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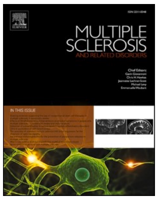

Spatial navigation performance in people with multiple sclerosis-a large-scale online study

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ABSTRACT

Objective: Spatial navigation has a crucial function in daily life activities, and is therefore strongly linked to quality of life, autonomy, and mobility. Navigation has been shown to be frequently impaired after forms of acquired brain injury, but the impact of MS on navigation ability has yet to be studied. A better understanding of potential navigation problems in this population could improve patient care. Therefore the aim of the current study was to measure objective and subjective navigation performance in people with MS.
Methods: Performance of a large sample of people with MS ($N = 359$) was compared to a group of matched controls. Additionally, the impact of ambulation and self-reported cognitive performance was studied within the MS sample. Participants filled out the Wayfinding Questionnaire, the patient-reported Expanded Disability Status Scale and the Multiple Sclerosis Neuropsychological Screening Questionnaire for self-report measures. Objective navigation performance was measured with an online navigation test using a virtual environment.
Results: Results indicate a lower subjective as well as objective performance in people with MS compared to healthy controls, and a substantial contribution of self-reported cognitive performance on navigation ability.
Conclusions: These findings indicate that spatial navigation can be a significant problem in people with MS, especially in people with MS with other cognitive impairments.

1. Introduction

Multiple sclerosis (MS) is a progressive disease of the central nervous system characterized by white matter lesions, axonal damage, and cerebral atrophy (Huijbregts et al., 2006). It is estimated that 2.3 million people around the world live with MS, with the average age at diagnosis being 30 years (Multiple Sclerosis International Federation, 2013). MS is manifested with a variety of sensory, motor, and cognitive symptoms and the course of the disease can follow different trajectories (Compston and Coles, 2002). Many aspects of the MS etiology and symptomatology have been under the scope of scientists; however, the cognitive ability of spatial navigation has not yet been explored in this clinical population, while there are some indications this cognitive ability may be of particular interest.

Cognitive impairment affects 40 to 65 percent of people with MS and has a negative impact on their life quality and employment (Amato et al., 2006; Goverover et al., 2007; Campbell et al., 2017). The main cognitive domains affected are processing speed, memory, attention, conceptual reasoning, and visual perception with the deficits being more prevalent for the first two domains (Grzegorski and Losy, 2017; Calabrese, 2006). Visuospatial impairments have been reported (Rao et al., 1991; Benedict et al., 2004), but these studies mostly focused on visuospatial processing and memory.

In the current study, we specifically examined spatial navigation. This visuospatial function is of particular relevance to daily life activities. Spatial navigation supports all activities in which movement from one place to another takes place, e.g. going to work, grocery shopping, and taking part in social events. A number of studies have shown that navigation impairment is a prominent phenomenon in people with acquired brain injury (ABI) (e.g. Rosenbaum et al. 2000; Barrash et al., 2000; Skelton et al., 2006; Claessen et al., 2016). Not only do they show lower levels of navigation performance, but also lower levels of autonomy, quality of life, and mobility (van der Ham et al., 2013). People with MS form a specific subgroup of people with ABI, with symptoms affecting locomotion. Yet, to our knowledge, navigation ability has never been specifically assessed in people with MS. Given the importance for daily life activities, the role of locomotion, and the lack of literature on this topic, we assessed navigation performance in a large

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sample of people with MS.

Neuropsychological assessment of navigation ability has not yet been formally standardized. Two main causes can be identified for this: neuropsychological assessment typically takes place within a small examination room, with table top assessment, and navigation ability is a complex cognitive function that requires several subtasks to reach proper assessment of navigation performance. The practical limitations can be overcome with digital tools, making use of virtual environments and digital navigation (e.g. Claessen et al. 2016). The complexity of navigation impairment in neuropsychological patients has first been systematically addressed by Aguirre and D'Esposito (1999) and has recently been updated by Claessen and van der Ham (2017). Based on existing patient reports, it is shown that navigation impairment can be found in three domains: landmark knowledge, location knowledge, and path knowledge (Claessen and van der Ham, 2017; Claessen et al., 2016). Landmark knowledge refers to recognition of distinct features in an environment, such as specific buildings (e.g. Montello, 1998). Location knowledge concerns specific points in space, either relative to the observer (egocentric), when pointing to a specific landmark, or relative to the environment itself (allocentric), such as the location of a landmark on a map (e.g. Klatzky, 1998). Lastly, path knowledge concerns the information about how to reach a specific location. This can be achieved with route knowledge; a sequence of turns and landmarks (Wolbers et al., 2004), or with survey knowledge, using a mental representation of the environment, from a bird's eye view (Gluck and Fitting, 2003).

The aim of the study was to examine how prominent navigation impairment is in a large, representative sample of people with MS. We were able to compare the people with MS to healthy controls, with our existing dataset of a large scale population study on navigation ability in the Netherlands (van der Ham et al., 2020). Both subjective and objective measures of navigation ability were included. Given the findings for ABI in general, a lower score for both subjective and objective navigation measures in comparison to healthy controls is expected for the

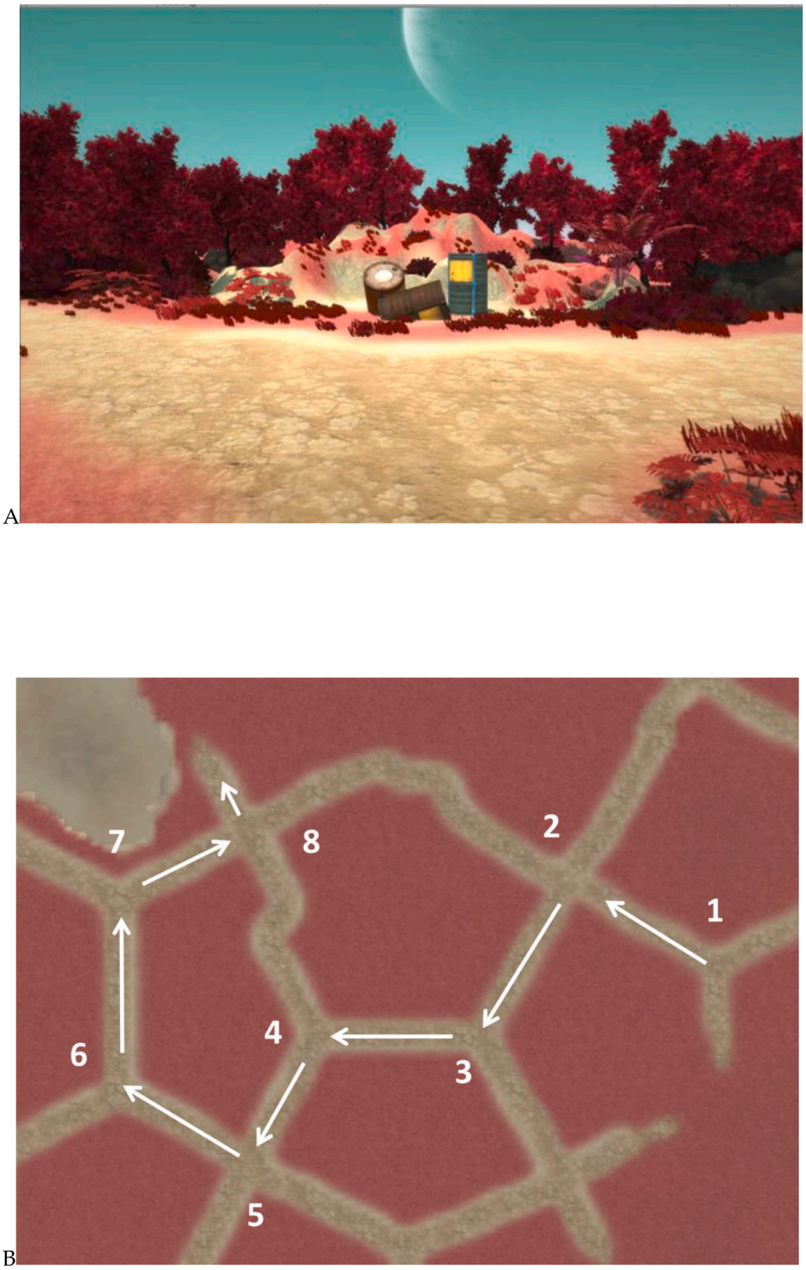

Fig. 1. (A) Example image taken from the route used, depicting one of the landmarks (B) Map of the route used in the experiment.

people with MS. Additionally, the role of physical mobility, in terms of ambulation was considered. Locomotion has been shown to contribute to aspects of navigation ability (Klatzky et al., 1998; Rey and Alcañiz, 2010; Chrastil and Warren, 2013), especially when a mental representation of an environment is needed to solve a task. Literature suggests that physical engagement with the environment in the form of active locomotion strengthens the quality of the mental map that is created, due to additional sensory input concerning metric properties of the environment, such as angles and distances (e.g. van der Ham et al. 2015). Therefore, lower performance is expected for people with MS with a lower level of ambulation, in comparison to people with MS with relatively intact ambulation. As cognitive performance varies substantially between people with MS (Chiaravalloti and DeLuca, 2008), the relationship between navigation ability and self-reported cognitive performance was also considered, to provide a more detailed description of the correlates of navigation performance. It is expected that lower cognitive performance in general is also reflected in navigation performance specifically Fig. 1.

2. Methods

2.1. Participants

359 individuals with MS completed the experiment and their data were compared to data of 359 healthy control participants (HC), taken from an existing dataset using propensity score matching (van der Ham et al., 2020). The propensity score matching procedure was performed using a plugin for IBM SPSS Statistics (Thoemmes, 2012). A propensity score was calculated for the variables age, gender and education, as these factors are known to affect navigation performance. The propensity scores of healthy participants and people with MS were matched using a 1-to-1 nearest neighbor matching algorithm without replacement. To limit inaccurate matching, a caliper with a width equal to 0.2 of the standard deviation of the logit of the propensity score was used (Austin, 2011b). The resulting matches were assessed for overall imbalance using Hansen and Bowers (2008) imbalance test and the relative multivariate imbalance L1 test (Iacus et al., 2009). The overall imbalance test was not significant, $\chi2(3) = .909$, $p = .823$, and the relative multivariate imbalance L1 test showed a reduction from 0.401 to 0.301. This procedure ensured the inclusion of a highly similar control participant for each patient with MS, based on gender, age, and education level. Consequently, there was no statistical difference between the MS and HC groups in these characteristics ($p > .10$, see Table 1). The sample characteristics are summarized in Table 1. The experiment was performed in accordance with the Declaration of Helsinki (2013) and ethical approval was obtained from the Leiden University Ethical Committee (CEP18-0305/129).

Table 1

Demographics for the patients with multiple sclerosis (MS) and the healthy controls (HC). Education level from 1 (low) to 7 (high) according to Verhage (1964). SD = standard deviation, CIS = clinically isolated syndrome, BMS = benign multiple sclerosis, RR = relapsing remitting, SP = secondary progressive, PP = primary progressive.

Variable		MS ($N = 359$)	HC ($N = 359$)
Age, *M (SD)*		50.8 (12.2)	50.6 (16.4)
Sex, Female, n (%)		295 (82.2)	300 (83.6)
Education level, *M (SD)*		5.6 (0.8)	5.7 (.8)
Disease duration in years, *M (SD)*		14.41 (9.82)	
MS Types, n (%)	*CIS*	4 (1.1)	
	BMS	35 (9.7)	
	RR	174 (48.5)	
	SP	104 (29.0)	
	PP	28 (7.8)	
	Unknown	14 (3.9)	

2.2. Measures

2.2.1. Subjective navigation complaints

The “Wayfinding Questionnaire” (WQ) (De Rooij et al., 2017; Claessen et al., 2016) was used to measure subjective navigation complaints. The WQ is a self-report screening tool of subjective complaints in spatial navigation. It consists of 22 questions in total and has three subscales. The “Navigation and Orientation” (NO) subscale consists of 11 questions, such as “I can always orient myself quickly and correctly when I am in an unknown environment”. The “Spatial Anxiety” (SA) subscale entails eight questions, such as “I am afraid of losing my way somewhere”. Finally, the “Distance Estimation” (DE) subscale consists of three questions, including “I am good at estimating distances (e.g., from myself to a building I can see)”. Responses for all questions are given in a Likert scale ranging from 1 (totally disagree) to 7 (totally agree). For NO and DE lower scores indicate more subjective navigation impairment. For SA higher scores reflect higher anxiety levels, related to spatial navigation.

2.2.2. Objective performance

An online navigation task (van der Ham et al., 2020) was used to measure five aspects of spatial navigation performance. A short video was shown (69 s) of a route through a forest-like, fictional environment. The route lead past eight distinguishable landmarks, with salient colors (oil drums, a shield, a crate, a boat, a car, a shipping container, a gemstone, and a buoy) placed at separate intersections. At the endpoint of the route, a spaceship was placed. The narrative used was that the participant had landed on an unknown planet and through the video would find their way to the space ship that could take them back home. Participants were instructed to memorize what they saw on the video, without specifying further details. The environment was created with Unity 3D software (version 2017.1.0f3), all models used as landmarks originated from the Unity asset store.

Five different tasks followed the video, assessing different aspects of navigation ability. In the *landmark task* eight pictures from the route were presented with the instruction to indicate whether or not this landmark was present in the video. Four of the pictures were present in the video and the other four were distractor items. Chance level performance in the landmark task was 50 percent (%). Two different sets of landmarks were randomly assigned to participants, ensuring all eight landmarks were used throughout all measurements. This task was always shown first due to the fact that it included distractor items, the order of the rest of the tasks was random. In the *location – egocentric task*, participants were shown a landmark and were asked which of the six provided options showed an arrow pointing in the direction of the spaceship, at the end of the route. Chance level performance in the location-egocentric task was 16.7%. The six arrows were presented in 3D and would be exactly 60 degrees different from one another, covering 360 degrees in total. A total of four trials were presented. The landmarks used were randomly selected for each participant.

For the *location-allocentric task*, participants were shown a landmark together with a map of the environment. Four possible locations were marked with the letters A, B, C, D and participants were asked to indicate at which of the four locations the landmark was positioned. Chance level performance in the location-allocentric task was 25 percent (%). Four trials were presented, one for each of four randomly selected landmarks. For the *path – route task* participants were asked to indicate in which direction the route continued for a given landmark. Depending on the landmark, two or three possible directions were provided; left, right, and straight ahead, mean chance level was 44% with a range of 37.5 to 50%. This was repeated for four randomly selected landmarks. Finally, the *path – survey task* consisted of three landmarks presented simultaneously, for which the two landmarks that were closest together should be selected, chance level for this task was 33.3%. It was indicated that this should be measured from a bird’s eye perspective, and thus relying on the mental representation of the environment a participant had made. This was repeated for four fixed sets of landmarks, presented in random order and positioning within each trial. The sum of correct answers was calculated for each task. On the landmark task, scores ranged from 0 (low performance) to 8 (high performance). For the location – egocentric, location – allocentric, path- route, and path survey tasks, scores ranged from 0 (low performance) to 4 (high performance).

2.2.3. Disease severity-physical disability

The Expanded Disability Status Scale (EDSS) (Kurtzke, 1983) was used to measure self-reported disease severity and physical disability. The EDSS questions were formulated based on the telephone questionnaire developed by Lechner-Scott and colleagues (2003). The telephone and internet-based equivalents of the EDSS are both considered valid tools, showing good agreement with physician-measured EDSS scores (Leddy et al., 2013; Lechner-Scott et al., 2003). The self–report version of the Kurtzke Expanded Disability Status Scale (EDSS) consisted of 11 questions. The outcome of the instrument is a total score on a scale that ranges from 0 (normal) to 10 (death). Participants who answered they can walk at least 200 meters without aid or rest with little to moderate effect on daily activities were categorized as being fully ambulatory. Participants who answered they were able to walk 100 meters or less without aid were categorized as having impaired ambulation.

2.2.4. Self-reported cognitive performance

The Multiple Sclerosis Neuropsychological Screening Questionnaire (MSNQ patient version; Sonder et al., 2012) was included to assess self-reported cognitive and neuropsychiatric functioning. In this questionnaire, the first 12 questions concern cognitive performance, and the remaining three items address neuropsychiatric functioning. Response options were 0 (no problems) to 4 (severe problems interfering with everyday life). A response of 2 or lower indicated that there was no interference with everyday life. Following Nauta et al. (2019), the cutoff point of $\geq$ 27 was used to distinguish between those with high self-reported cognitive performance ($<$ 27), and those with low self-reported cognitive performance ($>$ 26).

2.2.5. Visual impairment

Assessment of visual impairment was implemented by asking “Do you currently have problems with your eyesight, also with glasses or lenses?”. There were three response options: “No, no problems”, “Yes, some problems”, and “Yes, many problems”. This question was included due to the fact that vision impairment is a common symptom in MS and could influence performance on the navigation task. Participants that gave the answer “Yes, many problems” were excluded from the analyses.

2.3. Procedure

The study was made available through a web-based environment, set up with Qualtrics software and was promoted through the “Nationaal MS Fonds” (National MS Foundation, The Netherlands) and the “MS Vereniging Nederland’’ (Dutch MS Society). Participants started the experiment by providing informed consent, clicking the appropriate button on the opening screen, after reading the relevant information. Next, the demographic and descriptive questions were presented. Afterwards, the questionnaires were presented, which was followed by the online navigation task. A screen then appeared, indicating that the video would start when the participant clicked the ‘proceed’ button and warning them to be focused on the video and avoid any distractions during the experiment. The video could not be paused. Next, the five tasks were presented and the participant responded by using the mouse. After completion of the tasks the last questionnaire (WQ) was presented. All questions were presented in Dutch. The total duration of the study was around 30 min.

2.4. Statistical analyze

In order to test for differences in subjective navigation complaints between people with MS and HC, a one-way MANOVA with group (HC, MS) as independent variable and the mean scores on the three subscales (NO, SA, DE) of the WQ as the dependent variables, was conducted (Bonferroni corrected alpha: .05/3 = .017). The differences in objective navigation performance between MS and HC were assessed with a one-way MANOVA with group (HC, MS) as an independent variable and the scores on the five tasks (landmark, location - egocentric, location – allocentric, path- route, path - survey) of the online navigation task as dependent variables. Scores on the five tasks represent the total number of correct answers for each task (for details see “Objective Performance”) (Bonferroni corrected alpha: .05/5 = .010).

Next, the effect of ambulation ability on the objective navigation performance of people with MS was examined with one-way MANOVAs. The ambulation level (High, Low) as determined by the EDSS responses was the independent variable of the analysis. First, the analysis was performed with the subjective WQ scores (Bonferroni corrected alpha: .05/3 = .017). Next, the objective scores on the five tasks of the online navigation task were included (Bonferroni corrected alpha: .05/5 = .010). The same analyses were performed with self-reported cognitive performance (high, low), as determined by the MSNQ scores.

3. Results

The mean scores of both the HC and MS participants are provided in Table 2, for both the WQ subjective measures and the objective online test scores. The outcome of the MANOVA including participant group and the three WQ subscales is provided in Table 2. A significantly higher spatial anxiety score was found for the MS participants in comparison to HC (p = .001), and their score on distance estimation was lower at trend level, compared to HC scores (p = .023). For the objective measures a significant effect was found for landmark knowledge. HC performed significantly better than MS participants (p = .010).

Next, a more detailed analysis within the MS participants was performed, as shown in Table 3. Whether someone indicated high or low ambulation did not affect their scores on the WQ (all p’s $>$ .10). For objective performance, two strong trend level effects were found. Those with high ambulation outperformed low ambulation participants on allocentric location knowledge (p = .011) and path route knowledge (p = .013). As age differed significantly between the high and low ambulation groups F(1,357) = 64.21, $p < .001$, an additional MANCOVA was performed, using age as a covariate. This analysis indicated that the

Table 2
Performance of the patients with multiple sclerosis (MS) and the healthy controls (HC) and the MANOVA results. WQ = wayfinding questionnaire, NO = navigation and orientation, DE = distance estimation, SA = spatial anxiety. Standard deviation in parentheses.

Variable		MS (*N* = 359)	HC (*N* = 359)	*F*	*p*	ηp2
WQ	NO	4.38 (1.23)	4.51 (1.17)	2.11	.147	.003
	DE	3.78 (1.48)	4.02 (1.32)	5.17	*.023*	.007
	SA	3.65 (1.59)	3.26 (1.45)	11.80	**.001**	.016
Navigation tasks	Landmark	6.76 (1.07)	6.96 (0.99)	6.63	**.010**	.009
	Location - egocentric	1.24 (0.94)	1.29 (0.91)	0.42	.518	.001
	Location - allocentric	1.78 (1.05)	1.90 (1.11)	2.20	.139	.003
	Path - route	2.41 (1.01)	2.53 (0.92)	2.76	.097	.004
	Path - survey	2.23 (1.10)	2.32 (1.05)	1.31	.252	.002

Table 3
Performance of the high and low ambulation multiple sclerosis patients and the MANOVA results. WQ = wayfinding questionnaire, NO = navigation and orientation, DE = distance estimation, SA = spatial anxiety. Standard deviation in parentheses.

		Ambulation				
		High (*N* = 256)	Low (*N* = 103)	*F*	*p*	ηp2
Age, *M (SD)*		47.8 (12.0)	58.3 (9.3)			
Sex, Female, n (%)		215 (84.0)	80 (77.8)			
Education level, *M (SD)*		5.6 (0.8)	5.6 (0.8)			
WQ	NO	4.36 (1.26)	4.43 (1.17)	0.24	.623	.001
	DE	3.81 (1.52)	3.70 (1.39)	0.46	.500	.001
	SA	3.59 (1.64)	3.82 (1.46)	1.62	.204	.005
Navigation tasks	Landmark	6.79 (1.06)	6.70 (1.07)	0.48	.490	.001
	Location - egocentric	1.27 (0.96)	1.17 (0.88)	0.75	.388	.002
	Location - allocentric	1.87 (1.04)	1.55 (1.05)	6.60	*.011*	.018
	Path - route	2.50 (1.01)	2.20 (0.99)	6.21	*.013*	.017
	Path - survey	2.23 (1.08)	2.24 (1.17)	0.02	.900	.000

differences with regard to allocentric location knowledge and path route knowledge were no longer significant ($p > .010$ in both cases).

Lastly, we examined the impact of overall cognitive functioning, see Table 4. Based on their questionnaire responses, MS participants were subdivided based on self-reported cognitive performance. For the subjective WQ scores, the two groups differed significantly on all three subscales ($p < .001$ in all cases). The high cognitive performance group reported higher performance for navigation and orientation and for distance estimation, than the low cognitive performance group. Conversely, the high cognitive performance group reported a higher level of spatial anxiety, compared to the low cognitive performance group. With regard to the objective measures, clear trend level effects were found for path survey knowledge ($p = .011$), and landmark knowledge ($p = .037$). For both effects the high performance group outperformed the low performance group.

Table 4
Performance of the patients with multiple sclerosis (MS) reporting high or low cognitive performance, and the MANOVA results. WQ = wayfinding questionnaire, NO = navigation and orientation, DE = distance estimation, SA = spatial anxiety. Standard deviation in parentheses.

		Cognitive performance				
		High (*N* = 184)	Low (*N* = 175)	*F*	*p*	ηp2
Age, *M (SD)*		51.4 (13.0)	50.0 (11.1)			
Sex, Female, n (%)		145 (78.8)	126 (84.6)			
Education level, *M (SD)*		5.7 (0.8)	5.5 (0.8)			
WQ	NO	4.83 (1.07)	3.91 (1.22)	57.96	< **.001**	.140
	DE	4.18 (1.41)	3.36 (1.44)	29.56	< **.001**	.076
	SA	3.08 (1.40)	4.26 (1.55)	58.03	< **.001**	.140
Navigation tasks	Landmark	6.88 (1.04)	6.64 (1.09)	4.19	*.037*	.012
	Location - egocentric	1.32 (0.93)	1.17 (0.94)	2.60	.132	.006
	Location - allocentric	1.84 (1.11)	1.71 (0.99)	0.99	.271	.003
	Path - route	2.47 (0.94)	2.35 (1.08)	3.04	.246	.004
	Path - survey	2.38 (1.07)	2.08 (1.11)	7.26	*.011*	.018

4. Discussion

This study provides the first examination of navigation performance in a large, representative sample of people with MS. The main aim was to identify the extent and type of navigation impairments found in this population. Both subjective and objective measures were included in a large scale online study. The objective task consisted of five subtasks, to include measures of all domains of navigation ability. Additionally, the impact of mobility level and cognition in general on navigation performance was assessed.

Overall, the performance of the MS group was similar to the healthy controls, but differences are present. People with MS showed substantially more spatial anxiety. This means that they experience more anxiety when actively navigating by themselves, compared to their healthy counterparts. Also, they reported to have a somewhat lower ability to estimate distances, one of the two cognitive subscales of the self-report measure of navigation ability. So, in the experience of people with MS, they performed slightly worse and were more anxious. When examining the objective performance scores this effect was substantiated, but only for one of the navigation subtasks. People with MS were significantly worse in their memory for landmarks, a key element of spatial navigation. Their performance on the other four, more complex spatial subtasks was comparable. It appears that visuospatial memory is impaired, but spatial navigation itself is intact. This means that for MS in general, spatial navigation is not an impaired function. However, when focusing on subgroups within the MS population, a different pattern emerges.

As locomotion provides a substantial contribution to spatial navigation performance, and given that the ability to move around independently can be strongly limited in people with MS, we addressed ambulation. Those who were able to walk for 200 meters without assistance, where considered highly ambulatory, whereas those who were unable to do this, were grouped in the low ambulation group. The analyses showed that ambulation does not affect subjective navigation performance in any way. In contrast, it did affect the objective scores. Highly ambulatory people with MS outperformed the low ambulation group in allocentric location knowledge and in path route knowledge. Locomotion has been found to specifically affect the processing of metric information, as there is additional physical feedback concerning distances and angles when actively travelling through an environment (Klatzky et al., 1998; Rey and Alcañiz, 2010; Chrastil and Warren, 2013). This could affect allocentric location knowledge specifically, as a detailed mental representation of an environment needs to be constructed for accurate performance on this subtask. It should be mentioned here, that on average, the low ambulation group is somewhat older than the high ambulation group, as is to be expected in this population (e.g. Socie and Sosnoff, 2013). When controlling for the age difference between the two groups, the effects found were no longer present.

Lastly, we also considered cognitive performance in a general sense. For this, as it was a large scale online study, self-reported cognitive performance was used, because logistically individual objective assessment was not possible. The data clearly showed that those who indicated lower cognitive performance also reported lower navigation performance and spatial anxiety. This in itself may not be surprising, as it reflects lower self-ratings across a range of cognitive abilities. However, when examining the objective performance, those who indicated lower cognitive performance also performed worse in navigation; in path survey knowledge, and landmark knowledge in particular.

It should be noted here that the participants in the current study actively responded to a request through MS organizations. It could therefore be that there is response bias with regard to the profile of respondents. However, the sample was substantially large and well matched to the control population, in order to make informative inferences. Another limitation was the online administration and use of self-report measures. Online administration was a necessity to allow for a substantially large sample and has been successfully applied in highly similar previous work (e.g. van der Ham et al. 2020, van der Hamet al. 2021, van der Kuil et al. 2021). Yet it could result in less accurate information with regard to the clinical details that participants provide, and introduced variability in the hardware used, and other experimental conditions. Also, a factor like current mood could potentially affect subjective cognitive ratings, however, recent evidence suggests that spatial navigation performance is also affected by mood (Ruotolo et al., 2020). Furthermore, a recent analysis of the subjective and objective navigation measures used in the current study shows significant positive correlation between the two measures (van der Ham et al., 2021), Exclusion based on visual impairment also relied on self-report, which could potentially differ from actual level of visual impairment. Given the current findings, it would be advisable to continue to study navigation in people with MS in the future, with more elaborate and verifiable information concerning clinical characteristics.

To conclude, self-reported navigation impairment is observed in people with MS, as well as a heightened level of spatial anxiety related to navigation behavior. Additionally, visuospatial memory, as needed to memorize landmarks during navigation, is impaired. Furthermore, it is important to look into mobility and overall cognitive performance within people with MS, as clear differences are present between those who do and do not experience cognitive problems in general. These findings call for specific attention for spatial navigation performance in people with MS, especially when cognitive performance is reduced.

CRediT authorship contribution statement

Ineke J.M. van der Ham: Conceptualization, Methodology, Writing – original draft, Formal analysis, Project administration. **Vasiliki Koutzmpi:** Conceptualization, Methodology, Software, Writing – review & editing. **Milan, N.A. van der Kuil:** Conceptualization, Methodology, Formal analysis, Writing – review & editing. **Karin van der Hiele:** Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors report no conflicts of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.msard.2021.103423.

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