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Determining the Cognitive Profile of Patients with Multiple Sclerosis Based on the CANTAB Test

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A B S T R A C T

Purpose: The objective of this study was to determine the cognitive profile of patients with multiple sclerosis (MS) using the Cambridge Neuropsychological Test Automated Battery (CANTAB).

Methods and Materials: This descriptive-analytical study was conducted on 94 patients with MS recruited from Ibn Sina Hospital in Tehran, selected through convenience sampling. Inclusion criteria comprised a neurologist-confirmed MS diagnosis, age between 20 and 50, disease duration of at least five years, and an EDSS score of ≤5. All participants had normal intelligence scores based on the Raven-2 Progressive Matrices (IQ 90–110). After completing the Motor Screening Task (MOT) to ensure physical and technical capability, participants were assessed using CANTAB subtests including Reaction Time (RTI), Rapid Visual Processing (RVP), Paired-Associate Learning (PAL), Spatial Working Memory (SWM), and Emotion Recognition Task (ERT). Statistical analysis involved one-sample t-tests with bootstrapping (5,000 samples) and a 95% confidence level. Results from the healthy population were extracted from a prior normative study.

Findings: Statistically significant differences were found between MS patients and healthy individuals in all cognitive domains assessed except within and double errors in spatial working memory and the recognition of sadness, happiness, and surprise. MS patients exhibited higher motor screening error and latency scores ($p = .007$, $p = .001$), greater deficits in rapid visual processing ($p < .001$), prolonged reaction and movement times in both simple and choice tasks ($p < .001$), and poorer performance on paired-associate learning measures including total errors and trials ($p < .001$). Spatial working memory impairments were significant across several dimensions ($p \leq .005$), and emotion recognition was significantly reduced for fear, anger, disgust, and overall accuracy ($p \leq .002$).

Conclusion: The CANTAB test effectively distinguishes cognitive deficits in MS patients across multiple domains and can be used as a reliable neuropsychological tool for early detection and targeted cognitive rehabilitation planning in clinical settings.

Keywords: *Multiple sclerosis, cognitive profile, CANTAB, neuropsychological assessment, spatial memory, reaction time, emotion recognition.*

1. Introduction

Globally, approximately 2.8 million individuals live with multiple sclerosis (MS), equating to 35.9 per 100,000 people. Since 2013, the prevalence of MS has significantly increased across all regions of the world. The pooled incidence rate reported across 75 countries is 2.1 per 100,000 people per year, with the average age of diagnosis being 32 years. Women are twice as likely as men to be diagnosed with MS. Multiple sclerosis typically manifests during a period of life when individuals require optimal functioning and are engaged in planning for their professional and family lives; hence, the disease can have profound effects on individuals, families, and society (Vagias et al., 2024). One of the consequences of MS is cognitive impairment.

Cognitive impairment is a significant determinant of disability in individuals with multiple sclerosis (Chiaravalloti & DeLuca, 2008). Generally, the prevalence of cognitive deficits in these individuals has been reported to range between 40% and 70% (Chiaravalloti & DeLuca, 2008; Grzegorski & Losy, 2017). Due to the relatively mild severity of cognitive impairment in MS, it was historically not considered a core feature of the clinical profile of MS patients (Grzegorski & Losy, 2017; Messinis et al., 2018). However, it is now recognized as a central characteristic of the disease, affecting several cognitive domains, especially learning, episodic memory, and processing speed (Benedict et al., 2017; Chiaravalloti & DeLuca, 2008; Messinis et al., 2018; Sumowski & Benedict, 2018). Therefore, assessing cognitive impairment in patients with MS can provide several benefits, such as early detection of cognitive changes, guiding individuals toward cognitive rehabilitation, and identifying indirect or early signs of MS onset and progression (Bakirtzis et al., 2018).

Unfortunately, traditional assessments of MS-related cognitive decline have often relied on patients' self-reports or information provided by their caregivers via rating scales or brief standardized evaluations (Kim et al., 2017; Oreja-Guevara et al., 2019). These conventional methods are time-consuming, require supervision, and may be subject to biases in self-reported data, thus misrepresenting actual cognitive functioning (Rath et al., 2011). Moreover, as noted in prior research, variability in the choice of neuropsychological tests and inclusion criteria has led to heterogeneous findings regarding the extent of cognitive impairment in MS patients (Messinis et al., 2018).

Recently, cognitive deficits in MS patients have been assessed using the Cambridge Neuropsychological Test Automated Battery (CANTAB). This tool is widely used and boasts high validity and reliability (Fray et al., 1996; Roque et al., 2011). It is particularly suitable for assessing cognitive functioning across diverse cultures, as cultural background exerts minimal influence on test outcomes (Benedict et al., 2017; Cotter et al., 2018). Moreover, the CANTAB can evaluate a variety of cognitive functions—such as executive functioning, learning, memory, problem-solving, and attention—in a shorter time frame compared to minimal assessment batteries typically used for MS patients. One advantage of the CANTAB is its capacity to reduce human error and data inaccuracies. Additionally, CANTAB records results in real-time, enhancing the precision of signal detection and reaction time measurement. Its game-like design also motivates participants to engage more fully in the testing process (Khanlarzade et al., 2023). A review study by Sabahi et al. (2022) also confirmed that the CANTAB is an appropriate tool for detecting cognitive impairment (Sabahi et al., 2022).

Nevertheless, no prior study in Iran has examined the cognitive profile of MS patients using the CANTAB test, and in general, the literature assessing cognitive disorders in MS patients in the Iranian context is limited. Given the high global prevalence of MS (Vagias et al., 2024) and its incidence in Iran, as well as the necessity of identifying cognitive deficits that are now considered a major feature of the disease (Benedict et al., 2017; Chiaravalloti & DeLuca, 2008; Sumowski & Benedict, 2018), this study aimed to assess the cognitive profile of MS patients in Iran using the CANTAB. The findings may inform diagnosis and the implementation of targeted interventions for cognitive deficits in this population.

2. Methods and Materials

2.1. Study Design and Participants

Given that the present study aimed to gain a better understanding of the cognitive profile of patients with multiple sclerosis (MS) and to support the diagnosis and treatment of their cognitive components, it adopted a descriptive-analytical research design. The study population consisted of MS patients at Ibn Sina Hospital in Tehran (the main MS clinic), from which 100 individuals were selected through convenience sampling. After excluding those whose intelligence scores did not fall within the normal range, 94 participants were retained for further analysis. Inclusion

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criteria were: a confirmed diagnosis of MS by a neurologist, age range between 20 and 50 years, a disease duration of at least 5 years, and an Expanded Disability Status Scale (EDSS) score of 5 or below (EDSS $\leq$ 5). Furthermore, participants were excluded if they had any other major neurological disorder according to their physician and medical records, had intelligence scores outside the normal range (i.e., Raven's Progressive Matrices 2 score between 90 and 110; Mean Raven-2 IQ = 100), did not pass the CANTAB Motor Screening Test (MOT), or had upper limb physical impairments that would prevent them from completing the test. Exclusion criteria also included being in the acute or relapsing-progressive stage of MS and having a history of substance abuse.

Initially, necessary approvals were obtained from Ibn Sina Hospital in Tehran (main MS clinic) for conducting clinical interviews with MS patients and selecting the appropriate sample size based on the study's inclusion criteria. After visiting the clinic and introducing the researcher and study plan to the clinic staff, the next step was to obtain participants' informed consent. A consent form describing the study objectives and procedures was provided to the patients. Those who agreed to participate signed and returned the form to the research team.

Upon collecting the consent forms, the initial sample of 100 MS patients aged 20–50 years with EDSS scores of $\leq$ 5 was selected using convenience sampling. In the next step, the Raven-2 computerized intelligence test was administered. Individuals whose IQ scores fell outside the normal range (i.e., below 90 or above 110) were excluded from the study, and the remaining participants proceeded to the next phase. Ultimately, 94 individuals met the criteria for further participation.

Participants with IQ scores between 90 and 110 completed the specified CANTAB subtests. All participants were first administered the CANTAB MOT to assess motor function and confirm their ability to complete the test. Those who passed the MOT and had no upper limb impairments advanced to the main CANTAB subtests. During this session, the following tasks were administered: Reaction Time (RTI), Rapid Visual Information Processing (RVP), Paired Associate Learning (PAL), Spatial Working Memory (SWM), and Emotion Recognition Task (ERT).

2.2. Measures

2.2.1. CANTAB

The Cambridge Neuropsychological Test Automated Battery (CANTAB) is a computerized neuropsychological assessment battery originally developed by Barbara Sahakian, Trevor Robbins, and colleagues at the University of Cambridge during the 1980s. The university has continued to develop this software, and it is now recognized as one of the most valid and reliable cognitive assessment tools worldwide (Roque et al., 2011). Initially developed to assess memory deterioration in the elderly (Fray et al., 1996), the CANTAB battery contains entirely non-verbal stimuli (e.g., geometric designs and simple shapes), and language skills are only required for understanding the test instructions (Luciana, 2003). Although the CANTAB has not been specifically standardized for the Iranian population, studies indicate that cultural background has a negligible effect on test outcomes, making its use in Iran scientifically justifiable (Benedict et al., 2017; Cabeça et al., 2018).

2.2.2. MOT Test

The Motor Screening Task (MOT), part of the CANTAB battery, is a neuropsychological subtest that assesses psychomotor speed and familiarity with computerized systems. It stands for "Motor Screening Task." This subtest ensures that participants can understand basic instructions and complete the computerized procedures. The MOT test must be administered at the beginning of each assessment session to confirm participant suitability (Kuzmickienė & Kaubrys, 2015).

2.2.3. Raven's Progressive Matrices – Second Edition

The Raven's Progressive Matrices (RPM) is a non-verbal, multiple-choice intelligence test used to assess abstract reasoning and general cognitive ability, commonly interpreted as a measure of fluid intelligence (Bilker et al., 2012). The test is widely used across various populations, from children as young as five years to older adults. It includes 60 multiple-choice questions arranged in increasing order of difficulty. The format measures the reasoning ability of test-takers, corresponding to Spearman's g factor, often referred to as general intelligence (Kaplan & Saccuzzo, 2009).

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2.3. Data Analysis

To meet the objective of comparing the cognitive profiles of MS patients with those of healthy individuals, the assumption of normality was assessed using the Shapiro–Wilk test. The results indicated that four variables followed a normal distribution, whereas most did not. In cases where variables are not normally distributed, nonparametric methods must be used to test hypotheses. Data for the healthy group were extracted from a previous study (Lohrasbi et al., 2020). Because the researchers did not have access to median values and only had the means for each variable, a one-sample t-test along with bootstrapping was used. Bootstrapping is a nonparametric method that substitutes empirical distribution for theoretical normal distribution. The empirical distribution is obtained from a large number of resampled datasets with replacement (typically over 1,000 samples). A 95% confidence interval was used to assess statistical significance. If the confidence interval does not include zero, the null hypothesis is rejected and the result is considered statistically significant. In this study, 5,000 bootstrap samples were used.

3. Findings and Results

The results of the t-test for the Motor Screening Task, along with the 95% bias-corrected and accelerated confidence interval (BCa CI), are presented in Table 1. According to the results, patients with MS exhibited higher mean error scores (MD = 0.84) and greater mean latency (MD = 301.59) compared to healthy individuals ($p < .05$).

Before conducting dependent t-tests, the Kolmogorov–Smirnov test was used to examine the normality assumption of the data. None of the Z-values were significant, indicating that the score distributions were normal. Additionally, Levene's test for equality of variances was used to assess the homogeneity of variance assumption. Since the F-values in the table were non-significant, this assumption was also satisfied, justifying the use of independent t-tests.

Table 1

Comparison of Mean Errors and Mean Latency in Motor Screening Between Healthy Individuals and MS Patients

Variable	Mean	SD	Population Mean	Mean Difference	F	Sig.	t	*p*	CI Lower Bound	CI Upper Bound
Mean Error	7.67	2.92	6.83	0.84	0.31	.57	2.78	.007	0.246	1.47
Mean Latency	1114.80	384.89	813.21	301.59	0.24	.62	7.58	.001	230.05	376.32

As shown in Table 1, the t-test significance levels for mean error and mean latency are .007 and .001, respectively. Statistically, these values indicate that the likelihood of observing such differences between group means (MS and healthy) within the same population is extremely low (i.e., 7 in 1,000 and 1 in 1,000, respectively). Therefore, it is highly probable that these scores were measured in two distinct populations. In other words, if the null hypothesis were true, one would have to accept an extremely improbable event. Thus, the null hypothesis is rejected, and it is concluded that the observed differences between the two groups are statistically significant, and the scores on these variables can be used to distinguish between the groups.

Moreover, the confidence intervals further support this conclusion. Since neither the lower nor upper bounds of the 95% confidence intervals include zero, it can be stated with 95% confidence that the differences between the means are real and not due to sampling error. Hence, the null hypothesis is rejected at the 95% confidence level.

Table 2

Comparison of Rapid Visual Information Processing Scores Between Healthy Individuals and MS Patients

Variable	Mean	SD	Population Mean	Mean Difference	F	Sig.	t	*p*	CI Lower Bound	CI Upper Bound
RVP Total Hits	14.64	7.53	17.36	-2.72	0.30	.58	-3.50	.007	-4.17	-1.11
RVP Total Misses	13.06	4.85	9.61	3.45	0.40	.52	6.90	.001	2.47	4.41
RVP Total False Alarms	5.00	5.55	2.63	2.37	0.13	.71	4.14	.001	1.37	3.51
RVP Total Correct Rejections	244.57	60.41	248.35	-3.78	0.31	.57	-0.61	.565	-15.06	8.51
RVP A′	0.87	0.05	0.90	-0.03	3.20	.08	-6.34	.001	-0.04	-0.02
RVP Mean Latency	633.25	171.60	514.88	118.37	2.30	.12	6.62	.001	83.95	153.18

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As shown in Table 2, the t-test significance levels for all indicators—except for RVP Total Correct Rejections—are .007 and .001. Statistically, this means that the likelihood of observing such differences in a single population is extremely rare, thereby supporting the conclusion that the data were drawn from two distinct groups. If the null hypothesis were true, these results would represent events with very low probability, thus justifying the rejection of the null hypothesis and confirming that the differences between the groups are statistically significant. Therefore, these variables can be effectively used to differentiate between MS patients and healthy individuals.

Additionally, the 95% confidence intervals for all variables—except RVP Total Correct Rejections—do not include zero, which means that, with 95% confidence, the observed differences are real and not due to sampling error. Accordingly, the null hypothesis is rejected at the 95% confidence level.

The results of the t-test for rapid visual information processing are presented in Table 2. Compared to healthy individuals, MS patients had fewer successful total hits (MD = -2.72) and lower A-prime scores (MD = -0.03; $p < .05$). In contrast, they had higher mean values for total misses (MD = 6.90), false alarms (MD = 4.14), and mean latency (MD = 118.37; $p < .05$). There was no significant difference in the number of total correct rejections between the MS and control groups ($p > .05$).

Table 3

Comparison of Mean Reaction Times Between Healthy Individuals and MS Patients

Variable	Mean	SD	Population Mean	Mean Difference	F	Sig.	*t*	*p*	CI Lower Bound	CI Upper Bound
RTI Mean Simple Reaction Time	417.08	156.92	333.11	83.97	1.69	.19	5.13	.001	57.88	117.53
RTI Mean Five-Choice Reaction Time	427.15	167.33	342.58	84.57	3.30	.07	4.85	.001	54.96	118.70
RTI Mean Simple Movement Time	383.80	153.26	300.22	83.58	2.30	.12	5.23	.001	53.41	116.10
RTI Mean Five-Choice Movement Time	421.24	136.25	316.55	104.69	1.80	.17	7.37	.001	79.05	131.60

As shown in Table 3, the t-test significance level for all reaction time indices is .001. Statistically, this means that observing such differences between the two means (MS and healthy individuals) within the same population is highly improbable (i.e., one in a thousand). Therefore, these two sets of scores were most likely measured from two independent populations. In other words, if the null hypothesis were true, one would have to accept an event with an extremely low probability. Hence, the null hypothesis is rejected, and it is concluded that the observed differences in scores between the two groups are statistically significant, and the reaction time scores can be used to distinguish the groups.

Additionally, the confidence interval analysis reveals that neither the lower nor the upper bound of the 95% confidence intervals for any of the indices includes zero. This indicates that, with 95% confidence, the difference between the two group means is real and cannot be attributed to error. Thus, the null hypothesis is rejected at the 95% confidence level.

The t-test results for reaction time presented in Table 3 show that mean simple reaction time (MD = 83.97), five-choice reaction time (MD = 84.57), simple movement time (MD = 83.58), and five-choice movement time (MD = 104.69) were significantly higher in MS patients than in healthy individuals ($p < .05$).

Table 4

Comparison of Mean Paired-Associate Learning Scores Between Healthy Individuals and MS Patients

Variable	Mean	SD	Population Mean	Mean Difference	F	Sig.	*t*	*p*	CI Lower Bound	CI Upper Bound
PAL Total Errors	21.95	15.69	9.23	12.71	1.00	.31	7.82	.001	9.70	15.95
PAL Mean Errors to Success	2.89	2.27	1.17	1.72	2.20	.13	7.29	.001	1.31	2.16
PAL Mean Trials to Success	1.93	0.65	1.43	0.50	0.38	.53	7.48	.001	0.38	0.64

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PAL Total Trials	14.83	4.49	11.37	3.46	0.28	.59	7.43	.001	2.60	4.34
PAL First Trial Memory Score	16.48	4.16	20.82	-5.99	2.40	.11	-12.87	.001	-6.80	-5.16

As shown in Table 4, the *t*-test significance level for all paired-associate learning (PAL) indices is .001. Statistically, this means that such differences between the means of the MS and healthy groups are extremely rare events (one in a thousand), further suggesting that these scores reflect measurements from two different populations. If the null hypothesis were true, accepting such rare outcomes would be necessary. Therefore, the null hypothesis is rejected, and the differences between group scores are deemed statistically significant. The PAL test scores can thus be used to differentiate between the groups.

Additionally, the 95% confidence intervals for all indices do not include zero, indicating that the observed differences between the two means are real and not due to chance. Accordingly, the null hypothesis is rejected with 95% confidence.

According to the *t*-test for paired-associate learning scores (Table 4), MS patients demonstrated significantly higher total errors (MD = 12.71), mean errors to success (MD = 1.72), mean trials to success (MD = 0.50), and total trials (MD = 3.46) compared to healthy individuals ($p < .05$). Their first trial memory score was significantly lower than that of healthy individuals (MD = -5.99; $p < .05$).

Table 5

Comparison of Mean Spatial Working Memory Scores Between Healthy Individuals and MS Patients

Variable	Mean	SD	Population Mean	Mean Difference	F	Sig.	*t*	*p*	CI Lower Bound	CI Upper Bound
SWM Between Errors (4 to 8 boxes)	47.17	22.66	27.11	20.57	0.40	.52	8.92	.001	16.15	24.98
SWM Within Errors (4 to 8 boxes)	4.09	8.26	3.87	0.26	2.10	.15	0.30	.764	-1.05	1.87
SWM Double Errors (4 to 8 boxes)	2.68	5.30	1.97	0.74	2.40	.10	1.34	.184	-0.16	1.85
SWM Total Errors (4 to 8 boxes)	48.57	23.70	29.00	20.10	0.20	.62	7.33	.001	15.34	24.76
SWM Strategy (4 to 8 boxes)	47.07	8.70	43.81	3.76	2.90	.09	4.97	.001	2.26	5.12
SWM Mean Time to First Response	2363.00	1449.91	1911.27	430.11	1.90	.19	2.88	.005	159.68	718.88
SWM Mean Token-Search Preparation Time	1379.48	809.69	1056.55	290.73	2.80	.10	3.73	.001	167.45	445.41
SWM Mean Time to Last Response	31226.75	7397.58	25210.89	6015.86	0.50	.48	7.84	.001	4631.21	7474.61

As shown in Table 5, the *t*-test significance level for all variables—except SWM Within Errors (4 to 8 boxes) and SWM Double Errors (4 to 8 boxes)—is .005 or .001. Statistically, this indicates that such differences between group means (MS and healthy) are extremely rare occurrences (five in a thousand or one in a thousand). Therefore, it is highly likely that the scores were measured from two independent populations. If the null hypothesis were true, such rare outcomes would have to be accepted. Hence, the null hypothesis is rejected, and it is concluded that the observed differences in scores between the groups are statistically significant and useful in distinguishing between MS patients and healthy individuals.

Moreover, the 95% confidence intervals for all variables—except SWM Within Errors and SWM Double Errors—do not include zero. This means that, with 95% confidence, the differences between group means are real and not due to error. Accordingly, the null hypothesis is rejected at the 95% confidence level.

The comparison of spatial working memory (Table 5) shows that the mean between errors (MD = 20.57), total errors (MD = 20.10), strategy score (MD = 3.76), mean time to first response (MD = 430.11), mean token-search preparation time (MD = 290.73), and mean time to last response (MD = 6015.86) were higher in MS patients than in healthy individuals ($p < .05$). The within errors and double errors did not differ significantly between groups ($p > .05$).

Table 6

Comparison of Mean Emotion Recognition Scores Between Healthy Individuals and MS Patients

Variable	Mean	SD	Population Mean	Mean Difference	F	Sig.	*t*	*p*	CI Lower Bound	CI Upper Bound
ERT Percent Correct	50.42	9.91	55.82	-5.40	2.00	.16	-5.22	.001	-7.44	-3.44
ERT Percent Correct (Disgust Shown)	39.58	23.56	47.46	-7.88	2.07	.15	-3.22	.002	-12.41	-3.17
ERT Percent Correct (Sadness Shown)	62.56	19.13	66.05	-3.36	0.45	.50	-1.69	.095	-7.40	0.56
ERT Percent Correct (Happiness Shown)	74.85	11.84	74.34	-0.78	0.18	.65	-0.65	.520	-1.52	0.30
ERT Percent Correct (Surprise Shown)	70.41	13.75	67.76	2.65	1.90	.20	1.86	.066	-0.29	5.29
ERT Percent Correct (Anger Shown)	35.42	13.41	43.24	-7.82	1.65	.23	-5.63	.001	-10.55	-5.09
ERT Percent Correct (Fear Shown)	19.38	12.20	36.08	-16.70	2.80	.10	-13.20	.001	-19.04	-14.34

As shown in Table 6, the *t*-test significance level for all indices—except ERT Percent Correct (Sadness Shown), Happiness Shown, and Surprise Shown—is .001. Statistically, this means that the observed differences between the group means (MS and healthy) are extremely rare events (one in a thousand), thus confirming that the scores come from two distinct populations. If the null hypothesis were valid, these rare probabilities would need to be accepted. Therefore, the null hypothesis is rejected, and it is concluded that the observed differences are statistically significant and can be used to distinguish between the groups.

Additionally, the 95% confidence intervals for all indices—except Sadness Shown, Happiness Shown, and Surprise Shown—do not include zero, indicating that these differences are real and not due to sampling error. Thus, the null hypothesis is rejected with 95% confidence.

The comparison of mean emotion recognition percentages (Table 6) revealed that MS patients had lower scores in overall emotion recognition (MD = -5.40), disgust (MD = -7.88), anger (MD = -7.82), and fear (MD = -16.70) compared to healthy individuals ($p < .05$). There were no significant differences between the groups in recognition accuracy for sadness, happiness, or surprise ($p > .05$).

4. Discussion and Conclusion

The aim of the present study was to determine the cognitive profile of patients with multiple sclerosis (MS) using the CANTAB test. Based on the findings, the CANTAB test proved to be a suitable instrument for the precise and functional assessment of cognitive performance in MS patients; thus, the study objective of gaining deeper insight into the cognitive profile of this population was achieved. The results align with prior studies (Cotter et al., 2018; Grzegorski & Losy, 2017). Similarly, the study by Cebeca et al. (2018) demonstrated that the CANTAB test is capable of detecting subtle and early changes in cognitive performance and processing speed among individuals with MS (Cabeça et al., 2018). This early identification allows healthcare professionals to implement timely interventions, such as cognitive rehabilitation programs.

The CANTAB battery assesses multiple dimensions of cognitive decline, including motor screening, visual information processing, reaction time, paired-associate learning, spatial working memory, and emotion recognition. In this study, the MS group showed impairments in each of these domains when compared to the control group. Below, each cognitive dimension and its relationship to MS is discussed individually.

Theoretical and empirical evidence supports the current findings on motor screening, showing that MS patients exhibit higher error rates and greater latency compared to healthy individuals. This may be attributed to gait disturbances (Johansson et al., 2007) and fatigue (Bakshi, 2003; Schwid et al., 2002), which are among the most disabling symptoms in MS. Neurophysiological studies indicate that motor fatigue in these patients stems from central and peripheral neuromuscular system weaknesses, which slow down movement initiation and execution (Ng et al., 2004). These results are consistent with findings by Barr et al. (2014), who reported slower motor reaction times in MS patients.

The present findings on rapid visual information processing are consistent with those of López et al. (2016)

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and Vagias et al. (2024), who found deficits in visual processing speed among MS patients (Vagias et al., 2024). This is in line with earlier research identifying information processing deficits as the most prevalent cognitive impairments in MS (Guimarães & Sá, 2012), which can negatively affect other cognitive domains (Chiaravalloti & DeLuca, 2008). Moreover, visual system abnormalities are common throughout the course of MS (Frohman et al., 2010; Maxner, 2006). Both afferent and efferent visual pathways are vulnerable to MS, resulting in irregular eye movements (Niestroy et al., 2007). In addition, a study by Jahani et al. (2022) demonstrated that transcranial magnetic stimulation enhances sustained attention and processing speed in MS patients (Jahani et al., 2022).

The current study's findings on simple and choice reaction times in MS patients are consistent with those of Khanlarzadeh et al. (2023), who showed that MS patients display slower simple and choice reaction times. Furthermore, the study revealed that MS patients perform worse in spatial working memory tasks compared to healthy individuals. This can be explained by hippocampal damage, particularly in subregions of the hippocampus, which has been associated with poor spatial memory performance in MS (Longoni et al., 2015).

Results from the current study also indicated that MS patients had significantly higher total errors, mean errors to success, mean trials to success, and total trials in the paired-associate learning task, while their first trial memory scores were lower than those of healthy individuals. This may be explained by hippocampal region analysis, which has identified links between damage to specific hippocampal areas and deficits in paired-associate learning in MS (Longoni et al., 2015). These results are further supported prior studies which also found learning impairments in individuals with MS (Chiaravalloti & DeLuca, 2008; Tablerion et al., 2020).

Regarding emotion recognition deficits in MS patients, the present findings are supported by prior studies (Pfaff et al., 2021; Radlak et al., 2021). The ability to perceive others' emotions is closely linked to other cognitive functions, including attention and executive functioning such as working memory. Since these cognitive capacities are often impaired in MS, it is plausible that recognizing emotions is also more difficult for this population compared to healthy individuals (Bilker et al., 2012; Phillips et al., 2008; Radlak et al., 2021). Disruptions in neural transmission from the temporal visual processing regions to the prefrontal regulatory areas may explain facial emotion recognition difficulties. Specifically, white matter lesions in the temporal lobes may impair the interaction between facial recognition in the temporal cortex and emotional evaluation in the ventrolateral prefrontal cortex (Krass et al., 2009).

This study had several limitations. One was the limited sample size, partly due to the time-consuming nature of the assessments and the unwillingness of some MS patients to complete lengthy tests. Another limitation was that participants were not categorized according to the different stages of the disease (e.g., early vs. advanced phases). Future research is therefore encouraged to increase the sample size and categorize MS patients' cognitive profiles based on disease progression.

Authors' Contributions

All authors significantly contributed to this study.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

In this study, to observe ethical considerations, participants were informed about the goals and importance of the research before the start of the interview and participated in the research with informed consent.

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