Review article

Independent outdoor mobility of persons with multiple sclerosis – A systematic review

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ABSTRACT

Background: Multiple sclerosis (MS) can manifest itself in many ways, all of which can affect the independent outdoor mobility of persons with MS (pwMS). In most studies, mobility of pwMS is defined by the ability to walk. However, mobility comprises more than walking alone. This systematic review provides an overview of the literature on several types of independent outdoor mobility of pwMS. We aimed to identify which specific factors may influence outdoor mobility and how the lives of pwMS may be affected by a reduced mobility.
Methods: A systematic literature search was performed, using three databases (PubMed, PsychInfo and Web of Science). Studies had to describe a group of pwMS sclerosis and had to concern some type of mobility other than walking.
Results: The 57 studies that fulfilled the criteria included in total 10,394 pwMS and in addition, 95,300 pwMS in separate prevalence study. These studies showed that pwMS as a group have a decreased fitness to drive, make use of a wheelchair or mobility scooter more often and have difficulties making use of public transport. Mobility problems especially occur in patients with cognitive problems, secondary progressive MS or high disability scores.
Conclusions: The reduced mobility may prevent pwMS participating in society. However, few studies investigating interventions or rehabilitation options to improve mobility were found in the existing literature, highlighting an until now under recognised unmet need.

1. Introduction

Multiple sclerosis (MS) is a progressive inflammatory demyelinating disease that affects the central nervous system. With a mean age-of-onset of 29 years (Cierny et al., 2017), it is the most common non-traumatic cause of disability among young adults (Noseworthy et al., 2000). The average incidence of MS over the world is 3.6 cases per 100,000 in women and 2.0 in men (Alonso and Hernán, 2008) and is still increasing (Kramer et al., 2012). Since motor, sensory, visual, autonomic and/or cognitive systems can be affected, MS manifests itself in many different ways and vast individual differences are common (Compston and Coles, 2008). Fatigue, numbness or tingling, muscle weakness or spasticity, problems with balance, chronic pain, bladder and bowel problems, vision problems and cognitive problems are the

most prominent symptoms of the disease (Compston and Coles, 2008; Cosh and Carslaw, 2014).

Although generally of progressive nature, different courses can be distinguished: relapsing remitting (RRMS), secondary progressive (SPMS) and primary progressive (PPMS). Characteristic of the relapsing remitting type are the exacerbations with an increased severity of symptoms, which are followed by a period of full or almost full recovery. RRMS is the most common type, 85% of pwMS are initially diagnosed with this type. Within 15 years after the RRMS diagnosis, half of the patients who were diagnosed with RRMS progress to the secondary progressive type, in which symptoms gradually worsen without exacerbations or recovery. The primary progressive type is the least common type. Only 10% of pwMS are diagnosed with this type. It is characterized both by a gradual worsening of the symptoms and

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temporary stability (Cosh and Carslaw, 2014; Bishop and Rumrill, 2015).

One of the major consequences of MS is a loss of independent mobility. Ten years after diagnosis, 93% of pwMS experience difficulty walking (Asch, 2011). Walking impairment is a common manifestation of MS and loss of walking ability places a great burden on pwMS (Smrtka et al., 2016). Maintaining mobility has the highest priority among pwMS (Sutliff, 2010). Not surprisingly, there is an ample amount of literature on the impaired walking ability of pwMS and mobility of pwMS and is most often defined or assessed by the ability to walk (Bethoux et al., 2013). Recent reviews on walking in patients with MS showed that MS can have a great impact on gait and balance, even in patients with a low level of disability (Smrtka et al., 2016; Comber et al., 2017). However, mobility comprises more than only walking. The International Classification of Functioning, Disability and Health (ICF) model defines mobility as *"moving by changing body position or location by transferring from one place to another, by carrying,moving or manipulating objects by walking, running or climbing and by using various forms of transportation"* (WHO, 2001). Moreover, mobility impairment can also be caused by the sensory, visual and cognitive symptoms of MS, instead of primarily by motor symptoms.

Loss of mobility may have a great impact on daily life. For example, not being able to drive a car can lead to a decreased quality of life, social isolation and depression (Owsley and Mcgwin, 2010). In addition, the access to medical care also decreases with impaired mobility. Importantly, as half of the pwMS are diagnosed before 30, and 75% before the age of 40 (Fraser et al., 2006), most pwMS receive the diagnosis during their working life, when it is imperative to be mobile. Despite the clear relevance, no systematic review on outdoor mobility, other than walking, has been performed. We therefore provide an overview of the literature on mobility of pwMS, defined as an independent ways of outdoor mobility. Furthermore, the literature concerning the effect of reduced mobility on daily life is investigated. The impact of other factors, such as disability level, impairments and patient characteristics on the mobility of pwMS are also clarified.

2. Methods

A literature search was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (Moher et al., 2009). The keyword 'multiple sclerosis' was paired with keywords that indicated different types of mobility, such as 'driving', 'bicycle', 'wheelchair' and 'transportation' (Table 1). The search was conducted on the 3rd of December 2018, using the databases PubMed, PsychInfo and Web of Science. Through database searching, the combinations of keywords identified 10,755 records in total (Fig. 1). After the removal of all the duplicates, the remaining titles and abstracts were screened on the following predefined inclusion criteria: (a) the paper was a peer reviewed journal article, (b) the paper was written in English, (c) the study included a group of pwMS, (d) some type of mobility other than walking, e.g. driving or using a wheelchair was considered in the paper and (e) the results had to be reported for MS

participants separately. As there were already recent systematic reviews (Smrtka et al., 2016; Sutliff, 2010; Comber et al., 2017) performed on gait and walking in patients with MS, this form of mobility was excluded from the review. After screening the records, the full texts of the remaining papers were analysed for eligibility to include in the analysis. The reference lists of all the included papers were examined but no additional papers were identified.

Demographics and disease characteristics of the samples were listed in a table along with the study's aim, design and outcome measures related to mobility (Table 2). The main findings with regard to mobility were described.

3. Results

After removal of all duplicates, 8102 records were screened and 192 full-text papers were assessed for eligibility. By applying the inclusion criteria, a total of 57 papers remained (Fig. 1). These papers together described 10,394 pwMS, besides an estimated 93,500 pwMS from a large prevalence study (Gilmour et al., 2018). In 14 studies, general mobility or transportation was assessed. Driving was examined in 30 of the studies. In 14 studies wheelchair use was evaluated and one study evaluated the Segway device. Five studies examined the use of public transportation. The results are presented in Table 2.

3.1. General mobility and transportation

Ten studies (Braham et al., 1975; Devitt et al., 2004; Pateman et al., 2016; Patten et al., 2012; Simmons et al., 2010; Ozdemir and Asiret, 2011; Aronson et al., 1996; Baum and Rothschild, 1983; Roessler et al., 2013; Finlayson, 2004) on general mobility or transportation of pwMS revealed that pwMS are more likely to report having difficulties or needing assistance with mobility and transportation than the general population. In a Canadian study, a need for assistance to travel to appointments was reported by 44% of pwMS (Aronson et al., 1996). These difficulties increased with older age, older age at diagnosis, higher disease disability in terms of the Expended Disability Status Scale (EDSS) score (Kurtzke, 1983), and higher disease awareness (Braham et al., 1975; Patten et al., 2012; Baum and Rothschild, 1983). Moreover, one study performing in depth-interviews concluded that the physical symptoms of MS did not prevent pwMS to be mobile altogether, but they did influence the experienced mobility and the chosen kind of transportation (Finlayson and van Denend, 2003).

Decreased mobility may cause difficulties for pwMS in many ways. Braham and colleagues found that 25.5% of pwMS reported transportation needs related to social or recreational activities which were not always met (Braham et al., 1975). Due to these transportation difficulties, social activity of pwMS can be limited (Ozdemir and Asiret, 2011). Also, 36% of pwMS reported unmet transportation needs to go to doctor's appointments (Braham et al., 1975). In an Australian study (Pateman et al., 2016), mobility restriction was reported to be a barrier to access dental care. In addition, mobility restrictions may lead

Table 1
Search terms.

	Search term	Section restriction
First term AND	"Multiple Sclerosis"	Title or abstract
Second term	Driving OR driver OR "automobile driver" OR "driving skills" OR "driving ability" OR "fitness to drive" OR "driver fitness" OR "driving performance" OR "driver competence" OR car OR "motor vehicle" OR simulator OR automobile OR "driving assessment" OR "behind the wheel assessment" OR "in-vehicle assessment" OR "on-road" OR "road test" OR "driving licensing" OR "road safety" OR "traffic safety" OR cycling OR bicycle OR bike OR biking OR "mobility scooter" OR wheelchair OR scooter OR "mass transportation" OR "public transportation" OR Segway OR "alternative transportation" OR transport OR mobility OR "functional mobility" OR "physical activity" OR "physical mobility"	None

Note: an *at the end of a term indicates that all possible suffixes were included.
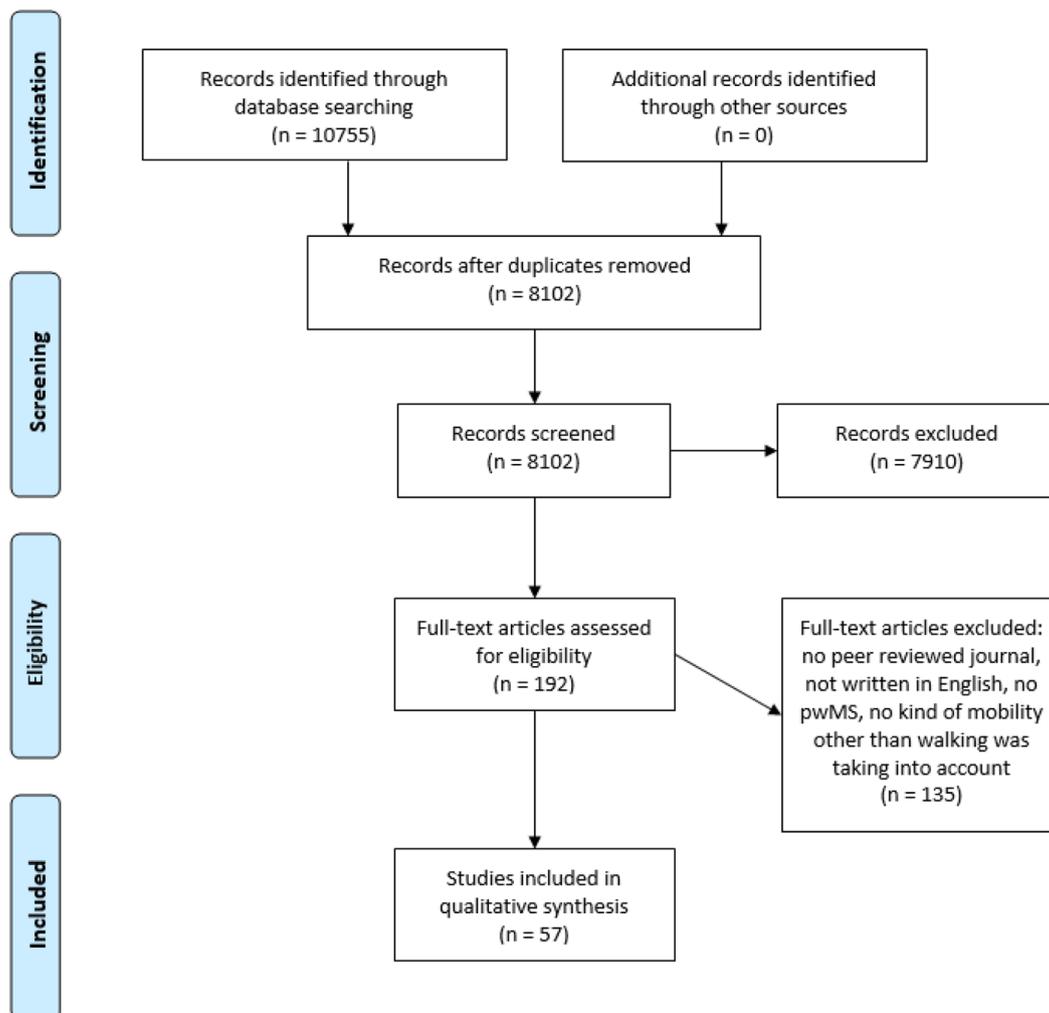
PRISMA 2009 Flow Diagram

Fig. 1. Flow diagram of systematic literature search (Moher et al., 2009).

to work-related difficulties for pwMS. The need for assistance for transportation to work was reported by 10% of pwMS in a study by Aronson and colleagues (Aronson et al., 1996). Gregory, Disler and Firth (Gregory et al., 1993) noted that the mobility problems on their own do not necessarily lead to unemployment in pwMS, as several pwMS in their study were able to work fulltime. However, other studies suggest that pwMS do need to leave their jobs because they were not able to get to or from work (13.6% – 17%), or due to inaccessibility of the workplace (2.9%–17.5%) (Simmons et al., 2010) and that mobility problems were the most important determinants of unemployment among pwMS (Edgley et al., 1991).

Restricted mobility may also have psychological implications for pwMS, which may lead to a negative self-image. Losing mobility is seen as an important negative aspect of living with MS (Finlayson et al., 2005), and a prominent fear among pwMS was the fear of loss of mobility and independence (Finlayson, 2004). Additionally, pwMS with restricted mobility were less optimistic about future independent living (Roessler et al., 2013; Finlayson, 2004). Moreover, mobility impairment as reported by pwMS was positively related to self-reported overall health impairment (Devitt et al., 2004).

3.2. Car driving

Eight studies focusing on car driving compared pwMS with healthy individuals and four of these found that pwMS showed higher accident, violation or crash rates (Dehning et al., 2014; Stueckle et al., 2005; Lings, 2002; Schultheis et al., 2002), while another study found no differences in motor vehicle violations and accidents (Schultheis et al., 2010). In a study using a driving simulator (Marcotte et al., 2008), it was found that pwMS maintained a higher driving speed and deviated 5.5 km per hour (kph) from the speed they were asked to maintain, while the healthy controls deviated only 2.9 kph. In addition, pwMS were less able to maintain their position on the road and performed worse at anticipating speed deviations of other road users. In a 23-mile on-road driving assessment pwMS were compared to healthy older adults (age 65 to 75 years old) (Classen et al., 2018). PwMS showed more errors in vehicle positioning and showed a higher number of wide lane turns. In addition, pwMS had a higher total number of driving errors than the older adults. This study also revealed that pwMS showed worse visual scanning and made more errors in responding to stimuli in driving situations compared to the healthy older adults. PwMS made,

Table 2
References, aim, study population, disease characteristics, outcome measures and main findings of the systematically included studies.

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
Akinwuntan (2012). Prediction of driving ability in people with relapsing-remitting multiple sclerosis using the Stroke Driver Screening Assessment. *International Journal of MS Care*[53].	To assess the accuracy of the Stroke Driver Screening Assessment (SDSA) to predict driving performance of pwMS.	34 pwRRMS who passed a driving test and 10 pwRRMS who failed a driving test. *Passed group:* **Age:** $M = 45.5$ ($SD = 11.1$) **Gender:** 82% female >20/60 binocular acuity 140° visual field **Education in years:** *Median* = 12 (*interquartile range* = 12 – 15) **Driving experience in years:** *Median* = 27 (*interquartile range* = 16 – 36) In possession of driver licence **Annual mileage 10^3:** *Median* = 12 (*interquartile range* = 8 – 15) **Daily miles:** *Median* = 30 (*interquartile range* = 10 – 40) *Failed group* **Age:** $M = 45.1$ ($SD = 11.4$) **Gender:** 90% female >20/60 binocular acuity 140° visual field **Education in years:** *Median* = 12 ($SD = 12$–12) **Driving experience in years:** *Median* = 30 (*interquartile range* = 25 - 36) In possession of driver licence **Annual mileage 10^3:** *Median* = 10 (*interquartile range* = 6 – 12) **Daily miles:** *Median* = 20 (*interquartile range* = 15 – 30)	*Passed group:* **Type of MS:** RRMS **Disease duration in years:** $M = 6.5$ (*range: 5 – 13*) **EDSS:** $M = 3$ (*range: 2 – 4*) **PASAT:** $M = 43.09$ ($SD = 10.33$) *Failed group* **Type of MS:** RRMS **Disease duration in years:** $M = 3$ (*range: 2 – 7*) **EDSS:** $M = 3$ (*range: 2 – 6*) **PASAT:** $M = 27.70$ ($SD = 15.37$)	**Driving:** **SDSA:** Dot cancellation (time, errors, false positives; DC), SMD, SMC, RSR. **Road test:** A 45-minute on-road test that is used for official licensing for novice and older drivers in Georgia, USA: pass/fail judgement was made by certified driving instructor	PwRRMS who failed the driving test had a significantly lower score on the PASAT than persons with RRMS who passed the on-road test. Scores on DC false positives, SMC and RSR were significantly lower for persons with RRMS who failed the on-road test in comparison to persons with RRMS who passed the on-road test.
Akinwuntan (2013). Predictors of driving in individuals with relapsing-remitting multiple sclerosis. *Multiple Sclerosis Journal.* (Akinwuntan et al., 2013).	To compare demographic, clinical and visual variables of participants who passed an on-road test to participants who failed the test.	34 pwRRMS who passed a driving test and 10 pwRRMS *Passed group:* **Age:** $M = 45.5$ ($SD = 11.1$) **Gender:** 82% female >20/60 binocular acuity 140° visual field **Education in years:** *Median* = 12 (*interquartile range* = 12 – 15) **Driving experience in years:** *Median* = 28 (*interquartile range* = 16 – 36) In possession of driver licence **Annual mileage 10^3:** *Median* = 12 (*interquartile range* = 8 – 15) **Daily miles:** *Median* = 30 (*interquartile range* = 10 – 40) *Failed group* **Age:** $M = 45.1$ ($SD = 11.4$) **Gender:** 90% female >20/60 binocular acuity 140° visual field **Education in years:** *Median* = 12 (*Interquartile range* = 12–12) **Driving experience in years:** *Median* = 30 (*interquartile range* = 25 - 36) In possession of driver licence **Annual mileage 10^3:** *Median* = 10 (*interquartile range* = 6 – 12) **Daily miles:** *Median* = 20 (*interquartile range* = 15 – 30)	*Passed group:* **Type of MS:** RRMS **Disease duration in years:** $M = 6.5$ (*range = 5 – 13*) **EDSS:** $M = 3$ (*range: 2 – 4*) *Failed group* **Type of MS:** RRMS **Disease duration in years:** $M = 3$ (*range: 2 – 7*) **EDSS:** $M = 3$ (*range: 2 – 6*)	**Demographic characteristics:** Age, sex, education, driving experience, mileage, daily miles **Clinical characteristics:** Duration of MS, EDSS, Barthel Index, MMSE score, MSFC, 25-foot walk, 9HPT, PASAT, Digit Symbol test, Block Design test, Stroop test, TMT ($A + B$), HADS, MFIS composite, Rey Complex Figure, SDSA (SMD, SMC, RSR, SOP), UFOV **Visual characteristics:** Contrast sensitivity, glare recovery, depth perception, Red & Green colour perception, Blue & Violet colour perception).	Groups did not differ with regard to demographic characteristics. For the clinical measures, the group of RRMS patients that failed the on-road driving test performed significantly worse on the 9HPT and the PASAT. They also scored less well on the SDSA compass and SDSA RSR-task. On all the UFOV measures (processing speed, divided attention and selective attention), the group that failed the test performed worse. Participants who failed the test also performed worse on the blue & violet colour perception test, no differences in the other visual characteristics were found.
Akinwuntan (2014). Improvement of driving skills in persons with relapsing-remitting multiple sclerosis: A pilot study. *Archives of*	To determine the potential to improve driving related skills using a simulator-based program in persons	36 pwRRMS who received training and 6 pwRRMS who did not receive training. *Training group:* **Age:** $M = 46$ ($SD = 11$) **Gender:** 83% female	*Training group:* **Type of MS:** RRMS **Disease duration in years:** $M = 5$ (*range = 3 – 13*) **EDSS:** *range: 1 – 7*	**On-road test** Performance a 45-minute on-road test that is used for official licensing for novice and older drivers in Georgia	>80% of participants passed the on-road test before the training and >92% of participants passed the on-road test after training. No differences between the training and control group in pass/fail

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Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
Physical Medicine and Rehabilitation (Akinwuntan et al., 2014)	with relapsing-remitting multiple sclerosis.	>20/60 binocular acuity ≥140˚ visual field **Education in years:** *Median* = 12 (*interquartile range* = 12 – 15) **Driving experience in years:** *Median* = 27 (*interquartile range* = 20 – 35) In possession of driver licence **Annual mileage 10³:** *Median* = 10 (*interquartile range* = 7 – 15) *Control group* **Age:** *M* = 48 (*SD* = 13) **Gender:** 83% female >20/60 binocular acuity ≥140˚ visual field **Education in years:** *Median* = 11 (*interquartile range* = 11 – 15) **Driving experience in years:** *Median* = 36 (*interquartile range* = 18 – 38) In possession of driver licence	*Control group:* **Type of MS:** RRMS **Disease duration in years:** *M* = 7 (*SD* = 6 – 13) **EDSS:** *range:* 1 – 7	(USA): pre- and post-training; pass/fail judgement was made by certified driving instructor	outcome before and after the training. 71% of participants who initially failed the test, passed the on-road test after training. In the mild severity group (EDSS = 1–2.5) 93% of participants passed the on-road test and in the moderate severity group (EDSS 3–7) 76% of participants passed the on-road test pre-training. PwMS with a low EDSS score also have little difficulty driving.
Akinwuntan (2018).Validation of a short cognitive battery to screen for fitness-to-drive of people with multiple sclerosis. *European Journal of Neurology* (Akinwuntan et al., 2018).	To validate the predictive accuracy of a cognitive battery to screen for fitness-to-drive that has been identified in a previous study.	**Annual mileage 10³:** *Median* = 14 (*interquartile range* 12 – 15) 118 pwMS **Age:** *M* = 48.05 (*SD* = 9.13) **Gender:** 82% female >20/60 binocular acuity 140˚ visual field Minimum requirements to drive in the state of Georgia In possession of driver licence **Driving experience in years:** *M* = 31.02 (*SD* = 9.16) **Annual mileage:** *M* = 7000 (*range* = 1000–12,000)	**Type of MS:** RRMS: 92% PPMS: 7% Unknown: 10% **Disease duration in years:** *M* = 11 (*range*: 5 – 16) **EDSS:** *Median* = 2.5 (*range*: 0 – 5)	**Clinical characteristics:** Stroop test,SDSA (SMD, SMC, RSR, SOP) **On-road driving performance** TRIP	84% of pwMS passed the on-road driving test. PwMS who passed this on-road test scored significantly better on the SMD, SMC, RSR and SOP measures.
Aronson (1996). Assistance arrangements and use of services among persons with multiple sclerosis and their caregivers. *Disability and Rehabilitation* (Aronson et al., 1996).	To describe assistance arrangements, use of and satisfaction with services, comparing perceptions of persons with MS and their caregivers with regard to assistance with activities of daily living, and discerning urban/rural differences in service provision and satisfaction.	697 pwMS and 345 of their caregivers *PwMS* **Age:** *M* = 48.3 **Gender:** 70% female *Caregivers* **Age:** *M* = 49.7 **Gender:** 50% female	**Type of MS (%):** Stable: 22 RR: 21 Relapsing-remitting/progressive: 18 Progressive: 39 **EDSS:** N/A **Disease duration in years:** N/A **Severity of symptoms (%):** Mild: 54 Moderate: 29 Severe: 17	Self-completed e-mail survey	10% of pwMS reported to need assistance for transportation to employment and 44% reported to need assistance for transportation to appointments.
Badeness (2014). Driving competences and neuropsychological factors associated to driving counselling in multiple sclerosis. *Journal of the International Neuropsychological Society* (Badenes et al., 2014).	To investigate driving difficulties in MS	50 pwMS and 50 education and age-matched controls. *MS patients* **Age:** *M* = 39.24 (*SD* = 8.7) **Gender:** 78% female **Education in years:** *M* = 13.42 (*SD* = 4.10). *Healthy Controls* **Age:** *M* = 39.34 (*SD* = 10.17) **Gender:** 70% female **Education in years:** *M* = 14.00 (*SD* = 3.85).	**Type of MS (%):** RRMS: 78 SPMS: 22 PPMS: 0 **EDSS (%):** EDSS: 0 – 3.5: 82 EDSS: 4 – 6: 18 EDSS: 7 – 8 : 0 **Disease duration in years:** N/A	**Neuropsychological testing:** RBANS, verbal fluency, TMT, Kohs Block test, PASAT. **Driving Performance:** ASDE Driver-Test N-845 (Anticipation Speed, motor coordination, multiple reaction time, concentrated attention and resistance to monotony) UFOV	PwMS performed worse on the motor coordination tasks, and on some, but not all of the multiple reaction time and concentrated attention and resistance to monotony tasks. Also, pwMW scored worse on the 2 of the 3 UFOV tasks. PwMS with cognitive impairment performed worse on one of the anticipation speed tests, all of the motor coordination tasks, 2 of the 3 multiple reaction time tasks, and one of the concentrated attention and resistance to monotony tests, and all of the UFOV tasks.
Baum (1983). Multiple sclerosis and mobility restriction.	To examine whether an individual needed	1145 patients with probable or possible multiple sclerosis *MS patients no assistance needed*	*MS patients no assistance needed*		40% of the pwMS reported to need no assistance, 9% only needed assistance

Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
Archives of physical medicine and rehabilitation (Baum and Rothschild, 1983).	assistance and the types of assistance that are needed.	**Age:** *M* = 43 **Gender:** N/A **Education:** N/A *MS patients outdoor assistance needed* **Age:** *M* = 49 **Gender:** N/A **Education:** N/A *MS patients indoor and outdoor assistance needed* **Age:** *M* = 52 **Gender:** N/A **Education:** N/A	**Type of MS:** N/A **Disease duration in years (%):** 0–3: 57.2 3–5: 54.5 5–10: 42.7 10–15: 27.4 15+: 12.8 **EDSS:** N/A *MS patients outdoor assistance needed* **Type of MS:** N/A **Disease duration in years (%):** 0–3: 13.9 3–5: 10.8 5–10: 7.3 10–15: 12.3 15+: 6.68 **EDSS** N/A *MS patients indoor and outdoor assistance needed* **Type of MS:** N/A **Disease duration in years (%):** 0–3: 28.9 3–5: 34.7 5–10: 50.0 10–15: 60.3 15+: 80.6 **EDSS:** N/A	**Data from interviews:** Questions concerning mobility	outdoors and 51% reported to need assistance outdoors and indoors. Of the pwMS who needed assistance, 40% used a wheelchair or the assistance of another person. A longer disease duration and disease awareness are associated with more assistance needed. The proportion of pwMS who needed assistance increased with age. Also, the proportion of pwMS who needed assistance increased with older age at diagnosis and disease duration. The proportion of pwMS who needed assistance both indoors and outdoors and who were aware of their diagnosis was twice as large as the proportion of pwMS who needed assistance indoors and outdoors and who were unaware of their diagnosis. PwMS who were married did not need assistance. Most pwMS who needed assistance outdoors and indoors were divorced, separated or widowed or were never married.
Boss (2006). Responses to the acquisition and use of power mobility by individuals who have multiple sclerosis and their families. *The American Journal of Occupational Therapy* (Boss and Finlayson, 2006).	To develop an understanding of family members' reaction to the acquisition of power mobility by pwMS.	7 pwMS and 4 of their spouses *MS patients* **Age:** Pt 1: 31 Pt 2: 60 Pt 3: 65 Pt 4: 66 Pt 5: 49 Pt 6: 72 Pt 7: 65 **Gender:** 5 female, 2 male *Family members* **Age:** FM 1: 32 FM 2: 62 FM 3: 65 FM 4: 69 **Gender:** 2 female, 2 male	**Disease duration in years:** Pt 1: 9 Pt 2: 22 Pt 3: 24 Pt 4: 28 Pt 5: 18 Pt 6: 30 Pt 7: 30 **Type of MS:** N/A **EDSS:** N/A	Data from semi-structured interviews designed to identify concepts related to the acquisition of power mobility and family members' reaction to this acquisition.	Three themes were most important In recognizing the need for power mobility: recognition of necessity, often due to worsened symptoms or not being able to participate in important activities. Often a lack of choice is experienced. Also, recognizing the need for power mobility can come from a specific expectation or desire that is only possible with power mobility. In recognizing the need for power mobility, the possibility of more independence was important. For family members, on the other hand, it was considered more important that their family member would be able to get around more easily. It might also lead to less caregiving. In the process of deciding, questions like what kind, whom, when, where and how were most prominent. The opinion of the resources available to find information was very negative, due to perceived lack of respect and availability. The positive outcomes reported were

Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
					mostly about better mobility, freedom and access to outside events. The negative outcomes were mostly minor annoyances. Also, the power mobility sometimes damaged the homes of the pwMS. Also, lack of access and maintenance were reported as a negative outcome. Sometimes, the social environment was influenced negatively by the use of power mobility. The family members, and not the pwMS were also afraid that the pwMS would get into unsafe situations. pwMS also would advise to get equipment earlier than pwMS in their disease course
Braham (1975). Evaluation of the social needs of nonhospitalized chronically ill persons. 1. Study of 47 patients with multiple sclerosis. *Journal of Chronic Diseases* (Braham et al., 1975).	To assess social needs of non-hospitalized pwMS.	47 pwMS **Age female:** *M* = 38.7 **Age male:** *M* = 43.4 **Gender:** 47% female	**Disease duration in years:** <5 **EDSS:** *range:* 1 – 8 **Type of MS:** N/A	**Structured questionnaire:** Social needs evaluation Measures of physical disability and dependency	17 out of 47 patients needed transportation assistance for medical care. These needs were met for 11 of the 17 patients. 6 of these 17 patients had unmet needs of medical transportation. 12 out of 47 patients needed transportation for social and recreational activities. These needs were met for 4 of these patients, and remained unmet for 8 patients. More transportation needs were observed for patients with a higher EDSS score (1 – 8). More unmet transportation needs were observed for patients with higher rates of dependence.
Chipchase (2003). A survey of the effects of fatigue on driving in people with multiple sclerosis. *Disability and Rehabilitation* (Chipchase et al., 2003).	To assess the effect of fatigue on driving in patients with MS.	75 pwMS and 63 driving-matched controls. *pwMS* **Age:** *M* = 43 (*SD* = 10.18) **Gender:** 64% female **Driving experience in years:** *range: 11 – 20)* *Controls* **Age:** *M* = age: 44 (*SD* = 10.32) **Gender:** 37% female **Driving experience in years:** *range: 11 – 20)*	**Disease duration in years:** *M* = 9 (*SD* = 8.14) **Type of MS:** N/A **EDSS:** N/A	Questionnaire measuring the effects of fatigue on driving in MS	PwMS reported a smaller maximum distance and length (time) of journey compared to the healthy controls. They also reported more problems that might affect the ability to drive: fatigue, numbness and eye problems. PwMS were also more likely to take short or longer journey compared to controls, drive only on some days and to avoid night driving or driving in bad weather. As a consequence of fatigue, pwMS also swap driving with another person, drive slower and take more breaks during driving than the healthy controls. 51% of the pwMS reported to wait to drive until the MS-related problems improved, 19% made adaptions to their car.
Christensen (1977). Social remedial measures for multiple sclerosis patients in Denmark. *Acta Neurologica Scandinavica*[66].	To examine the conditions of a group of pwMS.	57 pwMS **Age (n):** 20–29: 3 30–39: 3 40–49: 12 50–59: 23 60–69: 15	**Disease duration in years (n):** 10–19: 16 20–24: 20 ≥25: 30 **Type of MS:** N/A **EDSS:** N/A	Questionnaire comprising need for transportation	2 of the participants who had a disease duration of less than 10 years were in a wheelchair, 8 participants who had a disease duration of 10–19 years and 9 participants who had a disease duration of more than 10 years.

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Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
Classen (2017). Development and Validity of Western University's on-road assessments. *Occupation, Participation and Health* (Classen et al., 2017).	To provide clear direction on the inherent components of an on-road course and to provide face, content and construct validity for an on-road assessment.	≥70: 1 **Gender:** 56% female 30 pwMS who passed and failed an on-road test. **Age:** *range: 18 – 59* **Gender:** N/A	*Passed group* **Type of MS (%):** RRMS: 67 SPMS: 25 PPMS: 8 **Disease duration in years:** *M* = 12.17 (*SD* = 8.26) **Most recent EDSS:** *median:* 2.50 (*range::* 2.50) **First MS symptom:** *M* = 15.63 (*SD* = 8.90) **Most recent relapse in years:** *M* = 3.42 (*SD* = 4.67) **Number of medication:** *M* = 1.83 (*SD* = 1.21) *Failed Group* **Type of MS (%):** RRMS: 20 SPMS: 80 PPMS: 0 **Disease duration in years:** *M* = 18.40 (*SD* = 10.85) **Most recent EDSS:** *median:* 2.50 (*range:* 2.00) **First MS symptom:** *M* = 23.80 (*SD* = 9.73) **Most recent relapse in years:** *M* = 3.20 (*SD* = 6.61) **Number of medication:** *M* = 1.60 (*SD* = 1.14)	**Driving:** UWO On-road Assessment **Medical history:**	PwMS who failed the on-road test were more likely to have the SPMS type. The pwMS who passed were more likely to have the RRMS type. The pwMS who passed or failed the test did not differ in any other disease characteristics.
Classen (2018). Visual correlates of fitness to drive in adults with multiple sclerosis. *Occupation, Participation and Health* (Classen et al., 2018).	To quantify the relationships between visual abilities, visual attention and fitness to drive in pwMS.	30 pwMS and 145 older volunteer drivers *Patients with MS* **Age:** *M* = 50.37 (*SD* = 7.45) **Gender:** 60% female *Older volunteer drivers* **Age:** *M* = 69.90 (*SD* = 3.01) **Gender:** 43% female	**Type of MS (%):** RRMS: 57 SPMS: 33 PPMS: 10 **Disease duration in years:** *M* = 13 **EDSS:** *Median* = 2.5 (*range: 0 – 5*) **Number of medication):** *M* = 1.47 (*SD* = 1.20)	**Clinical assessment for visual abilities:** Visual acuity, peripheral field, depth perception, vertical phorias, lateral phorias, colour discrimination, Contrast sensitivity. **Clinical assessment for visual attention:** UFOV **On-road assessment:** Visual scanning, speed regulation, wide lane turns, encroach lane turns, vehicle positioning, adjustment to stimuli, gap acceptance, global rating score.	5 out of 30 pwMS failed the on-road assessment and only 16 out of 145 older drivers failed the on-road test. PwMS performed less well than the older drivers on visual scanning, vehicle positioning and adjustment to stimuli and made more wide lane turns. PwMS encroached less lane turns and made less speed regulation errors than older drivers. PwMS who passed and failed the test did not differ in any visual functions.
Dehning (2014). Neuropsychological performance, brain imaging	To examine the relationship between third ventricle width	35 pwMS and 35 age-, sex- and education-matched controls. *Patients with MS* **Age:** *M* = 43.83 (*SD* = 9.61)	**EDSS:** *M* = 2.87 (*SD* = 1.21) **Disease duration in years:**	**Motor vehicle violations:** Speeding, non-moving safety, administrative, alcohol-	PwMS had a higher rate of total violations, and non-moving safety and administrative violations than healthy controls. No

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Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
and driving violations in multiple sclerosis. *Archives of Physical Medicine and Rehabilitation* (Dehning et al., 2014).	and motor vehicle violation type and frequency.	**Gender:** 83% female **BDI score:** $M = 17.83$ ($SD = 11.38$) **Education in years:** $M = 13.66$ ($SD = 1.89$) *Healthy controls* **Age:** $M = 45.83$ ($SD = 10.94$) **Gender:** 83% female **BDI score:** $M = 3.80$ ($SD = 3.20$) **Education in years:** $M = 14.11$ ($SD = 1.57$)	$M = 5.8$ ($SD = 6.79$) **On medication:** 66% **Type:** N/A	related moving safety, total violations **Neuropsychological testing:** Digit Span, Grooved Pegboard, TMT ($A + B$), COWAT, Rey Complex Figure, RAVLT, Digit-symbol/Coding **MRI-data:** Third ventricle width	difference between the groups was found for speeding, alcohol-related and moving safety violations was found. Neuropsychological performance did not predict driving violations. Third ventricle width did predict driving violations positively.
Devitt (2004) The effect of wheelchair use on the quality of life of persons with multiple sclerosis. *Occupational Therapy in Health Care* (Devitt et al., 2004).	To describe the effect of wheelchair use on the quality of life of persons with multiple sclerosis.	16 pwMS who were in a manual wheelchair or powered wheelchair. **Age:** $M = 54.4$ (*range: 41 – 70*) **Time of wheelchair use in months:** 42 (2 weeks – 10 years) **Gender:** N/A	**Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** N/A	**PIADS:** evaluation of the impact of assistive devices on the quality of life of their users.	Most participants had a high satisfaction with their wheelchair use and most participants used their wheelchair every day. 8 reasons for wheelchair use were reported. All participants reported that it is the only way to get around (16), most that it is the only way they can be independent (11) and some said it is the only way they can approach someone (6). Other, but less reported reasons for wheelchair use were: 'Because it increases my sitting tolerance', 'so that I feel less anxious', 'because it relieves my pain', 'so that I feel less self-conscious' and 'because I can't tolerate being in bed'.
DiLorenzo (2008). A qualitative investigation of adaptation in older individuals with multiple sclerosis. *Disability and Rehabilitation* (DiLorenzo et al., 2008).	To characterize adaptation as an individual's perception of his or her satisfaction with current life circumstances, which include getting older and having MS.	13 older pwMS **Age:** $M = 68.3$ (*range: 62 – 75*) **Gender:** 69% female	**Disease duration in years:** $M = 22.5$ (*range: 8 – 42*) **EDSS:** N/A **Type of MS:** N/A	Perceptions of Aging Interview	PwMS who consider their mobility impaired, also consider their overall health more impaired. Perceptions of mobility do not always reflect more objective measures of mobility. Lack of mobility can lead to negative feelings about the self.
Devos (2013). Driving performance in persons with mild to moderate symptoms of multiple sclerosis. *Disability and Rehabilitation* (59).	To investigate differences in driving performance and driving-related divided attention in a group of drivers with mild to moderate MS and healthy controls.	15 pwMS and 17 age- and sex-matched healthy controls *Patients with MS* **Age:** $M = 50$ (*range: 42 – 55*) **Gender:** 40% female > 20/40 vision In possession of driver's licence *Healthy controls* **Age:** $M = 49$ (*range: 26 – 53*) **Gender:** 47% female > 20/40 vision In possession of driver's licence	**Type of MS (n):** RRMS: 8 SPMS: 5 PPMS: 2 **Disease duration in years:** $M = 9.25$ (*range: 7 – 16*) **EDSS median:** 3.5 (*range: 1.5 - 4.0*)	**Driving simulator:** Primary driving task: (Accidents, traffic tickets, speed variability, SDLP, time to collision) divided attention task (response time, correct responses) **Clinical assessment:** Motor and functional measures, Motricity index, MAS, functional reach, 25-ft Walk, 9HPT. Visual measures, Visual acuity, contrast sensitivity, Psychosocial measures, HADS anxiety, HADS	No difference between the pwMS and healthy controls was found on the primary driving tasks. PwMS performed less on the divided attention task while driving task. Most of the clinical characteristics did not correlate with driving performance, except for functional reach, that correlated with speed. HADS depression and HADS total correlated significantly with time to collision. Of the cognitive measures: scores on the PASAT, semantic fluency and RBANS coding correlated significantly with speed and figure recall with time to collision. Dot cancellation, TMTA, story memory and semantic fluency predicted divided attention during driving performance during driving in pwMS.

Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
				depression, HADS total and MFIS Cognitive measures RBANS, PASAT, Dot cancellation, directions, compass, road sign recognition, TMT(A + B)	Education positively correlated and traffic tickets negatively correlated with the road test. In the cognitive domain, all variables except MMSE, Stroop colour-word, errors on TMT (A + B) and dot cancellation were associated with the score on the TRIP. In the visual domain, binocular acuity, peripheral visual field and stereopsis correlated negatively with the TRIP scores. 9HPT correlated negatively with TRIP. Visual spatial ability, response inhibition and visual functioning predicted on-road scores of drivers with MS best.
Devos (2017). Determinants of on-road driving in multiple sclerosis. *Archives of Physical Medicine and Rehabilitation* (Devos et al, 2017).	To investigate the cognitive, visual, and motor deficits underlying poor performance on different dimensions of on-road driving in individuals with MS.	102 pwMS **Age:** $M = 47.91$ ($SD = 8.71$) **Gender:** 86% female **Driving experience in years:** $M = 31.06$ ($SD = 8.87$) **Annual mileage 10^3:** $M = 2.80$ (*range:* 1.04 – 10.00).	**Type of MS (n):** RRMS: 91 SPMS: 10 PPMS: 1 **Disease duration in years:** $M = 9$ (*range: 5 – 14*) **EDSS:** $M = 5$ (*range: 4 – 7*)	**Demographic and clinical characteristics:** age, driving experience, annual mileage, no. of tickets, no. of accidents, gender, EDSS, disease duration, Barthel Index, MMSE, HADS (depression, anxiety), MFIS and type of MS, 25-ft Walk, 9HPT, assistive device **Vision:** acuity (far, mid, near), Peripheral (horizontal and vertical), colour perception, stereopsis, glare recovery, contrast sensitivity **Cognition:** MMSE, UFOV (SOP, DA, SA, RA) ROCF, SDMT, TMT(A + B), DC (time, errors), Stroop (colour, word, colour-word) directions, compass, RSR, PASAT **Driving:** TRIP	
Dolan (2017). Comparison of seating, powered characteristics and functions and costs of electrically powered wheelchairs in a general population of users. *Disability and Rehabilitation* (Dolan et al., 2019).	To profile and compare seating, powered characteristics and functions and equipment costs of EPWs in a large, general population of adult clinical users.	122 pwMS *PwMS* **Age:** $M = 60.7$ ($SD = 10.6$) **Gender:** 65% female **Time of PWC use:** $M = 6.5$ ($SD = 5.6$)	**Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** N/A	Clinical notes and equipment records were reviewed for type of wheelchair, type of wheelchair seating, level of complexity of equipment, equipment costs, base price and additional costs of extra features and seating equipment costs.	81 of 122 pwMS had a powered wheelchair for outdoor as well as indoor use. 26 of 122 only used their powered wheelchair indoors. Some pwMS (15 of 122) used a powered wheelchair for indoors, but had the possibility to use the wheelchair outdoors also.
Edgley (1991). A survey of Multiple sclerosis part 2. Determinants of Employment status. *Canadian Journal of Rehabilitation* (Edgley et al., 1991)	To determine the relative contributions of age, gender, mobility, duration of illness, education, occupation and perceived cognitive difficulties to employment status.	602 pwMS under the age of 55 who work or have worked in the labour force. **Age:** $M = 43$ (*range:* 18 – 55) **Gender:** 71% female **Education in years (n):** 10: 16 12: 144 14: 158 16: 156 18: 126	**Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** N/A **Age at diagnosis:** $M = 34$	**Perceived Cognitive Problems:** PDQ Questionnaire to pertaining to employment status, including gender, age, occupation, level of education, duration of illness and mobility status.	Problems with mobility were most important in determining unemployment.
Einarsson (2006). Activities of daily living and social activities in people with multiple sclerosis	To describe independence in personal and instrumental activities	166 pwMS **Age:** $M = 51$ ($SD = 12$) **Gender:** 71% female	**Type of MS (n):** RRMS: 70 SPMS: 80 PPMS: 16	**Katz Extended ADL Index:** Outdoors transportation **Frenchay Activities Index:** driving a car, going on the bus	37.3% pwMS were independent on outdoors transportation. 43% van de pwMS never engaged in driving a car or going on the bus. 49% of pwMS

Table 2 (*continued*)

First author (year of publication). Title. Journal (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
Stockholm County. *Clinical Rehabilitation* (Einarsson et al., 2006).	of daily living (ADL), and frequency of social/ lifestyle activities in a population-based sample of people with multiple sclerosis in Stockholm.	**Driving experience in years:** $M = 31.06$ ($SD = 8.87$) **Annual mileage 10^3:** $M = 2.80$ ($range = 1.04 - 10.00$)	**Disease duration in years:** $M = 19$ ($SD = 11$) **EDSS (n):** $0 - 3.0$: 42 $3.5 - 5.5$: 35 $6.0 - 6.5$: 47 ≥ 7.0: 42		drives a car of goes on the bus on a weekly basis.
Fay (2004). Manual wheelchair pushrim dynamics in people with multiple sclerosis. *Archives of Physical Medicine and Rehabilitation* (Fay et al., 2004).	To define differences in pushrim dynamics during manual wheelchair propulsion by users with MS.	14 pwMS, 14 persons with spinal cord injury and 14 non-disabled persons. *pwMS* **Age:** $M = 48.4$ ($SD = 6.3$) **Gender:** 57% female **Wheelchair use in years:** $M = 8.07$ ($SD = 9.55$) *Persons with spinal cord injury* **Age:** $M = 45.8$ ($SD = 16.9$) **Gender:** 57% female **Wheelchair use in years:** $M = 8.50$ ($SD = 5.14$) *Non-disabled persons* **Age:** $M = 38.7$ ($SD = 9.8$) **Gender:** 57% female	**Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** N/A	Questionnaires that asked about the diagnosis, duration of wheelchair use, typical activities. **Pushrim kinematics:** Velocity, propulsion frequency, push angle, push and recovery phase duration, propulsion patterns, pushrim force, work (the force applied to move the wheelchair), work loss	PwMS had a lower speed and difficulty maintaining the speed of the wheelchair, even below walking speed, compared to the non-disabled participants and participants with spinal cord injury. Also, pwMS had a smaller push angle, which can lead to smaller input of power, however no significant differences between the groups in pushrim force was found. But, the work generated by pwMS was significantly lower. Also, there was more work loss as pwMS showed difficulty grabbing or letting go of the pushrim. PwMS chose a less efficient propulsion pattern.
Finlayson (2003). Experiencing the loss of mobility: perspectives of older adults with MS. *Disability and Rehabilitation* (Finlayson and van Denend, 2003).	To develop an understanding of the experience and meaning of mobility loss among older adults with MS	27 older pwMS **Age:** $M = 62$ ($SD = 7$, $range: 55 - 82$) **Gender:** N/A	**Self-reported health ratings (n):** Very good: 7 Good: 9 Fair: 8 Poor: 3 **Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** N/A	In depth-semi-structured interview focused on the participant's perspectives about aging with MS, the meaning of health and any associated concern. Multiple sclerosis Quality of Life Inventory, Older Adults Resources and Services Functional Assessment Questionnaire	14 pwMS still drove. 5 of those 14 pwMS had adjusted hand controls installed in the car and 10 reported to go to leisure or social activities more than 4 times per week. Only 4 of the 13 pwMS who did not drive went out as much as the pwMS who drove and 7 reported to be in need of more transportation access. Physical symptoms of MS did not prevent pwMS to be mobile, but they did influence the experienced mobility and the chosen kind of transportation. The environment of the community or their own homes were also of influence on mobility, as not everything is easily accessible. Friends and family who could help, help adapting the environment and assistive technology like a wheelchair or scooter had a positive influence on the mobility of pwMS. However, pwMS who experience loss of mobility needed time to adjust to the idea that they needed special equipment, or help from family. Some participants had great difficulty dealing with the loss of mobility.
Finlayson (2004). Concern about the future among older adults with multiple sclerosis. *The American Journal of*	To describe health-related concerns and service needs of older adults with MS.	27 older pwMS. **Age:** $M = 62$ ($SD = 7$, $range: 55 - 82$) **Gender:** 85% female	**Heath and functional status self-rated health (n):** Very good: 7 Good: 9 Fair: 8	Interviewer-administered survey, Multiple sclerosis Quality of Life Inventory, Older Adults Resources and	Further loss of mobility and independence was the most prominent fear of the future among older adults.

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Table 2 (*continued*)

First author (year of publication). Title. Journal (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
Occupational Therapy (Finlayson, 2004).			Poor: 3 **Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** N/A	Services Functional Assessment Questionnaire	
Finlayson (2005). Older Adults' perspectives on the positive and negative aspects of living with multiple sclerosis. *British Journal of Occupational Therapy* (Finlayson et al., 2005).	To examine the perspectives of older adults on living with multiple sclerosis.	27 pwMS **Age:** $M = 62$ (*range: 55 – 82*) **Gender:** 85% female	**Disease duration in years:** $M = 20$ (*range = 6 – 39*) **Type of MS:** N/A **EDSS:** N/A	In-depth semi-structured interviews to elicit positives and negatives of living with MS, SF-36 physical functioning subscale, Medical Outcomes Study, Modified Social Support Scale, Mental Health Inventory	12 of 27 participants named loss of mobility as one of seven most important negative aspects of living with MS.
Finlayson (2014). A cross sectional study examining multiple mobility devices use and fall status among middle aged and older adults with multiple sclerosis. *Disability and Rehabilitation: Assistive technology* (Finlayson et al., 2014).	To examine the use of multiple mobility aids among middle-aged and older adults with multiple sclerosis.	353 pwMS < 55 years old **Age:** $M = 66.8$ ($SD = 7.1$) **Gender:** 66.6% female	**Type of MS:** N/A **Disease duration in years:** $M = 22$ ($SD = 12$) **EDSS:** N/A **Self-reported health (n):** Poor or fair: 102 Good: 167 Excellent: 80 Missing: 4	**Mobility device use:** Series of questions about the frequency of using a mobility aid	38.2% used a manual wheelchair and 48.2% used a powered wheelchair or scooter.
Gilmour (2018). Multiple sclerosis: Prevalence and impact. *Statistics Catalogue* (Gilmour et al., 2018).	To examine the prevalence of MS and its impact on those diagnosed.	An estimated 93,500 Canadians with multiple sclerosis **Age** (**prevalence per 100,000; n**): 18–44: 233 45–64: 478 65–79: 470 65+: 267 0–17: unpublished **Gender (prevalence per 100,000; n):** Males: 159 Females: 418	**Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** N/A	2010/2011 Survey of Neurological Conditions Prevalence File, 2011/2012 Survey of Neurological Conditions in Institutions in Canada, 2011 Survey on Living with Neurological Conditions in Canada	29.8% of respondents that was aged 16 or older and had a valid driver's licence reported that having MS prevented them from driving.
Gregory (1993). Employment and multiple sclerosis in New Zealand. *Journal of Occupational Rehabilitation* (Gregory et al., 1993).	To ascertain the employment situations of people with MS to see if this was suboptimal, and if so, to what extent.	80 pwMS **Age (n):** 20–30: 2 31–40: 22 41–50: 17 51–60: 20 61–70: 17 >71: 2 **Gender:** 68.8% female **Employment:** 27.5% employed.	**Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** N/A	Interview on the perspectives on employment	Difficulties related to mobility did not prevent pwMS from being employed. Some of the pwMS in wheelchairs were able to work fulltime. Adjustment to employment difficulties related to mobility are relatively easy to accommodate than other difficulties.
Harand (2018). Evidence of attentional impairments using virtual driving simulation in multiple sclerosis. *Multiple sclerosis and related disorders* (Harand et al., 2018).	To investigate the usefulness of virtual reality assessment of attention in multiple sclerosis, especially to evaluate alertness and divided attention using driving simulation.	11 pwMS and 11 healthy controls *PwMS* **Age:** $M = 41.18$ ($SD = 7.17$) **Gender:** 90.1% female *Healthy controls* **Age:** $M = 41.18$ ($SD = 7.17$) **Gender:** 90.1% female	**Disease duration in years:** $M = 10.3$y ($SD = 3.62$) **EDSS:** $M = 1.95$ ($SD = 0.91$) **Type of MS:** N/A	**Driving:** SIM2INRETS fixed-base driving simulator equipped with ARCHISIM object database. Assessment conducted by trained study coordinator: LP, SDLP, mean speed, SDS, response time to visual cues, errors and omissions. 3 conditions were used: monotonous driving,	In the monotonous condition, pwMS only scored lower than healthy controls on SDLP. In the driving with divided attention conditions, pwMS, but not controls scored aberrant on SDLP and SDS. No other differences between the groups were found. In the urban driving condition no significant differences between the pwMS and controls were found.

Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
				driving with divided attention and urban driving with accident conditions	
Iezzoni (2009). Patterns of mobility aid use among working-age persons with multiple sclerosis living in the community in the United States. *Disability and Health Journal* (Iezzoni et al., 2009).	To explore perceptions of mobility problems related to MS and patterns of mobility use.	703 community-dwelling, working-age adults with self-reporting multiple sclerosis. **Age (%):** 23–39: 11.4 40–49: 26.8 50–59: 40.0 60–67: 21.5 **Gender:** 77.5% female **Education:** High school or less: 26.3% Some college: 33.1% College degree: 36.5% Postgraduate degree: 4.1%	**Type of MS (%):** RRMS: 68.6 SPMS: 20.8 Other: 10.6 **Disease duration in years (%):** 0–5: 9.7 6–10: 29.4 11–20: 37.2 >20: 23.5 **Self-reported overall health (%):** Excellent: 7.4 Very good: 23.0 Good: 39.0 Fair: 22.9 Poor: 7.4 **EDSS:** N/A **Total number of wheelchairs (%):** 1: 8.0 2: 18.5 Unknown: 20.0	**Demographic:** age, sex, race, Hispanic ethnicity, high poverty zip code, education, marital status employment status) and **disease characteristics** (overall health, disease duration, MS pattern, total number of wheelchairs. **Wheelchair use**	PwMS who had at least one mobility aid were more likely to be older, male, white, divorced, separated, widowed or never married, working part time or not working, have poorer health, longer disease duration and having PSMS. Employment status, overall health, MS pattern or 'had fallen in past year' were most predictive of having a mobility aid. 30.4% had a powered wheelchair, 26.7% a scooter and 52.6% a manual wheelchair. Manual wheelchairs were the most common aid among pwMS with 1, 2 and 3 mobility aids.
Iezzoni (2010). Experiences acquiring and using mobility aids among working-age persons with multiple sclerosis living in communities in the United States. *American Journal of Physical Medicine and Rehabilitation* (Iezzoni et al., 2010).	To examine patterns of mobility aids among working-age persons with multiple sclerosis.	703 community-dwelling, working-age adults with self-reporting multiple sclerosis. **Age (%):** 23–39: 11.4 40–49: 26.8 50–59: 40.0 60–67: 21.5 **Gender:** 77.5% female **Education (%):** High school or less: 26.3 Some college: 33.1 College degree: 36.5 Postgraduate degree: 4.1	**Type of MS (%):** RRMS: 68.6 SPMS: 20.8 Other: 10.6 **Disease duration in years (%):** 0–5: 9.7 6–10: 29.4 11–20: 37.2 >20: 23.5 **EDSS:** N/A **Self-reported overall health (%):** Excellent: 7.4 Very good: 23.0 Good: 39. Fair: 22.9% Poor: 7.4 **Total number of wheelchairs (%):** 1: 8.0 2: 18.5 Unknown: 20.0	**Demographic:** age, sex, race, Hispanic ethnicity, high poverty zip code, education, marital status employment status) and **disease characteristics** (overall health, disease duration, MS pattern, total number of wheelchairs. Wheelchair use: manual, powered or scooter (n).	156 pwMS had powered wheelchairs. More males than females had powered wheelchairs. Persons who did not work full time, with fair or poor health and SPMS had power wheelchairs more often. 277 pwMS had manual wheelchairs. PwMS who were older, Hispanic, not working full time, with fair of poor health, a longer disease duration, SPMS or another pattern had a manual wheelchair more often. 132 pwMS had mobility scooters. PwMS who were older, not working full time, had poorer health and a longer disease duration were more likely to have a mobility scooter. 269 pwMS had no mobility aid. PwMS who were younger, working full time, had better health and had RRMS were more likely to have no mobility aids. Almost half of the pwMS with a powered wheelchair, manual wheelchair or mobility scooter resisted the idea of getting a mobility aid. Most important factors were: Did not want to give in to MS, worried about loss of independence, worried that walking would worsen when using mobility aids and worried that other people would think he/she was weak.

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Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
Klewer (2001). Problems reported by elderly patients with multiple sclerosis. *Journal of Neuroscience Nursing* (Klewer et al., 2001).	To assess problems in elderly patients with MS.	53 elderly pwMS **Age:** *M* = 73 (*SD* = 6.4) **Gender:** 83% female	**Type of MS (%):** RRMS: 90.6 **Disease duration in years:** *M* = 25.3 (*SD* = 12.4) **Self-reported EDSS (%):** 4.5–6: 3.8 6.5–7.5: 54.7 ≥8: 41.5	**IRES:** Indicators of rehabilitation status questionnaire	A wheelchair was used by 69.8% of participants. 56.6% was unable to leave their house and 15.1% was unable to use public transportation.
Krasniuk (2017). Driving errors that predict on-road outcomes in adults with multiple sclerosis. *Occupation, Participation and Health* (Krasniuk et al., 2017).	To determine whether adjustment-to-stimuli and gap acceptance errors significantly predict passing/failing a standardized on-road assessment of pwMS.	37 pwMS, of which 29 passed and 8 failed an on-road driving test. *Passed group* **Age:** *M* = 49.97 (*SD* = 7.27) **Gender:** 55% female *Failed group* **Age:** *M* = 52.75 (*SD* = 6.80) **Gender:** 75% female	*Passed group* **Type of MS (%):** RRMS: 65 SPSM: 28 PPMS: 7 **Disease duration in years:** *M* = 13.35 (*SD* = 8.70) **EDSS:** *Median:* 2.50, (*range:* 3.00) **Time since last relapse in years:** *M* = 3.54 (*SD* = 4.72) *Failed group* **Type of MS (%):** RRMS: 37.5 SPSM: 62.5 PPMS: 0 **Disease duration in years:** *M* = 15.38 (*SD* = 9.83) **EDSS:** *Median:* 2.50, (*range:* 3.00) **Time since last relapse in years:** *M* = 2.88 (*SD* = 5.30)	**Demographic, medical and health information:** age, gender, country born, ethnicity, education level, employment, medication (number), MS type, MS diagnosis (years), First MS symptom, Time since last relapse, EDSS score **On-road driving assessment:** UWO (Errors: Adjusting to stimuli, gap acceptance, lane maintenance, signalling, speed regulation, vehicle positioning, visual scanning, total number of driving errors)	Of the demographic, medical and health information, only employment differed between the passed and the failed group: 16 of the passed participants had education, but none of the failed participants had education. Though not significant, pwMS who failed the driving assessment were more likely to have the secondary progressive type. Number of adjustment to stimuli errors and committed gap acceptance errors predicted passing or failing the on-road test: more errors predicted failing the test.
Lamargue-Hamel (2015). Cognitive evaluation by tasks in a virtual reality environment in multiple sclerosis. *Journal of the Neurological Sciences* (Lamargue-Hamel et al., 2015).	To determine the interest of cognitive evaluation in a virtual reality environment.	30 pwMS with at least moderate impairment and 22 healthy controls *PwMS* **Age:** *M* = 41.7 (*SD* = 7.2) **Gender:** 70% female **Education (% baccalaureate):** 50 *Healthy controls* **Age:** *M* = 37.8 (*SD* = 9.2) **Gender:** 72.7% female **Education (% baccalaureate):** 54.5	**EDSS:** *Median:* 2.50 (*range:* 0 – 8) **Type of MS:** N/A **Disease duration in years:** N/A **BDI:** *M* = 14.5 (*range:* 0 – 26)	**Clinical assessment** (EDSS, BDI, STAI, MFIS). UrbanDailyCog *®*. **Neuropsychological assessment** (MMSE, SDMT, TAP alertness, TAP visual scanning, TAP divided attention, TAP n-back, Stroop test, TMT(*A + B*), Span of Baddeley double task, verbal fluency, reverse span, CVLT, Rey Complex Figure, Naming Taks) **Driving simulator dual task** (Driving + DA) **Urban Daily Cog:** tasks in daily traffic	52% pwMS failed the driving simulator task and 80% of pwMS failed the UrbanDailyCog*®*. 88% of pwMS failed the divided attention task while driving.
Learmonth (2015). Perspectives on physical activity among people with multiple sclerosis who are wheelchair users.	To identify possible opportunities for accruing physical activity in the context of daily life and to	15 pwMS who were wheelchair users. **Age:** *M* = 52 (*SD* = 8.8) **Gender:** 80% female	**Type of MS (n):** RRMS: 7 SPMS: 6 PPMS: 2 **Disease duration in years:**	Interview on physical activities: meaning, motivations and outcomes	9 of the 15 participants did not drive (anymore). pwMS used their mobility aids to maximize participation in everyday tasks. All participants reported that life was more

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Table 2 (continued)

First author (year of publication). Title. Journal (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
International Journal of MS Care (Learmonth et al., 2015).	identify targets of an intervention for changing physical activity behaviours.		$M = 14.3$ ($SD = 8.5$) **Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** N/A **Wheelchair use (n):** Powered wheelchair: 11 Manual wheelchair: 4		difficult when using a wheelchair, especially due to unadapted environments. Participants reported that more planning and organizing transportation was needed due to wheelchair use.
Lincoln (2008). Cognitive abilities as predictors of safety to drive in people with multiple sclerosis. *Multiple Sclerosis* (Lincoln and Radford, 2008).	To determine whether cognitive tests predict safety to drive in people with MS.	34 pwMS **Age:** $M = 45.9$ ($SD = 10.4$) **Gender:** 50% female **Driving experience in years:** $M = 23.8$ ($SD = 9.07$). **Time since last having driven a car:** *Median:* 0 months (0 – 72).	**Disease duration in years:** $M = 9.3$ ($SD = 9.82$). **Type of MS:** N/A **EDSS:** N/A	**Driving assessment:** Nottingham Neurological Driving Assessment **Cognitive functioning:** SDSA (DC, Square matrices, RSR) PASAT Stroop Test Test of Motor Imperistence AMIPB	8 pwMS had assisted mobility and 5 pwMS were in a wheelchair. 13 pwMS failed the driving test, and 21 pwMS passed the test. Women with MS were more likely to be unsafe drivers than man. Time since driven discriminated between safe and unsafe drivers. The false positives of the dot cancellation task, the road recognition task, the figure recall copy, the design learning interference and IP discriminated between passed and failed pwMS.
Lings (2002). Driving accident frequency increased in patients with multiple sclerosis. *Acta Neurologica Scandinavica* (Lings, 2002).	To assess the influence of multiple sclerosis on the ability to drive safely.	197 pwMS and 545 age-, gender-, place of birth- and exposure period- matched controls with driver's licences. *pwMS:* **Age females:** $M = 47.9$ (*range:* 21.6 – 82.8) **Age males:** $M = 49.5$ (*range:* 22.3 – 81.4) **Gender:** 50.3% female **Exposure period:** *median:* 10.0 (*range:* 0.0 – 10.0) *Controls:* **Age females:** $M = 46.9$ (*range:* 21.0 – 82.8) **Age males:** $M = 49.4$ (*range:* 22.4 – 81.9) **Gender:** 51.0% female **Exposure period:** *median:* 9.8 (*range:* 0.8 – 10.0)	**Disease duration in years:** $M = 14.1$ (*range:* 21.6 – 82.8) **Type of MS:** N/A **EDSS:** N/A	Accident rates per 1000 person-years	PwMS had a significantly higher accident rate than matched controls.
Marcotte (2008). The contribution of cognition and spasticity to driving performance in multiple sclerosis. *Archives of Physical Medicine and Rehabilitation* (Marcotte et al., 2008).	To examine the independent and combined impact of cognitive dysfunction and spasticity on driving tasks involving high cognitive workload and lower-limb mobility in persons with multiple sclerosis	17 drivers with MS and 14 referent controls. *pwMS* **Age:** $M = 49.5$ ($SD = 7.9$) **Gender:** 65% female **Kilometres driven in past year:** $M = 6293$ (*range:* 3521 – 9938) *Referent controls:* **Age:** $M = 47.7$ ($SD = 11.7$) **Gender:** 65% female **Kilometres driven in past year:** $M = 9569$ (*range:* 5344 – 17,197)	**Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** *Median:* 6.0 **MAS:** 47% spastic	**Driving simulation:** Lane tracking (speed, speed deviation0, SDLP, DA (% missed at least one target), Car following (Coherence, time delay, modulus). **Neuropsychological testing:** Grooved pegboard Test, TMT($A + B$), Wechsler Digit Symbol, PASAT, HVLT-R **Spasticity assessment:** MAS	During the driving simulation, PwMS had a higher average speed and speed deviation and a greater deviation of lateral position, more pwMS missed at least one target during the divided attention task and were less able to track speed variations of a lead car compared to referent controls. Only deviation of lateral position correlated significantly with neuropsychological functioning, especially the TMT B, digit symbol, and HVLT total words. Spastic patients were less able to track speed and variations of a lead car, compared to patients without spasms.
McDonnel (2001). An assessment of the spectrum of disability and handicap in multiple sclerosis: a population-based study. *Journal of Rehabilitation and Research*	To establish the spectrum of disability and handicap.	288 pwMS **Age:** $M = 49.4$ ($SD = 7.4$) **Gender:** 69% female	**Type of MS (%):** RRMS: 35 RRMS and benign MS (EDSS ⟨3 and ⟩ 10 years from onset): 13 SPMS: 39.5	**EDSS scores** **Social performance or needs:** ESS score	73% of pwMS were not able to climb stairs. More than 30% of the pwMS was not able to drive a car or use public transport, even with the lowest ESS score.

(continued on next page)

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Table 2 (*continued*)

First author (year of publication). Title. Journal (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
Development (McDonnell and Hawkins, 2001).			PPM: 12.5 **Disease duration in years:** M = 18.5 **EDSS:** *Mode:* 6.0		8 of the 36 pwMS were considered not able to drive. Demographic of disease characteristics could not discriminate between pwMS who were fit and unfit to drive.
Morrow (2018). On-road assessment of fitness-to-drive in persons with MS with cognitive impairment: A prospective study. *Multiple Sclerosis Journal* (Morrow et al., 2018).	To assess fitness-to-drive in persons with MS with cognitive impairment and low physical ability.	36 pwMS **Age:** M = 49.9 (SD = 7.4) **Gender:** 61.1% female **Employment:** 44.4% **Driving as part of employment:** 16% **Vision:** >20/60 binocular acuity ≥120˚ visual field	**Type of MS (n):** RRMS: 22 SPMS: 13 PPMS: 1 **Disease duration in years:** M = 13 (SD = 9.0) **EDSS:** M = 3.0 (range: 1.0 – 5.0)	**Cognitive functioning:** MACFIMS battery (JLO, COWAT, CVLT2, BVMTR, PASAT, SDMT, DKEFS) **Fitness-to-drive:** Pass/fail outcome by driving school instructor or occupational therapist.	Processing speed and visual spatial skills were associated with failing the on-road driving test (SDMT and BVMTR-IR).
Neven (2013). Documenting outdoor activity and travel behaviour in persons with neurological conditions using travel diaries and GPS tracking technology: a pilot study in multiple sclerosis. *Disability and Rehabilitation* (Neven et al., 2013).	To examine outdoor activity and travel behaviour in relation to disease related disability.	17 persons with mild MS, 8 persons with moderate MS, 11 persons with severe MS and 24 age- and sex matched controls. *Mild MS group:* **Age (n):** 25–34: 2 35–44:6 45–54:6 55–64: 3 **Gender:** 71% female **Education (n):** Primary: 0 Secondary: 11 Higher: 6 **Driving ability:** No: 0 Adapted: 0 Independent: 17 **In Wheelchair:** 0 *Moderate MS group:* **Age (n):** 25–34: 1 35–44:3 45–54:1 55–64: 3 **Gender:** 83% female **Education (n):** Primary: 0 Secondary: 6 Higher: 2 **Driving ability (n):** No: 2 Adapted: 4 Independent: 2 **In Wheelchair:** 2 *Severe MS group:* **Age (n):** 25–34: 0 35–44:2 45–54:5 55–64: 4 **Gender:** 64% female **Education (n):**	*Mild MS group:* **Disease duration in years:** M = 10.3 (SD = 6.1) **EDSS:** M = 3.1 (SD = 0.9) **Type of MS:** N/A *Moderate MS group:* **Disease duration in years:** M = 17.0 (SD = 6.4) **EDSS:** M = 5.6 (SD = 0.8) **Type of MS:** N/A *Severe MS group:* **Disease duration in years:** M = 18.4 (SD = 11.2) **EDSS:** M = 7.1 (SD = 0.7) **Type of MS:** N/A	**Clinical outcomes:** EDSS, disease duration, MSFC (Timed 25 ft Walk, (9-HTP, PASAT) MSIF (total, physical, cognitive, psychosocial), HADS (total, anxiety, depression) HADS **Cognitive outcomes:** RBANS, DC (time, positives), TMT(A + B). **Mobility measures:** Self-reported travel diaries, GPS loggers	There were significantly more drivers in the mild group (66.5%) and the moderate group (25.5%), compared to the severe group in which 12.0% still drove. Only pwMS in the moderate group used public transport. No one in the mild group, 8.6% in the moderate group and 41.9% in the severe group used an assistive device. 3.2% in the moderate and 16.4% in the severe group had adapted transport. No one of the control or mild MS group had an assistive device or adapted transport. Compared to the severe MS group, pwMS in the mild MS group travelled shorter distances. The duration of the activity did not differ among the groups. However, pwMS in the severe group less often travelled for less than 30 min. The moderate group more often travelled for more than four hours, compared to the mild group

Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
		Primary: 1 Secondary: 8 Higher: 2 **Driving ability:** No: 9 Adapted: 2 Independent: 0 **In Wheelchair:** 11 *Control group:* **Age (n):** 25–34: 5 35–44:4 45–54:7 55–64: 8 **Gender:** 67% female **Education (n):** Primary: 0 Secondary: 15 Higher: 11 **Driving ability:** No: 0 Adapted: 0 Independent: 24 **In Wheelchair:** 0			
Ozdemir (2011). A holistic look at patients with multiple sclerosis: Focusing on social life, household and employment status. *Turkish Journal of Physical Medicine and Rehabilitation* (Ozdemir and Asiret, 2011).	To identify the impact of multiple sclerosis on social life, household and employment.	101 pwMS. **Age:** $M = 34.9$ ($SD = 10.8$) **Gender:** 65.3% female **Education:** 76.2% more than high school. **Employment:** 47.5% unemployed	**Disease duration in years:** > 4: 54.54% **Type of MS:** N/A **EDSS:** N/A	Data from open-ended and non-rated questions related to household tasks, attitudes of relatives, social support from families, social life, activities outside the home and the existence of disease symptoms	Transportation difficulties and not being able to go out with family are stated as problems influencing the social environment. Social activity levels were reduced when difficulties with transportation were experienced.
Pateman (2016). How do Australians living with MS experience oral health and accessing dental care? A focus group study. *Community Dental Oral Epidemiology* (Pateman et al., 2016).	To explore the oral health experiences, oral health behaviours and barriers to accessing dental care.	43 pwMS **Age (n):** ≤14: 0 15–44: 6 ≥45: 30 Unknown: 7 **Gender:** 81.4% female **Education (n):** Primary school or less: 3 Secondary school: 13 Trade of technical education: 7 Higher education: 20	**Type of MS (n):** Benign: 0 RRMS: 21 PPMS 4 SPMS:11 Don't know: 4 Other: 2 **Disease duration in years (n):** 0–10: 10 11–20: 19 21–30: 8 ≥ 30: 5 **EDSS:** N/A	**Focus groups:** views on the awareness of the general, dental and medical communities of dental needs.	Mobility limitations were reported as a barrier to access dental care.
Patten (2012). Perceived met and unmet health-care needs in a community population with multiple sclerosis. *International Journal of MS Care* (Patten et al., 2012).	To examine health status, the use of aids and supports, perceived needs and unmet needs, and participation in society by people with MS in Canada.	245 pwMS and 22,268 persons without MS, but with other disabilities (general population *MS group* **Age:** $M = 50.5$ **Gender:** 71% *General population:* **Age:** $M = 45.0$	**Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** N/A	**PALS interview:** Health related impaired mobility, use of mobility aids	PwMS were more likely to have some and a lot of mobility impairments, compared to the general population. PwMS also had a manual powered wheelchair, a scooter or an adapted motor vehicle more often.

Table 2 (*continued*)

First author (year of publication). Title. Journal (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
Ranchet (2015). Agreement between physician's recommendation and fitness-to-drive decision in multiple sclerosis. *Archives of Physical Medicine and Rehabilitation* (Ranchet et al., 2015).	To investigate the agreement of fitness-to-drive made by the referring physicians and by the on-road assessors in individuals with multiple sclerosis.	218 pwMS **Age:** *M* = 42.5 (*SD* = 11.10) **Gender:** 53% female **Driving experience in years:** 33 (*range: 25 – 39*) **Car collisions in last 5 years:** 0 (*range: 0 – 0*) **Traffic violations:** 0 (*range: 0 – 0*)	**Disease duration in years:** *M* = 11 (*range: 6 – 16*) **Type of MS:** N/A **EDSS:** N/A	**Fitness to drive decisions:** On-road assessor, physician **Binocular acuity**	14 pwMS failed the road test and 204 passed the test. PwMS who failed the driving test had significantly worse binocular acuity. The physician overestimated the fitness to drive of 11 patients and underestimated the fitness to drive of 16 patients.
Roessler (2013) Specialized housing and transportation needs and barriers of adults with multiple sclerosis. *Work* (Roessler et al., 2013).	To evaluate the specialized housing, transportation and resource needs and barriers of adults with MS.	615 pwMS of the NARCOMS patient registry. **Age:** N/A **Gender:** N/A	**Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** N/A	Mobility issues	PwMS reported that restricted mobility influences the ability to live independently. PwMS with restricted mobility are less optimistic about future independent living. Some respondents were positive about the accessibility of public transport in the US. However, some were negative, indicating that public transportation lacked adaptations for wheelchairs, or that public transportation was too far away. Most of the respondent still drove.
Ryan (2009). Fitness to drive in multiple sclerosis: awareness of deficit moderates risk. *Journal of Clinical and Experimental Neuropsychology* (Ryan et al., 2009).	To examine characteristics related to MS that may affect driving status.	60 pwMS and their significant others who still drove and 18 pwMS who do not drive and their significant others. *Drivers* **Age:** *M* = 45.4 (*SD* = 9.6) **Gender:** 80% female **Education in years:** *M* = 15 (*SD* = 2.4) *Nondrivers* **Age:** *M* = 48.9 (*SD* = 11.1) **Gender:** 72.2% female **Education in years:** *M* = 13.9 (*SD* = 2.4)	*Drivers* **Type of MS (%):** RRMS: 93.3 SPMS: 22.2 **Disease duration in years:** *M* = 9.2 (*SD* = 6.7) **EDSS:** *M* = 3.1 (*SD* = 1.6) *Nondrivers* **Type of MS (%):** RRMS: 6.7 SPMS: 77.8 **Disease duration in years:** *M* = 14.2 (*SD* = 8.7) **EDSS:** *M* = 6.3 (*SD* = 2.0)	**Neuropsychological functioning:** Composite score (Oral Symbol Digit Modalities Test, PASAT, JLO-short form, Modified Stroop Test, COWAT, HVLT-R, TMT(A + B), Benton Visual Naming test. **Awareness of Deficit Questionnaire Driving Survey** BDQ: Social barriers subscale of the barriers to driving questionnaire **Driving records:** Number of driving accidents and traffic violations	Non-drivers with MS had a longer disease duration, a higher EDSS-score, and had SPMS more often, and not RRMS, compared to drivers with MS. Non-drivers with MS performed worse on the neuropsychological tests, reported more social barriers to driving, and have greater unawareness of deficit, compared to drivers. Driving frequency did not change for 65% of MS drivers, 30% felt the frequency decreased and 5% felt the frequency increased since the diagnosis. The decision to stop driving is mostly made by the individual themselves (44.4%). Some decisions were made by their families (5.6%), and some by their physician (11.1%). Some pwMS had to stop driving due to legal issues (5.6%). PwMS who are more aware of their deficits, are more likely to use compensatory behaviours for driving.
Sawatzky (2007). The Segway Personal Transporter as an alternative mobility device for people with disabilities. *Archives of Physical Medicine and Rehabilitation* (Sawatzky et al., 2007).	Prospective study to determine the functional measures that best correlate with the skill levels of people with disabilities who operate a Segway Personal Transporter and to explore subjects' experiences with the Segway.	6 pwMS and 17 persons with other disabilities of injuries. **Age:** N/A **Gender:** N/A	**Type of MS:** N/A **Disease duration in years:** N/A **EDSS:** N/A	Segway Task Assessment Berg Balance Scale Timed Up & Go Test	All participants were able to use the Segway.
Schultheis (2001). The influence of cognitive impairment on driving performance in	To examine the influence of impaired cognitive processing on	15 pwMS without cognitive impairment, 13 pwMS with cognitive impairment and 17 age- sex and years of driving experience-matched healthy controls	*pwMS without cognitive impairment* **Disease duration in years:**	**Driving:** UFOV (Vision and processing, divided attention, selective	The groups did not differ on total errors of the NDT. The groups did differ on the latency

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Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
multiple sclerosis. *Neurology* (Schultheis et al., 2001).	measures of driving skills in persons with MS.	*pwMS without cognitive impairment* Age: *M* = 45.6 (*SE* = 2.1) Gender: 67% female Education in years: *M* = 16.8 (*SE* = 0.46) Number of years driving: *M* = 28.5 (*SE* = 2.1) Average number of days per week driving: *M* = 6.7 (*SE* = 0.23) *pwMS with cognitive impairment* Age: *M* = 40.9 (*SEM* = 2.1) Gender: 54% female Education in years: *M* = 14.7 (*SE* = 0.55) Number of years driving: *M* = 22.7 (*SE* = 2.8) Average number of days per week driving: *M* = 5.3 (*SE* = 0.73) *Healthy controls* Age: *M* = 43.8 (*SE* = 2.0) Gender: 76% female Education in years: *M* = 15.1 (*SE* = 0.53) Number of years driving: *M* = 26.7 (*SE* = 2.0) Average number of days per week driving: *M* = 6.9 (*SE* = 0.00)	*M* = 10.4 (*SE* = 2.2) **Type of MS:** N/A **EDSS:** N/A *pwMS with cognitive impairment* **Disease duration in years:** *M* = 8.9 (*SE* = 1.8) **Type of MS:** N/A **EDSS:** N/A	attention), NDT (total error and total latency score)	measure of the NDT. The pwMS with cognitive impairment showed a slower response time than the pwMS without cognitive impairment and healthy controls. A higher percentage of pwMS had a high probability for driving difficulties, compared to the healthy controls. The pwMS with cognitive impairment scored lower than the pwMS without cognitive impairment on vision and processing, and pwMS without cognitive impairment scored lower than the healthy controls.
Schultheis (2002). Motor vehicle crashes and violations among drivers with multiple sclerosis. *Archives of Physical Medicine and Rehabilitation* (Schultheis et al., 2002).	To investigate differences in the incidence of motor vehicle crashes and violations among drivers with multiple sclerosis with cognitive impairment.	14 pwMS without cognitive impairment, 13 pwMS with cognitive impairment and 17 age- sex and years of driving experience-matched healthy controls *pwMS without cognitive impairment* Age: *M* = 45.5 (*SE* = 2.3) Gender: 71% female Education in years: *M* = 16.9 (*SE* = 0.49) Number of years driving: *M* = 28.3 (*SE* = 2.2) Average number of days per week driving: *M* = 6.6 (*SE* = 0.25) *pwMS with cognitive impairment* Age: *M* = 40.9 (*SE* = 2.6) Gender: 54% female Education in years: *M* = 14.7 (*SE* = 0.55) Number of years driving: *M* = 22.7 (*SE* = 2.8) Average number of days per week driving: *M* = 5.3 (*SE* = 0.73) *Healthy controls* Age: *M* = 43.8 (*SE* = 2.0) Gender: 76% female Education in years: *M* = 15.1 (*SE* = 0.53) Number of years driving: *M* = 26.7 (*SE* = 2.0) Average number of days per week driving: *M* = 6.9 (*SE* = 0.00)	**Type of MS (%):** RRMS: 59 SPMS: 7 PPMS: 4 Not obtainable: *n* = 8 *pwMS without cognitive impairment* **Disease duration in years:** *M* = 10.3 (*SE* = 2.3) **EDSS:** N/A *pwMS with cognitive impairment* **Disease duration in years:** *M* = 8.9 (*SE* = 1.8) **EDSS:** N/A	**Driving:** Documented incidence of MCV's, motor vehicle violations **Cognitive functioning:** WAIS-R (block design, digit symbol), MVPT-R, Stroop (word, colour, colour-word), TMT(*A* + *B*), PASAT)	PwMS with cognitive impairment drove significantly less days in a week than pwMS without cognitive impairment or healthy controls. 78% pf pwMS reported no change in driving behaviour since diagnosis. PwMS with cognitive impairment had a significantly greater incidence of one or more crashes, compared to pwMS without cognitive impairment or healthy controls. No difference was found between pwMS without cognitive impairment and healthy controls. 3 pwMS with and 3 without cognitive impairment had one or more violation, and 4 healthy controls, which is a non-significant difference.
Schultheis (2009). Driving behaviors among community-dwelling persons with Multiple sclerosis. *Archives of Physical Medicine and Rehabilitation* (Schultheis et al., 2009).	To examine driver behaviours and pattern among drivers with multiple sclerosis as a function of disease severity.	66 pwMS (with low (EDSS: 1.5–3.0, moderate (EDSS: 3.0–5.0) an high (EDSS: 5.5–6.5) levels of disability and 30 education and sex-matched healthy controls *pwMS* Age: *M* = 43.2 (*SD* = 8.07) Gender: 78.8% female Education in years: *M* = 15.3 (*SD* = 2.07) Driving experience: *M* = 24.8 (*SD* = 7.56) *Healthy controls* Age: *M* = 37.3 (*SD* = 10.33) Gender: 63.3% female	**Type of MS (%):** RRMS: 86.4 SPMS: 7.6 PPSM: 3 Unknown: 3 **Disease duration in years:** *M* = 8.88 (*SD* = 6.43) **EDSS:** *M* = 3.42 (*range:* 1.5 – 6.5)	**Driving behaviours:** Self-reported driving behaviours: DBQ (frequency, ability, limitation, bad weather, heavy traffic, at night, highway) **Driving performance:** Behind-the-Wheel assessment	PwMS had more driving experience. PwMS drove fewer days per week compared to healthy controls, but no other differences were found. A higher EDSS score predicted less days per week driving and less miles driven per week. In the low disability group, work was reported as primary reason to drive, followed by errands and leisure. In de moderate and high disability group, errands were the primary reason to drive, followed by work and leisure. Medical appointments were not reported as a reason to drive in the low and moderate

Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
					disability group, but was reported in 7% of the high disability group. The moderate disability group reported to implement the most self-limiting behaviours, in comparison to the low and high group. In overall driving behaviour, pwMS with high disability reported the most changes, followed by the moderate and low disability groups. All pwMS in the low disability group passed the BTW assessment, 22.5% changed their driving behaviour. Only 50% of the pwMS with high disability passed the BTW assessment, while 45.8% changed their driving behaviour.
Schultheis (2010). Examining the relationship between cognition and driving performance in multiple sclerosis. *Archives of Physical Medicine and Rehabilitation* (M. Schultheis et al., 2010).	To identify cognitive predictors of driving performance after multiple sclerosis.	66 pwMS **Age:** *M* = 43.24 (*SD* = 8.07) **Gender:** 78.8% female **Education in years:** *M* = 15.29 (*SD* = 2.07) **Number of years driving:** *M* = 24.77 (*SD* = 7.56) **Days per week driving:** 2–3: 9% 4–5: 23% 6–7: 68% **Frequency of driving since diagnosis:** Same: 60% Less: 34% More: 6%	**Type of MS (%):** RRMS: 86 SPMS: 8 PPSM: 3 Unknown: 3 **Disease duration in years:** *M* = 9.07 (*SD* = 6.44) **EDSS:** *M* = 3.41 (*range:* 1.5 – 6.5)	**Driving:** Clinical Behind-the-wheel assessment (BTW: Initial movement, Turning/tracking, speed control, road law, lane use) Collision and violation involvement in past 5 years. **Cognition:** Executive functioning (TMT B), Information processing (SDMT, PASAT), Visual perception (MVPT-R), Language (Wechsler vocabulary subtest), Verbal learning memory (CVLT-II), Visuospatial learning and recall (V-SMART 7/14)	52 pwMS passed the BTW and 12 failed the BTW. The SDMT (information processing) predicted driving performance, but not the other neuropsychological tests scores. PwMS who failed performed poorer on the SDMT than the pwMS who did pass the test. PwMS who failed the test had a higher EDSS (*M* = 5.5 (*SD* = 0.98)) (greater impairment) than pwMS who passed the test (*M* = 3.0 (*SD* = 1.5)).
Schultheis (2010). Vision and driving in multiple sclerosis. *Archives of Physical Medicine and Rehabilitation* (M. Schultheis et al., 2010).	To examine the relationship between measures of visual dysfunction and driving performance in pwMS.	26 pwMS with visual difficulty, 40 pwMS without visual difficulty and 26 age- and sex-matched healthy controls *pwMS with visual difficulty* **Age:** *M* = 43.23 (*SD* = 8.85) **Gender:** 81% female **Number of years driving:** *M* = 24.88 (*SD* = 8.76) *pwMS without visual difficulty* **Age:** *M* = 43.25 (*SD* = 7.64) **Gender:** 74% female **Number of years driving:** *M* = 24.70 (*SD* = 6.77) *Healthy controls* **Age:** *M* = 38.42 (*SD* = 9.70) **Gender:** 63% female **Number of years driving:** *M* = 18.65 (*SD* = 8.76)	*pwMS with visual difficulty* **Disease duration in years:** *M* = 13.36 (*SD* = 8.40) **EDSS:** *M* = 3.34 (*range:* 1.5 – 6.5) **Type of MS:** N/A **Vision:** Acuity: (20/20): 35% Depth perception: : *M* = 4.04 (*SD* = 0.52) Colour perception (normal): 17% *pwMS without visual difficulty* **Disease duration in years:** *M* = 14.22 (*SD* = 9.59) **EDSS:** *M* = 3.46 (*range:* 1.5 – 6.5) **Type of MS:** N/A	**Driving:** Incidence of MVC's and motor vehicle violations in the past 5 years. **Vision:** Visual acuity, depth perception, colour perception.	No difference between the documented accidents and violations was found between the three groups. No relationship with visual acuity, depth perception and colour perceptions with the incidence of crashes and violations were found.

Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
Shawaryn (2002). Assessing Functional Status: Exploring the relationship between the multiple sclerosis functional composite and driving. *Archives of Physical Medicine and Rehabilitation* (Shawaryn et al., 2002).	To explore the relationship between the MSFC and driving performance.	29 pwMS **Age:** *M* = 43.3 (*SEM* = 1.6) **Gender:** 58.6% female **Education in years:** *M* = 15.9 (*SD* = 1.6).	**Vision:** Acuity: (20/20): 63% Depth perception: : *M* = 4.81 (*SD* = 0.44) Colour perception (normal): 48% **Type of MS (%):** RRMS: 48 SPMS: 7 Unknown: 45 **Disease duration in years:** *M* = 9.7 (*SEM* = 1.4) **EDSS:** N/A	**Driving-related variables:** Number of years driving, average number of day per week driving, change in driving after MS diagnosis, self-reported vehicle crashes. Registered motor vehicle crashes and violations, accidents post-MS diagnosis **Driving measures:** UFOV, NDT **Multiple Sclerosis Functional Composite:** TWT (leg and arm ambulation), hand function (9HPT), cognitive function (PASAT).	The overall MSFC score correlated with the UFOV score, and also with the visual-information processing UFOV and the selective attention UFOV. Selective attention of UFOV correlated with the overall MSFC, and the hand and arm ambulation and cognitive function. In addition, cognitive functioning correlated with all the UFOV measures. Of the NDT, only latency correlated with the MSFC, the overall score, hand ambulation and cognitive function. Years of driving, registered violations and self-reported crashes did not correlate with the MSFC, but days driving per week correlated with all of the composites. Registered crashed did correlate with MSFC, but only the overall score. Also years of education correlated with the overall UFOV score and the selective attention of UFOV.
Simmons (2010). Living with multiple sclerosis: longitudinal changes in employment and the importance of symptom management. *Journal of Neurology* (Simmons et al., 2010).	To describe reasons by which employment had been lost or was perceived at risk of being lost.	1135 pwMS in 2003 and 1329 pwMS in 2007 *pwMS 2003* **Age (n):** <35: 106 34–44: 243 45–54: 366 55–64: 294 >65: 105 10 unknown **Gender:** 79% female *pwMS 2007* **Age (n):** <35: 101 34–44: 145 45–54: 405 55–64: 399 >65: 170 10 unknown **Gender:** 78% female	**Type of MS:**N/A **Disease duration in years:** N/A **EDSS:** N/A **Physician-reported disability level in 2003 (%):** Functionally normal: 19.8 Mild disability: 26.2 Abnormal gait: 17.1 Early cane: 9.6 Late cane: 5.4 Bilateral support: 9.9 Wheelchair bound: 11.0 Unclassifiable: 1.0	Self-reported reasons people left employment.	For 17.0% of pwMS in 2003 and for 13.6% in 2007, 'unable to get to or from work' was the reason to leave their jobs. 5.4% of pwMS in 2003 and 5.0% of pwMS in 2007 was unable to find appropriate parking and therefore left their jobs. Also barriers of the workplace itself were mentioned: architectural barriers (17.5% in 2003 and 17.4% in 2007), general area accessibility (6.7% in 2003 and 4.5% in 2007), inaccessible bathroom (3.4% in 2003 and 3.9% in 2007) and inaccessible tearoom (2.9% in 2003 and 2007).
Stueckle (2005). Assessment of driving performance in patients with relapsing remitting multiple sclerosis by a driving simulator. *European Neurology* (Stueckle et al., 2005).	To compare the driving performance with physical and cognitive functions.	31 pwRRMS **Age:** *M* = 35.6 (*SD* = 8.3) **Gender:** 58% female	**Type of MS:** RRMS **Disease duration in years:** *M* = 5.2 (*SD* = 4.6) **EDSS:** *M* = 2.8 (*SD* = 1.4) **On medication:** 48%	**Driving** C.A.R (Number of accidents, no. of concentration faults) **Cognitive functioning:** MSFC (Timed 25-ft Walk, 9HTP, PASAT)	Patients and controls drove the same distance in 60 min. PwMS had more accidents and more concentration faults than controls. Level of disability (EDSS) was not related to accidents or concentration faults. Accident rate was only correlated with the cognitive domain of the MSFC.

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Table 2 (*continued*)

First author (year of publication). Title. *Journal* (ref)	Aim	Study population	Disease characteristics	Outcome measures	Main Findings
Vrkljan (2013). Evaluating medically at-risk drivers: a survey of assessment practices in Canada. *Canadian Journal of Occupational Therapy* (Vrkljan et al., 2013).	To examine actual practices being used to assess fitness to drive at driver assessment centre in Canada.	47 driving assessors **Age:** N/A **Gender:** N/A	–	Survey on: assessor background, caseload, sources of referral for medical FTD, clientele profile, intake process, off- and on-road assessment protocols, debriefing, documenting and reporting.	Cognitive decline had a greater impact on accidents than physical impairment. 7.5% of the caseload of the assessment centres were MS diagnoses.

Note: 9HPT = 9 Hole Peg Test; AMIPB = Adult Memory and Information Processing Battery; BDI = Beck Depression Inventory; BDQ = Brief Disability Questionnaire; BTW = Behind the Wheel; BVMT-R = Brief Visual Spatial Memory Test revised; CAR = Computer Aided Risk simulator; CMOP = Canadian Model of Occupational Performance; COWAT = Controlled oral word association test; CVLT = California Verbal Learning Test; DA = Divided attention; DBQ = Driver Behaviour Questionnaire; DC = Dot Cancellation; DKEFS = Delis-Kaplan Executive Function System; EDSS = Expanded Disability Status Scale; ESS = Environmental Status Scale; FTD = Fitness to Drive; HADS = Hospital Anxiety and Depression Scale; HVLT-R = Hopkins Verbal Learning Test Revised; IRES = Indicators or Rehabilitation status; JLO = Judgement of Line Orientation; LP = Lateral Position; MACFIMS = Minimal assessment of cognitive function in multiple sclerosis; MAS = Motivational Assessment Scale; MMSE = Mini Mental State Examination; MVC = Motor Vehicle Crashes; MFIS = Modified Fatigue Impact Scale; MSFC = Multiple sclerosis Functional Composite; MVPT-R = Motor-free Visual perception test –revised; NDT = Neurocognitive driving Test; NRS = Numeric Rating Scale; PALS = Participation and Activity Limitation Survey; PASAT = Paced auditory serial addition test; PDQ = Perceived Deficits Questionnaire; PIADS = Psychosocial Impact of Assistive devices scale; PPMS = Primary Progressive Multiple Sclerosis; pwMS = persons with multiple sclerosis; pwRRMS = persons with relapsing remitting multiple sclerosis; PWC = Powered wheelchair; RA = Risk assessment; RAVLT = Rey Auditory Verbal Learning Test; RBANS = Repeatable battery for the assessment of neuropsychological status; ROCF = Rey-Osterrieth Complex Figure; RRMS = Relapsing Remitting Multiple Sclerosis; RSR = Road Sign Recognition; SA = Selected Attention; SDLP = Standard Deviation of Lateral Position; SDMT = Symbol Digit Modalities Test; SDS = Standard Deviation of fixed-goal Speed; SDSA = The Stroke Drivers Screening Assessment; SF-36 = Short Form-36; SLOP = Single loop over propulsion; SMC = Square Matrix Compass; SMD = Square Matrix Direction; SOP = Speed of Processing; SPMS = Secondary Progressive Multiple Sclerosis; STAI = State-Trait Anxiety Inventory; TAP = Test of Attentional Performances; TMT = Trail Making Test; TRIP = Test Drive for Investigating Practical fitness to drive; TWT = Timed 25Foot Walk Test; UFOV = Useful Field of View; UWO = University of Western Ohio; V-SMART: Visual-Spatial Memory and Recall Test; WAIS-R = Wechsler Adult Intelligence Scale-Revised.

however, less speed regulation errors than healthy older adults and crossed the adjoining lanes less often while making a turn. When pwMS were compared with healthy controls in different Virtual Reality-driving situations, pwMS performed worse on the driving tasks during the simple driving and dual task driving conditions, but not during the complex driving condition (Harand et al., 2018).

3.2.1. Compensatory driving behaviour

MS symptoms may cause driving difficulties. In a study by Ryan and colleagues, 30% of pwMS reported that they drove less often since their diagnosis and more than half of the pwMS temporarily stopped driving after diagnosis (Ryan et al., 2009; Chipchase et al., 2003). In terms of Michon's model of driving (Michon, 1985) pwMS may compensate for impairments on the operational level by compensation on a tactical and strategic level. On the tactical level, pwMS may decrease their driving speed (Chipchase et al., 2003), while on the tactical level pwMS may drive only when the weather conditions are favourable, drive shorter distances, drive for a shorter duration, take more breaks or change drivers more often, compared to healthy adults (Chipchase et al., 2003). A fifth of pwMS reported to have made adaptations to their car when symptoms increased (Neven et al., 2013; Schultheis et al., 2009).

For some pwMS however, compensating does not suffice. In that case, MS can result in the decision to stop driving altogether. In a large prevalence study, 29.8% of pwMS ceased driving altogether (Gilmour et al., 2018). This decision was mostly made by pwMS themselves (44.4%). In other cases, the decision is made for them, for example due to legal issues or by physicians (Ryan et al., 2009). This may however not be an appropriate measure, as fitness to drive may both be overestimated and underestimated by physicians (Ranchet et al., 2015). A study that examined the implications of the decision to stop driving on daily life showed that most of the older drivers with MS who had ceased driving engaged in fewer outdoor activities than those who were still driving (Finlayson and van Denend, 2003).

3.2.2. Fitness to drive

Six studies assessing fitness to drive of pwMS by means of an on-road driving test showed pass rates of 78%–84% (Classen et al., 2018; Akinwuntan et al., 2014; Krasniuk et al., 2017; Morrow et al., 2018; Schultheis et al., 2010; Akinwuntan et al., 2018). However, one study (Ranchet et al., 2015) found a pass rate of 94%, while another study similar in design found a lower pass rate of 62% (Lincoln and Radford, 2008). When a driving simulator was used to assess fitness to drive, 48% of the pwMS passed a driving test (Lamargue-Hamel et al., 2015).

The relationship between disease course and severity of MS was assessed in ten studies (Chipchase et al., 2003; Schultheis et al., 2009; Akinwuntan et al., 2014; Krasniuk et al., 2017; Morrow et al., 2018; Schultheis et al., 2010; Akinwuntan et al., 20122013; Classen et al., 2017; Shawaryn et al., 2002). Firstly, pwMS with a higher EDSS score more often failed the driving test than pwMS with a lower EDSS score and applied more compensatory driving behaviours (Chipchase et al., 2003; Schultheis et al., 2009; Akinwuntan et al., 2014; Schultheis et al., 2010). Two studies (Krasniuk et al., 2017; Classen et al., 2017) found that type of MS rather than EDSS score could differentiate between those pwMS who failed and those who passed a driving test. These studies showed that individuals with SPMS failed more often than individuals with RRMS or PPMS. The four remaining studies (Morrow et al., 2018; Akinwuntan et al., 20122013; Shawaryn et al., 2002) did not find any relation between driving and disease course or severity of MS.

Besides disease course and severity of MS, cognition plays an important role in the fitness to drive of pwMS and may have a greater impact on fitness to drive than physical impairments (Stueckle et al., 2005). Decreased speed of processing was often negatively associated with fitness to drive (Dehning et al., 2014; Morrow et al., 2018;

Schultheis et al., 2010; Lincoln and Radford, 2008; Akinwuntan et al., 20122013; Shawaryn et al., 2002; Schultheis et al., 2001). Another important cognitive domain that was found to determine fitness to drive was attention (Harand et al., 2018; Akinwuntan et al., 2018; Lincoln and Radford, 2008; Akinwuntan et al., 20122013; Shawaryn et al., 2002). PwMS who failed the driving test performed worse on tests that measured divided attention, selective attention and vigilance as compared to pwMS who passed the test. These findings are in line with two studies (Badenes et al., 2014; Devos et al., 2023) that compared driving and driving related skills between pwMS and healthy controls. Both studies found that pwMS performed worse than healthy controls on tasks measuring driving related divided attention, selective attention and vigilance. Two additional studies found that visuospatial skills were positively related to driving performance in pwMS (Morrow et al., 2018; Devos et al., 2017).

Visual functioning also may affect fitness to drive. When pwMS were asked what factors might affect their fitness to drive, visual problems were reported as one of the most important factors, among fatigue and numbness (Chipchase et al., 2003). Several studies (Schultheis et al., 2010; Classen et al., 2018; Ranchet et al., 2015; Akinwuntan et al., 2013; Devos et al., 20232017) assessed visual functioning of pwMS in relation to car driving. Peripheral vertical visual field, stereopsis and binocular near acuity, but not binocular distance acuity correlated positively with the outcome of an on-road driving test (Devos et al., 2017). Other studies found that binocular acuity (Ranchet et al., 2015) and blue-purple colour vision (Akinwuntan et al., 2013) could discriminate between participants who passed and failed a driving test. However, in other studies (Classen et al., 2018; Akinwuntan et al., 2013; Devos et al., 20232017) tests for contrast sensitivity, depth perception, and colour vision did not discriminate between being fit or unfit to drive. The different outcomes of these studies could possibly be explained by different levels of visual functioning of the participants. Two of these studies (Classen et al., 2018; Akinwuntan et al., 2013), for example, only included individuals who fell within the legal visual requirements for driving and therefore had relatively intact visual functioning.

Other characteristics of pwMS have also been related to the fitness to drive. These studies revealed that males with MS more often pass a driving test than females (Lincoln and Radford, 2008) and that lower education was associated with a greater chance of failing a driving test or failing such a test with more violations (Krasniuk et al., 2017; Devos et al., 2017). Furthermore, in one study it was observed that education was positively associated with driving related attention (Shawaryn et al., 2002).

3.3. Wheelchair use

The literature describes several reasons for acquiring a wheelchair or powered wheelchair for pwMS. The possibility of more independence, freedom, access to outside events and increased participation were the most important prospects of acquiring a wheelchair according to two small studies (Devitt et al., 2004; Boss and Finlayson, 2006). Other reasons described in these studies were increased sitting tolerance, decreased anxiety, pain relieve and decreased self-consciousness. Despite these important prospects, recognizing the need for a wheelchair or powered wheelchair was challenging for some pwMS and a lack of choice whether to acquire a wheelchair or not was experienced (Boss and Finlayson, 2006). However, even if pwMS did recognize that acquiring a wheelchair could be necessary and might increase quality of life, being dependent on using a wheelchair also might have detrimental effects on quality of life (Finlayson and van Denend, 2003; Boss and Finlayson, 2006; Iezzoni et al., 2010; Learmonth et al., 2015), mostly due to poorly accessible environments or lack of access, for example to public transport (Roessler et al., 2013) or to work environments (Simmons et al., 2010). Moreover, more planning and organizing was needed for transportation when using a

wheelchair (Boss and Finlayson, 2006; Learmonth et al., 2015).

Compared to the general population, pwMS made significantly more use of a manual or powered wheelchair or a mobility scooter (Patten et al., 2012). In a telephone survey by Iezzoni and colleagues (Iezzoni et al., 2010; Iezzoni et al., 2009) 703 pwMS were asked about their mobility aids. More than half of pwMS used one or more mobility aids (62%). Of these patients, 64% used a manual wheelchair, 36% a powered wheelchair, and 30% a mobility scooter. Dolan and colleagues (Dolan et al., 2019) found a larger percentage (66.4%) of pwMS using a powered wheelchair in a file examination study of 112 pwMS. Patients with poorer overall health, SPMS, longer disease duration, patients who do not work full-time and older pwMS were more likely to be using a wheelchair (Iezzoni et al., 2010; Christensen and Clausen, 1977; Klewer et al., 2001). In two studies with only older pwMS, 38% – 70% were using a wheelchair (Klewer et al., 2001; Finlayson et al., 2014).

Wheelchairs are not always optimally operated by pwMS. Maintaining speed in a wheelchair may be difficult for pwMS, who sometimes not even reach walking speed of healthy adults (Fay et al., 2004). A study regarding the dynamics of pushing a manual wheelchair forward showed that pwMS used a less efficient pattern of pushing, compared to healthy controls and compared to individuals with spinal cord injury. Only 5% of the pwMS examined used the most efficient strategy of pushing the wheelchair forward.

For some patients, an alternative to for example an electrically powered wheelchair or mobility scooter might be the Segway (Segway Inc), a two-wheeled, self-balancing scooter. One study among a wide range of disabilities, that included 6 pwMS (disease duration 6–8 years; no other disease characteristics reported), showed that all patients were able to use the Segway (Sawatzky et al., 2007).

3.4. Public transportation

In five studies, the ability to make use of public transportation was evaluated. In three studies pwMS were asked whether they were able to make use of public transport and/or to drive a car and 16% to 43% of pwMS were not able to do so (Klewer et al., 2001; McDonnell and Hawkins, 2001; Einarsson et al., 2006). In a survey by Roessler et al. (2013), some respondents were positive about the accessibility of the public transport in the United States, but others indicated that public transport was not always accessible for persons in a wheelchair, or that bus stops or stations were too far away. Neven et al. (2013) found that only pwMS with a moderate disability (in this case a mean EDSS of 5.6) used public transport, which could indicate that persons with severe disability were not able to make use of public transport.

4. Discussion

To our knowledge, this is the first systematic review that provides an overview of the literature on several types of independent outdoor mobility of pwMS. We aimed to identify which specific factors may influence outdoor mobility and how the lives of pwMS may be affected by a reduced mobility. As there was already extensive knowledge about the effects of MS on gait and the ability to walk (including recent reviews), walking was not included.

The present review showed that MS in general has a detrimental effect on independent outdoor mobility; pwMS often are bound to using some kind of wheelchair. Using a wheelchair may have positive effects on outdoor mobility in some pwMS, but also brings its own challenges, such as inaccessibility of buildings, and decreased independence. In addition to that, pwMS may push a wheelchair forward less efficiently. Making use of public transport also implicates difficulties for pwMS. Moreover, fitness to drive of pwMS may be reduced. Some pwMS manage to adapt the driving behaviours in order to maintain fitness to drive, others may eventually be forced to stop driving.

Some factors were found to be related to the mobility of pwMS. PwMS with SPMS, pwMS with overall poorer health, and pwMS who do not work full-time were more likely to be dependent on using a wheelchair. However, no clear conclusion can be drawn as the majority of studies on wheelchair use and general mobility did not report disease or patient characteristics, nor any information on cognitive functioning. While decreased fitness to drive was related to SPMS and with physical disability, cognitive functioning seemed to have a greater impact on fitness to drive. Especially speed of processing and visual attention were key determinants. Although in the literature the results on the relationship between visual functioning and fitness to drive varied across studies, the review provided indications that impaired visual functioning impairs fitness to drive of pwMS. Visual acuity, visual field and visual attention appeared to be important functions to maintain fitness to drive. This is in line with other studies investigating the relationship between visual function and fitness to drive in other neurological conditions (Yale et al., 2003). Additionally, the studies in which no relationship was found between fitness to drive and visual functioning only included pwMS or controls who already had sufficient visual functioning to be allowed to drive. In contrast to studies using driving simulators, studies examining on-road driving performance required participants to be still driving regularly in their daily lives and having relatively intact visual functioning. This may not always be the case in pwMS (e.g. when driving is primarily taken over by the patient's partner). Indeed, in the reported studies, the pass rates of pwMS in on-road driving tests were higher than the pass rates in driving simulators, which had less stringent inclusion criteria for participation in the study. These inclusion criteria may include important factors in determining fitness to drive, such as cognitive functioning, visual functioning and overall disability and should be examined in relation to fitness to drive.

The reduced independent mobility may have a negative effect on the social and work lives of pwMS. Although the use of a wheelchair or mobility scooter can facilitate outdoor mobility on the one hand, it may also decrease overall mobility, since transportation over longer distances requires more planning and accessibility of vehicles (for public transport) or buildings may not be guaranteed. PwMS may therefore less often leave the house, less often join social events, or have difficulties to reach their work environments.

It is therefore surprising that very few studies on interventions or rehabilitation options for pwMS to improve mobility were found in the literature, especially since rehabilitation is essential in managing an incurable and progressive disease. Moreover, when impairment and disabilities become more severe, rehabilitation shows to be more effective in improving participation than symptom treatment (Freeman, 2001). We would therefore firstly advise to conduct more research on interventions and rehabilitations aimed at the improvement of mobility in pwMS. With regard to improving fitness to drive, cognitive and perceptual difficulties should be taking into account. Including cognitive training in a driving training has shown to be more effective than driving training alone in older drivers and in patients with neurological disabilities other than MS (Hay et al., 2016; Klonoff et al., 2010; Ross et al., 2018). Regarding interventions to improve wheelchair use, one could consider focussing on improving pushing the wheelchair forward, as it was found that this may be difficult for pwMS and to make use of electronically powered wheels. It would also be advised to look for alternative routes or destinations that are more accessible for wheelchairs, or practice moving around in a wheelchair, possibly under supervision of an occupational therapist specialized in wheelchair use (Smith et al., 2019). Earlier research has shown that these kind of interventions are beneficial in a general clinical population (Tu et al., 2017) and individuals with spinal cord injury (Best et al., 2017). In addition, for elderly people and people with neurological conditions such as stroke, spinal cord injury and traumatic brain injury, but not MS, an evidence based set of guidelines and recommendations was developed for maintaining wheelchair mobility (Requejo et al., 2015). These set of guidelines might also be used or adapted for pwMS. Besides this, while ample research has been done on the effects of pharmacological therapies on the ability to walk

([Baird et al., 2018](#)), no studies investigated effects of these therapies on other kinds of mobility. To be able to tailor interventions to improve or maintain mobility, we also recommend to include pwMS with a broader range of disease duration, disability level, as well as patients with different types of MS, as most of the studies only considered a part of the pwMS group. For example, most studies concerning driving only included pwMS with RRMS and a relatively low disability level, while studies on wheelchair use only included pwMS with higher disability levels and longer disease duration. Findings can therefore only be generalized to certain groups, but not be applied to the entire population of pwMS. In addition, by systematically reporting disease characteristics in publications, further risk factors for mobility loss could be identified, allowing a more specific design of treatment approaches (e.g. rehabilitation). Performing longitudinal studies on the mobility of pwMS could also contribute to this. Knowledge about the long-term development of patients' needs regarding mobility may be of significant use for pwMS and their caretakers, as such knowledge may improve estimation of the patients' future needs, in order to better prepare and to initiate steps of support in time.

Furthermore, no other mobility options than driving, wheelchair use and public transport were described in het literature. For example, despite including cycling related search terms, no studies were found examining outdoor cycling as a way of transportation for pwMS. Especially for shorter distances or smaller errands, the use of a bicycle, E-bike, tricycle or a balance bike could provide an additional option. Furthermore, other slow motorised vehicles could help to improve mobility and to facilitate independence. Studies on these types or mobility have yet to be performed.

5. Conclusions

A systematic review of 57 publications showed that MS has a detrimental effect on mobility. Physical disability, but especially impaired cognitive functioning and impaired visual functioning affect mobility. Driving, the use of wheelchairs and public transport may all—in their own way—cause problems for pwMS which may lead to a decrease in quality of life. As it is highly important to maintain mobility in order to participate in society, more research is needed to advise pwMS or professionals who are aiming to improve mobility, by means of an evidence based guideline. Moreover, it is advised to scientifically explore other mobility options, such as tricycles, e-bikes or other slow motorised or electrically powered vehicles.

Declaration of Competing Interest

None.

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