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Slip avoidance strategies in children with bilateral spastic cerebral palsy and crouch gait

Ana Francisca Rozin Kleiner[a,d], Ilaria Pacifici[a,b], Claudia Condoluci[c], Chiarella Sforza[b], Manuela Galli[a,*]

[a] Department of Electronics, Information and Bioengineering, Politecnico di Milano, Piazza Leonardo da Vinci 32, Milan, Italy
[b] Department of Biomedical Sciences for Health, Università degli Studi di Milano, via Mangiagalli 31, Milan, Italy
[c] IRCCS San Raffaele Pisana, Via della Pisana, 235, Rome, Italy
[d] University Center of Anápolis - Uni Evangélica, Anápolis, Goiás, Brazil

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ABSTRACT

Background: A slip occurs when the required friction (RCOF) to prevent slipping at the foot/floor interfaces exceeds the available friction. The RCOF is dependent upon the biomechanics features of individuals and their gait. On the other hand, the available friction depends on environmental features. Once individuals with crouch gait have their biomechanics of gait completely altered, how do they interact with a supporting surface? The aim was to quantify the RCOF in children with bilateral spastic cerebral palsy (BSCP) and crouch gait.
Methods: 11 children with crouch gait and 11 healthy age-matched children were instructed to walk barefoot at self-selected speed over a force platform. The RCOF curve was obtained as the ratio between the tangential forces (FT), and the vertical ground reaction force (FZ). Three points were extracted by the RCOF, FT and FZ curves at the loading response, midstance and push-off phases.
Findings: Children with BSCP presented higher values of RCOF in all support phase and lower gait velocity relative to the healthy controls. For BSCP group no correlation between FT and FZ were found, indicating that this group is not able to negotiate the forces during the support phase.
Interpretation: Children with BSCP and crouch gait are not able to negotiate the forces applied on the ground in support phase, so to avoid the fall, their strategy is to reduce the gait velocity.

1. Introduction

Cerebral palsy (CP) describes a group of permanent disorders of the development of movement and posture causing activity limitation that are attributed to non-progressive disturbances that occurred in the brain before or at birth (Morris, 2009; Rosenbaum et al., 2007). Bilateral spastic CP (BSCP), affects bilaterally the lower extremities more than the upper extremities in most cases. Crouch gait, one of the most common gait pathologies in patients with BSCP (Wren et al., 2005), is characterized by increased knee flexion throughout stance phase and, frequently, increased hip flexion and internal rotation (Rodda et al., 2004). The crouch gait progressively worsens over time, decreasing walking efficiency and leading to joint degeneration (Hicks et al., 2008). Moreover, crouched postures reduce the capacity of muscles to extend the hip and knee during the single limb stance phase of gait (Hicks et al., 2008) and may delay the ability to walk independently or cause tripping, falling and functional impairment (Goldstein and Harper, 2001; Rab, 1992).

A slip occurs when the required coefficient of friction (RCOF) to prevent slipping at the foot/floor interfaces exceeds the available friction (Chang et al., 2011; Redfern et al., 2001). The RCOF depends on individual and gait biomechanics features; while the available friction depends on environmental features, such as the tribology of shoes/foot soles and supporting surface characteristics (Chang et al., 2011; Redfern et al., 2001). The RCOF is calculated as the ratio of the tangential (FT – Fig. 1b) to the vertical ground reaction force (FZ – Fig. 1a) during stance phase (Chang et al., 2011; Redfern et al., 2001). During walking the FT applied to the floor cannot exceed the FZ, if it happens, a slip or a fall will occur (Redfern et al., 2001). So, the correlation between FT and FZ is an interesting tool to detect which phase of the stance is more critical to lead the children with BSCP to a fall or slip; or to observe which strategy is adapted by these patients to avoid the imbalance.

The RCOF curve is characterized by two peaks and one valley (Fig. 1c). The two peaks indicate the phases where the shear forces are higher and occur, respectively, at the loading response phase and the push-off phases (Chang et al., 2011). These are the moments when slips

* Corresponding author.
E-mail address: manuela.galli@polimi.it (M. Galli).

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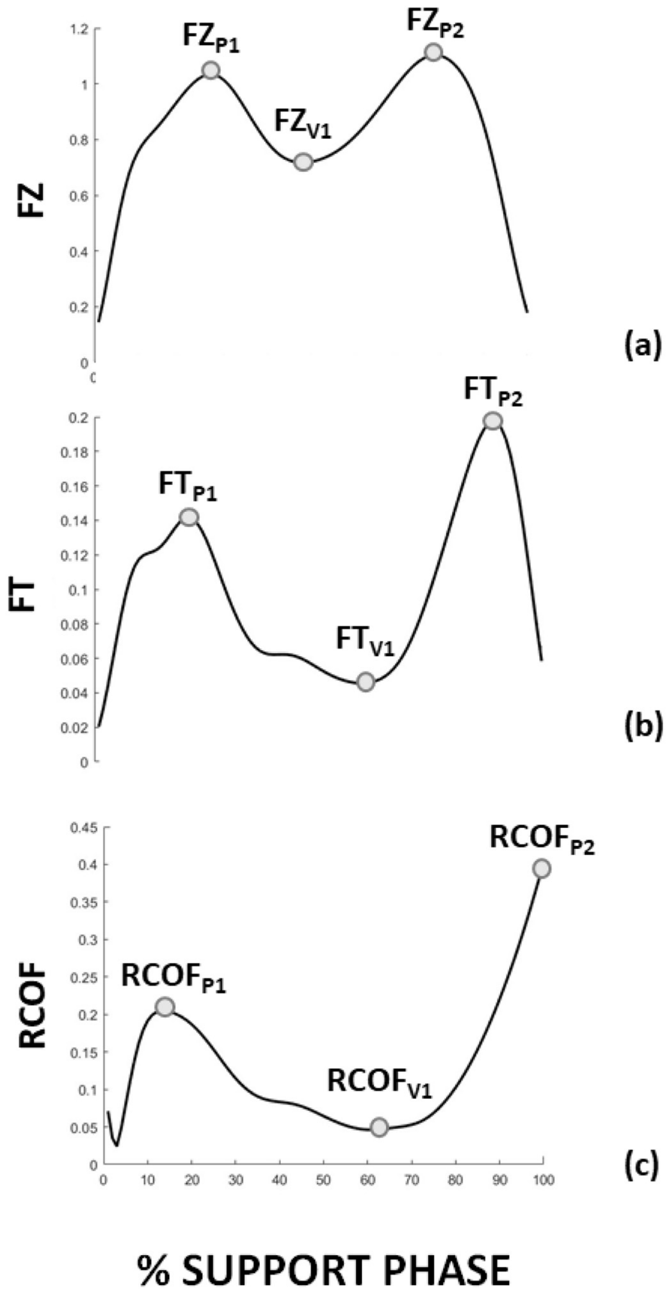

Fig. 1. Illustration of FZ (a), FT (b) and RCOF (c) curves of one child of the reference group.

are more likely to occur (Chang et al., 2011; Redfern et al., 2001). Additionally, the valley is observed in the mid-stance phase (Kleiner et al., 2015b; Kleiner et al., 2017; Pacifici et al., 2016). The lower the value of the valley, the higher the lower limb joints range of motion (Kleiner et al., 2015b; Kleiner et al., 2017; Pacifici et al., 2016).

The RCOF has already been quantified in elderly (Anderson et al., 2014; Kleiner et al., 2015b) and in subjects with Parkinson's disease, stroke and multiple sclerosis (Kleiner et al., 2014; Kleiner et al., 2015a; Kleiner et al., 2017; Pacifici et al., 2016), where the strategies used by these populations to avoid a slip or a fall were described. Subjects with Parkinson's disease, thanks to their shuffling gait pattern, presented lower RCOF values in loading response and push-off phases and higher RCOF values during mid-stance phase when compared to healthy controls (Kleiner et al., 2017). The impaired ankle range of motion control in subjects with multiple sclerosis causes an increased RCOF in the push-off phase when compared to a reference group (Pacifici et al., 2016). The stroke affected and non-affected lower limbs presented higher RCOF values at midstance and push-off phases compared to the reference group; this behavior can be explained by the stroke patients dropped foot (Kleiner et al., 2014; Kleiner et al., 2015a).

However, this parameter has never been quantified in a pediatric population. Thus, the aim was to quantify the RCOF in children with BSCP and crouch gait. The complete description of the RCOF parameters could bring us new insights about the crouch gait related kinetics, helping to identify the most critical support phase instants that could lead this population in a slip or a fall.

2. Methods

2.1. Participants

Eleven children with bilateral spastic cerebral palsy (BSCPG) were involved in this study. The inclusion criteria were: (a) children with the diagnosis of BSCP in the prenatal, perinatal or postnatal period; (b) aged between 6 and 12 years old; (c) cognitively competent and able to understand and follow instructions; (d) able to walk independently and without walking aids; (e) no history of upper or lower limb functional surgeries and of pharmacological treatments received during the last past year or within the period of study; (f) Gross Motor Function Classification System level 2 (Palisano et al., 2008); (g) had no orthopaedic conditions or fixed deformities that interfere with lower limb functions; and, (h) present crouch gait according to Rodda et al. (2004). As reference group, additional 11 healthy children, paired by age, were selected from our data base and evaluated. Table 1 presents the sample characteristics.

Written informed consent was obtained from the parents and/or guardians of the children prior to their enrolment in this study, which was conducted in compliance with the current revision of the Declaration of Helsinki and the Good Clinical Practice Guidelines.

2.2. Experimental procedures

Data collection was performed at the motion analysis laboratory of IRCCS San Raffaele Pisana, Rome (Italy), using an optoelectronic system involving 12 infrared cameras (Elite 2002, BTS, Milan, IT) with a sampling rate of 100 Hz, synchronized with 2 tri-axial force platforms (Kistler, CH) with a sampling rate of 500 Hz, and with 2 TV camera video recording systems (Video System, BTS, Italy). For data acquisition, 1 spherical retro-reflective passive marker (14 mm diameter) was placed on the child sacrum. Based on the displacement of this marked the gait mean velocity (m/s) was calculated.

The subjects were asked to walk at their self-selected speed, barefoot, along an 8-meter parquet pathway and at least six walking trials were recorded. All the data acquisition procedures were performed in the same day. The trails in which we were able to acquire the kinetic data were considered for the analysis. So, at least 3 trials were used to calculate the variables and, for the statistical analysis, the average value

Table 1
Mean and standard deviation of the anthropometric data.

Variables	Reference group	BSCP group	Comparison
N	11	11	–
Age (years)	8.13 (2.47)	7.82 (2.52)	$t_{20} = -0.264$; $p = 0.795$
Weight (kg)	35.81 (10.58)	30.09 (13.09)	$t_{20} = -1.128$; $p = 0.273$
Height (m)	1.39 (0.17)	1.28 (0.17)	$t_{20} = -1.291$; $p = 0.214$
Body Mass Index ($kg \cdot m^{-2}$)	17.50 (2.86)	16.66 (2.70)	$t_{20} = -0.649$; $p = 0.525$