunomodulatory DMTs are Avonex, Rebif, Betaseron, Plegridy, Copaxone, Tecfidera and Aubagio (Dobson & Giovannoni, 2019; Pardo & Jones, 2017). Nevertheless, recently, there has been an increase in the use of immune reconstitution therapies (IRTs) to treat MS. IRTs – such as Lemtrada, Mavenclad and Novatrone - operate by eliminating components of the immune system via suppression or depletion that subsequently allows for the reconstruction of a healthy immune system (Dobson & Giovannoni, 2019; Lünemann et al., 2020). In addition to disease modifying and immune reconstruction treatments, pwMS may rely on symptomatic therapies to target mobility and cognitive difficulties, fatigue, pain, mood, and bladder and bowel dysfunction (Dobson & Giovannoni, 2019).

Manifestations of Multiple Sclerosis

Visual symptoms are a common manifestation of MS (Costello, 2016). Visual dysfunction can be a consequence of demyelination, inflammation or degeneration of the afferent and efferent visual pathways (Beh et al., 2016; Graves & Balcer, 2010; Sakai et al., 2011). Approximately half of pwMS develop optic neuritis (ON), a disturbance in the afferent visual pathway, throughout the disease course (Beh et al., 2016; Graves & Balcer, 2010). Visual manifestations of MS may be transient or more enduring, and include reduced visual acuity (Balcer & Frohman, 2010), contrast sensitivity (Balcer & Frohman, 2010; Balcer et al., 2015), nystagmus (Costello, 2016), defective binocular vision, blurred vision, diplopia and oscillopsia (Balcer et al., 2015; Costello, 2016). Although difficult to treat, acute visual disturbances often require high dose intravenous corticosteroids (Costello, 2016).

Mobility impairments are a significant consequence of MS, occurring in up to 90% of pwMS (Hemmett et al., 2004). Mobility is affected in pwMS via decreased muscle strength and control, which hinders the coordinated movements that underlie walking; nonetheless, deficits in sensory and proprioceptive domains (e.g., vision and balance) may also contribute to mobility dysfunction (Campea & Haselkorn, 2016). Aspects of physical function and mobility that are frequently impacted in MS include weakness, spasticity, stiff and unsteady gait, decreased cadence and stride length, and walking speed (Campea & Haselkorn, 2016). In the MS population, limited mobility has been associated with reduced engagement in activities of daily living (Salter et al., 2010) and social activities (Johansson et al., 2020), poorer self-efficacy (Sikes et al., 2019), unemployment (LaRocca, 2011; Salter et al., 2010), and lower socioeconomic status (LaRocca, 2011; Salter et al., 2010); moreover, reduced mobility is the most significant concern of pwMS related to their quality of life (Heesen et al., 2008; LaRocca, 2011). In addition to the aforementioned consequences, physical and mobility impairments contribute to fall risk (Matsuda et al., 2012; Mazumder et al., 2014).

Falls are highly prevalent in MS, with several studies showing rates of falls ranging from 58.5 to 71.2% in a six month period (Matsuda et al., 2011; Mazumder et al., 2014). While a majority of studies assess falls within a three-to-six-month period, Dibble et al. (2013) found that 61% of pwMS endorsed falling within the last year. Further, half of the fallers in the study conducted by Dibble and colleagues had inaccurately estimated the actual number of falls sustained in the preceding year. Given that between 42.5-58.5% of the falls sustained by pwMS result in medical injury (Matsuda et al., 2011; Mazumder et al., 2014; Peterson et al., 2008), falls are a significant concern for this population. A range of physical and mobility factors have been associated with falls in MS including muscle weakness (Matsuda et al., 2011), spasticity

(Nilsagård et al., 2009), balance difficulties (Finlayson et al., 2006; Gianni et al., 2014), use of assistive walking devices (Gianni et al., 2014; Nilsagård et al., 2009), postural sway (Gianni et al., 2014; Sosnoff, 2011), walking speed (Gianni et al., 2014), endurance (Sosnoff, 2011), and disability level (Gianni et al., 2014). Treatments to manage falls, as well as mobility and physical impairments, may include assistive devices (e.g., cane, walker, wheelchair), physical therapy and rehabilitation, ankle-foot orthotics, functional electrical stimulation, and physical activity (Campea & Haselkorn, 2016).

Sensory domains are the most frequently effected amidst an acute relapse and up to 85% of pwMS experience sensory symptoms within the first year of diagnosis (Fox et al., 2015; Nazareth et al., 2018). Pain, paresthesias (e.g., numbness, tingling, burning sensations), temperature sensitivity, and sexual dysfunction are amongst the most prominent sensory complaints in MS (Nazareth et al., 2018). Pharmacological approaches such as analgesic, antidepressant, antiepileptic and spasmolytic medications are highly utilized to treat sensory complaints, and pain-related complaints in particular (Murphy et al., 2017a); however, there is increasing evidence supporting the efficacy of non-pharmacological approaches including psychotherapy, cannabinoids, physical therapy and exercise, neuromodulation, hydrotherapy, and reflexology to treat sensory symptoms in pwMS (Amatya et al., 2018; Urits et al., 2019).

Cognitive dysfunction, although estimated to affect between 43-70% of pwMS (Benedict et al., 2006; Chiaravalloti & DeLuca, 2008; Rao et al., 1991a), may be underdiagnosed in MS due to the reliance on patient-reporting (Kinsinger et al., 2010). Research has shown that cognitive deficits emerge early in the disease course and progress gradually over time (Sahraian & Etesam, 2014). PwMS often exhibit deficits in domains of attention (Chiaravalloti & DeLuca, 2008; Rao et al., 1991a; Sahraian & Etesam, 2014), processing speed (Chiaravalloti & DeLuca, 2008; DeLuca et al., 2004; Sahraian & Etesam, 2014), memory (Chiaravalloti & DeLuca, 2008; Rao et al., 1991a; Sahraian & Etesam, 2014), visuospatial perception (Rao et al., 1991a), and executive functioning (Sahraian & Etesam, 2014). The effects of cognitive dysfunction are widespread, and may be exacerbated by comorbid fatigue and severe depression (Golan et al., 2018). Furthermore, Rao and colleagues (1991b) showed that cognitive impairment was associated with reduced social participation, increased difficulties engaging in activities of daily living, unemployment, sexual dysfunction and a higher number of psychiatric comorbidities. Depending on the type and severity of cognitive deficits, treatment may involve cognitive rehabilitation, pharmacological regimens (e.g., stimulant medications, cholinesterase inhibitors, memantine, gingko biloba), and daily exercise (Lovera & Kovner, 2012).

Fatigue is amongst the most commonly endorsed symptoms by pwMS, with 74% of respondents to the North American Research Committee on MS (NARCOMS) survey endorsing severe fatigue within the past week (Hadjimichael et al., 2008). Research has shown that severe fatigue is associated with more severe disability (Mills & Young, 2011), lower education (Hadjimichael et al., 2008), unemployment (Hadjimichael et al., 2008), and poorer quality of life (Nagaraj et al., 2013). Complaints of fatigue may be treated using pharmacological (e.g., amantadine, stimulant medications) and, or, non-pharmacological approaches such as exercise, physical therapy, cognitive strategies, and psychotherapy (Induruwa et al., 2012).

<u>Psychiatric Disorders and MS</u>

Psychiatric disorders have been reported in up to 60% of pwMS (Marrie et al., 2009). Studies have suggested that pwMS have a higher prevalence of psychiatric disorders than the general population. Specifically, the lifetime prevalence rates in pwMS range from 22.8-50.0% for major depressive disorder (Chwastiak & Ehde, 2007; Feinstein et al., 2014), 22.1-36.0% for anxiety disorders (Boeschoten et al., 2017; Chwastiak & Ehde, 2007; Marrie et al., 2015), 0.3-5.8% for bipolar disorder (Chwastiak & Ehde, 2007; Marrie et al., 2015), and 13.6-14.8% for alcohol abuse (Chwastiak & Ehde, 2007; Marrie et al., 2015). Psychiatric disorders can have complex and pervasive effects on functioning. Although dependent on a number of individualistic factors, treating psychiatric diagnoses in pwMS may include pharmacotherapy, psychotherapy, or exercise-based programs (Fiest et al., 2016; Razazian et al., 2016).

Major depressive disorder (MDD) is the most prevalent psychiatric disorder affecting pwMS (Marrie et al., 2009). The etiology of depression in MS has been suggested to include hypothalamic-pituitary-adrenal axis dysfunction, brain pathology (e.g., reductions in grey matter in the frontal lobe, reductions in hippocampal volume), lesion burden (Murphy et al., 2017b), and inflammation (Feinstein et al., 2014). Depression may also serve as a consequence of the process of adjusting to a chronic and progressive medical condition, in which pwMS may endure significant alterations in functioning. Despite being two to three times more prevalent in MS than in the general population (Patten et al., 2017), depressive episodes are often under-detected and undertreated in pwMS; for instance, analysis of data from the NARCOMS registry showed that 16% of pwMS who did not report having a psychiatric comorbidity had endorsed clinically significant depressive symptoms on the Center for Epidemiologic Studies Depression Scale (CESD) (Marrie et al., 2009). However, the overlap in symptomology with MS (i.e., insomnia, difficulties with concentration, changes in weight, fatigue) may support the under-detection and undertreatment of depression. In the MS population, depression has been associated with younger age (Beal et al., 2007), longer disease duration (Beal et al., 2007), greater physical disability (Beal et al., 2007; McKay et al., 2018), alcohol dependence and tobacco use (McKay et al., 2016), and poorer health-related quality of life (Biernacki et al., 2019). Depression has also been linked to suicidality in pwMS. The rate of death by suicide in pwMS is two times higher than in the general population (Feinstein & Pavisian, 2017). Pompili and colleagues (2012) identified younger age, lower income, earlier and progressive disease courses, higher levels of physical disability, social isolation, depression severity, and driving cessation as risk factors for suicidal behavior in pwMS.

Although less extensively researched, anxiety disorders are also common in MS. Literature has proposed that in pwMS, anxiety is triggered by critical life events (e.g., MS onset, fears related to disability) and that avoidance-based coping mechanisms maintain maladaptive thoughts and anxiety (Beck, 2011; Butler et al., 2016); this link is further supported by the relationship between high levels of anxiety and avoidance and humor-based coping styles (Butler et al., 2016; Tan-Kristanto & Kiropoulos, 2015). Anxiety disorders in MS have been associated with cognitive dysfunction, poor medication adherence, disability level, longer disease durations, lower quality of life (Butler et al., 2016), alcohol dependence and tobacco use (McKay et al., 2016). Notwithstanding the range of implications, a significant portion of pwMS endorsing threshold anxiety symptoms do not receive any type of treatment (Beiske et al., 2008). The undertreatment of anxiety disorders in MS may result from denial of treatment, a failure to diagnose such disorders (Butler et al., 2016), or under-detection resulting from the overlap in symptomology (e.g., unsteadiness, temperature regulation issues) (Ó Donnchadha et al., 2013).

<u>Motor Vehicle Safety Outcomes</u>

According to the National Highway Traffic Safety Administration (NHTSA) in 2019 there were 6.756 million motor vehicle accidents (MVAs) in the United States. Of these MVAs, 33,244 resulted in a fatality, 1.916 million resulted in injury requiring medical attention, and 4.806 million resulted in property damage (National Highway Traffic Safety Administration, 2021b). While the number of MVAs in the United States in 2020 have yet to be released, preliminary estimates have indicated 38,680 MVA fatalities in 2020; such findings represent a 7.0% increase in MVA fatalities from 2019 despite a decrease in the annual number of miles traveled, which is likely a consequence of the global pandemic of Coronavirus disease 2019 (COVID-19. Demographic and crash factors showing the most significant increases in fatality rates in comparison to 2019 were: African American/Black individuals (up 23%), ejection of vehicle occupants (up 20%), unrestrained passengers (up 15%), and urban interstates (up 15%) (National Highway Traffic Safety Administration, 2021a).

Research estimates that more than 20 million motorists are stopped by the police annually in the United States (Baumgartner et al., 2018; Pierson et al., 2020). Although data regarding the annual rates of traffic violations received in the United States have not been made available, this data is made available by some cities and states. Preliminary reports of traffic violations issued in New York State show that more than 2.2 million tickets were issued to drivers in 2020 (New York State Department of Motor Vehicles, 2020). Similarly, in 2020, the Florida Department of Highway Safety and Motor Vehicles reported that 2.05 million traffic violations were issued to motorists (Florida Department of Highway Safety and Motor Vehicles, 2021). Amongst the most common violations cited in both New York and Florida were speeding, disobeying traffic devices, and expired or failed vehicle inspections (Florida Department of Highway Safety and Motor Vehicles, 2021; New York State Department of Motor Vehicles, 2020).

Models and Assessment of Driving Performance

Although there are a range of theoretical conceptualizations about driving behavior, the field of driving research lacks a broadly accepted and extensively examined model. Early skill-based perspectives of driving capacity focused on the level of driving proficiency and failed to delineate the complexities of driving, which subsequently led to the development of functional driving models (Ranney, 1994). Functional approaches to driving behavior, consisting of motivation and information processing models, emphasize the internal state of the driver (Michon, 1985; Ranney, 1994). Specifically, motivational driving models concentrate on individualistic motives and risk toleration, whereas information processing models are action oriented and characterize driving based on a sequence of stages (e.g., perception, decision making, response selection, and execution) (Ranney, 1994). Both models have been highly criticized: motivational models for dismissing driving mechanisms and for poor specification of internal mechanisms, and information processing approaches for inadequately addressing psychological states and advancements in cognitive theory (Michon, 1985; Ranney, 1994).

In working towards a more comprehensive model, recent driving capacity models have embraced a hierarchical structure of control and mechanisms that enables fluidity between levels (Michon, 1985; Ranney, 1994). Michon's (1979) Hierarchical Control Model of driving organizes driving behavior into three components that operate simultaneously on strategical, tactical, and operational levels (Michon, 1976; Michon, 1979; Rothengatter & Huguenin, 2004). The strategical level refers to decision making and planning-related tasks such as the selection of trip goals and route, fuel efficiency and comfort. Tactical level (maneuvering) actions are characterized by obstacle avoidance, turning, overtaking, and gap acceptance, while the operational level reflects basic driving skills (e.g., steering, braking, accelerating) and automatic patterns of action (Michon, 1979; Michon, 1985; Rothengatter & Huguenin, 2004). Based on the Hierarchical Control Model of driving, that emphasizes cognitive and maneuver-based abilities, drivers with neurodegenerative conditions such as MS are especially susceptible to unsafe driving behaviors. Furthermore, given the prominence of cognitive, visual and sensory dysfunction in MS, there are likely widespread implications for strategical, tactical and operational level driving abilities. For instance, slowed processing speed, visual difficulties and sensory dysfunction can theoretically hinder safe braking and steering, in addition to hampering a driver's ability to avoid on-road obstacles, safely overtake other vehicles and maintain an acceptable distance from other vehicles; all of the aforementioned driving skills and maneuvers are essential to avoiding MVAs and MVA-related fatalities.

Another conceptualization of driving behavior that focuses on control through various levels of activity is the Driver-in-Control (DiC) model. The DiC model assumes that the driver and vehicle are a joint system functioning through multiple simultaneous processes (e.g., tracking, regulating, monitoring, targeting), which connect a driver's objectives with their actions and outcomes (Hollnagel, 2002). The four processes that comprise this model reflect domains of activity that are involved in driving (Hollnagel, 2002). More specifically, tracking consists of driving maneuvers that are easily carried out by skilled drivers like speed maintenance, gap acceptance, and lateral positioning; regulating involves the standards and objectives that inform tracking such as target speed, position, and movement in relation to elements of traffic. Monitoring is responsible for developing plans implemented by other loops and keeping track of indications of direction, warnings or restrictions, whereas targeting is involved in the ongoing assessment of driving criteria and goals (Hollnagel, 2002; Hollnagel et al., 2003). Control can exist on several levels of this model concurrently and, given the link between levels, disruptions can have residual effects on multiple levels of activity (Hollnagel et al., 2003). While the DiC model highlights behavioral control, this emphasis makes it difficult to account for the cognitive implications of medical conditions on driving safety.

Various methods of assessment have been used to evaluate driving capability and safety. Among the most predominant measures used in driving research are on road (e.g., behind the wheel evaluations) and off-road evaluations (e.g., closed-course evaluations, driving simulators), certified driving records from the Department of Motor Vehicles (DMV), and cognitive assessments (e.g., Useful Field of View Test (UFOV), Stroke Drivers Screening Assessment (SDSA)).

On road evaluations have been widely utilized in driving capacity research and, given the high face validity, are considered the ideal standard for determining competence (Fox et al., 1998). Traditionally, on road assessments consist of a standardized route to satisfy specific driving condition requirements and scoring by a driving rehabilitation specialist. Driving specialists score drivers based on a range of maneuvers and performance-based tasks, as well as management of specific environmental conditions (Di Stefano & Macdonald, 2012). Despite the scant attention devoted to investigating the reliability, validity, and standardization of behind the wheel (BTW) evaluations (Fox et al., 1998), the structured nature of these evaluations presents limitations. Specifically, with the prearranged driving conditions (e.g., route, time of day, traffic pattern) and instructions provided by the driving specialist, there are fewer demands for a driver to employ fundamental tactical and strategic driving skills (Ryan et al., 2009); thus, driving difficulties stemming from tactical and strategical skill deficits may remain undetected. Other limitations of BTW evaluations include an inability to evaluate how drivers manage in hazardous driving scenarios and evaluator bias (Fox et al., 1998).

Studies evaluating driving capacity using off-road, closed-course assessments have largely focused on operational level abilities such as basic maneuvering (e.g., braking, driving through cones, straight tracking) (Fox et al., 1998). Closed-course evaluations demonstrate poor ecological validity based on the failure to assess a range of components essential for real-world driving like complex maneuvering, tactical skills and decision making (Fox et al., 1998; Odenheimer et al., 1994). Although offering a safe and controlled environment to evaluate driving performance, off-road assessments do not involve enough complexity to gauge the integration of skills necessary to safely drive in traffic (Fox et al., 1998). Thus, closed-course evaluations alone are not adequate to assess driving ability (Odenheimer et al., 1994), however these assessments may be useful in determining if the minimum driving standards are met (Fox et al., 1998).

The use of driving simulators as means of evaluating driving capacity, in a safe and controlled environment, have grown significantly in prominence in recent years (Mayhew et al., 2011). Driving simulation programs have the ability to assess complex driving skills through immersion in scenarios ranging from mundane to life-threatening without posing risks to driver safety. Studies involving healthy adult (Shechtman et al., 2009) and aging populations (Lee, 2003) have shown that performance on driving simulations were comparable to on road assessment outcomes, which further supports the validity of driving simulators as an evaluation tool. Other benefits to utilizing driving simulators include the standardization of driving scenarios and objective assessment of driving performance (De Winter et al., 2009). However, driving simulation programs may contain oversimplified road environments that poorly reflect actual driving conditions and place fewer demands on information process both of which serve as central limitations to their use (Shechtman et al., 2009).

DMV records are an objective assessment of driving safety through a drivers' history of traffic violations, suspensions and MVAs. Records can be retrieved from state licensing agencies and detail all motor vehicle related events within a driver's lifetime or designated time frame.

Traffic violations detailed on DMV records include non-moving safety (e.g., parking violations, expired inspection/registration, faulty vehicle equipment) and moving safety violations (e.g., speeding, reckless driving, driving while under the influence/intoxicated, distracted driving, failure to use turn signals, operating a vehicle without a license). DMV records have the advantage of providing information about violations and MVAs that are unable to be assessed through BTW or off-road evaluations. Driving records are also more reliable than self-report data, as drivers have been found to overestimate the number of violations and MVAs recorded on DMV reports (Arthur Jr et al., 2001). Nevertheless, the most central limitations to utilizing DMV records as a measure of driving safety is the exclusion of information about near crashes, minor MVAs, or injuries sustained from MVAs (Margolis et al., 2002).

Given the role of cognition in driving, several cognitive assessments have been utilized to evaluate driving safety. Amongst the most commonly employed measures to assess driving performance is the Useful Field of View Test (UFOV); this computerized test involves the timed identification of stimuli in the central and peripheral fields of view, in order to measure visual attention and processing (Marcotte & Scott, 2004). Research has shown that the UFOV is associated with MVA history, simulated driving performance, BTW assessment outcomes, as well as future MVAs in aging populations (Clay et al., 2005). Another measure frequently used to evaluate driving fitness is the Stroke Drivers Screening Assessment (SDSA). The SDSA is comprised of three subtests (Dot Cancellation, Square Matrices and Road Sign Recognition), and predictions about driving fitness are calculated based on aspects of the driver's performance on each subtest (Lincoln & Radford, 2008). Reported findings regarding the validity of the SDSA have been mixed. While the SDSA has been a strong predictor of driving performance in stroke, PD (Akinwuntan et al., 2011) and MS (Akinwuntan et al., 2012; Lincoln & Radford, 2008) populations, it has been inadequate as a standalone measure in predicting on road assessment outcomes in samples of individuals with cognitive deficits/dementia (Selander et al., 2010) and TBI (Radford, 2003).

Demographic and Neuropsychological Factors and Driving

Driving is an instrumental activity of daily living that contributes to independence and quality of life. An array of driving behaviors and outcomes have been significantly associated with demographic characteristics, cognition, vision, mobility function, falls, fatigue, and psychological factors.

Demographic Factors. Demographic characteristics have been associated with a range of driving behaviors. Several studies have shown that males are more prone to violating traffic regulations (González-Iglesias et al., 2012), issued more traffic violations (Factor, 2018) and fines, and self-report more accidents (González-Iglesias et al., 2012) than females. Moreover, in a sample of motorists in Israel, younger age, fewer years of education, lower social class and family income, and religious affiliation were associated with a higher number of traffic violations issued (Factor, 2018) and MVA involvement (Factor et al., 2008). Similarly, Palumbo et al. (2019) found that the rate of traffic violations in older drivers was 72% lower than in middle-aged drivers. Nevertheless, research regarding the involvement of older drivers in MVAs has yielded mixed results. In a sample of heavy goods drivers, younger drivers had higher rates of MVAs that declined and plateaued until age 63 when MVA rates increased again (Duke et al., 2010); these findings are consistent with the high rates of self-reported MVAs in drivers over age 70 (Papa et al., 2014). Older adult drivers have also been found to demonstrate slower reaction times and driving speeds, have more difficulty maintaining a constant distance behind a pace car, and were involved in more MVAs on a simulated driving assessment (Doroudgar et al., 2017).

Cognition. Rudimentary cognitive processes such as attention and information processing are fundamental to driving behavior and safety. Drivers must attend to critical visual information and ignore irrelevant stimuli (visual attention), while also reacting, breaking, and adapting to hazardous situations as they arise (processing speed) (Wolfe & Lehockey, 2016). Given the foundational role of attention in other cognitive processes, inattention amid driving not only delays information processing, but it also obstructs higher-order cognitive processes that are required to maintain safety. Supporting this theoretical link, data from the 100-Car Naturalistic Driving study showed that about 78% of MVAs and 65% of near-crashes were contributed to by inattention; a large portion of the MVAs and near-crashes in this study were due to interference of a secondary task distraction (Dingus et al., 2006; Neale et al., 2005), indicating that deficits in attention and processing pose a serious risk to driving safety. Furthermore, impairments in selective attention have predicted on road assessment outcomes in motorists with Huntington's disease (HD) (Devos et al., 2014). In aging populations, attention deficits were associated with a higher number of MVAs on simulated driving tasks (Cuenen et al., 2015) and a higher risk for future MVAs (Anstey et al., 2005). Similarly, visual processing and attention measured by the UFOV were related to the overall number of MVAs and to the number of at-fault accidents over seven years in older adult drivers (Cross et al., 2009). Cognitively distracted drivers have also been found to commit more driving safety errors such as making incomplete stops at stop signs and delayed breaking initiation at pedestrian crossings on simulated driving tasks (Cuenen et al., 2015). In a mixed sample of drivers with Alzheimer's disease (AD) or Parkinson's disease (PD), processing speed predicted driving safety errors made during an on road assessment (Aksan et al., 2015). Additionally, concurrent deficits in attention and processing speed, as well as impaired perception, have been linked to limited operational driving skills in motorists with PD (Stolwyk et al., 2006).

From a theoretical perspective, executive function plays a role in safe driving via planning, self-monitoring, response inhibition, and judgments made BTW (Wolfe & Lehockey, 2016). Several studies have shown that executive functioning deficits have been associated with on road assessment outcomes across populations of individuals with HIV (Marcotte & Scott, 2004), HD (Devos et al., 2012), PD (Classen et al., 2015; Devos et al., 2013b), and brain disorders such as stroke, TBI (Hargrave et al., 2012) and AZ (Innes et al., 2007). Executive function has also been linked to driving safety outcomes measures (e.g., traffic violations, MVAs); more specifically, adults with executive impairments were more likely to receive traffic violations (Hayashi et al., 2018; Tabibi et al., 2015) and to be involved in MVAs (Hayashi et al., 2018). With regard to specific driving behaviors, drivers with executive dysfunction engaged in more aberrant driving behaviors (Tabibi et al., 2015) and in particular, speeding, texting while driving, failing to wear a seatbelt, and driving while intoxicated (Hayashi et al., 2018). Reduced tactical level driving skills (speed adjustment, maneuvering and obstacle avoidance) were also observed in drivers with PD and executive deficits (Stolwyk et al., 2006).

Visuospatial functioning is one of the most studied neuropsychological domains in relation to driving capacity. Safe driving demands visuospatial abilities to make judgements about the space available in relation to other vehicles when maintaining a constant position, managing intersections and turns, and changing lanes. In samples of individuals with PD (Amick et al., 2007; Grace et al., 2005), AD (Grace et al., 2005; Reger et al., 2004), stroke (Akinwuntan et al., 2002) and community dwelling older adults (Mathias & Lucas, 2009), visuospatial abilities were related to determinations about driving fitness made using on road assessments. Rizzo et al.

(1997) also reported that visuospatial deficits predicted MVA involvement on a simulated driving task among drivers with AD. Given the role of visuospatial function in a driver's understanding of a vehicle in time and space, impairment in such areas can lead to unintentional engagement in dangerous driving behaviors. Further, visuospatial dysfunction has been associated with a higher number of driving safety errors in motorists with PD (Amick et al., 2007), and specific safety errors like unsafe passing, tailgating and poor lane observance in AD (Dawson et al., 2009). In addition to impacting safe driving behaviors, operational level driving skills (e.g., steering, braking, maintaining lane position) were largely affected by visuospatial abilities in drivers with PD (Stolwyk et al., 2006).

Vision. Visual abilities are fundamental to driving, as drivers are required to scan, identify, and distinguish stimuli in the environment in order to maintain safety (Classen, 2017; Elgin et al., 2012). Studies have yielded mixed findings regarding visual acuity and MVA involvement, with a significant portion of research showing no evidence of a relationship (Anstey et al., 2005; Cross et al., 2009; Ivers et al., 1999; Margolis et al., 2002). However, literature has suggested that visual assessments provide a better determination of driving capacity when considered alongside cognitive and motor measures, then when considered independently (Wolfe & Lehockey, 2016). When examined with cognition, cognitive and visual factors accounted 83-95% of the variance in safe driving capacity scores in a sample of community-dwelling older adults (Anstey et al., 2012). Similarly, Akinwuntan and colleagues (2002) found that a model including both visual acuity and visuoconstruction abilities was the best predictor of on road assessment outcomes in stroke survivors.

Mobility and Falls. Physical and mobility related factors are essential to engagement in various independent activities of daily living and, in particular, driving. Research investigating the effects of physical functions on driving has been inconsistent, likely resulting from discrepancies in the definition and measurement of physical function. Based on data from the longitudinal multisite LongROAD study, Ng and colleagues (2020) found that lower extremity function measured by the Short Physical Performance Battery (SPPB) was associated with MVA involvement within the past four years amongst older drivers. However, in the same cohort of drivers, when general physical activity engagement was examined by intensity (e.g., vigorous versus moderate) there was no significant relationship to crash involvement (Talwar et al., 2019). Studies examining MVAs and specific physical domains have found that foot reaction time (Margolis et al., 2002) and neck rotation (Marottoli et al., 1998) were associated with MVAs in aging populations.

Fall status has been linked to a range of driving behaviors and safety outcomes across clinical and aging populations. Theoretically, falls may affect driving behavior through the physical and, or, psychological consequences of sustaining falls (Scott et al., 2017). Physical consequences of falls, such as physical injury, can hinder functional mobility and thus may impact driving ability (Tinetti & Williams, 1998). With regard to the psychological sequalae, falls can contribute to fears of falling and other negative psychological consequences that lead to reduced physical engagement followed by deconditioning or changes in driving behavior, which precipitate poorer driving abilities (Bruce et al., 2002; Scott et al., 2017). Moreover, there is extensive evidence that provides support for fall history as a strong predictor of MVAs in older adult drivers. For instance, in a longitudinal study of drivers over age 55, Pope et al. (2020) found that women endorsing a fall at baseline were 2.6 times more likely to report MVA involvement over 15 years than men; these findings are largely supported by the literature on falls and driving in samples of older adult (Cross et al., 2009) and older female drivers (Margolis et al., 2002). Similarly, in a mixed sample of drivers over age 55 with either cardiovascular disease or diabetes mellitus, higher MVA risk was associated with fall history, low baseline systolic blood pressure, sleep apnea, and depression (Joseph et al., 2014). Falls have also been linked to a range of dangerous driving behaviors, which in part may be due to the relationship to lower limb dysfunction. In aging populations, fall history has been associated with brake and hazard response times (Gaspar et al., 2013). Fallers with PD have also been found to drive at slower speeds and to have more episodes of hard breaking than non-fallers (Crizzle et al., 2015).

Fatigue. Fatigue has profound implications for driving safety due to the interference with essential cognitive processes that are required for driving. Driving research has tended to operationalize fatigue through both objective and subjective measures of drowsiness. In a study conducted by the National Sleep Foundation, in a period of one year, 36% of drivers endorsed nodding off or having fallen asleep BTW and 2% had an accident or near-accident as a result of drowsiness (National Sleep Foundation, 2008). Drivers admitted to the emergency department for MVAs and MVA-related injuries endorsed more severe fatigue and had a higher prevalence of sleep dysfunction compared to controls (Bener et al., 2017); in the same cohort of drivers, fatigue, sleepiness and dangerous driving behaviors (excessive speed, lapses, errors, traffic violations and cell phone use) were associated with higher odds of sustaining injuries as a result of an MVA (Bener et al., 2017). Few studies have examined the impact of fatigue on driving ability in drivers with medical conditions. Within this context, in a study of drivers with PD, daytime sleepiness and sudden onset of sleep were predictive of MVA causation (Meindorfner et al., 2005). Similarly, fatigue – operationalized as endorsing yes to “after driving, I feel tired?” – was associated with collisions on simulated driving scenarios in drivers with minimal and overt hepatic encephalopathy (Bajaj et al., 2009). Fatigue has also been shown to affect drivers differently based on roadway geometrics. Further, fatigued drivers exhibited faster longitudinal speeds on curved roadway, poorer management of curved paths via steering wheel movements, and more difficulties with lane position maintenance (Du et al., 2015). Lower rates of deterioration in steering wheel movement and lane position maintenance have also been found in simulated driving scenarios with higher geometric variety (Farahmand & Boroujerdian, 2018).

Psychological Factors. Given that driving is a complex activity requiring the integration of various cognitive, visual and motor processes, personality factors and psychiatric disorders can affect the cognitive underpinnings of driving. The literature has suggested that personality factors manifest in behavior through impacting attitudes that precede behavioral intention and action (Fishbein & Cappella, 2006; Lucidi et al., 2019). Supporting this relationship within the context of driving, Lucidi et al. (2014) found that hostility and social nonconformity in older adult drivers was predictive of negative attitudes about traffic safety, and such attitudes were associated with traffic violations, lapses and errors. Several studies have also found that extraversion (Wang et al., 2019), neuroticism (Alavi et al., 2017b; Wang et al., 2019), and agreeableness (Alavi et al., 2017a; Cellar et al., 2000) were associated higher risk for traffic violations and MVAs. Moreover, characteristics such as sensation-seeking (Dahlen et al., 2005; Lucidi et al., 2019; Lucidi et al., 2014), impulsivity (Dahlen et al., 2005), and hostility (Lucidi et al., 2014) have appeared to be the most frequently implicated in unsafe driving behaviors and outcomes.

Given the well-established link between psychiatric disorders and cognitive dysfunction, it is possible that such deficits hinder safe driving abilities in mental health populations. Literature has focused predominantly on driving safety outcomes in individuals with depression and anxiety; however, a meta-analysis has provided mixed support for violation and MVAs rates being higher in drivers with schizophrenia, bipolar disorder, personality disorders and psychosis (Ménard & Korner-Bitensky, 2008). Drivers with a psychiatric diagnosis were also found to have higher rates of MVA-related deaths (Ménard & Korner-Bitensky, 2008).

Research has shown that depression has a significant impact on driving safety outcomes and behaviors. Further, in a sample of male heavy goods drivers in Iran, depression diagnosed by a semi-structured interview was associated with a 2.4-fold increased risk for MVAs over two years (Alavi et al., 2017b); similarly, Hilton and colleagues (2009) found that depression severity was related to MVA odds, with drivers self-reporting severe and very severe depressive symptoms having a four to five-fold increase in MVA and near crash risk in the past month. These findings are consistent with Bulmash et al. (2006), which showed that severely depressed drivers had a higher prevalence of MVAs on a simulated driving task. Although less frequently studied, depression has also been related to increased odds of traffic violations in heavy goods drivers (Alavi et al., 2017a) and unsafe driving behaviors. More specifically, depressed drivers have demonstrated slower steering reaction times (Bulmash et al., 2006), which is consistent with the observed slowing in processing and psychomotor speed secondary to depression. Depression has also contributed to driving restriction and cessation in aging drivers (Keay et al., 2009) over five years; as depression was examined longitudinally, it is likely that depression is an antecedent of driving restrictions and cessation rather than a consequence.

Anxiety has also been examined within the context of driving safety in a range of adult populations. Specifically, anxiety disorders have been associated with a 2.7-fold increased risk for MVAs in heavy goods drivers in Iran (Alavi et al., 2017b). In a sample of community-dwelling adults, drivers with severe anxiety had more at-fault MVAs in the last three years than drivers with mild and moderate anxiety (Dula et al., 2010). Severely anxious drivers also received more seatbelt-related violations, endorsed more instances of cutting off other motorists, had more episodes of driving while under the influence, and higher engagement in tailgating compared to mild and moderately anxious drivers (Dula et al., 2010). Similarly, anxiety disorders and anxiety severity have been linked to a higher number of total traffic violations (Alavi et al., 2017a), as well as ordinary (e.g., highway code violations) and aggressive (e.g., tailgating, reckless passing, swerving) traffic violations (Shahar, 2009). In addition, several studies have shown that anxiety is associated with more driving errors and lapses (Pourabdian & Azmoon, 2013), higher overall velocity, lateral acceleration, and speeding (Roidl et al., 2014); while these findings contrast with appraisal tendency perspectives that assume anxiety would facilitate more cautious driving (Roidl et al., 2014), it has been suggested that anxiety hinders working memory function that subsequently decreases the cognitive resources available for driving (Dula et al., 2010).

Although the collective influence of depression and anxiety on driving has not been previously considered, several studies have examined the role of psychological distress (a measure of mental health that encompasses symptoms of depression and anxiety) within the context of driving safety. Studies examining psychological distress and MVA outcomes have yielded mixed results, which may be a function of how psychological distress is operationalized and measured. More specifically, Martiniuk and colleagues (2010) found that non-specific psychological distress in young adult drivers was not associated with MVA risk. However, high levels of psychological distress on the General Health Questionnaire (GHQ-12) – a measure that is comprised of two factors: depression-anxiety and social functioning – were related to an increased odds of MVA involvement (Mann et al., 2010). Non-specific psychological distress has also been associated with risky driving behaviors in young adult drivers (Scott-Parker et al., 2011).

Driving and Multiple Sclerosis

Driving is vital to maintaining mobility and functional autonomy in MS (Devos et al., 2013a). While approximately 23% of pwMS stop driving post-diagnosis (Ryan et al., 2009), more than half of pwMS report changing their driving habits (Chipchase et al., 2003). PwMS tend to drive less frequently (Schultheis et al., 2009), shorter distances, restrict the conditions under which they drive (e.g., avoidance of driving at night or inclement weather), and make decisions about their ability to drive on a daily basis (Chipchase et al., 2003). While research investigating driving outcomes and demographic factors in MS is scarce, drivers with MS have been characterized by shorter disease durations, more mild disability, and greater awareness of their deficits compared to non-drivers (Ryan et al., 2009). However, pwMS had higher rates of nonmoving safety (e.g., parking violations), administrative (e.g., expired registration), and total driving violations (Dehning et al., 2014), in addition to an increased risk for MVAs (Lings, 2002) compared to healthy controls.

Neuropsychological Factors and Driving in MS

Cognition. Cognitive impairment is one of the most extensively studied correlates of driving behavior and safety in MS. PwMS with cognitive impairments had a higher incidence of MVAs and similar rates of traffic violations to cognitively intact pwMS and healthy controls (Schultheis et al., 2002). Several studies have found that pwMS who failed either an on road or simulated driving assessment performed more poorly on tasks of sustained attention (Lincoln & Radford, 2008), information processing (Schultheis et al., 2010b), visual memory (Lincoln & Radford, 2008), visuospatial abilities (Lincoln & Radford, 2008; Morrow et al., 2018), and executive function (Lincoln & Radford, 2008). Further, in a study of drivers with MS, a model consisting of both neuropsychological and visual factors (visuospatial function, response inhibition, binocular acuity, stereopsis and vertical visual field) best determined variation in on road assessment scores (Devos et al., 2017). Visuospatial abilities were also the most significant predictor of violation and MVA history in a sample of drivers with MS (Schultheis et al., 2010b). Nevertheless, the relation between neuropsychological function and specific driving errors in pwMS have been given little research attention. Within this context, the UFOV visual processing speed subtest has been associated with on road gap acceptance errors (Classen et al., 2018) and the divided attention subtest has predicted reaction time on driving simulations (Krasniuk et al., 2021). Krasniuk et al. (2021) also found that the UFOV divided attention subtest and California Verbal Learning Test-II (CVLT-II) immediate recall were insufficient predictors of driver response type, errors and driving speed in driving simulation scenarios.

Visual Factors. Visual acuity and stereopsis are crucial to safe driving, as a result of their role in visuo-integrative driving abilities (e.g., identifying road signs and traffic signals, understanding and quality of traffic participation, behavior and communication with other drivers) (Devos et al., 2017). Yet, research examining the relation between vision and driving safety in MS – similar to the general population – has yielded mixed results. In a mixed sample of drivers with MS (with and without visual deficits) and healthy controls, there were no differences amongst groups in the number of violations, MVAs or self-restricted driving practices (Schultheis et al., 2010a). In contrast, visual complaints were associated with poor lane position maintenance and slower reactions to changes in speed among pwMS (Marcotte et al., 2008). Nonetheless, visual factors when considered with cognitive and motor domains have been linked to driving behaviors. More specifically, Devos et al. (2017) showed that the strongest predictors of operational level driving abilities were stereopsis, glare recovery, attentional shift, and use of assistive devices. Binocular acuity, stereopsis, visuospatial function, response inhibition and reasoning were significantly associated with tactical level driving abilities (Devos et al., 2017).

Mobility and Falls. Drivers with MS reported that physical symptoms, leg issues and numbness in particular, were the most significant MS-related symptoms interfering with driving ability (Chipchase et al., 2003). Studies have shown that greater functional impairments measured by the MS Functional Composite (MSFC; comprised of the Paced Auditory Serial Addition Task, Nine-Hole Peg Test and Timed 25-Foot Walk) were associated with a higher number of crashes on a simulated driving task (Kotterba et al., 2003), MVAs recorded by the DMV (Shawaryn et al., 2002) and more difficulties with maintaining lane position (Raphail et al., 2020); MSFC scores have not been significantly related to the number of recorded traffic violations recorded by the DMV (Shawaryn et al., 2002). Further, overall level of physical disability in drivers with MS has been associated with driving frequency (Schultheis et al., 2009; Shawaryn et al., 2002), self-imposed restrictions, and changes in driving behavior (Schultheis et al., 2009). With regard to specific domains of physical function, drivers with lower limb spasticity were found to have slower responses to speed changes and poorer tracking abilities in simulated driving scenarios (Marcotte et al., 2008). Despite the high prevalence of mobility impairments in MS (Hemmett et al., 2004) as well as the association between physical deficits and falls (Matsuda et al., 2012; Mazumder et al., 2014), the relation between falls and driving safety have yet to be examined in the MS population.

Fatigue. In drivers with MS, fatigue has been reported to effect driving plans, the amount of time spent driving, and the locations driven to (Chipchase et al., 2003). Of the limited research examining the role of fatigue in driving in MS, Devos et al. (2021) found that pwMS exhibited more severe symptoms of daytime sleepiness after engaging in monotonous driving simulator scenarios than healthy controls (Devos et al., 2021). While the aforementioned study did not include specific driving behaviors or safety outcomes, insight into the relationship between fatigue and driving safety in drivers with MS remains unclear.

Psychological Factors. Although depression and anxiety are highly prevalent in pwMS, little is known about the influence of mood on driving in the MS population. To date, one study has evaluated mood in their investigation of driving performance in pwMS. In a sample of 15 drivers with MS and 17 healthy controls, Devos and colleagues (2013a) found that depression in pwMS was associated with less time for two vehicles to collide if their current speeds were maintained and no action were taken (time to collision) on a simulated driving task; thus, the authors concluded that depressed drivers with MS may engage in more unsafe driving practices than non-depressed drivers. In the same cohort of drivers with MS and healthy controls, anxiety was associated with poorer performance on the divided attention subtest of the UFOV, and was not related to performance on any driving simulation measures (Devos et al., 2013a).

Rationale

Cognitive, visual, and physical sequelae of MS may contribute to the increased rates of traffic violations, MVAs, and driving difficulties. Literature on driving in MS has focused extensively on the cognitive correlates of driving performance and safety, which involves extensive and costly neuropsychological assessments. However, no studies have explored whether falls and psychological symptoms are associated with driving safety outcomes recorded by the DMV or self-reported driving difficulties in drivers with MS. This study aims to explore the impact of mobility and mood factors that are easily gathered during a routine neurology appointment. Additional knowledge on the role of prominent MS symptoms on driving is essential to developing future interventions targeting driving safety.

Innovation

To date, there are no published studies that explore the association between fall history and driving outcomes and difficulties in drivers with MS. Furthermore, there is scant literature addressing the contribution of depression and anxiety to driving safety outcomes among pwMS. Thus, the present study addressed these gaps in the literature and examined whether negative driving outcomes (e.g., traffic violations and MVAs) and self-reported driving characteristics (e.g., driving difficulties due to MS symptoms and driving restrictions) were related to falls and psychological symptoms. As such, the findings of this study may enhance identification of pwMS at risk for unsafe driving behaviors and negative driving outcomes, and thus allow for earlier rehabilitation-based driving interventions.

Hypotheses

Specific Aim 1: The present study aimed to evaluate falls within the context of driving safety outcomes and behaviors among drivers with MS. We sought to examine fall history (defined as the presence or absence of falls within the last year) as a predictor of MVAs, traffic violations, and self-reported driving difficulties and restrictions. There were few specific hypotheses under this aim due to the dearth of literature on falls and driving in MS.

Hypothesis 1a: Fall history would be associated with a higher number of MVAs.

Hypothesis 1b: Fall status would be associated with a greater number of self-reported driving difficulties due MS symptoms.

Hypothesis 1c: Fall history would not be associated with a higher number of reported restricted driving conditions.

Hypothesis 1d: There were no specific hypotheses about falls and traffic violations due to the lack of research exploring the link between DMV recorded violations and falls.

Specific Aim 2: The second aim of the study was to evaluate depressive symptoms as a predictor of DMV outcomes and self-reported driving characteristics among pwMS. Given the scarcity of literature on depression in drivers with MS, the following hypotheses were based on research in aging and psychiatric populations.

Hypothesis 2a: Depressive symptoms would be associated with a higher number of MVAs within the last five years.

Hypothesis 2b: Higher depressive symptoms would be associated with a greater number of traffic violations received within the last five years.

Hypothesis 2c: Higher depressive symptoms would be associated with a higher number of self-reported MS symptoms hindering driving ability.

Hypothesis 2d: Higher depressive symptoms would be associated with a higher number of conditions under which participants restrict their driving.

Specific Aim 3: The third aim sought to determine if anxiety symptoms were associated with DMV outcomes and driving characteristics in drivers with MS. As a result of the scant literature investigating the impact of anxiety on driving in MS, the subsequent hypotheses were based on research in aging and psychiatric populations.

Hypothesis 3a: Anxiety symptoms would be associated with a greater number of MVAs.

Hypothesis 3b: Self-reported anxiety symptoms would be associated with a higher number of traffic violations received within the last five years.

Hypothesis 3c: Higher anxiety symptoms would be associated with a higher number of self-reported driving difficulties due to MS manifestations.

Hypothesis 3d: Higher anxiety would be associated with a higher number of conditions under which driving is restricted.

Specific Aim 4: The fourth aim was to explore whether age interacted with either falls or psychological symptoms in the relationships to DMV outcomes. While there is a dearth of literature exploring the relationship between age and DMV outcomes in MS (e.g., traffic violations and MVAs), the following hypotheses are based on the literature in healthy and aging populations.

Hypothesis 4a: The interaction between age and fall history would be significantly associated with a higher number of MVAs and traffic violations received in the last five years.

Hypothesis 4b: The interaction between age and depression would be significantly associated with a higher number of MVAs and traffic violations received in the last five years.

Hypothesis 4c: The interaction between age and anxiety would not be associated with a higher number of MVAs, nor would it be associated with the number of traffic violations received in the last five years.

Exploratory Aim 1: The first exploratory aim sought to examine if fatigue and personality traits were associated with DMV outcomes and driving characteristics. With the limited research examining the impact of fatigue and personality traits among drivers with MS, hypotheses were generated as a result of research in healthy adult, aging, psychiatric and neurological populations.

Exploratory Hypothesis 1a: Higher fatigue severity would be associated with a greater number of MVAs; however, given the lack of literature on fatigue and traffic violations, there are no specific hypotheses regarding this relationship.

Exploratory Hypothesis 1b: Higher neuroticism, extraversion and agreeableness would be associated with a greater number of MVAs and traffic violations, respectively.

Exploratory Hypothesis 1c: More severe fatigue would be associated with a higher number of driving restrictions reported. With regard to symptoms hindering driving ability, there are no specific hypotheses about the relation with fatigue, as no prior literature has examined this relationship.

Exploratory Hypothesis 1d: There are no specific hypotheses about personality traits, symptoms hindering driving ability, and driving restrictions.

Chapter II: Methods

Funding

The Leonard Diller Dissertation Award in Neurorehabilitation from the Foundation for Rehabilitation Psychology was awarded to provide support for this study.

IRB Oversight

This study was reviewed and approved by the Western Copernicus Group Institutional Review Board (IRB Protocol #: 20210664).

Participants

Inclusion criteria for the present study: age between 18-80 years; a diagnosis of MS based on the McDonald criteria (Thompson et al., 2018); a valid driver's license; at least two years of driving experience; a Patient Determined Disease Steps (PDDS) score between 1-7. Exclusion criteria included: driving less than two days in the last month; a comorbid neurodegenerative condition other than MS (e.g., dementia).

Participants were all existing patients at the MS Center at Holy Name Medical Center in Teaneck, NJ. Of the 220 patients agreeing to undergo screening between November 2020 and July 2021, 114 were included in the study sample.

Procedure

As shown on Figure 1, 1,270 pwMS were approached for this cross-sectional survey study through one of three methods: at neuropsychological evaluation, by telephone, or by email.

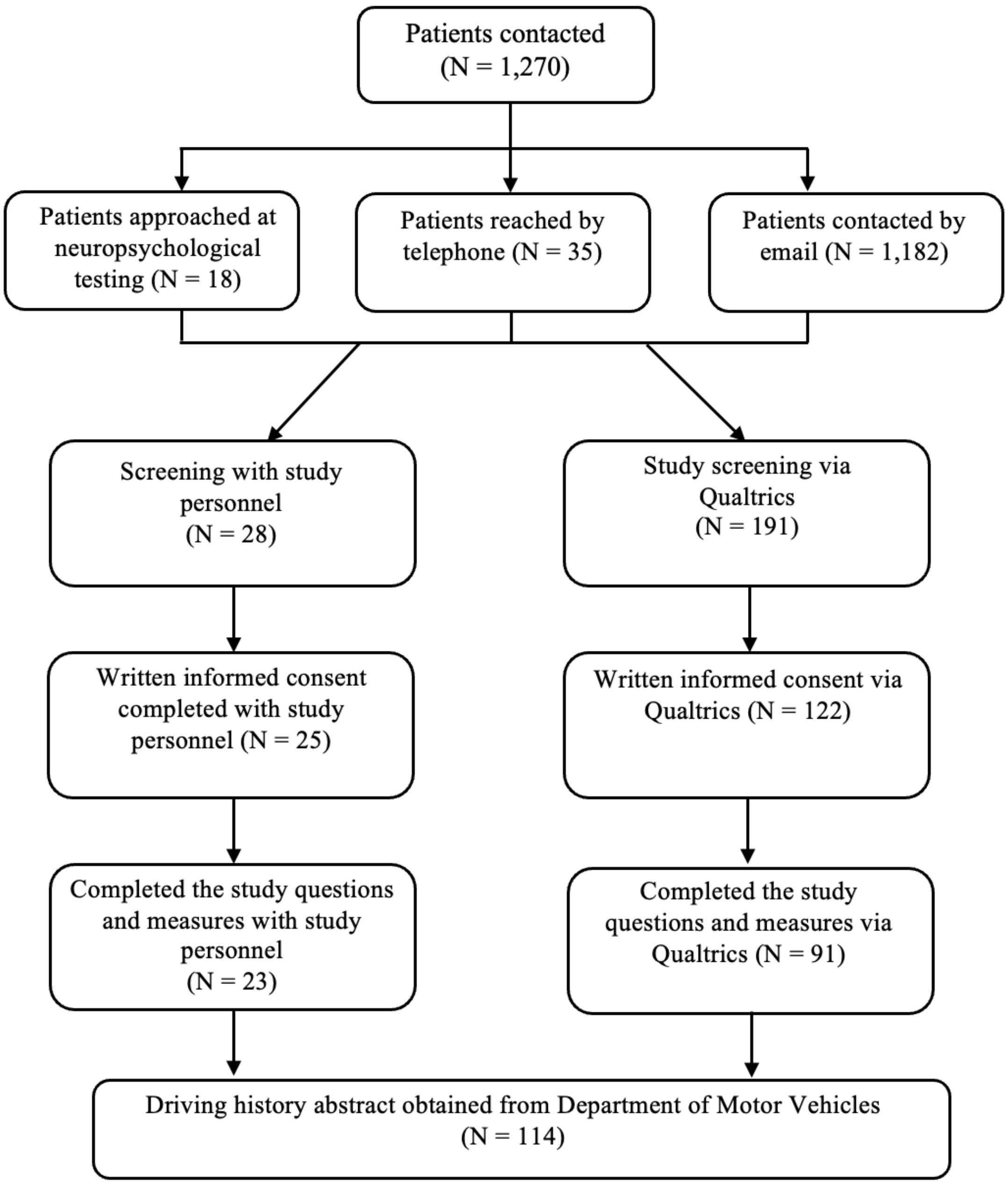
All patients who were approached (at neuropsychological assessment, by telephone or email) were provided with brief information regarding the study and assurance that driving records as well as self-reported driving behaviors would not be shared with anyone, placed into their medical chart, nor shown to their neurologist. For patients who were contacted via email, the aforementioned information was included in the body of the email along with the Qualtrics link to access the study; patients who did not complete the survey received two emails per month over a three-month period to remind them about the study and to thus encourage participation (patients who had completed the study through the Qualtrics survey link did not receive any additional emails following survey completion).

Patients who were interested in the present study were screened by study personnel based on questions pertaining to study eligibility criteria. Interested patients contacted by telephone were given the choice to complete the screening – and study – questions with study personnel or through the Qualtrics survey link. For patients who were contacted by email, screening questions were presented on their device when opening on the Qualtrics survey link; patients who did not meet eligibility criteria were taken to the end of the Qualtrics survey, while those meeting eligibility criteria were presented with study consent forms on Qualtrics. Written informed consent was obtained from all interested and eligible patients (irrespective of method of contact).

For those electing to complete the study during their neuropsychological evaluation, study questions were included in the clinical interview portion of their assessment. Patients contacted by telephone electing to complete the study questions with study personnel scheduled at time to complete the study, while those participating in the study on Qualtrics were presented with study questions after completing study consent forms. All participants were presented with the same study questions regardless of the method of contact and study completion (with study personnel versus through Qualtrics).

Once informed consent was obtained, and study questions and measures were complete, patients received a $10.00 Amazon e-gift card for their participation. Driver history abstracts were also then requested from the DMV in the state of a participant's licensure.

Figure 1. Study Flow Diagram



Measures

Information regarding demographic factors, disease and clinical characteristics as well as fall history, psychiatric symptoms and driving practices were either gathered through a clinical interview with study personnel or online survey response. After informed consent and all study measures were completed, a driver abstract history was requested from the DMV in the state of participant licensure. The measures that were used are described in further detail below.

Demographic, Disease and Clinical Characteristics. Participants were prompted to answer questions pertaining to demographic information including: gender identity, racial background, employment history and marital status. With regard to disease and clinical characteristics, participants were prompted to detail their current medication regimen, the year of MS diagnosis, and history of psychiatric diagnoses. Information about MS subtype was either provided by a participant or by clinical staff at Holy Name Medical Center.

Fall History. A fall was defined as unintentionally moving downwards to the floor or a lower level that is unrelated to an extrinsic or intrinsic event (Allali et al., 2017). Participants were prompted to answer a question about whether they had sustained a fall within the last year in a nominal format (e.g., no falls, 1-2 falls, 3-6 falls, 7-9 falls, more than 10 falls). If participants endorsed yes to the aforementioned question, they were presented with a closed-ended (yes/no) question about whether they had sustained an injury from falling in the last year. Falls data was recorded in dichotomous (presence/absence of falls within the last year) and nominal formats; however, given that a majority of pwMS inaccurately self-report the number of falls sustained over the course of one year (Dibble et al., 2013), the dichotomized version of falls was used in study analyses.

Self-Reported Driving Behavior. Closed-ended questions were used to obtain information about current driving behaviors, in addition to questions about perceived difficulties due to MS symptoms and restrictions. Based on information about driving disclosed in routine neuropsychological evaluations, we generated questions about driving domains that appeared relevant to pwMS; such domains included perceptions about ability to maintain lane position, curb hitting, hitting objects, concerns about driving expressed by others, and use of adaptive equipment. Specifically, participants were prompted to answer the following questions: "Have you noticed any difficulties with staying in your lane while driving?" "Do you find yourself hitting the curb often?" "Have you hit an object (i.e., garbage cans, poles) while driving in the last year?" "Has anyone (family members, friends, or doctors) expressed any concerns about your driving within the last few years?" and "Do you use any adaptive automobile equipment? This may include hand controls, spinner knobs, wide angle or enlarged mirrors, specialized seats to ease vehicle transfers, etc." Responses to the previously questions were coded dichotomously (with 0 representing a response of "no" and 1 reflecting "yes") and examined independently. Participants were also prompted to answer a question about driving preference (e.g., "do you prefer driving yourself, having someone else drive you, or use public transportation?") with response options including driving myself, having someone else drive me, and using public transportation.

Symptoms impacting driving ability were evaluated through closed-ended questions that were generated based on theoretical and empirical findings for the purpose of this study. Symptoms interfering with driving ability were characterized as sensory, physical, visual, cognitive and, or, fatigue-related. Participants were presented with the following nine questions to elicit perceptions about MS-related driving difficulties: "Do numbness or tingling in your arms or legs impact or make it challenging to drive?" "Does stiffness in your legs or feet impact or make it challenging for you to drive?" "Does weakness in your arms or legs impact or make it challenging for you to drive?" "Does spasticity impact or make it challenging for you to drive?" "Do vision issues (i.e., involuntary and uncontrolled eye movements or double vision) impact or make it challenging for you to drive?" "Does feeling "foggy" impact or make it challenging for you to drive?" "Does confusion or difficulties with directions impact or make it challenging for you to drive?" "Do cognitive difficulties such as issues with attention, processing speed or memory impact or make it challenging for you to drive?" and "Does fatigue impact or make it challenging for you to drive?" As response options were in a dichotomous format (no/yes), "no" was coded as 0 and "yes" was coded as 1. Responses to all nine questions were summed to generate a total number of MS symptoms hindering driving ability, and scores in this domain ranged from 0 to 9.

Driving restrictions were assessed using a series of closed-ended questions. Through consideration of theoretical and empirical findings, we generated nine questions about driving restrictions for the purpose of this study. The following questions were presented to participants pertaining to common driving restrictions: "Do you restrict your driving to any of the following conditions: daylight hours (yes/no), short distances (yes/no), times of low traffic (non-rush hours; yes/no), slow speeds (yes/no), local roads (yes/no), familiar places (yes/no), places with non-crowded parking lots (yes/no), driving only with a passenger present (yes/no), good weather (when it's not raining or snowing; yes/no)." "No" responses were coded as 0, and "yes" responses were coded as 1. Responses to all nine questions were summed to generate a total number of driving restrictions, with scores ranging from 0 to 9.

Driver History. A driver history abstract is a detailed record of all motor vehicle-related events (MVEs) that are generated by a state's DMV. The abstracts utilized in this study included all MVEs, including violations, accidents and suspensions, within the last five years. Consistent with prior studies, the number of traffic violations received were summed to generate a total number of violations for each participant (Dehning et al., 2014; Shawaryn et al., 2002); MVAs recorded by the DMV were also summed to generate a total number of MVAs for each participant within the last five years (Shawaryn et al., 2002).

Patient Health Questionnaire – 9-item (PHQ-9). The PHQ-9 is a nine-item self-report measure evaluating depressive symptoms (Kroenke et al., 2001). Symptoms are scored based on occurrence during the last two weeks and possible total scores range from 0 to 27. Scores of less than 5, 6-10, 11-15, 16-20 and 21-27 indicate no depression, mild, moderate, moderately severe and severe depression, respectively (Kroenke et al., 2001). An MS validated cut off of 10 is used to identify threshold depressive symptoms (Marrie et al., 2018). The PHQ-9 demonstrates good convergent validity with other measures of depression (Center for Epidemiological Studies Depression Scale-10 (CESD-10), Patient Reported Outcome Measurement System (PROMIS) Depression Short Form) (Amtmann et al., 2014), quality of life (Short-Form General Health Survey)(Kroenke et al., 2001), fatigue (Fatigue Impact Scale) and pain (MOS-Modified Pain Effects Scale) (Marrie et al., 2018); the PHQ-9 shows good criterion validity with the Structured Clinical Interview for DSM-IV Disorders and is moderately capable of discriminating between depressed and non-depressed pwMS (AUC = 0.86, 95% CI: 0.80, 0.93) (Marrie et al., 2018). Similar to the internal reliability in the general ($\alpha = 0.89$) (Kroenke et al., 2001) and MS populations ($\alpha = 0.87$) (Marrie et al., 2018), the PHQ-9 demonstrated good reliability in the present sample ($\alpha = 0.82$).

Hospital Anxiety and Depression Scale – Anxiety (HADS-A). The HADS is a 14-item scale assessing anxiety symptoms (HADS-A) during the past week and depressive symptoms (HADS-D) in the past two weeks (Zigmond & Snaith, 1983). This measure demonstrates good convergent validity with measures of fatigue (Fatigue Impact Scale) and pain (MOS-Modified Pain Effects Scale) (Marrie et al., 2018), and discriminant validity with measures of social support (Revised Social Provisions Scale), quality of life (SF-36), self-transcendence (Self-Transcendence Scale), and self-meaning (Purpose-in-life test (PIL) (Haugan & Drageset, 2014); the HADS also has adequate criterion validity with the Structured Clinical Interview for DSM-IV Disorders and is moderately capable of discriminating between depressed and non-depressed, and anxious and non-anxious pwMS (HADS-D: AUC = 0.84, 95% CI: 0.77, 0.92; HADS-A: AUC = 0.83, 95% CI: 0.69, 0.98) (Marrie et al., 2018). Further, the HADS shows fair to good internal reliability in adult (HADS-D: $\alpha = 0.77$; HADS-A: $\alpha = 0.73$)(Al Aseri et al., 2015), older adult (HADS-D: $\alpha = 0.60 – 0.75$; HADS-A: $\alpha = 0.65 – 0.83$) (Haugan & Drageset, 2014) and MS (HADS-D: $\alpha = 0.82$; HADS-A: $\alpha = 0.86$) (Marrie et al., 2018) populations; like other studies of pwMS, in the present sample the HADS-A also showed good internal reliability ($\alpha = 0.86$). Given that the HADS-D is less sensitive than the PHQ-9 in measuring depression (Hansson et al., 2009), only the HADS-A was utilized to evaluate participant anxiety symptoms the present study. Scores on the HADS-A range from 0 to 14, with a score of 8 or above indicating possible anxiety (Marrie et al., 2018).

Fatigue Severity Scale (FSS). The FSS is a nine-item self-report measure evaluating fatigue severity based on the extent to which respondents agree or disagree with statements about their fatigue within the last week (Krupp et al., 1989). Scores on the FSS range from 7 to 63, with higher scores indicating higher fatigue; a cut-off score of 4 or higher (total score divided by

9) has been used to identify significant fatigue (Krupp et al., 1989). This measure has good convergent validity with measures of perceived disease burden (Multiple Sclerosis Impact Scale (MSIS-29)), quality of life (EuroQol-5D-3L) and disease severity (Expanded Disability Status Scale (EDSS)) (Rosti-Otajärvi et al., 2017). Consistent with the internal reliability of the FSS in samples of individuals with MS (α = 0.81 – 0.95) (Krupp et al., 1989; Rosti-Otajärvi et al., 2017), Lupus (α = 0.89), and healthy adults (α = 0.88) (Krupp et al., 1989), this measure also demonstrated good internal reliability in the current sample (α = 0.94).

Brief Version of the Big Five Personality Inventory (BFI-10). The BFI-10 is a 10-item self-report measure evaluating personality dimensions of extraversion, agreeableness, conscientiousness, neuroticism and openness. Respondents are asked to rate each of the items on a 5-point scale ranging from 1 (disagree strongly) to 5 (agree strongly) (Rammstedt & John, 2007). The BFI-10 demonstrates good convergent validity with the Revised NEO Personality Inventory (NEO-PI-R) (Rammstedt & John, 2007); further, the five subscales of the BFI-10 show fair to poor internal reliability in samples of adolescents (extraversion α = 0.44; agreeableness α = 0.78; conscientiousness α = 0.43; neuroticism α = 0.45; openness α = 0.76) (Kunnel John et al., 2019) and undergraduate students (extraversion α = 0.45; agreeableness α = 0.24; conscientiousness α = 0.62; neuroticism α = 0.55; openness α = 0.36) (Balgiu, 2018). Moreover, in the present study, the BFI-10 showed poor to adequate internal reliability (extraversion α = 0.72; agreeableness α = 0.30; conscientiousness α = 0.47; neuroticism α = 0.74; openness α = 0.29).

Patient Determined Disease Steps (PDDS). The PDDS was used to evaluate disability status (Rizzo et al., 2004) based on respondent perceptions of walking ability using a nine-point scale. Scores range from 0 (normal) to 8 (bedridden), with higher scores indicating more severe disability (Learmonth et al., 2013). The PDDS shows strong convergent validity with measures of disability (Functional system (FS) scores in visual, pyramidal, cerebellar, sensory, bladder/bowel domains), ambulation (Timed 25 Foot Walk (T25FW), Timed-Up-and-Go (TUG), Multiple Sclerosis Walking Scale-12 (MSWS-12)) and lower extremity function (Abbreviated Late-Life Function and Disability Inventory (LL-FDI)) (Learmonth et al., 2013); this measure also has adequate discriminant validity with the FS visual, mental and brainstem scale scores (Learmonth et al., 2013). The PDDS demonstrates strong criterion validity with the Expanded Disability Status Scale (EDSS), which is one of the most widely used clinical outcome measure in MS (Learmonth et al., 2013).

Data Analysis Plan

Descriptive statistics (e.g., means, standard deviations, frequencies and percentages) were calculated for all variables of interest and calculated for the sample. Data was evaluated for normality, homogeneity of variance, and appropriateness for parametric statistical analysis (linearity). All statistical analyses were performed using IBM SPSS Version 27.0 (IBM Corp, Armonk, NY).

Bivariate statistics were used to examine outcome variables, demographic and disease-related variables, and driving characteristics. Pearson’s and Spearman’s correlations, independent t-tests, Fisher’s Exact, analysis of variance (ANOVA), Mann-Whitney U and Kruskal-Wallis tests were used to assess the aforementioned relationships. Factors significantly related to outcome variables were assessed as covariates in the respective Generalized Linear Model (GLM). Since the distribution of MVAs and traffic violations – as count variables – approximated a Poisson distribution, Poisson regression models were used to examine relationships between falls, psychological factors, MVAs and traffic violations. Self-reported driving characteristics (e.g., the number of symptoms hindering driving ability and driving restrictions) demonstrated a Gaussian distribution, and thus were evaluated using linear regression models. Both adjusted and unadjusted linear regression analyses were examined and reported.

Specific Aim 1: This aim sought to examine whether fall status was associated with DMV outcomes and self-reported driving characteristics. Poisson regression analyses were used to examine the effects of falls (predictor) on MVAs (hypothesis 1a) and traffic violations (hypothesis 1d) (outcome variables). Linear regression analyses were used to evaluate falls as a predictor of the total number of MS-related driving difficulties (hypothesis 1b) and the number of driving restrictions (hypothesis 1c).

Specific Aim 2: The second aim sought to evaluate the association between depression, MVAs, traffic violations, and self-reported driving characteristics. The relationship between depressive symptoms, MVAs (hypothesis 2a) and traffic violations (hypothesis 2b) were examined using Poisson regression models; depressive symptoms was the predictor variable and MVAs and traffic violations were the outcome variables. Separate linear regression analyses were used to evaluate depressive symptoms as a predictor of total number of MS symptoms hindering driving ability (hypothesis 2c) and the number of driving restrictions (hypotheses 2d) (outcome variables).

Specific Aim 3: The third aim was to examine the relationship between self-reported anxiety, DMV outcomes, and driving characteristics. Poisson regression analyses were used to evaluate anxiety symptoms as a predictor of objective driving outcomes including MVAs (hypothesis 3a) and traffic violations (hypothesis 3b). Linear regression models were used to examine whether anxiety symptoms – predictor – were associated subjective outcome variables such as the number of MS symptoms hindering driving ability (hypothesis 3c) and the number of driving restrictions (hypotheses 3d).

Specific Aim 4: This aim sought to explore whether age interacts with fall history or psychological symptoms, respectively, in relation to DMV outcomes. Multiple Poisson regression models were utilized; relevant covariates, main effects of independent variables (age, fall history or psychological symptoms), and interactions between age and either fall history or psychological symptoms were included in the models. The outcome variables in such models were the number of MVAs and traffic violations received within the last five years.

Exploratory Aim 1: This exploratory aim sought to determine whether fatigue and personality traits were associated with DMV outcomes and self-reported driving characteristics. Pearson's and Spearman's correlations were used to evaluate the relationships between fatigue, personality traits, MVAs, traffic violations, driving difficulties and driving restrictions.

Power analysis

G*Power version 3.1 was used to evaluate adequate power. Given the novelty of this study a moderate effect size was selected for study analyses. Proportions were used to determine group and total sample sizes. Based on the literature on prevalence of falls in a one-year period, the estimated ratio of fallers to non-fallers is 1.7 to 1. At $\alpha = 0.05$ with a power of .90 and an estimated effect size of .3, the total sample size was estimated at N = 89 (sample size group 1 = 33, group 2 = 56). An N of 89 was selected, as it provides a balance between the financial feasibility of the study with the statistical confidence in our findings.

Chapter III: Results

Participant Enrollment and Demographic Characteristics

Between November 2020 and July 2021, a total of 1,270 patients were approached about the present study (Figure 1). Eighteen patients were approached at the time of their neuropsychological evaluation, 70 patients who recently underwent neuropsychological evaluation or without an email listed in their medical chart were contacted by phone, and 1,182 patients were contacted via email. Of the patients approached at their neuropsychological evaluation, 3 patients preferred to complete the Qualtrics version of the survey, 1 patient was ineligible due to an invalid driver's license and another declined participation. Of the patients contacted by phone, 35 were successfully reached; among those 35 reached by phone, 15 elected to complete the brief interview with study personnel, 9 preferred completing the study using the Qualtrics survey link, 2 were ineligible due to driving cessation, and 9 declined to participate. Of the patients contacted via email, 192 patients started the survey (including the patients who elected for the Qualtrics survey at the time of neuropsychological testing or when contacted by telephone) and completed the required screening questions. A total of 220 patients agreed to undergo screening for the present study.

Of the 220 patients that underwent screening, 29 failed to meet study inclusion criteria (due to having an invalid driver's license or driving less than two days in the last month), 71 recorded incomplete responses on the virtual version of the survey, 3 failed to return study consent forms, and 3 withdrew participation due to apprehension about the DMV accessing their driving records. As a result, 114 patients were eligible, provided written informed consent, and completed all study measures (See Figure 1).

Demographic and disease-related characteristics of the study sample are included on Table 1. The sample largely consisted of participants identifying as Caucasian (68.4%) and female (73.7%), with a relapsing remitting disease course (89.5%). Participants reported receiving a diagnosis of MS an average of 14.89 years (*SD* = 9.3) years prior to study participation. Sixteen participants (14.0%) were not currently on a DMT; the most common DMTs in the present sample were Ocrevus (n = 30), Copaxone (n = 17) and Aubagio (n = 14).

Table 1. Sample demographic characteristics

Variable	Total (N = 114) Mean (SD) or N (%)
Age	52.87 (12.7)
Biological Sex	
Female	84 (73.7%)
Male	30 (26.3%)
Race/Ethnicity	
White/Caucasian	78 (68.4%)
Black/African American	22 (19.3%)
Hispanic or Latino/a/x	7 (6.1%)
Other	7 (6.1%)
Marital Status	
Single/Never Married	24 (21.1%)
Married/Cohabitating	71 (62.2%)
Separated or Divorced	16 (14.0%)
Widowed	3 (2.6%)
Employment Status	
Employed	69 (60.5%)
Unemployed	45 (39.5%)
MS Subtype	
Relapsing Remitting MS	102 (89.5%)
Secondary Progressive MS	9 (7.9%)
Primary Progressive MS	3 (2.6%)
Disease Duration	14.89 (9.3)
PDDS	1.7 (1.8)

Note: Age (years); Disease duration (years); PDDS = Patient Determined Disease Steps (0-8 range of scores)

Clinical Characteristics

Approximately 47% (n = 53) of participants endorsed falling at least once in the last year (Table 2). Of these participants, 29 (58.5%) reported sustaining one to two falls in the past year, 17 (32.1%) reported sustaining three to six falls, 3 (5.7%) reported sustaining seven to nine falls, and 2 (3.8%) reported sustaining more than 10 falls. PwMS with a history of falls were on average 53.51 (*SD* = 12.5) years old, mostly identifying as Caucasian (67.9%) and female (83.0%), with moderate gait disability (*M* = 2.5, *SD* = 1.9); those with a fall history had an average number of 15.9 years (*SD* = 9.3) since MS diagnosis. Nine (17.0%) participants with a fall history endorsed sustaining an injury from a fall within the last year. Participants with an injurious fall were a mean age of 56.7 years old (*SD* = 13.3), predominantly Caucasian (77.8%) and female (88.9%), with moderate gait disability (*M* = 2.22, *SD* = 1.9) and a relapsing remitting disease course (100.0%).

Table 2. Clinical characteristics

Variable	Total (N = 114) Mean (SD) or N (%)
Fall History	
No	61 (53.5%)
Yes	53 (46.5%)
History of injurious falls	9 (7.9%)
PHQ-9 Total Score	5.5 (4.7)
HADS-A Total Score	5.7 (4.3)
FSS Total Score	34.6 (15.6)
BFI-10: Extraversion	6.8 (2.3)
BFI-10: Agreeableness	7.7 (1.9)
BFI-10: Conscientiousness	8.4 (1.7)
BFI-10: Neuroticism	5.8 (2.3)
BFI-10: Openness	7.1 (1.9)

Note: PHQ-9 = Patient Health Questionnaire-9; HADS-A = Hospital Anxiety and Depression Scale – Anxiety subscale; FSS = Fatigue Severity Scale; BFI-10 = Big Five Inventory-10 items

Thirty-nine participants (34.2%) self-reported threshold psychological symptoms. Twenty-one (18.4%) participants endorsed clinically significant depressive symptoms. The mean PHQ-9 score was 5.49 (*SD* = 4.7), indicating subthreshold depressive symptoms. Based on participant report and medical chart documentation, 58 (50.9%) of participants in the sample had a history of significant symptoms of a mood disorder (e.g., major depressive disorder, bipolar disorder) and 45 participants (39.5%) were currently prescribed an antidepressant medication. A total of 32 participants (28.1%) reported threshold anxiety symptoms at the time of study participation. The mean HADS-A total score for the sample was 5.67 (SD = 4.3), which reflects subclinical levels of anxiety. Of the 114 participants in the sample, 40 (35.1%) had either chart documentation or self-reported a history of at least one anxiety disorder and 23 (20.2%) were prescribed at least one benzodiazepine medication. Of the 21 participants reporting threshold depressive symptoms, 14 (66.7%) had also self-reported clinically significant anxiety symptoms on the HADS-A.

Driving Characteristics

Driving characteristics of the sample are included on Table 3. Approximately 75% of participants reported driving four or more days per week (n = 85), 23.7% reported driving between one and three days per week (n = 27), and 3.8% reported driving less than once a week but more than once per month in the last year (n = 2). A majority of participants (87.7%) denied having family, friends or physicians express concern about their driving ability (n = 100). Three participants (2.6%) endorsed using adaptive equipment in their vehicle. Lane position maintenance was endorsed as difficult by 10.5% of participants (n = 12). Seven participants (6.1%) endorsed hitting the curb often and 14 participants (12.5%) reported hitting an object or another vehicle (not reported to the police as an accident) while driving.

Participants (n = 52) endorsed an average of 1.53 (*SD* = 2.3) MS-related symptoms as impacting their driving ability. The most prominent symptoms interfering with driving ability were fatigue (57.5%; n = 30), visual issues (44.2%; n = 23), feeling "foggy" (42.3%; n = 22), and cognitive difficulties (40.4%; n = 21). Of these 52 participants, 32 (61.5%) also endorsed restricting their driving in one or more conditions. A total of 51 participants (44.7%) reported an average of 1.49 (*SD* = 2.3) conditions under which they restricted their driving. Amongst these participants 62.7% endorsed limiting their driving to only daylight hours (n = 32), 51.0% endorsed restricting their driving to only times of low and non-rush hour traffic (n = 26), 47.1% endorsed limiting their driving to only short distances (n = 24), and 43.1% endorsed to limiting their driving to only familiar places (n = 22).

Table 3. Driving characteristics

Variable	Total (N = 114) Mean (SD), Median [IQR], or N (%)	Range of Scores
Driving Frequency		
>1 day per week	2 (1.8%)	
1-3 days per week	27 (23.7%)	
4-7 days per week	85 (74.5%)	
Lane Maintenance Difficulties		
Yes	12 (10.5%)	
No	102 (89.5%)	
Curb Hitting		
Yes	7 (6.1%)	
No	107 (93.9%)	
Concerns About Driving		
Yes	14 (12.3%)	
No	100 (87.7%)	
Driving Preference		
Driving Oneself	83 (72.8%)	
Having Others Drive	31 (27.2%)	
Number of Symptoms Interfering with Driving	1.53 (2.3)	0 – 9
Number of Driving Restrictions	1.49 (2.3)	0 – 9
DMV Driving Record		
Number of Violations	0.00 [1.0]	0 – 3
Number of MVAs	0.00 [0.0]	0 – 8

With regard to DMV records, 48 participants (42.1%) had one or more MVEs (traffic violation or MVA) detailed on their driving abstract within the last five years (See table 3). Thirty-one participants (27.2%) received a total of 64 traffic violations. Of these participants, 15 (48.4%) had one traffic violation detailed on their DMV abstract, 9 (29.0%) received 2 violations, 1 (3.2%) received 3 violations, 5 (16.2%) received 4 violations, and 1 (3.2%) received 8 violations within the last five years. Amongst the most common violations incurred were: speeding (n = 8), improper display or factitious plates (n = 7), obstructing the passage of other vehicles (n = 6), using a cellphone while driving (n = 5), and delaying traffic (n = 5). Eight of the 31 (25.8%) participants who received a traffic violation had also been involved in an MVA. In all, 25 (21.9%) participants had a total of 33 DMV recorded MVAs in the last five years.

Bivariate Relationships

As shown on Table 4, fall history was associated with self-reported disability ($t(112) = -4.53$, $p < 0.001$), with fallers ($M = 2.49$, $SD = 1.94$) endorsing higher levels of disability than non-fallers ($M = 1.05$, $SD = 1.45$). Non-fallers had a higher number of MVAs recorded by the DMV within the last five years compared to fallers ($U = 1344.00$, z = -2.15, $p = 0.031$). Fallers more frequently endorsed having family, friends or physicians express concerns about their driving ability ($p = 0.043$, Fisher's Exact Test) and preferred having others drive them ($p = 0.002$, Fisher's Exact Test) (see Tables 5 and 6).

Higher depression scores were related to greater levels of self-reported physical disability ($r = 0.24$, $p = 0.011$) and with hitting the curb often ($t(112) = -3.33$, $p < 0.001$) (Table 6). Higher depressive symptoms were also associated with a higher number of traffic violations ($\rho = 0.23$, $p = 0.014$), a higher number of MS symptoms interfering with driving abilities ($r = 0.418$, $p < 0.001$), and a higher number of conditions in which driving is restricted ($r = 0.411$, $p < 0.001$).

Table 4. Bivariate relationships among DMV outcomes, driving characteristics, demographic and clinical factors

1. MVAs[a]	-											
2. Violations[a]	0.07	-										
3. Interference	-0.05	0.18	-									
4. Restrictions	-0.06	-0.17	0.50**	-								
5. Age	-0.17	-0.32**	-0.12	0.14	-							
6. Sex	-0.90	-3.08**	-1.58	-0.80	0.05	-						
7. Employment	0.86	-2.22*	0.11	2.90*	3.37**	-0.16	-					
8. Disease Duration	0.02	0.17*	-0.04	0.07	0.56**	0.03	-0.30**	-				
9. PDDS	-0.09	-0.07	0.21*	0.33**	0.34**	0.02	-0.37**	0.29**	-			
10. Falls	-2.15*	-0.33	-1.16	-1.97	0.50	0.20*	-0.18	-1.11	-4.53**	-		
11. PHQ-9	0.00	0.23*	0.42**	0.41**	-0.06	0.13	-0.13	-0.09	0.24*	-1.85	-	
12. HADS-A	-0.09	0.22*	0.34**	0.23*	-0.23*	0.17	-0.00	-0.01	0.10	-0.71	0.59**	-

Note. Interference = number of MS symptoms interfering with driving ability; Restrictions = number of reported driving restrictions

[a] Nonparametric statistic (Spearman's ρ correlations); all other correlations parametric statistics used Pearson's r correlations.

Dichotomous/continuous relations: z-statistic when non-parametric statistics used; t-statistic for parametric statistics
Dichotomous/dichotomous associations: Phi coefficients reported.
* $p < 0.05$, ** $p < 0.001$

Higher anxiety symptoms were associated with younger age (r = -0.23, p = 0.015) and difficulties with maintaining consistent lane positions (t(112) = -2.10, p = 0.038) (Table 6). Higher anxiety symptoms were also associated with higher numbers of traffic violations (ρ = 0.22, p = 0.022), a higher number of MS-related symptoms hindering driving ability (r = 0.34, p < 0.001), and a higher number of driving restrictions (r = 0.27, p = 0.016).

As shown on Table 4, MVAs recorded by the DMV were not significantly related to any demographic or disease-related factors in the sample; however, the association with age was nearing significance (ρ = -0.17, p = 0.063). For violations, younger age (ρ = -0.32, $p \leq$ 0.001), male sex (U = 885.50, z = -3.08, p = 0.002), and fewer years since MS diagnosis (ρ = -0.19, p = 0.047) were associated with a higher number of traffic violations received in the last five years.

Table 5. Bivariate relationships among driving concerns and preference, DMV outcomes, driving characteristics, falls and psychological symptoms

	Driving Concerns				Driving Preference			
	Yes M (SD)	**No** M (SD)	test statistic	p-value	**Self** M (SD)	**Others** M(SD)	test statistic	p-value
MVAs[a]	0.0 [0.0]	0.0 [0.0]	-0.81	0.416	0.0 [1.0]	0.0 [0.0]	-1.43	0.154
Violations[a]	0.0 [0.0]	0.0 [0.0]	-0.97	0.334	0.0 [1.0]	0.0 [0.0]	-1.23	0.220
Interference	2.5 (2.9)	1.4 (2.2)	-1.72	0.088	1.1 (2.0)	2.6 (2.7)	-3.24	0.002*
Restrictions	2.7 (2.7)	1.3 (2.2)	-2.15	0.034*	0.8 (1.7)	3.3 (2.7)	-5.89	<0.001**
Falls[b]			0.19	0.043*			0.30	0.001**
Yes	10	43			31	22		
No	4	57			52	9		
PHQ-9	6.9 (4.2)	5.3 (4.8)	-1.16	0.249	5.2 (5.0)	6.2 (3.7)	-0.93	0.356
HADS-A	6.2 (4.4)	5.7 (4.8)	-0.39	0.698	5.7 (4.8)	6.1 (3.7)	-0.42	0.675

Note: [a] Mann Whitney U-tests (non-parametric statistics) with Median [IQR], z statistic reported
[b] Dichotomous/dichotomous relationships: Fisher's Exact Test used, Phi's coefficient reported
* p < 0.05, ** p < 0.001

Within the context of driving difficulties, an ANOVA test indicated a main effect of race on the number of MS symptoms hindering driving ability, *F* (3, 110) = 5.28, *p* = 0.002. Post hoc analyses using Tukey's HSD showed that participants identifying as Hispanic or Latino/a/x (*M* = 4.29, *SD* = 3.50; n = 7) self-reported more driving difficulties than participants identifying as Caucasian (*M* =1.35*, SD* = 2.0; n = 78), African American/Black (*M* = 0.91*, SD* = 1.9; n = 22), and Other (e.g., Asian, Native Hawaiian/Pacific Islander, American Indian/Alaska Native or Middle Eastern) (*M* = 2.7, *SD* = 2.6; n = 7). As shown on Table 6, a higher number of MS-symptoms impacting driving ability were associated with self-reported difficulties with lane position maintenance (*t* (112) = -2.42, *p* = 0.017) and curb hitting (*t*(112) = -3.07, *p* = 0.003). Greater physical disability (*r* = 0.21, *p* = 0.027) was also related to a higher number of symptoms contributing to driving difficulties (Table 4).

Table 6. Bivariate relationships among lane maintenance issues, curb hitting, DMV outcomes, driving characteristics, falls and psychological symptoms

	Lane Maintenance Issues				Curb Hitting			
	Yes M (SD)	**No** M (SD)	test statistic	p-value	**Yes** M (SD)	**No** M(SD)	test statistic	p-value
MVAs[a]	0.0 [1.0]	0.0 [0.0]	-1.81	0.070	0.0 [1.0]	0.0 [0.0]	-1.20	0.232
Violations[a]	0.0 [2.0]	0.0 [1.0]	-1.44	0.150	0.0 [2.0]	0.0 [1.0]	-0.94	0.345
Interference	3.0 (3.0)	1.4 (2.1)	-2.42	0.017*	4.0 (3.1)	1.4 (2.1)	-3.07	0.003*
Restrictions	2.1 (3.0)	1.4 (2.2)	-0.94	0.351	5.7 (2.4)	1.2 (2.0)	-5.62	<0.001**
Falls[b]			0.02	0.517			0.13	0.165
Yes	6	47			5	48		
No	6	56			2	59		
PHQ-9	6.3 (4.8)	5.4 (4.7)	-0.59	0.558	11.0 (7.9)	5.1 (4.2)	-3.33	<0.001**
HADS-A	8.3 (6.0)	5.5 (4.3)	-2.10	0.038*	7.3 (5.5)	5.7 (4.5)	-0.91	0.364

Note: [a] Mann Whitney U-tests (non-parametric statistics) with Median [IQR], z statistic reported
[b] Dichotomous/dichotomous relationships: Fisher's Exact Test used, Phi's coefficient reported
* p < 0.05, ** p < 0.001

Self-imposed driving restrictions were associated with employment status ($t(112) = 3.36$, $p = 0.001$), with unemployed participants ($M = 2.2$, $SD = 2.6$) endorsing a higher number of driving restrictions than employed participants ($M = 1.0$, $SD = 2.0$; Table 4). A higher number of driving restrictions were associated with concerns about driving ability expressed by family, friends or physicians ($t(112) = -2.15$, $p = 0.034$), and frequent curb hitting ($t(112) = -5.62$, $p < 0.001$) (as shown on Tables 5 and 6). Greater self-reported physical disability levels were also associated with a higher number of driving restrictions ($r = 0.33$, $p < 0.001$; Table 4).

Aim 1: Fall History, Driving Outcomes and Characteristics

DMV Outcomes. Non-fallers had 2.3 (95% CI 1.08, 4.99) times more MVAs within the last five years than fallers (Wald χ^2 (1) = 4.62, $p = 0.032$). Fall status was not associated with traffic violation history in an adjusted regression model (Table 7).

Table 7. Poisson regression examining fall history and DMV outcomes

	Estimate	*SE*	Wald-Chi Square	Exp (B)	95% CI	p-value
MVAs						
Intercept	-1.77	0.33	28.29	0.17	0.09-0.33	<0.001**
Fall History[a]	0.84	0.39	4.62	2.32	1.08-4.99	0.032*
Traffic Violations						
Intercept	1.45	0.50	8.41	4.27	1.60-11.39	0.004*
Age	-0.06	0.01	20.14	0.95	0.92-0.97	<0.001**
Sex	0.94	0.26	13.02	2.55	1.53-4.24	<0.001**
Years Since Diagnosis	0.01	0.02	0.18	1.01	0.97-1.05	0.669
Fall History[a]	-0.47	0.26	3.22	0.63	0.38-1.04	0.073

Note: [a]Non-fallers (participants with a fall history are the reference group)
* p < 0.05, ** p < 0.001

Self-Reported Driving Characteristics. Fall history was not associated with the number of MS symptoms interfering with driving ability in unadjusted nor adjusted linear regression models (Table 8). The number of self-reported driving restrictions were not significantly associated with fall history, although this relationship was nearing significance ($p = 0.051$).

When adjusting for disability level and employment status, fall status was not associated with the number of driving restrictions reported (Table 8).

Table 8. Linear regression for fall history, symptoms interfering with driving, and restrictions

	Symptom Interference				
	Coeff	β	*SE*	*P*	R^2
Unadjusted Model					0.012
Constant	1.30		0.29	<0.001**	
Fall History[b]	0.50	0.11	0.43	0.247	
Model 1					0.168
Constant	0.97		0.29	0.001**	
Race[a]					
Black/African American	-0.66	-0.12	0.52	0.207	
Hispanic or Latino/a/x	2.87	0.30	0.84	<0.001**	
Other	1.04	0.11	0.85	0.222	
PDDS	0.26	0.21	0.11	0.021	
Model 2					0.175
Constant	0.83		0.32	0.011*	
Race[a]					
Black/African American	-0.66	-0.11	0.52	0.210	
Hispanic or Latino/a/x	3.03	0.32	0.85	<0.001**	
Other	1.05	0.11	0.85	0.217	
PDDS	0.21	0.17	0.12	0.082	
Fall History[b]	0.45	0.10	0.44	0.315	
	Driving Restrictions				
	Coeff	β	*SE*	*P*	R^2
Unadjusted Model					0.034
Constant	1.10		0.29	<0.001**	
Fall History[b]	0.85	0.18	0.43	0.051	
Model 1					0.133
Constant	1.38		0.45	0.003*	
Employment Status	-0.78	-0.16	0.45	0.087	
PDDS	0.34	0.27	0.12	0.005*	
Model 2					0.135
Constant	1.30		0.47	0.007*	
Employment Status	-0.76	-0.16	0.45	0.093	
PDDS	0.31	0.25	0.13	0.016	
Fall History[b]	0.26	0.06	0.45	0.575	

Note: [a]Reference group for race is White/Caucasian
[b]Non-fallers (participants with a fall history are the reference group)
* $p < 0.05$, ** $p < 0.001$

Aim 2: Depressive Symptoms, Driving Outcomes and Characteristics

DMV Outcomes. Higher depressive symptoms (Wald χ^2 (1) = 17.46, p < 0.001), identifying as male sex (Wald χ^2 (1) = 15.99, p < 0.001) and younger age (Wald χ^2 (1) = 22.71, p < 0.001) were associated with a higher number of traffic violations received in the last five years. Specifically, higher depressive symptoms were associated with 1.10 times (95% CI 1.05, 1.14) more traffic violations. With regard to MVA involvement, there were no significant relationships with self-reported depressive symptoms (Table 9).

Table 9. Poisson regression examining depressive symptoms and DMV outcomes

	Estimate	*SE*	Wald-Chi Square	Exp (B)	95% CI	p-value
MVAs						
Intercept	-1.46	0.28	27.69	0.23	0.14-0.40	<0.001**
PHQ-9	0.04	0.03	1.22	1.04	0.97-1.11	0.270
Traffic Violations						
Intercept	1.07	0.50	4.62	2.91	1.10-7.70	0.032
Age	-0.06	0.01	22.71	0.95	0.92-0.97	<0.001**
Sex	1.02	0.25	15.99	2.77	1.68-4.55	<0.001**
Years Since Diagnosis	0.01	0.02	0.50	1.01	0.98-1.05	0.480
PHQ-9	0.09	0.02	17.46	1.10	1.05-1.14	<0.001**

* p < 0.05, ** p < 0.001

Self-Reported Driving Characteristics. Depressive symptoms were significantly related to the number of MS symptoms interfering with driving ability in an unadjusted regression model (F (1,113) = 23.65, p < 0.001), indicating that participants who endorsed higher depressive symptoms also reported a higher number of MS symptoms interfering with their driving (β= 0.42, *SE* = 0.03); this association remained significant when the model was adjusted for race and disability level (β= 0.39, *SE* = 0.04). The overall race and disability adjusted regression model was significant (F (5, 113) = 9.73, p < 0.001), and accounted for 31.0% of the variance in reported MS-related driving difficulties. Depressive symptoms, respectively, explained 14.3% of the variance in the number of self-reported MS symptoms interfering with driving ability. Identifying as either Hispanic or Latino/a/x was associated with a higher number of MS-related driving difficulties (β= 0.30, *SE* = 0.84), and this relation remained significant when depressive symptoms were entered into the model (β= 0.29, *SE* = 0.77) (Table 10).

Table 10. Linear regression for depressive symptoms, symptom interfering with driving and restrictions

	Symptom Interference				
	Coeff	β	*SE*	*P*	R^2
Unadjusted Model					0.174
Constant	0.42		0.30	0.168	
PHQ-9	0.20	0.42	0.03	<0.001**	
Model 1					0.168
Constant	0.97		0.29	0.001**	
Race[a]					
Black/African American	-0.66	-0.12	0.52	0.207	
Hispanic or Latino/a/x	2.87	0.30	0.84	<0.001**	
Other	1.04	0.11	0.85	0.222	
PDDS	0.26	0.21	0.11	0.021*	
Model 2					0.310
Constant	0.18		0.31	0.572	
Race[a]					
Black/African American	-0.94	-0.16	0.48	0.053	
Hispanic or Latino/a/x	2.71	0.29	0.77	<0.001**	
Other	0.57	0.06	0.78	0.470	
PDDS	0.16	0.13	0.10	0.120	
PHQ-9	0.19	0.39	0.04	<0.001**	
	Driving Restrictions				
	Coeff	β	*SE*	*P*	R^2
Unadjusted Model					0.113
Constant	0.55		0.33	0.097	
PHQ-9	0.17	0.34	0.05	<0.001**	
Model 1					0.133
Constant	1.38		0.45	0.003*	
Employment Status	-0.78	-0.16	0.45	0.087	
PDDS	0.34	0.27	0.12	0.005*	
Model 2					0.245
Constant	0.56		0.46	0.231	
Employment Status	-0.70	-0.15	0.42	0.101	
PDDS	0.25	0.19	0.12	0.035*	
PHQ-9	0.17	0.35	0.04	<0.001**	

Note: [a]Reference group for race is White/Caucasian
* $p < 0.05$, ** $p < 0.001$

As shown on Table 10, with only depression in the model, higher depressive symptoms were associated with a higher number of driving restrictions (β= 0.34, *SE* = 0.05); the relation between depressive symptoms and driving restrictions remained significant when the model was adjusted for disability level and employment status (β= 0.35, *SE* = 0.04). The overall adjusted model was statistically significant (F (3, 113) = 11.93, $p < 0.001$) and explained 24.5% of the variance in the number of driving restrictions. Depressive symptoms alone accounted for 11.3% of the variance. Greater levels of disability were associated with a higher number of driving restrictions (β= 0.27, *SE* = 0.12) and this relationship remained significant with the addition of depression into the model (β= 0.19, *SE* = 0.12).

Aim 3: Anxiety Symptoms, Driving Outcomes and Characteristics

DMV Outcomes. Higher anxiety symptoms (Wald χ^2 (1) = 21.67, $p < 0.001$), identifying as male sex (Wald χ^2 (1) = 14.30, $p < 0.001$) and younger age (Wald χ^2 (1) = 10.33, $p < 0.001$) were associated with a higher number of traffic violations received. Higher anxiety symptoms were associated with 1.11 times (95% CI 1.06, 1.16) more traffic violations within the last five years. Anxiety symptoms were not significantly associated with MVA history (Table 11).

Table 11. Poisson regression examining anxiety symptoms and DMV

	Estimate	*SE*	Wald-Chi Square	Exp (B)	95% CI	p-value
MVAs						
Intercept	-1.18	0.28	17.73	0.31	0.18-0.53	<0.001**
HADS-A	-0.01	0.04	0.08	0.99	0.92-1.07	0.773
Traffic Violations						
Intercept	0.29	0.60	0.23	1.33	0.41-4.30	0.634
Age	-0.04	0.01	10.33	0.96	0.94-0.98	0.001**
Sex	0.94	0.25	14.30	2.57	1.58-4.19	<0.001**
Years Since Diagnosis	0.00	0.02	0.01	1.00	0.97-1.04	0.920
HADS-A	0.11	0.02	21.67	1.11	1.06-1.16	<0.001**

Note: * p < 0.05, ** p < 0.001

Table 12. Linear regression for anxiety symptoms, symptoms interfering with driving, and driving restrictions

	Symptom Interference				
	Coeff	β	*SE*	*P*	R^2
Unadjusted Model					0.174
Constant	0.42		0.30	0.168	
HADS-A	0.20	0.42	0.03	<0.001	
Model 1					0.137
Constant	0.97		0.29	0.001**	
Race[a]					
Black/African American	-0.66	-0.12	0.52	0.207	
Hispanic or Latino/a/x	2.87	0.30	0.84	<0.001**	
Other	1.04	0.11	0.85	0.222	
PDDS	0.26	0.21	0.11	0.021	
Model 2					0.239
Constant	0.08		0.35	0.822	
Race[a]					
Black/African American	-0.68	-0.12	0.49	0.168	
Hispanic or Latino/a/x	2.84	0.30	0.79	<0.001**	
Other	1.27	0.13	0.80	0.115	
PDDS	0.22	0.18	0.11	0.041*	
HADS-A	0.17	0.33	0.04	<0.001**	
	Driving Restrictions				
	Coeff	β	*SE*	*P*	R^2
Unadjusted Model					0.051
Constant	0.83		0.34	0.018*	
HADS-A	0.12	0.23	0.05	0.016*	
Model 1					0.133
Constant	1.38		0.45	0.003*	
Employment Status	-0.78	-0.16	0.45	0.087	
PDDS	0.34	0.27	0.12	0.005*	
Model 2					0.173
Constant	0.85		0.49	0.086	
Employment Status	-0.81	-0.17	0.44	0.067	
PDDS	0.31	0.25	0.12	0.010*	
HADS-A	0.10	0.20	0.05	0.022*	

Note: [a]Reference group for race is White/Caucasian
* $p < 0.05$, ** $p < 0.001$

Self-Reported Driving Characteristics. As shown on Table 12, with only anxiety symptoms in the model, higher anxiety symptoms were associated with a higher number of MS symptoms interfering with driving abilities (β = 0.42, *SE* = 0.03); this relationship remained significant when adjusting for race and disability level (β = 0.33, *SE* = 0.04). The overall adjusted model was significant (F (5, 113) = 8.12, $p < 0.001$) and explained 27.3% of the variance in reported MS-related driving difficulties. Anxiety, independently, explained 10.5% of the variance in the number of driving difficulties. Identifying as Hispanic or Latino/a/x was significantly associated with a higher number of MS symptoms hindering driving ability (β = 0.30, SE = 0.84); this association remained after anxiety was added into the model (β = 0.30, SE = 0.79). Greater levels of disability were also associated with more driving difficulties (β = 0.21, SE = 0.11) and such associations remained with anxiety symptoms in the model (β = 0.18, SE = 0.11).

Higher anxiety symptoms were associated with a higher number of driving restrictions (β = 0.23, SE = 0.05) in the unadjusted regression model. Anxiety remained significantly associated with driving restrictions after adjusting for employment status and disability level (β = 0.20, SE = 0.05). The overall adjusted model (F (3, 113) = 7.67, $p < 0.001$) was significant and explained 17.3% of the variance in the number of driving restrictions. Anxiety symptoms accounted for 4.0% of the variance explained by the model. Higher levels of disability were significantly associated with a higher number of restricted driving conditions (β = 0.27, SE = 0.12), and this relation remained significant when anxiety was entered into the model (β = 0.25 SE = 0.12) (See Table 12).

<u>Aim 4: Age interactions with falls and psychological symptoms in relation to driving outcomes</u>

Falls. For traffic violations, a significant age X fall interaction effect (Wald χ^2 (1) = 5.86, p = 0.015) modified significant main effects of fall status (Wald χ^2 (1) = 8.14, p = 0.004) and age (Wald χ^2 (1) = 4.70, p = 0.030). Non-fallers received a lower number of traffic violations than fallers (B = -2.59, SE = 0.91); older drivers received a lower number of traffic violations in the last five years than younger drivers (B = -0.08, SE = 0.02). Overall, older drivers without a history of falls received 1.05 (95% CI 1.01, 1.09) times more traffic violations (See Table 14). With regard to MVA involvement, there were no significant interaction effects between age and falls (Table 13).

Table 13. Age Interaction with Falls and Psychological Symptoms in Relation to MVAs

	Estimate	*SE*	Wald-Chi Square	Exp (B)	95% CI	p-value
Fall Status						
Intercept	0.65	1.28	0.26	1.92	0.16-23.39	0.611
Age	-0.05	0.03	3.29	0.95	0.90-1.00	0.070
Fall History[a]	-0.21	1.49	0.02	0.81	0.04-14.91	0.888
Age X Fall History[a]	0.02	0.03	0.47	1.02	0.96-1.09	0.492
Depressive Symptoms						
Intercept	-1.20	1.15	1.09	0.30	0.03-2.86	0.296
Age	-0.00	0.02	0.02	1.00	0.95-1.04	0.883
PHQ-9	0.26	0.13	3.85	1.03	1.00-1.69	0.050
Age X PHQ-9	-0.01	0.00	3.06	1.00	0.99-1.00	0.080
Anxiety Symptoms						
Intercept	0.30	1.03	0.08	1.35	0.18-10.06	0.772
Age	-0.03	0.02	1.56	0.98	0.94-1.02	0.212
HADS-A	0.06	0.13	0.21	1.06	0.82-1.39	0.644
Age X HADS-A	-0.00	0.00	0.53	1.00	0.99-1.00	0.998

Note: [a]Non-fallers (fallers are the reference group)
*p < 0.05, ** p < 0.001

Depression. Though the age X depressive symptom interaction effect was not significant within the context of MVA involvement, there was a significant main effect of depressive symptoms (Wald χ^2 (1) = 3.85, p = 0.05) (Table 13). Higher depressive symptoms were associated with 1.3 (95% CI 1.00, 1.69) times more MVAs. Similarly, for traffic violations there were no significant interaction effects between age and depression (Table 14); however, there was a modified main effect of depressive symptoms (Wald χ^2 (1) = 5.47, p = 0.019), indicating that higher depressive symptoms were associated with a higher number of traffic violations (B = 0.22, SE = 0.09).

Anxiety. For MVAs and traffic violations, there was no significant interaction between age and anxiety symptoms; the presence of the interaction between age and anxiety symptoms did not modify any main effects in the model (Tables 13 and 14).

Table 14. Age Interaction with Falls and Psychological Symptoms in Relation to Violations

	Estimate	*SE*	Wald-Chi Square	Exp (B)	95% CI	p-value
Fall Status						
Intercept	3.05	0.67	20.82	21.18	5.71-78.62	<0.001**
Age	-0.08	0.02	22.88	0.92	0.89-0.95	<0.001**
Sex	0.96	0.26	13.97	2.62	1.58-4.34	<0.001**
Years Since Diagnosis	0.01	0.02	0.10	1.01	0.97-1.04	0.756
Fall History[a]	-2.59	0.91	8.14	0.08	0.01-0.44	0.004*
Age X Fall History[a]	0.05	0.02	5.86	1.05	1.01-1.09	0.015*
Depressive Symptoms						
Intercept	0.13	0.84	0.24	1.14	0.22-5.91	0.876
Age	-0.04	0.02	3.54	0.97	0.93-1.00	0.060
Sex	1.11	0.26	17.67	3.04	1.81-5.09	<0.001**
Years Since Diagnosis	0.01	0.02	0.07	1.01	0.97-1.04	0.795
PHQ-9	0.22	0.09	5.47	1.25	1.04-1.50	0.019*
Age X PHQ-9	-0.00	0.00	1.99	1.00	0.99-1.00	0.158
Anxiety Symptoms						
Intercept	0.39	0.88	0.20	1.47	0.37-8.20	0.658
Age	-0.04	0.02	4.78	0.96	0.92-1.00	0.029*
Sex	0.94	0.25	14.30	2.57	1.58-4.19	<0.001**
Years Since Diagnosis	0.00	0.02	0.01	1.00	0.97-1.04	0.909
HADS-A	0.09	0.09	1.11	1.10	0.92-1.30	0.292
Age X HADS-A	0.00	0.00	0.03	1.00	0.99-1.00	0.873

Note: [a]Non-fallers (fallers are the reference group)
* p < 0.05, ** p < 0.001

Exploratory Aim 1: Fatigue, Personality Factors, Driving Outcomes and Characteristics

DMV Outcomes. There were no significant relationships between fatigue, personality dimensions and DMV recorded traffic violations and MVAs. See Table 15.

Self-Reported Driving Characteristics. Higher fatigue severity was associated with a higher number of reported MS symptoms hindering driving ability ($r = 0.43$, $p < 0.001$) and a higher number of conditions in which driving is restricted ($r = 0.35$, $p < 0.001$). Of the personality domains, only higher levels of agreeableness (*r* = 0.23, *p* = 0.016) and lower levels of extraversion (*r* = -0.24, *p* = 0.009) were related to a higher number of MS symptoms interfering with driving ability (shown on Table 15).

Table 15. Bivariate relationships between fatigue, personality traits, DMV outcomes and driving characteristics

	MVAs	**Violations**	**Interference**	**Restrictions**
FSS	-0.12	-0.03	0.43**	0.35**
BFI-10: Extraversion	-0.08	0.03	-0.24*	-0.14
BFI-10: Neuroticism	-0.02	-0.01	0.12	0.05
BFI-10: Openness	0.06	0.00	0.01	0.05
BFI-10: Agreeableness	0.10	-0.06	0.23*	0.09
BFI-10: Conscientiousness	0.02	-0.09	-0.00	-0.00

Note: * p < 0.05, ** p < 0.001

Chapter IV: Discussion

Discussion and Interpretation

Driving research in the MS population has largely focused on the cognitive, motor, and visual characteristics associated with unsafe driving behaviors and outcomes. Nevertheless, there is limited understanding of the effects of prominent manifestations of MS such as falls and psychological symptoms on driving safety in this population. As such, this study evaluated the association between falls, psychological symptoms, DMV outcomes and self-reported driving characteristics amongst drivers with MS.

Aim 1: Fall History, Driving Outcomes and Characteristics

The findings of this study provide preliminary support for the association between fall status and MVA involvement in drivers with MS. More specifically, in this sample, participants without a history of falls were involved in more MVAs in the last five years than those with a history of falls. Although this was the first study to examine this relationship in drivers with MS, our findings are inconsistent with the literature on aging drivers that has shown an increase in MVA involvement for drivers with a history of falls (Cross et al., 2009; Margolis et al., 2002; Pope et al., 2020). As the mechanisms underlying the association between fall history and MVAs in MS are unclear, it is possible that this relationship is moderated by driving frequency, self-imposed restrictions that limit driving exposure, or engagement in unrelated functional interventions that have secondary effects on driving safety. It is also possible that our findings are in part a consequence of deficit awareness. Poorer deficit awareness has been linked to reduced engagement in compensatory driving strategies – via fewer appraisals about the need to utilize such strategies – which has been associated with a higher number of driving incidents and miles driven (Ryan et al., 2009). Nevertheless, future research is crucial to elucidating some of the pathways that may underlie the connection between falls and MVAs in drivers with MS.

Traffic violation history and driving difficulties due to MS symptoms were not associated with fall history. These findings are particularly important as no known studies to date have examined whether falls are associated with traffic violations or symptoms hindering driving ability. In addition, we found that the number of driving restrictions were not associated with fall history, which may be a consequence of limited deficit awareness. PwMS with poorer deficit awareness have been shown to be less apt to utilizing strategies to compensate while driving, such as avoiding driving at night and in inclement weather (Ryan et al., 2009). Though falls may serve as an overt reminder of MS, it is possible that participants in the present sample do not perceive falls to be an indicator of disease (or disability) progression; thus, participants may not perceive a significant need for restrictive driving behaviors to compensate for the impact of MS on their driving. Consequently, it is recommended that studies consider utilizing a measure of deficit awareness, such as the Awareness Questionnaire, to evaluate the impact of deficit awareness on the relationship between fall status and driving restrictions.

Aim 2: Depressive Symptoms, Driving Outcomes and Characteristics

Symptoms of depression were strongly associated with traffic violations. Higher depressive symptoms were related to a higher number of traffic violations received within the last five years, which is consistent with the findings of Alvai et al. (2017a) in a sample of heavy goods drivers. It is possible that the cognitive deficits secondary to depression contribute to the increased likelihood of traffic violations in drivers. Further, more severe levels of depression have been implicated in processing speed (Niino et al., 2014), working memory (Arnett et al., 1999a; Arnett et al., 1999b; Feinstein et al., 2014) and executive function (Arnett et al., 2001;

Feinstein et al., 2014) deficits in pwMS. Given the role of processing speed, working memory and executive function in driving safety, deficits in such domains may contribute to the increased risk of violations in depressed drivers with MS. Although less studied in MS, depression has also been linked to memory deficits in the general population (McDermott & Ebmeier, 2009). As the sequelae of both MS and depression may include memory dysfunction, there may be a synergistic effect on traffic violations and more specifically administrative, non-moving violations (e.g., expired registration, license not in possession, maintenance of lamps, etc.).

Self-reported driving behaviors were also significantly related to depressive symptoms in the present sample. Higher depressive symptoms were associated with a higher total number of MS symptoms hindering driving ability, and accounted for a portion of the variance in the number of symptoms reported. Our findings are supported by the literature examining the influence of depression on subjective symptom reporting. Specifically, depressed affect has been linked to higher reports of retrospective physical symptoms in healthy populations (Howren & Suls, 2011) and subjective complaints of cognitive dysfunction in pwMS (Maor et al., 2001); heightened symptom endorsement amongst people with depression has been suggested to be related to inherent biases towards recalling negative information (Mineka et al., 1998). We also found that higher depressive symptoms were associated with a higher number of conditions under which participants restricted their driving. Watson & Pennebaker's (1989) symptom perception hypothesis suggests that negative affectivity enhances attention to somatic sensations, which are misattributed as signs of physical illness due to negative biases (Howren & Suls, 2011; Watson & Pennebaker, 1989; Williams, 2004; Williams & Wiebe, 2000). Given the symptom perception hypothesis and that depressed pwMS are more likely to self-report higher levels of disability than their physician's perception (Smith & Young, 2000), depressed pwMS may be more inclined to limit the conditions under which they drive. With the high rates of comorbidity between depression, anxiety and fatigue in MS, it is also possible that pwMS restrict their driving due to fear or fatigue. It is important to consider the effects of driving restrictions on mood; as such, driving restrictions may serve to reinforce depressive symptoms by highlighting the significant impact of MS and related disability. As that the temporal nature of the connection between depressive symptoms and driving restrictions was not assessed in this study, future research should consider a longitudinal study design to examine such relations further.

When examined independently, depressive symptoms were not related to MVA involvement. Our findings are inconsistent with studies of depressed drivers, which have shown that depression (Alavi et al., 2017b) and depression severity (Bulmash et al., 2006; Hilton et al., 2009) are related to an increased risk for MVAs. The discrepancy amongst findings may be a result of a fewer participants in the present sample endorsing moderate to severe depressive symptoms. It is also possible that these inconsistencies are due differences in study design (the present study involves retrospective data (DMV records), while the aforementioned studies are either longitudinal or cross-sectional in nature). Alternatively, depression in MS may be more complex etiologically than in healthy populations given the neurodegenerative processes inherent to the MS disease course.

Aim 3: Anxiety Symptoms, Driving Outcomes and Characteristics

In our sample, drivers with higher self-reported anxiety symptoms received a higher number of traffic violations within the last five years. Our findings are largely consistent with the literature on anxiety and traffic violations, which has shown that anxious drivers receive more overall traffic violations (Alavi et al., 2017a), ordinary and aggressive traffic violations (Shahar, 2009), and seatbelt-related violations (Dula et al., 2010). Although these findings are inconsistent with an appraisal tendency framework, Dula and colleagues (2010) proposed that working memory impairments – resulting from anxiety – decrease the availability of cognitive resources necessary to safe driving.

Anxiety symptoms were also significant related to self-reported driving behaviors. More specifically, higher anxiety was associated with a higher number of reported MS-related symptoms interfering with driving ability. Our findings are consistent with studies on the symptom perception hypothesis and anxiety, which have shown that anxious affect is associated with a higher number of concurrent self-reported physical symptoms (Howren & Suls, 2011). Higher anxiety was also associated with a higher number of driving restrictions, and accounted for a small amount of the variance in reported restrictions in our sample. Similar to depression, according to the symptom perception hypothesis, pwMS with anxiety may be more prone to misattribute somatic symptoms to their MS progressing subsequently leading to driving restriction. It is also possible that anxious drivers with MS with driving concerns, are more likely to restrict their driving to specific situations to avoid intense negative emotions resulting from a tendency towards avoidance-based coping strategies. Nevertheless, it is essential to explore the direction of the association between anxiety and driving restrictions further through longer-term, longitudinal research designs.

MVA involvement was not significantly related to anxiety in the present sample, which is inconsistent with studies of heavy goods (Alavi et al., 2017b) and older adult drivers (Dula et al., 2010). One other study to date has examined the influence of anxiety on driving behavior in pwMS on a simulated driving task. Devos et al. (2013) reported that anxiety was not significantly related to any of the driving behaviors evaluated, including a metric of time-to-collision. Although this is the first known study to consider the influence of anxiety on MVAs, it is possible that methodological limitations had an effect on this relationship. Given the association between anxiety and driving restrictions, it is also possible that anxious drivers more frequently restrict their driving leading to lower overall driving exposure and less exposure to complex driving conditions, thus impacting the association between anxiety and MVAs.

Despite the high rates of comorbidity amongst depressive and anxiety disorders (Kessler et al., 2015), the present study examined such symptoms independently in relation to driving outcomes. Given the cognitive consequences of comorbid depression and anxiety, it is possible that such comorbidities would be associated with higher rates of negative driving outcomes and increased engagement in hazardous driving behaviors. Nonetheless, to date, no known studies have explored the impact of psychological comorbidities on driving safety and behaviors. With the high prevalence, understanding the impact of comorbid depressive and anxiety disorders on driving safety is essential and should be considered as an area of exploration for future research.

Aim 4: Age interaction with falls and psychological symptoms in relation to driving outcomes

With regard to the moderating effects of age on fall history in relation to DMV outcomes, we found that drivers without a history of falls had received a higher number of traffic violations in the last five years. Given the role of cognition in falls and in the aging process, it is possible that cognitive function contributes to the aforementioned relationship. More specifically, approximately half of older pwMS demonstrated impairments on measures of processing speed and verbal fluency (Jakimovski et al., 2019). Although not extensively examined in MS or in healthy populations, visuospatial abilities in drivers with MS (Schultheis et al., 2010b) and executive dysfunction in healthy drivers (Hayashi et al., 2018; Tabibi et al., 2015) have been associated with a higher number of traffic violations. Unlike traffic violations, MVAs were not significantly related to the interaction between falls and age.

Our findings also indicated that there were no significant effects of age on psychological symptoms in relation to driving outcomes. Thus, age did not moderate the relationship between depressive symptoms, traffic violations, and MVA involvement respectively; similar findings were noted for anxiety symptoms. However, it is likely that such analyses were significant impacted by the majority of the present sample endorsing subthreshold depressive and anxiety symptoms. As such, future replication and expansion of this study is fundamental.

Exploratory Aim 1: Fatigue, Personality Factors, Driving Outcomes and Characteristics

Fatigue was related to self-reported driving characteristics. More specifically, higher fatigue severity was associated with a higher number of MS symptoms interfering driving ability. The mechanisms underlying the relationship between fatigue and subjective symptom reports are unclear. Although, it is possible that this link is supported by the role of fatigue in negative affectivity (depression and anxiety). Within this context, in the present sample, participants with more severe fatigue had endorsed higher depressive and anxiety symptoms, and higher negative affectivity has been associated with inflated symptom reporting (Howren & Suls, 2011). Given that fatigue is associated with higher levels of disability in MS (Kroencke et al., 2000) and that greater disability is often accompanied by more intrusive symptoms, participants with severe fatigue in our sample had endorsed higher levels of disability and thus may be more symptomatic. Additionally, we also found that more severe fatigue was related to a higher number of conditions under which participants restricted their driving in our sample; these findings are consistent with those of Chipchase and colleagues (2003) that showed that fatigue in drivers with MS affected the time of day (e.g., avoidance of night driving), weather conditions (e.g., avoidance of driving in poor weather) and locations to which they drove, as well as the length of time spent driving to a destination.

Although the role of fatigue in driving safety has not been previously examined in pwMS, our findings revealed no significant differences in fatigue severity amongst drivers with and without MVAs or traffic violations. Inconsistent with the present findings, fatigue has been associated with an increased risk for MVAs in the general population (Bener et al., 2017). Similarly, drivers with Parkinson's disease (Meindorfner et al., 2005) and hepatic encephalopathy (Bajaj et al., 2009) with more severe fatigue were also found to have an increased risk for MVAs. The inconsistencies amid findings of the previously mentioned studies and the present study may be a result of discrepancies in the operationalization of fatigue (daytime sleepiness, sudden onset sleep, endorsing "after driving, I feel tired?" versus using the Fatigue Severity Scale).

Higher agreeableness and lower extraversion were associated with a higher number of MS symptoms impacting driving ability. These findings are similar to studies showing a link between agreeableness, somatic symptom presentation (Mostafaei et al., 2019), and medical symptoms (Van Dijk et al., 2016); more specifically, higher levels of agreeableness have been reported by patients with medically unexplained symptoms compared to medically explained symptoms and controls (Van Dijk et al., 2016). In addition, health anxiety and somatization have been associated with low extraversion (Van Dijk et al., 2016).

Personality traits assessed by the BFI-10 were not significantly associated with any DMV outcomes (e.g., MVAs and violations) or with the number of driving restrictions. Our findings are inconsistent with several studies examining personality traits and DMV outcomes, which showed that extraversion (Wang et al., 2019), neuroticism (Alavi et al., 2017b; Wang et al., 2019) and agreeableness (Alavi et al., 2017a; Cellar et al., 2000) were associated with a higher risk for traffic violations and MVAs. Such disparities amongst findings may result from differences in the populations assessed (e.g., healthy young drivers versus drivers with MS). Given that MS is a multifaceted disease with potentially pervasive effects on functioning, it is possible that the relation between personality and driving outcomes are confounded by MS symptoms such as cognitive, physical or visual deficits.

Interestingly, in our sample, demographic factors were associated with objective driving outcomes and subjective driving behaviors. Consistent with the literature (Factor, 2018), we found that younger age and identifying as male were both associated with a higher number of traffic violations. While prior studies have indicated that younger drivers also have higher rates of MVAs (Duke et al., 2010; Factor et al., 2008), the relationship between age and MVA-involvement was trending toward significance in the present study. The discrepancies amongst our findings and those of other studies may be related to the limited number of drivers involved in MVAs in the current sample.

The present study also identified racial disparities in the number of reported MS symptoms hindering driving ability. More specifically, we found that pwMS identifying as Hispanic or Latino/a/x had endorsed a higher number of MS symptoms interfering with their driving ability. To our knowledge, no prior studies have examined racial differences within the context of symptoms interfering with driving ability in MS. Nevertheless, a recent study showed that pwMS identifying as Hispanic or Latino/a/x and African American had endorsed higher symptom severity, greater overall disability and poorer self-reported health than pwMS identifying as Caucasian (Kister et al., 2021). In samples of women with uterine fibroids (Marsh et al., 2018) and community dwelling older adults with depression (Vyas et al., 2020), people identifying as Hispanic or Latino/a/x were found to endorse higher symptom severity than other racial groups. In contrast, in a sample of oncology patients, African American participants reported a higher symptom burden and severity than Hispanic or Latino/a/x and Caucasian participants; there were also no significant differences in symptom burden or severity between Hispanic or Latino/a/x and Caucasian participants (Jim et al., 2020). Given that, in the present study, the racial disparities in symptom reporting are exclusively subjective, it is important to note that perceived impairments in pwMS have been weakly related to objective performance (Merlo et al., 2021).

Clinical Implications

The present study sought to determine whether falls and psychological symptoms – that are usually secondary to MS – are associated with driving outcomes and characteristics. Ultimately, this study aimed to identify additional factors associated with driving safety in MS in order to improve the recognition of pwMS at risk for unsafe driving and allow for earlier rehabilitation-based interventions. Notably, our findings indicated that pwMS without a history of falls had a higher number of MVAs and that older drivers without a history of falls had received a higher number of traffic violations. As pwMS without a history of falls may have previously evaded concerns, especially within the context of driving safety, our findings highlight a need to address such issues will all drivers with MS rather than predominantly those drivers exhibiting significant symptoms.

Our findings highlight the link between depression and anxiety symptoms and traffic violations, although the direction of this relationship remains unclear (e.g., psychological symptoms occurring prior to receiving violations, or developing as a consequence of violations or changes in driving ability). Depression and anxiety symptoms can not only affect perceptions of driving ability, quality and safety, but it can also limit the availability of cognitive resources that are required for managing potentially hazardous driving scenarios. Moreover, treating depression and anxiety symptoms may have secondary effects on driving safety via improvements in cognition, supplementing a driver's ability to manage dangerous driving scenarios, and enhancing coping with MS symptoms affecting driving and changes to driving ability.

Some pwMS approached about this study expressed substantial concerns about having their license revoked as a result of the retrieval of their driving records from the DMV, indicating the significance of maintaining a driver's license. Taking these concerns with the loss of autonomy and functioning that is often noted in MS as the disease progresses, it is encouraged that physicians broach the topic of driving with their patients carefully.

Study Limitations

Limitations of this study include a small sample size of participants with a history of MVAs and reliance on DMV records as a measure of MVA involvement. Although DMV records note all major MVAs and serve as an objective measure of driving safety, there are a number of instances in which MVAs are not recorded by the DMV. More specifically, these situations may include accidents in which no damage is incurred, minor accidents that have been settled without police involvement, minor accidents that did involve the police but were considered minor and not recorded on their driving record, or the driver flees the scene of an accident when perceiving that there were no other witnesses. That being said, it is probable that the number of participants who have been involved in MVAs within the last five years is higher than the number of participants with DMV recorded MVAs.

While fall history was ascertained through a retrospective question about falls, it is possible that participant responses were subjected to recall biases as a result. To limit the variance associated with inaccurately recalling the number of falls sustained within the last year, this variable was examined dichotomously.

Another limitation of our study was the concerns of potential participants about their license being revoked if their records were requested from the DMV, which led them to decline participation. It was unclear if these participants were concerned about their license as a result of a significant history of MVAs and traffic violations that would be called to the attention of DMV officials if their file were examined, or if this concern was motivated by anxiety. Nevertheless, it is possible that the data on driving outcomes and mood symptoms are skewed, in that the consenting participants had fewer MVAs or violations in the last five years and reported more mild mood symptoms.

Clinically significant depression and anxiety are especially prominent in MS, however our sample reported subclinical depression and anxiety symptoms. This is particularly notable as the self-report data collected is not consistent with the plethora of existing literature on psychological symptoms in pwMS. The disparities in prevalence of psychological symptoms in existing literature versus the present sample may be due to impression management. It is also possible that, despite the explanation of confidentiality and its limits, participants were fearful that the data on psychological symptoms would be shared with either their neurologist of the DMV resulting in revocation of their license. Alternatively, pwMS with more severe psychological symptoms may have been less likely to participate, especially if they were only contacted by email, or to only partially complete study measures.

With regard to statistical analyses, it is important to note that the present study includes 15 central aims and four exploratory aims; as such, there is an increased risk of a type I error occurring.

While participants were recruited by various methods of contact, the main source of recruitment was by email. As email recruitment relies on patients having access to and being able to navigate technological devices, our sample may be limited in the inclusion of patients of lower socioeconomic statuses, older age, and more severe disability levels. Additionally, pwMS who did not have an email listed in their chart, did not regularly check their email, or mistrust the security of their device and the transmission of virtual information were not able to be recruited for this study.

Future Directions

Further research is warranted to replicate and expand upon the findings of the present study. Our findings indicated that pwMS without a history of falls had a higher number of MVAs, which may be related to deficit awareness, driving exposure and frequency, and intervention engagement. Future research should explore the mechanisms that potentially underlie this relationship, as such insights may serve useful to enhancing the identification of pwMS at risk for unsafe driving outcomes.

It may also be useful to create a composite measure of MVAs, which includes DMV data and self-reported information about minor accidents that went unreported. Examining MVAs through both DMV and self-report data may enhance our understanding of the psychological and mobility-related factors associated with MVAs in pwMS.

Although depression and anxiety are highly prevalent in MS, participants in the present study largely endorsed subthreshold depression and anxiety symptoms. As a result, further examination of such symptoms within the context of driving outcomes and behaviors in drivers with MS are crucial. Studies should consider investigating differences in driving outcomes between drivers with MS with comorbid depression and anxiety, with only depression, with only anxiety, and with no depression or anxiety.

Gender and racial differences in objective driving outcomes and subjective driving behaviors were observed in the present sample. Thus, future studies should seek to examine such differences in detail and aim to determine if other demographic, disease or clinical factors moderate or mediate those relationships.

While this study included only pwMS with an active driver's license who have driven more than two days per month in the last year, other studies should include all pwMS with an active driver's license. Although the likelihood of negative DMV outcomes diminishes with less driving exposure, comparing drivers based on frequency on clinical measures (e.g., falls, mood symptoms, fatigue, personality traits) and self-reported driving behaviors may be useful in providing further insight into the factors affecting driving frequency in MS.

Given that this study examined the relation between falls, mood symptoms and objective driving outcomes, future studies should consider exploring the link between the aforementioned factors and aberrant driving behavior using the Driving Behavior Questionnaire (DBQ). The DBQ is a widely used self-report measure assessing aberrant driving behaviors through questions about lapses, dangerous errors and violations (Reason et al., 1990); examination of the clinical outcomes included in this study and aberrant driving behavior will allow for further understanding of how falls and mood symptoms influence the mechanisms that underlie risky driving in MS.

Conclusions

This study aimed to explore associations between DMV outcomes, subjective driving characteristics, fall history, and psychological symptoms in drivers with MS. While the literature has focused extensively on the cognitive and physical factors related to driving safety in MS, the relation to fall history and psychological symptoms had yet to examined. This study found that drivers with MS without a history of falls were involved in a higher number of MVAs. Additionally, higher depression and anxiety symptoms were associated with a higher number of traffic violations, a higher number of MS symptoms interfering with driving ability, and a higher number of driving restrictions. This study also found a significant interaction between age and falls in relation to traffic violations, which indicated that older drivers without a history of falls received a higher number of traffic violations in the last five years. Future research should aim to examine the mechanisms underlying the connection between fall history and MVAs, develop a more comprehensive metric for MVAs (to include minor non-DMV recorded MVAs), and differences in driving outcomes between drivers with comorbid depression and anxiety; such investigation is crucial to improving identification of drivers with MS at risk for unsafe driving outcomes.

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