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Arm Swing Movements during Walking as an Early Predictor of Multiple Sclerosis Progression

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Abstract: Persons with Multiple Sclerosis (pwMS) are at a high risk of falling, with abnormal gait pattern. The upper limbs play an important role in postural control and gait stability. The presence of arm swing changes during walking in pwMS, especially in the early period, may be an indicator of balance problems. The current study aimed to assess arm swing during walking in early MS. A total of 18 pwMS were evaluated in two time points. The first time was after their first (stable) diagnosis (pre-evaluation) and the second time was 3 months after the pre-evaluation. In addition, 10 healthy controls were evaluated once. Arm swing analysis during walking, using video recording, was applied to both groups. Additionally, the MS group performed the Two-Minute Walk Test, Timed Up and Go, and Timed 25-Foot Walk Test. The pwMS showed similar joint angles at both the first and second evaluations. Only the elbow ROM value on the least affected side was lower in pwMS than healthy controls at the second evaluation ($p = 0.027$). The early MS patients showed altered arm swing pattern. As walking speed and mobility scores did not change over time, the decrease in elbow amplitude over a 3-month period indicates that the arm swing may present a pattern resulting from MS-specific disorders rather than being a compensatory mechanism in walking. From the earliest stages of the disease, variations in arm swing movements during walking may be considered as a disease progression-predictor for MS.

Keywords: upper extremity; gait; multiple sclerosis; arm swing; early stage of multiple sclerosis

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1. Introduction

Multiple sclerosis (MS) is the most common inflammatory and demyelinating disease of the central nervous system [1] characterized by motor and sensory deficits, cerebellar symptoms, and balance problems. Due to these symptoms, gait abnormalities are common in MS, even in patients with low degrees of impairment [2]. Given the disease's progression, persons with MS (pwMS) are at a high risk of falling [3], with abnormal gait pattern as one of the disease's most prevalent impairment that affect gait stability and increase fall risk [4].

The upper limbs play an important role in postural control and gait stability [5,6]. Natural upper limb movements during walking in healthy persons lower the energetic cost of walking, facilitate leg movements [6] and enhance dynamic balance during locomotion [7] compared to when the upper limbs are not allowed to move or are moving in an altered coordination pattern. Affected arm swing movement and asymmetry during gait are common in neurological disorders such as Parkinson's disease (PD), even in early stages of the disease [8,9] and in patients after stroke [10], which can affect their gait pattern [6]. Several papers have even acknowledged that upper extremity treatment enhances gait and normalizes arm swing, for various diagnoses such as PD [11], stroke [12] and juvenile idiopathic arthritis [13]. Considering the progression of unilateral and bilateral upper extremity dysfunction associated with disease severity in individuals with MS [14], it can be hypothesized that arm swing movements may be impacted during walking. Such alterations could potentially influence overall walking patterns and dynamic balance in pwMS.

Studies on arm swing movements during gait in pwMS are scarce. A study found that pwMS walked slower and with decreased amplitude of elbow flexion compared to healthy control participants [15]. A recent study does indicate a preliminary link between upper limb function and balance in pwMS [16]. Abasıyanık et al. researched arm swing during walking in pwMS, but their focus was specifically on dual-task assessment [17]. A separate study investigating the influence of upper extremity movements on balance during tandem walking in individuals with early-stage MS indicated that such movements may serve as an early marker for balance impairment in the progression of the disease [18]. During walking, pwMS may exhibit arm swing modifications that resemble those seen in people with PD, particularly in the early stages of the disease. These swing variations may be a sign of balance issues. This finding implies that changes in arm movement may indicate an onset of balance problems. This was, however, not investigated as such. More knowledge is needed on how these early alterations in arm swing can indicate the beginning and development of the disease because prior research has primarily concentrated on other motor symptoms or on more advanced stages of the disease. Comprehending these alterations in arm swing may offer a significant understanding of the wider range of motor function decline in pwMS, ultimately improving patient outcomes through early and focused therapy interventions. The innovative aspect of this study is examining changes in upper extremity movements in the early stages of MS and their potential importance as a predictive criterion.

Therefore, the aim of the current study is to assess the arm swing during walking in pwMS shortly after their diagnosis in early MS. Additionally, we assess whether there are changes in the arm swing in the same pwMS in a short period (after three months). Finally, we will evaluate associations between the arm swing (changes) and functional mobility tasks which are related to balance and gait stability.

2. Materials and Methods

This study was designed as a single-center, prospective non-randomized controlled study. The pwMS were evaluated at two distinct time points. The first evaluation took place after their initial stable diagnosis, referred to as the pre-evaluation phase. The second evaluation occurred three months after the pre-evaluation, allowing researchers to assess any changes or progress in the patients' condition over this period. The participants did not undergo any physiotherapy and rehabilitation program during the three-month period. Additionally, healthy controls were included in the study and were evaluated once, providing a benchmark for comparison against the pwMS group. This methodological approach was created to produce thorough data on the course and effects of multiple sclerosis within a brief period, providing insightful information for further studies and therapeutic approaches.

MS participants were recruited at the Istanbul Dr. Sadi Konuk Training and Research Hospital. Age-matched healthy controls were invited to participate in the study. Inclusion criteria for MS participants were to be diagnosed with MS in the last six months recovered from their symptoms, clinically stable, and able to walk uninterrupted for two minutes. Exclusion criteria were having an acute medical illness in the past six months, any other neurological and psychiatric diseases, or any orthopedic, rheumatologic, or vestibular conditions that affect walking were excluded. Patients who had exacerbations between the first and second evaluations (three months after the first evaluation) were excluded.

The researcher asked the participants to walk in the confined space of a medical office which provides basic information about the patient's gait pattern (observationally and from video recording) and biomechanical information from a foot pressure analysis system (FreeMed, Sensor Medica, Guidonia Montecelio). The participants walked barefoot back and forth at their comfortable walking speed for two minutes over a three-meter walkway, which included a foot pressure system positioned in the middle of the path. This setup allowed for the collection of detailed foot pressure data as the participants walked. The foot pressure system was instrumental in capturing various metrics, with a particular focus on gait speed. This method provided a controlled environment to assess and compare the walking dynamics of pwMS and healthy controls.

A Panasonic Lumix DMC-FZ300 digital camera was used to record a gait video at fifty frames per second at a resolution of 1280×720 pixels. The researcher fixed the camera laterally on a tripod placed two and a half meters away and one meter above the floor with respect to the participants. As such, a sagittal plane video of the walking was recorded (Figure 1).

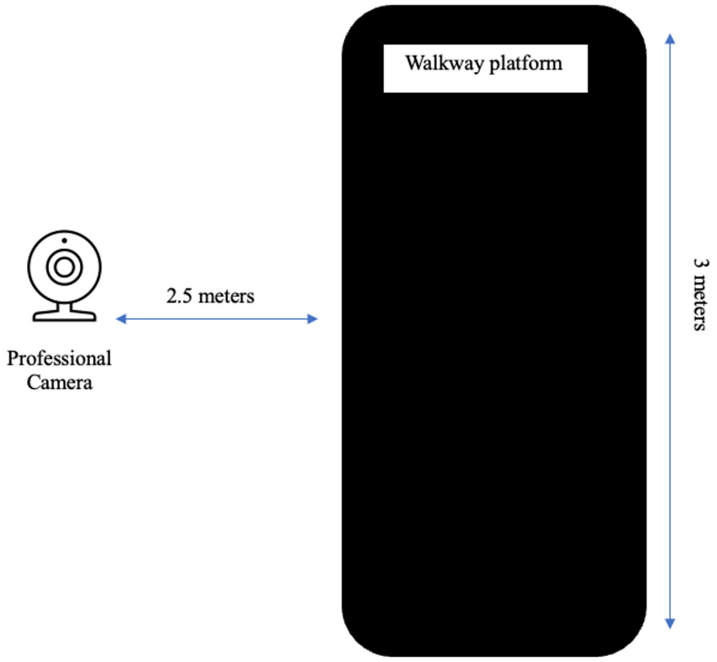

Figure 1. Schematic representation of the experimental setup.

The arm swing movements during walking were evaluated with free version of Kinovea 2D motion analysis software (Kinovea 0.8.15., GPLv2 license, 2019). It is a reliable method to analyze the upper extremity movements and gait analysis [19–21]. For tracking the segments of the upper limbs during walking, sticker markers were placed in specific anatomical areas (left/right acromions, left/right medial and lateral epicondyles, and left/right distal radius and ulna landmarks) [22]. The shoulder, elbow, and wrist joints were manually positioned within the Kinovea software to accurately map the participants' upper body movements. Based on the identified joint centers, the upper arm, lower arm, and full arm segments were determined. Detailed analyses were conducted to evaluate the shoulder angle (measured from the shoulder joint marker to the elbow joint marker), the elbow angle (measured from the elbow joint marker to the midpoint of the wrist joint marker), and the overall arm swing angle (measured from the shoulder joint marker to the midpoint of the wrist joint marker) during gait (Figure 2). These angles were analyzed individually in the sagittal plane by calculating the difference in the angle between the relevant segment and the vertical axis at two specific points in time during the gait cycle.

Figure 2. The arm swing movements video recording during the gait.

The timing for this analysis was aligned with key gait events of the lower limbs; (1) Heel strike, this event corresponds to the most extended position of the upper limb on the same side and (2) Push-off, this event corresponds to the most flexed position of the upper limb on the same side. The angle difference for each joint segment between these two frames were calculated as arm swing outcome. The range of motion (ROM) for the different joints was determined by measuring the angles between these two gait events. This comprehensive approach enabled a detailed examination of how the shoulder, elbow, and wrist joints contributed to arm swing during walking.

A total of seven trials for each patient from each side (most affected and least affected side, based on the nine-hole peg test scores) were collected using 2D video analysis. For the healthy controls, the dominant side was designated as the least affected side, while the non-dominant side was considered the most affected side, based on their verbal response when asked about their limb preference. The variability of the joint angles was assessed by calculating the standard deviation between the trials.

To understand the changes in functional mobility, Two-Minute Walk Test (2MWT), Timed Up and Go (TUG) and Timed 25-Foot Walk Test (T25FW) were conducted in addition to walking for the included pwMS.

The 2MWT is a valid test that evaluates a person's endurance by having them walk a distance over two minutes [23]. For two minutes, the patients were instructed to walk as quickly as they could safely without help, and the researcher recorded the distance.

The TUG test evaluates the dynamic balance and functional mobility in older adults, as well as in the neurological population and it is valid for pwMS [24]. The researcher asked the participants to stand from a seated position on a chair, walk three meters, return, and sit on the chair again. The researcher measured the total time taken by the test.

T25FW test assesses patients' quantitative mobility and leg function using a timed 25-foot walk [25]. The researcher instructed the participant to move from one marked end to the other in a 25-foot gait that is as rapid and safe as possible and recorded the time that is starting when the patient is told to start and continuing until the patient reaches the 25-foot mark.

The study protocol is schematized in Figure 3.

For statistical analysis, SPSS software version 20.0 (SPSS Inc.) was used, and parameters showed normal distribution. To compare most affected and least affected joint angles in pwMS (per evaluation), paired sample *T*-tests were used. To compare the outcomes (joint angles and functional tests) between the first and second evaluation in pwMS, paired sample *T*-tests were used. To compare the difference in joint angles between healthy controls and the first and second evaluation in pwMS on the one hand and on the other, independent sample *T*-test was used. For the relation between functional mobility tests and arm swing movements during walking, Spearman correlation was used. Significant correlation coefficient values were interpreted as <0.3 = low correlation, 0.31–0.70 = moderate correlation, and >0.70 = high correlation [26]. The level of significance was set at $p < 0.05$.

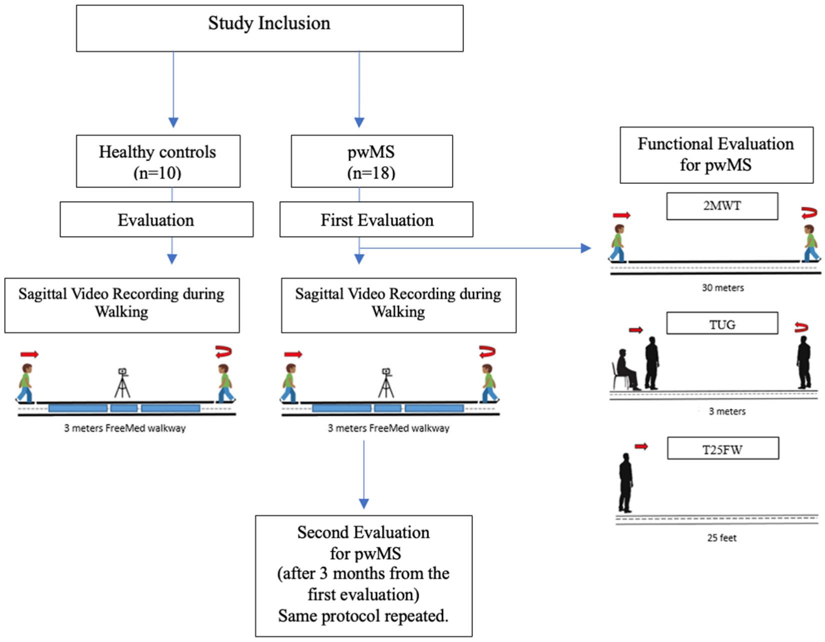

Figure 3. Evaluation protocol for the participants conducted at the first evaluation and after three months (second evaluation).

3. Results

3.1. Participants

Overall, 18 pwMS and 10 healthy controls were included. The demographics and clinical features of the participants are given in Table 1.

Table 1. The demographic and clinical features of the participants.

	Healthy Mean ± SD (Min–Max)/n(%)	**pwMS (n = 18) Mean ± SD (Min–Max)/n(%)**	***p* Value**
Age (years)	26.91 ± 8.57 (19–40)	27.89 ± 9.20 (18–48)	0.54
BMI (kg/m^2)	22.9 ± 4.45 (16.3–34.4)	24.31 ± 3.22 (19.97–32.18)	0.84
Gender Female Male	 8 (%80) 2 (%20)	 16 (%89) 2 (%11)	0.19
Disease Duration (months)	-	3.26 ± 1.40 (1–6)	
EDSS	-	1.18 ± 0.58	

Abbreviations: SD, standard deviation; min, minimum; max, maximum; BMI, body mass index; kg, kilogram; m, meter; EDSS, expanded disability status scale.

3.2. Arm Swing Group Differences

- In comparison with healthy controls, pwMS showed similar joint angles at both the first and second evaluations.
- Only the elbow ROM value on the least affected side was lower in pwMS than healthy controls at the second evaluation (Table 2).

Table 2. Comparison of interested parameters within and between groups.

	Healthy Controls (Group 1)			pwMS First Evaluation (Group 2)			pwMS Second Evaluation (Group 3)			Between Groups § Most Affected Side		Between Groups § Least Affected Side	
	Affected Mean ± SD	**Contralateral Mean ± SD**	**Paired *T*-test p */r/d**	**Affected Mean ± SD**	**Contralateral Mean ± SD**	**Paired *T*-test p */r/d**	**Affected Mean ± SD**	**Contralateral Mean ± SD**	**Paired *T*-test p */r/d**		**p **/r**		**p ***/r**
Shoulder (°)	21.9 ± 10.0	19.2 ± 6.5	0.365/0.32/0.15	23.2± 10.1	17.5 ± 9.3	**0.019/0.58/0.28**	17.5 ± 7.8	14.0 ± 7.3	0.158/0.46/0.22	1 vs. 2 1 vs. 3 2 vs. 3	0.180/0.85 0.188/0.68 0.190/0.69	1 vs. 2 1 vs. 3 2 vs. 3	0.217/0.75 0.210/0.67 0.218/0.68
Shoulder SD	6.5 ± 2.4	5.7 ± 1.4	0.385/0.40/0.19	6.9 ± 2.5	6.9 ± 3.6	0.952/0/0	6.7 ± 3.3	5.5 ± 2.4	0.143/0.41/0.20	1 vs. 2 1 vs. 3 2 vs. 3	0.934/0.09 0.931/0.09 0.929/0.09	1 vs. 2 1 vs. 3 2 vs. 3	0.305/0.42 0.308/0.400.310/0.41
Elbow (°)	36.5 ± 19.2	32.1 ± 13.2	0.415/0.26/0.13	31.3 ± 14.7	24.4 ± 11.9	0.050/0.51/0.24	25.6 ± 12.4	19.2 ± 10.2	**0.030/0.56/0.27**	1 vs. 2 1 vs. 3 2 vs. 3	0.218/1.11 0.182/1.06 0.215/1.10	1 vs. 2 **1 vs. 3** 2 vs. 3	0.218/1.10 **0.027/1.40** 0.218/1.11
Elbow SD	8.6 ± 4.9	7.8 ± 3.1	0.606/0.19/0.09	9.4 ± 4.1	8.3 ± 4.8	0.309/0.24/0.12	9.4 ± 4.0	6.6 ± 2.7	**0.022/0.82/0.37**	1 vs. 2 1 vs. 3 2 vs. 3	0.861/0.15 0.859/0.16 0.862/0.16	1 vs. 2 1 vs. 3 2 vs. 3	0.378/0.40 0.378/0.44 0.365/0.42
Overall Arm Swing (°)	30.1 ± 13.8	25.5 ± 9.3	0.244/0.39/0.19	27.3 ± 12.1	20.7 ± 10.4	**0.029/0.58/0.28**	21.4 ± 9.6	16.7 ± 9.3	0.082/0.49/0.24	1 vs. 2 1 vs. 3 2 vs. 3	0.137/1.02 0.130/1.06 0.144/1.05	1 vs. 2 1 vs. 3 2 vs. 3	0.082/1.06 0.075/1.07 0.081/1.05
Overall Arm Swing SD	7.6 ± 4.9	6.5 ± 2.3	0.444/0.28/0.14	7.0 ± 2.7	6.8 ± 4.3	0.839/0.05/0.02	7.3 ± 2.9	5.8 ± 1.9	**0.033/0.61/0.29**	1 vs. 2 1 vs. 3 2 vs. 3	0.914/0.12 0.916/0.14 0.915/0.12	1 vs. 2 1 vs. 3 2 vs. 3	0.617/0.26 0.617/0.26 0.617/0.26

* Affected sides vs. contralateral sides, paired sample *T*-test. r; effect size value, d; Cohen's d value. § Comparison groups, One way ANOVA, 1; healthy controls, 2; first evaluation in MS, 3; second evaluation in MS, Scheffe correction. ** First evaluation vs. second evaluation for most affected sides; Independent *T*-test for 1 vs. 2 and 1 vs. 3, Paired sample *T*-test for 2 vs. 3. *** First evaluation vs. second evaluation for least affected sides; Independent *T*-test for 1 vs. 2 and 1 vs. 3, Paired sample *T*-test for 2 vs. 3. Abbreviations: pwMS, people with Multiple Sclerosis; SD, standard deviation.

3.3. Side Differences (at the First and Second Evaluation)

- Several significant differences between the joint angles of most affected and least affected sides were present at the first and the second evaluation in MS, whereas no side differences were present in healthy controls (Table 2).

3.4. Longitudinal Changes in pwMS (Difference between the First and Second Evaluation)

- No significant changes were found between the first and second evaluation with respect to walking speed and functional tests in pwMS (Table 3).

Table 3. Comparison of the functional parameters between groups.

	Healthy Controls (Group 1)	pwMS First Evaluation (Group 2)	pwMS Second Evaluation (Group 3)	Between Groups §
Walking speed (mm/s)	462.5 ± 17.5	495.2 ± 62.2	456.6 ± 54.8	0.126 (1 vs. 2) (r = 0.33, d = 0.64) 0.125 (2 vs. 3) (r = 0.31, d = 0.65) 0.130 (1 vs. 3) (r = 0.35, d = 0.61)
2MWT (m)	-	207.0 ± 15.7	195.8 ± 50.3	0.367 (r = 0.14, d = 0.30)
TUG (s)	-	6.0 ± 0.7	5.8 ± 0.5	0.196 (r = 0.16, d = 0.32)
T25FW (s)	-	4.8 ± 0.6	4.6 ± 0.4	0.139 (r = 0.19, d = 0.39)

Abbreviations: pwMS, people with Multiple Sclerosis; SD, standard deviation; mm, millimeter; sec, second; 2MWT, two-minute walk test; m, meter; TUG, timed up and go; T25FW, timed 25-foot walk test. r; effect size value, d; Cohen's d value.

3.5. Functional Tests and Relation with Arm Swing

- There was no significant correlation between arm swing parameters and functional mobility tests ($p > 0.05$).

4. Discussion

In this study, we aimed to reveal the changes in arm swing during walking following a short period after diagnosis in early MS, and it was found that the elbow ROM value on the least affected side was lower in pwMS than in healthy controls.

The novel aspect of this study lies in its detailed description of the changes in arm swing among pwMS during the early stages of the disease. Previous research has predominantly focused on other motor symptoms or on more advanced stages of MS, leaving a gap in our understanding of how these early changes in arm swing might signal the onset and progression of the disease. By concentrating on this specific aspect, our study aimed to reveal the changes in arm swing during walking even in a short period after diagnosis in early MS. Understanding these changes in arm swing could provide valuable insights into the broader spectrum of motor function deterioration in pwMS, ultimately contributing to better patient outcomes through timely and targeted therapeutic approaches.

Even though the arm swing movements during walking were similar between early MS patients and healthy controls, asymmetry between the most and least affected side was evident in early MS patients and not in healthy controls. Additionally, after short period from diagnosis, the elbow amplitude was decreased on the least affected side in pwMS compared to healthy controls which corroborates results from a previous study in pwMS [15]. According to that study, patients with low EDSS scores may experience alterations in gait and arm swing due to the condition. However, in their study involving pwMS with low EDSS scores, the authors reported a reduced walking speed, which was confirmed by other researchers [27]. As such, Elsworth-Edelsten et al. [15] indicated that, in their sample of low EDSS pwMS, the decrease in elbow amplitude may be connected to walking speed. In the current study, on the other hand, any differences were detected in walking speed between our sample of early MS patients with low EDSS and healthy controls. This suggests that the presented arm swing pattern is a direct effect of the MS rather than being a gait compensation. Walking speed, which is one of the main factors affecting arm swing during walking [28], was found to be similar both between the groups and between the first and second assessments. Therefore, decreased elbow amplitude and increased arm swing asymmetry without any change in walking speed may be associated with disease progression in individuals with MS, especially in the early period.

In this study, the results of functional tests repeated at 3-month intervals showed no functional deterioration. However, this may be due to a wide variety of factors affecting functional mobility. Since patients were included early in their diagnosis, they had low initial EDSS scores. As a result, functional mobility was only mildly affected, which may have hindered the detection of a relationship with arm swing parameters in MS. Although it was stated that arm swing was not effective in dual task assessment [17], given the disease progression, it is expected that functional mobility will worsen and arm swing during gait may further affect the gait pattern. This, however, remains to be explored in this population. Future research is required to examine the relationship between deteriorating functional mobility and alterations in arm swing, as well as determine whether these alterations could be used as early markers of deteriorating gait in MS patients.

While there was no difference in arm swing between the affected and contralateral sides in healthy people, it was found that people with MS had an asymmetry in shoulder amplitude during the initial assessment. At the second evaluation, the shoulder amplitude asymmetries shifted to asymmetries in the elbow and overall arm swing ranges. These findings are consistent with the asymmetry in arm swing reported in Parkinson's patients, even in the early stages of the disease [8]. The finding that the elbow amplitude in the unaffected upper limb was significantly lower compared to the affected side in pwMS suggests that upper extremity movements are compensating for impairments on the affected side during walking. While there was no difference in arm swing between individuals with MS and healthy individuals in the initial evaluation immediately after diagnosis, a decrease in elbow movements on the unaffected side was observed in the second evaluation after just 3 months. This may indicate potential functional loss, even if there is no change in EDSS scores or clinical status. We believe that this result provides evidence for the existence of possible changes that may mark the beginning of functional loss in individuals with MS, which have not yet been clinically demonstrated in the early stages, similar to the situation in which walking and balance losses were not previously reflected in clinical scores in the literature [18,27].

In addition to the clinical tests conducted during the diagnosis of MS, monitoring motor symptoms is crucial due to the disease's progression characterized by attacks and remissions [29]. Motor signs observed during an attack or worsening of the patient's condition play a significant role in predicting progression. Therefore, the arm swing changes especially at the elbow level, may be an early marker of MS. However, the rate of change in arm swing should be further investigated with regard to the type and prognosis of MS. Based on previous studies, it is known that the arm swing has an important role during gait [6,30–33] and that an alternate arm swing can also negatively affect gait. Therefore, it is worth investigating whether changing the arm swing is beneficial for these patients. Upper extremity therapies may help different neurologic patients (i.e., hemiplegic cerebral palsy patients [34,35], and patients after stroke [36–39]) to improve their gait balance. Arm swing asymmetries in early-stage MS patients have been scarcely studied. While existing literature suggests that they are generally early markers of Parkinson's disease, there is limited research on their significance in MS. Our initial findings on arm swing during walking in pwMS raise important questions for future research. More research may be conducted to determine whether therapies like arm swing training or other upper limb interventions can affect how people with MS walk or balance. Improved therapeutic approaches targeted at improving mobility and lowering the risk of falls in this population may result from a better understanding of the possible advantages of these interventions. Future research could provide insight on how arm swing asymmetries affect the progression of MS and whether they should be the focus of early treatments.

Limitations

The results of the current paper should be interpreted with caution as it is not free from limitations. The walking assessed is a clinical test used in a confined space the hospital, and perhaps results may not be generalizable to normal walking. The included sample was limited and is not generalizable for the whole population of pwMS but is specific to close to their diagnosis. A priori sample size calculations were not possible given the scarcity of information about this topic on arm swing in pwMS in a short period after diagnosis in the current literature. However, based on the calculated and presented effect sizes, it is assumed that the sample is sufficient in size to draw relevant conclusions. Clear differences between pwMS and healthy controls were apparent for arm swing asymmetry and elbow joint angles. The results may therefore be underestimated.

5. Conclusions

In early MS patients, even after a short period following diagnosis, elbow amplitude was decreased on the least affected side compared to healthy controls during gait and they showed an altered arm swing pattern. As walking speed and mobility scores did not change over time, the decrease in elbow amplitude over three months indicates that the arm swing may represent a pattern resulting from MS-specific disorders rather than being a compensatory mechanism in walking. Therefore, from the earliest stages of the disease, variations in arm swing movements during walking may be considered a disease progression predictor for MS.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Local Ethics Committee (Istanbul University-Cerrahpasa, Non-interventional Studies Ethics Committee/2021-18), and was registered at ClinicalTrials.gov (NCT05821257).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patients to publish this paper.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

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