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# The Required Coefficient of Friction for evaluating gait alterations in people with Multiple Sclerosis during gait

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ABSTRACT

*Background:* Required Coefficient of Friction (RCOF) is one of the most critical gait parameters associated to the occurrence of slipping in individuals affected by neurological disorders characterized by balance impairments. This study aims to calculate RCOF in people with Multiple Sclerosis (MS) on the basis of three-dimensional Gait Analysis (GA) data.

*Methods:* This study enrolls 22 people with MS (pwMS) who were characterized by an Expanded Disability Status Score in the range 1.5–6 and 10 healthy controls (HC). All participants underwent to three-dimensional GA from which we extracted kinematic and kinetic data (i.e. the Ground Reaction Forces, GRF, and joint moments and powers in the sagittal plane). RCOF was calculated as the ratio of the shear to normal GRF components during the stance phase of gait cycle, and normalized by the walking velocity. Thus, the following variables were extracted: first peak (named P1COF), valley (named V1COF), and second peak (named P2COF) in RCOF curve; also computating the maximum ankle dorsi-plantarflexion moment (MOMmax) and the maximum ankle joint power (PWRmax).

*Results:* Our data revealed that P2COF results are significantly lower in pwMS when compared to HC (p=0.043; Z=−2.025). In pwMS, the study found a moderate, positive correlation between V1COF and MOMmax (r=0.558; p & $2lt;0.001) and a moderate, positive correlation between EDSS score and MOMmax (rho=0.622; p=0.001). While, in HC group, the study detected a moderate positive correlation between P1COF and MOM max (r=0.636; p=0.008).

*Conclusion:* Friction during mid stance and push off phases is critically important to determine whether the frictional capabilities of foot/floor interface are sufficient to prevent slips in pwMS. The impaired ankle moment in MS group causes increased P2COF in comparison to HC, increasing the risk of slipping in the critical phase of transmission of the developed forces to kinematic chain. Also, the correlation analysis among RCOF values and kinetic variables describe the interplay between V1COF and MOMmax: the higher V1COF is, the higher is MOMmax; and the different correlation the study found between COF and kinetic parameters in MS and HC group highlightes the different gait patterns of the two classes of subjects.

## 1. Background

Multiple Sclerosis (MS) is a demyelinating disease characterized by an abnormal response of the immune system directed against self components of the central nervous system (CNS) (Scheinberg et al., 1980). Eighty five per cent of people with MS (pwMS) report gait disturbance as their main complain (Cameron and Lord, 2010). Also, a range of symptoms including muscle weakness, sensory and cerebellar

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dysfunctions, spasticity, gait ataxia and the reduction of aerobic capacity due to the deconditioning may impact walking ability (Morris et al., 2002). Previous studies have shown that pwMS walk slowly with shorter stride length and longer double support phase than healthy controls (Benedetti et al., 1999; Orsnes et al., 2000; Piperno et al., 1991; Rodgers et al., 1999).

Once falls are associated with the abnormal gait patterns (Kleiner et al., 2015a), it is important to estimate the fall risk in pwMS aiming to program intervention for falls prevention. Several clinical assessments have been related to fall risk in MS, such as high Expanded Disability Status Scale (EDSS) score, Berg Balance Scale (BBS), and self-reported measurements (Sosnoff et al., 2011). However, these measures are subjective, evaluator's experience dependent and not enough sensitive to evidence the treatment outcomes. So, to explore quantitative, reliable and robust techniques to investigate different aspects of movement in MS is mandatory. Those measures can help us to better understand the risk of falls in these patients, and also to be able to quantify the effectiveness of rehabilitation techniques seeking to reduce the falls events.

Among other factors, the occurrence of slips is originated by loss of friction between the foot and the floor (Redfern et al., 2001; Chang et al., 2011). The required coefficient of friction (RCOF), which represents the ratio between the shear of the horizontal GRF components (resultant of medio-lateral and anterior-posterior GRF) and the vertical GRF, is one of the most critical gait parameters for the prediction of the risk of slipping (Chang et al., 2011; Cham et al., 2002; Lockhart et al., 2003; Redfern et al., 2001; Tsai and Powers, 2009).

This variable has been used to characterize the pathological gait in patients with stroke and Parkinson's Disease (PD). The RCOF of patients with stroke (Kleiner et al., 2014, 2015a, 2015c) and PD (Kleiner et al., 2015a) exhibited patterns that were different than those of the healthy subjects. In patients with stroke, the initial contact, the mid stance and the terminal stance seem to be critical phases for the incidence of slips. The PD patients performed lower RCOF values during the loading response and terminal stance phases in comparison with the control group. These analyses represent the first attempt to explore the RCOF curve parameters during the gait analysis; moreover, they might be used in the prediction of the real fall propensity of stroke and PD patients.

Then, the characterization of the RCOF during the gait of MS patients should provide some information about the gait features of this population. Moreover, a complete description of the interplay between the RCOF values and the ankle kinetic (flexor and extensor moment and power) could bring us new insights about the control of the dynamic balance of these patients during the gait, once the kinetics variables are able to describe the muscles reactions to maintain the balance (Redfern et al., 2001) and are related with the risk of falls (Kemoun et al., 2002; Schwenk et al., 2013; Spink et al., 2011; Lord et al., 2003; Menz et al., 2006).

Thus, the aim of this study was to calculate the RCOF values in pwMS and to correlate these variables with the kinetic gait parameters, which are fundamental in the evaluation of the adopted gait patterns and extremely powerful in the diagnosis of the pathological gait (Winter et al., 1983).

## 2. Methods

The study was approved by the local Ethics Research Committee and written informed consent was obtained by the patients.

### 2.1. Participants

Participated in this cross sectional observational study 22 pwMS currently followed at the Regional Multiple Sclerosis Center of Cagliari (Sardinia, Italy) and 10 healthy aged-matched control group subjects (HC). The pwMS were recruited on a voluntary basis according to the following inclusion criteria: (1) a clinically established diagnosis of MS defined according to the 2005 McDonald criteria (Polman et al., 2005); (2) age between 18 and 65 years; (3) EDSS score between 1.5 and 6; (4) absence of other associated medical conditions that would prevent participants from performing physical activity such as cardiorespiratory and severe osteoarticular pathologies; (5) not to be engaged in any training or rehabilitative program in the 3 months prior the beginning of the study. Neurological examination was conducted by neurologists expert in MS (EC, GC, MGM) and disability was quantified by the EDSS. Currently the EDSS is the most widely used method to estimate disability in MS. It is designed as a quantified neurological examination that consider 7 functional systems (FS): pyramidal, sensory, cerebellar, visual, brainstem, bowel/bladder and mental (Kurtzke et al., 1983). Each FS subscale range from 0 to 5 or 0 to 6 (Kurtzke et al., 1983). The EDSS global score depends from the single FS values plus the ambulatory autonomy and range from 0 (no disability) to 10 (death by MS), (Kurtzke et al., 1983).

At the time of the study, patients were on treatment with corticosteroids and disease modifying drugs, mainly, interferon-β, glatiramer acetate, fingolimod and/or with natalizumab.

### 2.2. Kinematic and kinetic data acquisition

The participant's gait was assessed at the Biomechanics and Industrial Ergonomics Lab of the Department of Mechanical, Chemical and Materials Engineering (Cagliari, Italy), using two strain-gages based force platform (BTS Bioengineering, Italy, P6000 model) for the acquisition of the kinetic variables and an optoelectronic system composed of eight Smart-D cameras (BTS Bioengineering, Italy) set at a frequency of 120 Hz for the kinematic analysis.

Twenty-two spherical retro-reflective passive markers (14 mm diameter) were placed on the skin of individuals' lower limbs and trunk at specific landmarks according to the protocol described by Davis et al. (1991). Participants were then asked to walk barefoot at a self-selected speed in the most natural manner possible at least six times on a 10 m walkway, allowing suitable rest times between the trials. As the RCOF is affected by the friction between the foot/shoes and floor, to avoid the shoes type influence the participants were asked to perform all the tests barefoot.

The raw data were then processed using the dedicated software BTS Elite Clinic, Version 3.4.109 (BTS Bioengineering, Italy) to calculate the following variables:

a) 3D Ground Reaction Force GRF [N]: i.e. the force exchanged between body and ground during the gait cycle. In particular, the three-dimensional GRF was decomposed in Anterior-Posterior (AP), Medio-Lateral (ML) and Vertical (V) components;
b) Ankle dorsi-plantarflexion moment [$N\,m\,kg^{-1}$]: it is the product between the applied force and the distance of its point of application from the ankle joint center of rotation;
c) Ankle joint power [$W\,kg^{-1}$]: it is the product between the ankle joint moment and the angular velocity at which the ankle joint is flexing or extending.

### 2.3. Required coefficient of friction (RCOF)

On the basis of the previously mentioned variables calculation, the instantaneous RCOF was first calculated as the ratio of the tangential to the vertical GRF during stance (Chang et al., 2011; Redfern et al., 2001) as follows:

$$\mathrm{RCOF} = \frac{\sqrt{(\mathrm{AP})^2+(\mathrm{ML})^2}}{\mathrm{V}} \tag{1}$$

According to Chang et al. (2011), the RCOF is typically considered