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Novel characterization of gait impairments in people with multiple sclerosis by means of the gait profile score

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ABSTRACT

The assessment of gait abnormalities in individuals with multiple sclerosis (MS) represents a key factor in evaluating the effectiveness of rehabilitation treatments. Despite the availability of sophisticated equipment to objectively evaluate the kinematic aspects of gait, there are still some difficulties in processing the large and complex amount of data they produce in the daily clinical routine. On the basis of the above-mentioned considerations we propose a novel characterization of gait kinematics in individuals with MS, based on a single measure (gait profile score, GPS) obtained from a quantitative three-dimensional analysis of gait performed using an opto-electronic system. We also investigated the correlation between GPS and the Expanded Disability Status Scale (EDSS) values. Thirty-four patients suffering from relapsing–remitting MS (13 female, 21 male, mean age 46.7 years) with an EDSS score of ≤6 underwent a gait analysis from which the GPS index was calculated. Their results were compared with those of a control group of healthy age- and gender-matched subjects. The GPS of individuals with MS was found significantly higher with respect to controls (9.12° vs. 5.67°, $p < 0.001$) as the result of kinematic differences in gait patterns referring to pelvic tilt and rotation, hip flexion–extension and rotation, knee flexion–extension and ankle dorsi- and plantar-flexion. A moderate correlation was also found between the EDSS score of the participants and their GPS values ($r = 0.63$, $p < 0.001$). The GPS index thus appears suitable to represent gait deviations from physiological patterns in individuals affected by MS and potentially useful in assessing the outcomes related both to rehabilitation programs and pharmacologic/physical therapies.

1. Introduction

Multiple sclerosis (MS) is a chronic disease of the central nervous system (CNS) that affects a wide range of neurologic functions including cognition, vision, muscle strength and tone, coordination, sensation and balance. Individuals with MS often exhibit gait abnormalities (e.g. reduced walking speed, step length, cadence and increased step width [1]) and 35–60% of them are forced to use mobility aids 15 years after the onset [2,3]. Such impairment is one of the main determinants of neurological disability that produces a reduction in autonomy and quality of life and this justifies the huge efforts put into the development of physical therapies and rehabilitation programs necessary to improve, at least partly, some functionalities damaged by the progression of the disease [4]. The best approach to improving MS patients' quality of life is to prevent disability accumulation through the use of available "disease modifying drugs". However, the response to available drugs is not optimal in all MS patients and frequently an escalating approach, using more powerful but less safe drugs, will be needed to stop the disease.

Thus, it is very important to have available reliable and accurate techniques to assess the degree of deviation from a physiological gait pattern as well as to detect even slight changes in it consequent to pharmacological or rehabilitative treatment.

As in many neurological disorders, such evaluations are typically approached by direct observation of the clinician supported by a timed analysis (such as 10 m/25 ft walking test), functional scales (Ambulation Index, Rivermead Mobility Index etc.) and questionnaires [1,5]. Information derived from neurological evaluation is included in the "Expanded Disability Status Scale" (EDSS), the instrument most widely used to evaluate disability in MS, in both daily clinical practice and trials. The EDSS scale, despite being the gold standard for classifying MS impact severity, presents several critical points and an important inter- and intra-rater variability [6]. It is therefore essential to find new tools, complementary to the clinical scales, able to supply objective and quantitative data useful in supporting clinical assessment of the disability as well as its variations across time.

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In the last decade, limited attempts to objectively acquire quantitative data on gait alterations of MS patients have been performed using video analysis [7] computerized walkways[8–11], accelerometers [12, 13] and three-dimensional quantitative movement analyses based on optoelectronic stereophotogrammetry [14–19]. In particular, the latter technique, which is often referred to as gait analysis (GA) when gait is specifically investigated, is able to supply a very detailed and accurate representation of gait patterns through a combination of kinematic, kinetic and electromyographic (EMG) data.

Nevertheless, the use of GA in the clinical diagnostic routine for MS has been questioned as it requires highly specialized personnel (for both data acquisition and interpretation) and is expensive and time-consuming [1,8].

In particular, the large amount and complexity of available data, usually expressed in the form of kinematic and kinetic trends across the gait cycle for each articular district of interest (pelvis, hip, knee and foot) and EMG signals associated with muscular activation, make it difficult for physicians to easily assess the patient's status in a short time and with a single or reduced set of measures.

To overcome such difficulties and make GA at least partly suitable for clinical uses, researchers have attempted to define summary measures that should immediately give either an idea of gait quality or define the degree of deviation from a normal gait pattern. A detailed historical and technical overview of the several indexes proposed for this purpose can be found in a recent paper by Cimolin and Galli [20].

Among such indexes, the gait profile score (GPS [21]) has recently gained popularity. It represents a single index able to summarize the overall quality of an individual's gait on the basis of a set of kinematic measurements.

This approach has already been found reliable when tested on children and adults affected by cerebral palsy [21], Ehlers–Danlos syndrome [22] and a wide spectrum of orthopedic and neurologic pathologies [23]. Thus, GPS appears suitable for use in evaluating gait alteration associated with both neurological and non-neurological disorders, and has been found well correlated with clinicians' ratings of kinematic gait deviations [24]. However, to the authors' knowledge, no studies have yet been performed to assess the usefulness of such an approach in individuals affected by MS. Given the huge impact of this pathology on patients' mobility (and thus quality of life), it would be desirable to have available a summary measurement able to monitor the progression of the disease as well as to assess the effectiveness of pharmacological and rehabilitative treatments.

On the basis of the aforementioned considerations, this study intends: 1) to verify the feasibility of the use of GPS to characterize gait alterations in a sample of individuals affected by MS by comparing their GPS values with those of a control group of healthy subjects, 2) to investigate the existence of possible correlations between the Expanded Disability Status Scale (EDSS) and the GPS value, as well as with its distinct kinematic components and 3) to evaluate the potentiality of GPS as a complementary parameter in the follow-up of motor impairment in MS.

2. Methods

2.1. Subjects

Thirty-four patients suffering from relapsing–remitting MS (13 female, 21 male, mean age 46.6 ± 10.9 years) with an EDSS score of ≤6 (range 1.5–6, mean EDSS 3.5 ± 1.1) currently followed at the Multiple Sclerosis Centre of Cagliari (Sardinia, Italy) were enrolled in the study. The main criteria for inclusion were a diagnosis of MS according to the 2005 McDonald criteria [25], the ability to walk independently without any assisting devices (i.e. canes, crutches or walking frames) for at least 20 m and the absence of lower limb traumas able to affect gait. Neurological disability was evaluated for each patient by a neurologist expert in MS.

A control group (CG) of the same size, composed of healthy subjects free of any musculoskeletal disorder and gender- and age-matched (mean age 45.8 ± 12.3), was recruited after a public announcement. The main anthropometric features of the participants are shown in Table 1.

The ethics committee of the local Health Agency approved the study and all participants signed an informed consent agreeing to participate in the study.

2.2. Kinematic data collection and processing

Prior to the tests, a number of participants' anthropometric measures were collected. In particular, data on height, weight, anterior superior iliac spines (ASIS) distance, pelvis thickness, knee and ankle width, leg length (distance between ASIS and medial malleolus) were acquired using a digital scale, an ultrasonic height measurement device, a pelvimeter and a flexible meter. Then, 22 spherical retro-reflective passive markers (14 mm diameter) were placed on the skin of individuals' lower limbs and trunk at particular landmarks following the protocol described by Davis et al. [26].

The participants were asked to walk barefoot at a self-selected speed (which was recorded for each trial) in the most natural manner possible on a 10 m walkway for at least six times, allowing suitable rest times between the trials.

The acquisition of kinematics associated with the body segments of interest (trunk, pelvis, thigh, shank and foot) was performed using an optoelectronic system composed of eight Smart-D cameras (BTS Bioengineering, Italy) set at a frequency of 120 Hz.

The raw data were then processed with the dedicated software Smart Analyzer (BTS Bioengineering, Italy) to calculate the summary measure values for each limb (i.e. the gait profile score) as described below.

2.3. Gait profile score (GPS)

This summary measure of gait quality was recently proposed by Baker et al. [21] on the basis of the previously defined gait deviation index [27]. Basically, the GPS (expressed in degrees) represents the root mean square (RMS) difference between a patient's data and the mean value obtained from tests performed on the unaffected population calculated for a set of kinematic variables on the whole gait cycle [21]. In particular, the use of nine relevant variables, namely pelvic tilt, rotation and obliquity, hip flexion–extension, adduction–abduction and rotation, knee flexion–extension, ankle dorsiflexion and foot progression was suggested; the RMS difference referring to each of them is defined as the gait variable score (GVS).

Fig. 1 shows an example of GVS calculation referring to knee flexion–extension during the gait cycle for two MS patients characterized by different disability levels. As seen in the diagram, a more severe impairment leads to a greater distance between the patient's curve and that of the unaffected subject; correspondingly, the GVS score increases, thus indicating larger deviations from a hypothetical "normal" gait.

Table 1
Anthropometric features of the participants. Values are expressed as mean ± SD. The symbol * denotes a significant difference between MS and CG ($p < 0.05$).

	MS	CG	*p*-value
Participants # (M,F)	34 (21 M, 13 F)	34 (21 M, 13 F)	–
Age (years)	46.6 ± 10.9	45.8 ± 12.3	0.523
Body mass (kg)	66.5 ± 14.3	68.3 ± 12.9	0.578
Height (cm)	167.9 ± 6.9	166.6 ± 7.3	0.454
BMI (kg m^{-2})	23.4 ± 3.9	24.5 ± 3.9	0.250
Walking speed (s^{-2})	0.90 ± 0.28	1.35 ± 0.08	<0.001*
EDSS score	3.5 ± 1.1	–	–