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The "butterfly diagram": A gait marker for neurological and cerebellar impairment in people with multiple sclerosis☆·☆☆

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ABSTRACT

People with multiple sclerosis (PwMS) frequently experience walking and balance impairments. In our previous report, we demonstrated that spatio-temporal gait parameters, collected by the Zebris FDM-T instrumented treadmill (Zebris Medical GmbH, Germany), serve as valid markers of neurological impairment in the MS population. In the current study, we focused on a unique outcome statistic of the instrumented treadmill, the "butterfly" diagram which reflects the variability of the center of pressure trajectory during walking. Therefore, the aim of the study was to examine the relationship between parameters related to the gait butterfly diagram and the level of neurological impairment in PwMS. Specifically we examined whether the gait butterfly parameters can differentiate between MS patients with normal cerebellar function and those suffering from ataxia. Demographic, neurological and gait parameters were collected from 341 PwMS, 213 women, aged 42.3 (S.D. = 13.8). MS participants with ataxia demonstrated higher scores relating to the butterfly gait variability parameters compared to PwMS with normal or slightly abnormal cerebellar function. According to the results of the binary regression analysis, gait variability in the ant-post direction was found to explain 18.1% of the variance related to cerebellar function; $R^2 = 0.181$, $\chi^2_{(1)} = 67.852$, $P < 0.001$. Measurements derived from the butterfly diagram are proper estimators for important neurological functions in PwMS and should be considered in order to improve diagnosis and assessment of the MS population.

1. Introduction

Multiple sclerosis (MS) is the most common progressive neurological disease [1] and the main cause of non-traumatic neurological disability in young adults [2]. Symptoms of MS are multifold and varied. They include visual disturbances, pyramidal signs (muscle weakness and spasticity), sensory dysfunction, incoordination, mobility difficulties and cognitive impairment [3]. People with MS (PwMS) frequently experience walking and balance impairment. Approximately 85% of PwMS report gait disturbances as their main complaint [4], and within 15 years of MS onset, up to 50% PwMS require walking assistance [5].

Walking and balance impairments are significant risk factors for falls [6]. Furthermore, PwMS with walking difficulties may fear falling, thus leading to activity curtailment, reduced participation, physical deconditioning and substantial reduction in quality of life [7]. Worth noting, any decline in mobility and function of PwMS dramatically increases the economic burden of the disease [8,9]. Therefore, gait assessment on a regular basis is essential for proper management of PwMS.

Measures of gait and balance in PwMS usually include clinically based tests (e.g., the 2-minute walk test, the Timed Up and Go test, the Timed 25-Foot Walk test) and laboratory based tests that are accessible in many medical settings. The latter option includes instrumented equipment, i.e. electronic walking mats, pressure insoles and posturography devices. The primary advantages of these tools are their ability to generate quantified values of gait and balance components, thus enabling exposure of subtle variations usually invisible to the naked eye. Moreover, early identification of walking and balance impairments, can promote intervention programs at a stage when patients will be able to benefit the most, focusing on decreasing accidental falls.

A common parameter collected by many of the instrumented devices is the center of pressure (CoP) movement [10,11]. Previous studies have demonstrated that CoP trajectory measurements during walking and standing relate to the clinical and radiological aspects of MS. In a series of papers published by Prosperini et al. [12–14], elevated trajectories of CoP during standing, were associated with falls, atrophy of the spinal cord, supratentorial associative white matter bundles and gray matter atrophy of the cerebellum in PwMS.

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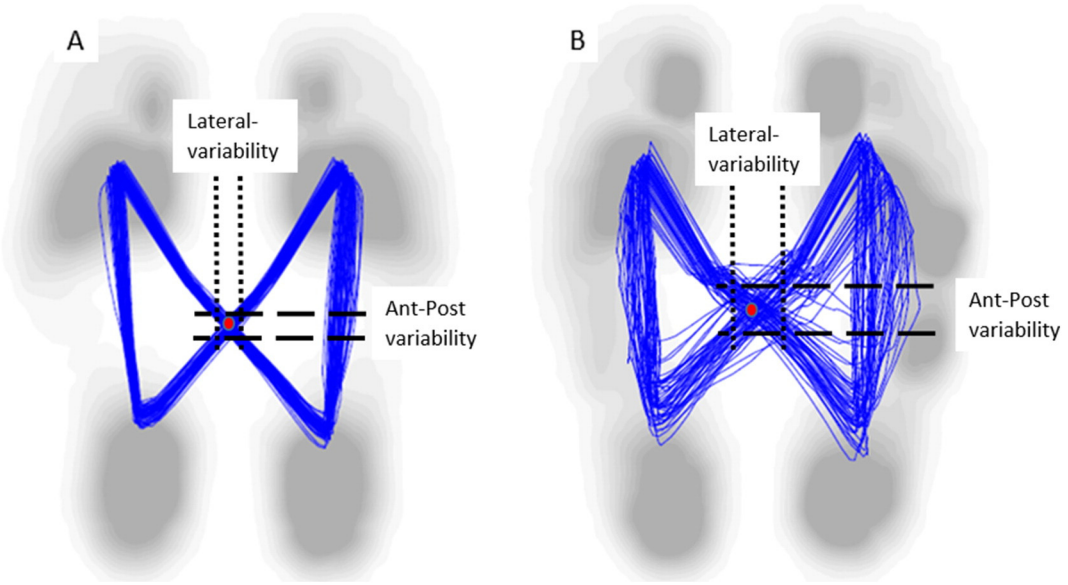

Fig. 1. Title: A butterfly diagram derived from the instrumented treadmill. Legend: Gait variability parameters derived from the butterfly diagram. Red dot indicates the intersection point of the center of pressure trajectory during walking. Dashed lines represent CoP variability in A-P and lateral directions. (A) Healthy person. (B) Person with MS (EDSS = 4.0).

During the last decade, instrumented treadmills have been introduced for gait and balance measurements. Recently, the Zebris instrumented treadmill (Zebris Medical GmbH, Germany) was found to be a valid and reliable measuring instrument for gait and balance performance [15,16]. An advantage of this device is that it measures walking over relatively long distances, possibly reflecting the fatigue component common in PwMS. In our previous report, we demonstrated that spatiotemporal gait parameters, collected by the instrumented treadmill, serve as valid markers of neurological impairment in the MS population [17].

In the current study, we focused on a unique outcome statistic of the instrumented treadmill, the "butterfly" diagram, also named the cyclogram (Fig. 1). This diagram, detailed in the method section, reflects the repeated movement of the CoP during ambulation on a treadmill, capturing in a single frame many gait characteristics essential for efficient walking. For example, the diagram represents gait variability, stride width, single/double support and symmetry in terms of weight shifting between the legs.

From a clinical standpoint, simplified graphs such as the butterfly diagram are easier to use compared to long detailed tables, especially in MS clinical settings where each medical practitioner is busy managing many patients in a relatively short time frame. Moreover, neurologists and physical therapists may view this diagram as beneficial in estimating important neurological characteristics of PwMS, such as the EDSS score and cerebellar involvement. However, to date, information regarding the relationship between the butterfly diagram characteristics and the neurological condition of PwMS are still lacking.

Therefore, our aim was to examine the relationship between parameters related to the gait butterfly diagram and the level of neurological impairment in PwMS. We also focused on cerebellar function by examining whether the gait butterfly parameters can differentiate between MS patients with normal cerebellar function and those suffering from ataxia. We hypothesized that a positive correlation exists between the butterfly gait variability parameters, level of neurological impairment and impaired cerebellar function.

2. Methods

2.1. Study participants

This study was an observational cross-sectional study comprising 341 PwMS, 213 women and 128 men, aged 42.3 (S.D. = 13.8) from the Multiple Sclerosis Center, Sheba Medical Center, Tel-Hashomer, Israel. Inclusion criteria included: (1) a neurologist-confirmed diagnosis of definite MS according to the revised McDonald criteria [18]; (2) <7.0 on the Expanded Disability Status Scale (EDSS) [19], equivalent to the ability to walk at least 20 m without resting; and (3) relapse-free

Table 1
Descriptive statistics.

	Mean (S.D.)			
	Very mild (EDSS = 0–2.5)	Mild (EDSS = 3–4)	Moderate (EDSS = 4.5–5.5)	Severe (EDSS = 6.0–6.5)
Number of patients (n = 341)	185	89	40	27
Age; years	37.8 (13.7)	47.6 (12.6)	46.8 (10.2)	48.5 (12.4)
Female	122	50	24	17
Male	63	39	16	10
Disease duration; years	4.0 (6.3)	8.1 (6.6)	7.6 (8.0)	9.8 (7.6)
Type of MS; RR/PP/SP	183/1/1	81/7/1	37/2/1	23/1/3
Mean EDSS	1.4 (0.9)	3.7 (0.4)	4.8 (0.4)	6.1 (0.2)
Cerebellar	0.4 (0.6)	1.5 (1.0)	2.1 (0.8)	2.0 (1.2)
Pyramidal	0.8 (0.8)	2.5 (0.8)	2.7 (0.9)	3.3 (0.6)
Sensory	0.5 (0.8)	1.2 (1.1)	1.4 (1.2)	1.6 (1.2)

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