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published in
Human Movement Science
2017

DOI (link to publisher)
10.1016/j.humov.2017.04.014

document version
Publisher's PDF, also known as Version of record

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Human Movement Science 54 (2017) 137–143

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

Dynamical structure of center-of-pressure trajectories with and without functional taping in children with cerebral palsy level I and II of GMFCS

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ARTICLE INFO

Keywords:
Cerebral palsy
Functional taping
Postural control
Sensory-motor integration

ABSTRACT

Postural control during quiet standing was examined in typical children (TD) and children with cerebral palsy (CP) level I and II of GMFCS. The immediate effect on postural control of functional taping on the thighs was analyzed. We evaluated 43 TD, 17 CP children level I, and 10 CP children level II. Participants were evaluated in two conditions (with and without taping). The trajectories of the center of pressure (COP) were analyzed by means of conventional posturography (sway amplitude, sway-path-length) and dynamic posturography (degree of twisting-and-turning, sway regularity). Both CP groups showed larger sway amplitude than the TD while only the CP level II showed more regular COP trajectories with less twisting-and-turning. Functional taping didn't affect sway amplitude or sway-path-length. TD children exhibited more twisting-and-turning with functional taping, whereas no effects on postural sway dynamics were observed in CP children. Functional taping doesn't result in immediate changes in quiet stance in CP children, whereas in TD it resulted in faster sway corrections. Children level II invest more attention in postural control than level I, and TD. While quiet standing was more automatized in children level I than in level II, both CP groups showed a less stable balance than TD.

1. Introduction

The levels of activity and participation in daily life of children with cerebral palsy (CP) are limited (Dos Santos, Pavão, Campos, & Rocha, 2011; Pavão, dos Santos, Oliveira, & Rocha, 2013; Pavão, Nunes, dos Santos, & Rocha, 2014), in part related to impaired postural control (Burtner, Woollacott, Craft, & Roncesvalles, 2007; Chen & Woollacott, 2007; Nashner, Shumway-Cook, & Marin, 1983). Neuromuscular impairments, muscle spasticity and muscle weakness are important determinants of postural deficits (Quinby & Abrahan, 2005; Verschuren et al., 2011). In addition, deficits in sensory processing play an important role in the impaired postural control of children with CP (Barela et al., 2011; Hadders-Algra et al., 2007; Saavedra, Woollacott, & van Donkelaar, 2010). For example, children with CP show in general larger postural perturbations (e.g. steps or falls) when sensory information is experimentally modified than typically developing children (Pavão, Silva, Savelsbergh, & Rocha, 2015, for a review).

Several studies on postural control in children with CP have explicitly addressed such sensory input variations, for example by reducing or enhancing available visual information for postural control (Barela et al., 2011; Donker, Ledebt, Roerdink,

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http://dx.doi.org/10.1016/j.humov.2017.04.014
Received 29 August 2016; Received in revised form 26 April 2017; Accepted 30 April 2017
Available online 06 May 2017

Savelsbergh, & Beek, 2008; Ledebt et al., 2005; Saavedra et al., 2010) and/or by manipulating the base of support (Chen & Woollacott, 2007; Corrêa, Corrêa, Franco, & Bigongiari, 2007). These studies showed that, compared to typically developing children, children with CP have an impaired ability to adapt postural control to sensory input variations.

In order to keep balance and avoid falls, children with CP commonly use specific postural strategies, such as standing with increased co-contraction in lower-limb musculature (Burtner, Qualls, & Woollacott, 1998; Nashner et al., 1983; Park, Park, Lee, & Kim, 2003). Although such a stiffening strategy may afford postural stability, the involved high levels of co-contraction are energetically and attentionally costly (Nashner et al., 1983; Stins, Roerdink, & Beek, 2011).

Functional bandages, such as kinesio taping and neoprene bandages, have been used in children with CP to provide an alternative means to support postural stability when applied around specific joints (Iosa, 2015; Iosa et al., 2009) or along the trajectory of specific muscles (Kara et al., 2015). It has been suggested that, in healthy young adults, the tape provides tactile stimulation that could activate gamma motor neurons to modulate Ia afferent activity allowing the continued firing of alpha neurons, leading to muscle contraction (Konishi, 2013). According to this suggestion the effect of tapping should be immediate.

To date, however, no studies are available that quantified the effects of functional neoprene bandage on postural control in children with CP, although two studies reported improvement of the sitting posture (Karabay, Doğan, Ekiz, Köseoğlu, & Ersöz, 2016; Şimşek, Türkücüoğlu, Çokal, Üstünbaş, & Şimşek, 2011). In children with CP (GMFCS level III to V), sitting posture improved after 12 weeks wearing kinesio tape applied on their back (Şimşek et al., 2011). Despite these positive effects on sitting (assessed by an observation scale), no improvements in other domains of the gross motor function or functional independence were observed. Recently, a combination of kinesio taping and neurodevelopmental therapy during four weeks improved the kyphosis in children with CP as well as the sitting posture (Karabay et al., 2016).

Interestingly, applying functional taping to children with CP is believed to influence neuromuscular function by means of stimulating cutaneous receptors (Kara et al., 2015). However, the question is to what extent children with CP may effectively utilize such taping-induced tactile information for postural control, in view of the earlier identified impairments in sensory-motor integration.

Thus, the aim of the present study was to (1) analyze postural control according to the level of gross motor function (typically developing, GMFCS I, GMFCS II); (2) examine the effects of functional taping on postural control in children with CP level I and II of GMFCS and in typically developing children. Functional taping was applied by means of neoprene bandage on the lower limbs. Postural control was examined on a force platform in quiet stance with and without functional taping, quantified using conventional posturography capturing the amount of postural sway (sway amplitude, sway path length) and dynamic posturography capturing the time-varying structure of postural sway (degree of twisting and turning, sway regularity). In line with the premise that functional taping may enhance afferent input and improve postural stability, we hypothesize a lower amount of sway with taping, most compellingly so for the CP children given their impaired postural control. We further expect changes in the dynamics of postural control with functional taping, with the additional somatosensory information provided by the taping exerts positive effect in postural control resulting in a reduction in regularity of postural sway, suggesting that they need to invest lower amount of attention in postural control (Donker, Roerdink, Greven, & Beek, 2007; Donker et al., 2008; Roerdink, Hlavackova, & Vuillerme, 2011a; Roerdink et al., 2006).

2. Methods

2.1. Participants

Three groups of children participated in the experiment. The first group consisted of 43 children with typical development, all born full term and without any musculoskeletal disorder (22 male and 21 female), aged ranged from 5 to 15 years old (mean ± SD; age: 9.9 ± 3.1 years old; height: 141.9 ± 19.7 cm; weight: 40.3 ± 17.7 kg). All the parents of the children gave their signed informed consent prior to their participation.

The second and third group comprised children with spastic CP classified according to the Gross Motor Function Classification System (GMFCS) as level I (17 children; 10 male, 7 female; 15/2 hemi-/diplegic; mean ± SD; age: 9.7 ± 3.2 years old; height: 130.7 ± 37.4 cm; weight: 31.4 ± 12.0 kg) or level II (10 children; 5 male, 5 female; 3/7 hemi-/diplegic; mean ± SD; age: 11.1 ± 2.7 years old; height: 139.9 ± 17.7 cm; weight: 35.5 ± 15.4 kg). All the children with CP demonstrated internally rotated thighs (on their affected side for children with hemiplegia and on both sides for children with diplegia). The children's classification in the level of GMFCS was performed by an experienced pediatric physical therapist.

Children with CP were recruited in specialized centers of child care. Children with CP whose parents gave informed consent to participation and complied with the following criteria were included. Inclusion criteria were: (a) ability to follow simple instructions; (b) attending physical therapy at least twice per week during the last six months. Exclusion criteria were: (a) presence of physical deformity that could compromise postural control; (b) orthopedic surgery and/or neurochemical block in the previous six months; (c) visual impairments not corrected by glasses or contact lenses. The study was approved by the local Ethics Committee (CAAE 17495213.8.0000.5504).

2.2. Procedures

Participants were instructed to stand barefoot on a force platform (Bertec400, sampling frequency 1000 Hz) with their feet parallel to and aligned with the side of their hips. While standing on the platform, the children were asked to stand as steady as

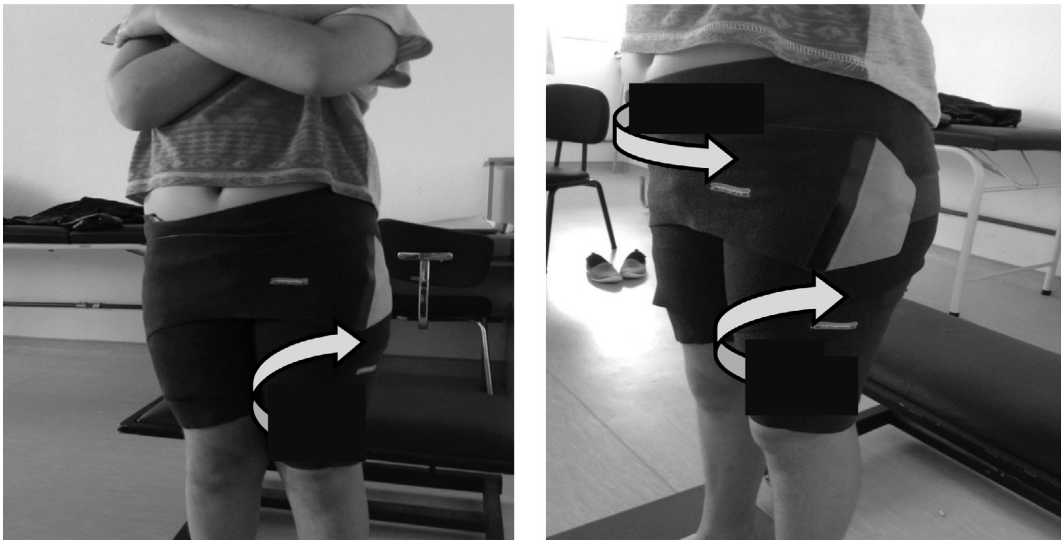

Fig. 1. Functional taping applied in lower limbs of the evaluated children.

possible for 30 s while looking at a dot positioned at eye level 1 meter in front of them. Participants performed three trials per control and functional taping condition. The order of the conditions was randomized over participants by drawing lots.

In the functional taping condition, neoprene bandage was applied bilaterally to the thigh segments. The length of the each neoprene band was 100 × 10 cm. The bandage was applied around the thigh molding a shorts in the children's thighs. It was distally anchored to the medial femoral condyles, passing through the anterior and posterior region of the thigh, continuously spiraling. The bandage was finalized proximally just cranial to the iliac crest. The traction we exerted was in the direction of external rotation of the thighs (see Fig. 1). All the children with CP presented internal rotation of one (in hemiplegic CP) or both their legs (in diplegic CP). Thus, the bandage was applied favoring the external rotation of the thighs aimed at neutralizing their alignment in the transversal plane. The placement of the taping involved the whole thigh in ascending direction. When the taping was applied on a leg that was not internally rotated (in hemiplegic children and typically developing children), its tension was neutral, not affecting the alignment of the leg.

2.3. Data analysis

We first low-pass filtered medio-lateral and anteroposterior center-of-pressure (COP) time series with a second-order Butterworth filter with a cut-off frequency of 12.5 Hz (Donker et al., 2007, 2008). Prior to further analyses, the center 20 s of the time series was selected, from which each signal's mean was subtracted. The amount of sway was quantified using two scale-dependent measures: 1) mean amplitude (MA, in mm), defined as the average COP distance to the origin of the mean-centered posturogram and 2) sway path length (SP, in mm), defined as the sum of the distances between consecutive points in the posturogram. See for more details Donker et al. (2008). The dynamical structure of postural sway was quantified using two scale-independent measures, which first required that the posturogram was normalized to unit variance by dividing medio-lateral and anteroposterior COP time series to their respective standard deviations. The normalized sway path length was determined, defined as the sum of the distances between consecutive points in the normalized posturogram (SPn, unitless). Note that a larger SPn value indicates a greater degree of 'twisting and turning' or 'curviness' in the normalized posturogram (Donker et al., 2007, 2008). The second scale-independent measure we quantified was sample entropy (SampEn, unitless; Lake, Richman, Griffin, & Moorman, 2002; Richman & Moorman, 2000), a measure reflecting the regularity in COP trajectories (Roerdink et al., 2006). SampEn is the negative logarithm of an estimate of the conditional probability that subseries of a certain number of samples matching pointwise within a specific tolerance range also match at the next sample. In other words, the smaller the sample entropy value, the greater the likelihood that matching subseries in a time series will be followed by another matching sample (hence, more regular postural sway). Likewise, highly irregular COP time series are characterized by sets of matching subseries that differ when extended by another sample (hence, yielding high sample entropy values). Sample entropy was quantified from the resultant distance time series r, normalized to unit variance, with template length $m = 2$ and tolerance range $r = 0.03$ set based on an established parameter optimization procedure (cf. Lake et al., 2002; Roerdink et al., 2006, 2011a).

2.4. Statistics

Statistical analyses were performed in SPSS (version 17.0). Repeated-measures ANOVA with Functional taping as a within-subject factor (two levels: with and without bandage) and Group as a between-subject factor (three levels: typical, CP I and CP II) was applied to all dependent variables (MA, SP, SPn, SampEn). For main effects of Group, Tukey post hoc tests were performed. Effect sizes for

Table 1
Main and interaction effects of Group (between-subject factor, three levels: Typical Development, Cerebral Palsy GMFCS level I and Cerebral Palsy GMFCS level II) and Functional taping condition (within-subject factor, two levels: with and without bandage) on Mean Amplitude (MA) and Sway Path length of the conventional posturogram (SP) and of the normalized posturogram (SPn) and Sample Entropy (SampEn).

	Group F (2, 67)	p	η_p^2	Functional taping F (1, 67)	p	η_p^2	Interaction F (2, 67)	p	η_p^2
MA	20.8	< 0.001	0.383	0.137	0.065	0.002	2.943	0.555	0.06
SP	7.627	0.001	0.185	0.344	0.559	0.005	0.993	0.376	0.029
SPn	11.181	< 0.001	0.250	0.925	0.340	0.014	4.417	0.016	0.116
SampEn	9.924	< 0.001	0.229	0.635	0.428	0.009	1.135	0.327	0.033

main and interaction effects are reported as partial eta squared (η_p^2). Significance was set at $p < 0.05$. Post-hoc paired-samples *t*-tests were used for significant interactions with Bonferroni correction.

3. Results

Statistical results for main and interaction effects of Functional taping and Group for all dependent variables are presented in Table 1.

3.1. Main effects of group and functional taping

Significant main effect of Group was found for all dependent variables (Table 1). Post-hoc analyses revealed that sample entropy (SampEn) and the degree of twisting and turning (SPn) were significantly lower for children with CP level II than for children with CP level I and typically developing children, while no significant difference was found between CP level I and typically developing children (Fig. 2). With regard to scale-dependent posturography, post hoc between-group comparisons revealed a significantly lower amount of sway for typically developing children than for children with CP level I (MA, SP) and level II (MA
Fig. 2). For none of the dependent variables, significant main effects of Functional taping were found (Table 1).

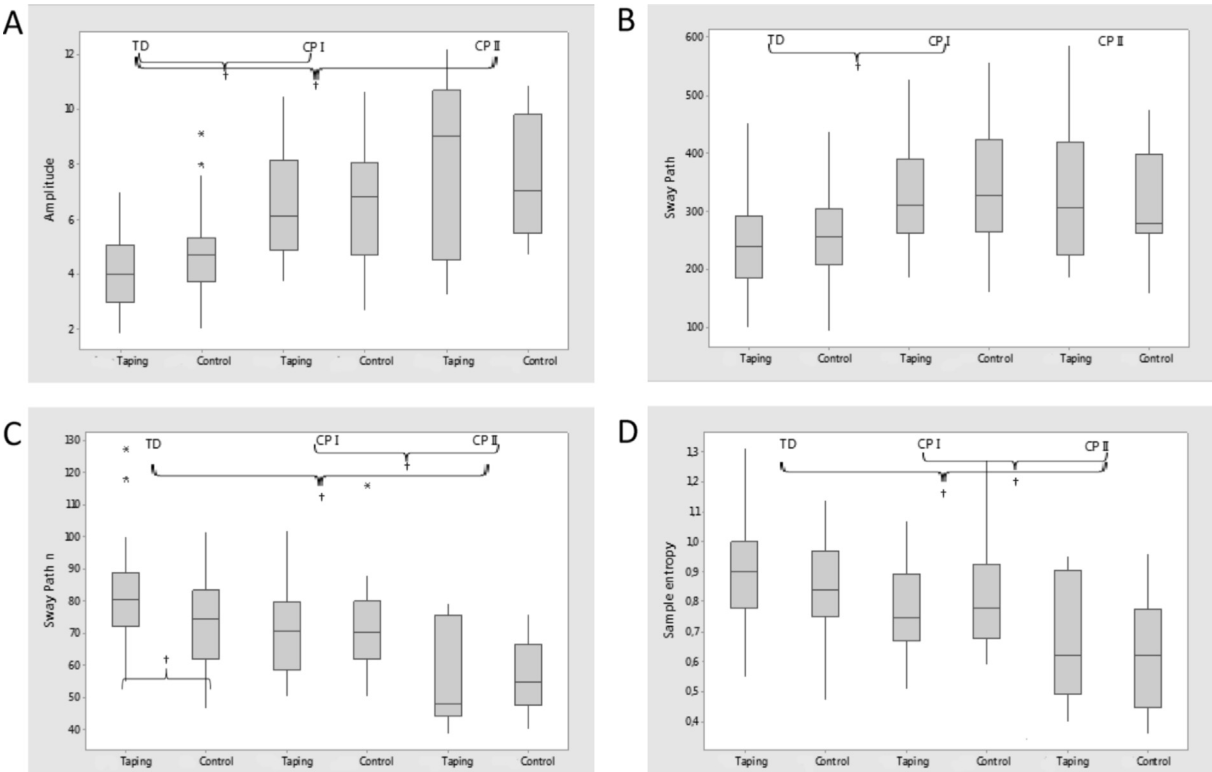

Fig. 2. Box plots as a function of group (TD: typical development; CP I: cerebral palsy level I; CP II: cerebral palsy level II) and condition (taping and control) on: (A) mean Amplitude (MA); (B) Sway Path length (SP); (C) normalized Sway Path length (SPn); (D) sample entropy ()SampEn. Asterisks represent outliers. † represent significative comparisons with post hoc analisys.

3.2. Interaction between group and functional taping

A significant interaction between group and functional taping was observed for the degree of twisting and turning (SPn) but not for the other dependent variables. Post-hoc tests revealed that in typically developing children neoprene bandage applied to the lower limbs resulted in a stronger degree of twisting and turning (M = 81.8, SE = 2.1) than without functional taping (M = 73.5, SE = 1.9), $t(42) = 4.003$, $p < 0.001$. No significant difference between the conditions was observed for the group children with CP level I, $t(16) = 0.58$, $p = 0.56$ and CP level II, $t(9) = 0.18$, $p = 0.85$.

4. Discussion

The objective of the present study was twofold: to examine conventional and dynamical characteristics of center-of-pressure trajectories in children with CP with GMFCS level I and II and in typically developing children, and to investigate whether this was affected by functional taping. We expected different postural sway dynamics with functional taping, particularly so for children with CP in relation to their gross motor impairment. We further expected that functional taping would reduce the amount of sway, most compellingly so for the CP children given their impaired postural control. However, in none of the groups did functional taping affect the amount of postural sway (Table 1). Although we found more twisting and turning with functional taping in the typically developing children, no effects of functional taping on postural sway dynamics were observed in children with CP.

Compared to previous studies examining dynamic posturography by means of the time-varying structure of postural sway during quiet stance in children with CP (Deffeyes, Harbourne, Stuberg, & Stergiou, 2011; Donker et al., 2008), the strength of the current study is the stratification of children with CP with regard to their GMFCS levels. While in both GMFCS levels I and II children are able to stand and walk independently (regardless of the type of movement impairment), children in level II may require a hand held mobility device for safety and hold onto a railing when climbing stairs. The actual results show that this difference in gross motor function between level I and level II is related to difference in patterns of postural control while standing. Overall, our results showed that the amount of sway and mean amplitude of displacement increased from typically developing children to children with CP level II, suggesting a progressive decline of postural stability related to the mobility level that was not immediately influenced by functional taping. Also the scale-independent measures showed quantitative changes over groups, with more irregular sway (higher sample entropy and more twisting and turning) for typically developing children than for children with CP. The more regular sway dynamics of children with CP suggests that they more tightly regulated their posture in terms of a higher level of co-contraction (Stins et al., 2011) and/or a greater amount of attention invested in the regulation of posture (Donker et al., 2007; Roerdink, Hlavackova, & Vuillerme, 2011b; Roerdink et al., 2006, 2011a; Stins, Michielsen, Roerdink, & Beek, 2009). In children with CP, the presence of neuromuscular (Barela et al., 2011; Quinby & Abrahan, 2005) as well as somatosensory impairments (Pavão et al., 2015; Smorenburg, Ledebt, Deconinck, & Savelsbergh, 2012) might require such a tight regulation of posture. The current study thus not only showed a clear increase in the amount of sway from typically developing children to children with CP level II, but also an increase in the tightness of postural control from typically developing children to children with CP level II. The children with CP level I did not differ that much from typically developing children, as one might expect in a group with rather mild motor impairment that does not functionally restrict performance of everyday activities (Pavão et al., 2014).

Possible reasons for the absence of functional taping effects in children with CP may be the short period of time in which the children were exposed to functional taping and the quiet stance paradigm, which may not be sensitive enough to capture functional taping effects in children with CP. So far, positive effects of functional taping have just been reported over relatively long intervention periods wearing taping (Iosa, 2015; Iosa et al., 2009), showing gains in outcome measures related to gross motor functions, such as functional independence, gross and fine motor capacity (Iosa et al., 2009; Kara et al., 2015). According to Słupik, Dwornik, Białoszewski, and Zych (2007) an improvement in the recruitment of motor units should be observed after 24 h of functional taping. In young healthy adults Kinesio taping did affect dynamic postural control after 24 h but not immediately after taping (Nakajima & Baldridge, 2013). Nevertheless, the present study evaluated the immediate effect of functional neoprene, since the children used it for few minutes, during the period of data collection. In this context we verified the absence of immediate effects only for the children with CP but not in TD children.

Although the use of functional taping could provide functional improvements in global measures of movement behavior like the Gross Motor Function Measure (Iosa et al., 2009), its use seems to be more effective for dynamical activities than static ones (Iosa, 2015). It is important to note that the working mechanism underlying functional taping remains speculative (Iosa, 2015; Kara et al., 2015; Nakajima & Baldridge, 2013). One possible mechanism is that bandage might increase skin receptor output, stimulating supraspinal centers and thereby enhancing kinesthetic and joint position sense that may be exploited in the regulation of posture (Iosa et al., 2009; Şimşek et al., 2011). In that regard, one may pose that the quiet standing task is too static to stress the tape strips and evoke a stretch-related response in cutaneous mechanoreceptors, and hence that taping does not provide eloquent additional sensory information for postural control. However, this position was not supported by our data because functional taping changed the degree of twisting and turning in typically developing children, suggesting faster corrections of sway deviations, despite the fact this group showed the smallest amount of sway. This immediate and fast effect in typically developing children suggest that local and short circuits at the spinal level are involved as suggested by Konishi (2013). It thus seems that in contrast to typically developing children, children with CP cannot immediately exploit this additional local tactile information (at thighs) to enhance short feedback loops to motor neurons. In addition, the threshold of cutaneous stimulation required to trigger a response by the receptors might also be increased in children with CP.

Another potential mechanism might involve the mechanical effect of taping the thigh muscles that affected the rotation of the lower limbs. The evaluated children with CP presented a pattern of internal rotation of either one (in hemiplegic children) or both (in children with diplegia) lower limbs from the hips to the feet. The direction of the applied bandage (external rotation) sought to counter this pattern of alignment and to improve the stabilization of the pelvis segment. Although we have not used kinematic analyses, with taping the thighs of the children appeared better aligned on visual inspection. Nevertheless, while positioning of the legs with taping resulted in a more parallel position of the feet on the floor, it clearly did not affect the posturogram.

This lack of immediate effects of functional taping in children with CP might be related to the sensory-motor integration deficits (Bair, Barela, Whitall, Jeka, & Clark, 2011; Papadelis et al., 2014; Pavão et al., 2015), which might include peripheral dysfunction (e.g., reduced sensitivity of the tactile and/or muscular receptors), central processing dysfunction (at subcortical and cortical levels) or both (Papadelis et al., 2014; Reid, Dagia, Ditchfield, Carlin, & Reddihough, 2013). While functional taping is expected to affect the sensory input at the periphery, it might not be sufficient to influence central processing in children with CP, bearing in mind i) the limited movements associated with quiet standing, ii) the limited exposure duration, iii) the application of functional taping limited to the thigh region and iv) the sensory-motor integration deficits children with CP face. Future studies on the effects of functional taping in children with CP are recommended to evaluate effects over longer time scales in both static and dynamic tasks.

Among the main limitations of our study are the small sample sizes in the groups of children with CP. Further studies with larger sample size should be conducted.

5. Conclusion

A progressively greater amount of sway and more regular sway dynamics was found from typically developing children to children with CP level I to children with CP level II, stressing the importance of GMFCS level stratification in the study of postural control. Functional taping does not result in immediate changes in quiet stance in children with CP, whereas in typically developing children it seems to result in faster sway corrections. Future studies are recommended to examine the time scale of functional taping effects in children with CP, thereby including dynamic tasks in order to increase the sensitivity of finding putative functional taping effects.

Acknowledgments

The authors declare that the study was financially supported by a grant from FAPESP (2013/13380-6) and FAPESP (2014/10562-9). The authors gracefully acknowledge Melvyn Roerdink for his invaluable suggestions and discussions and the anonymous reviewers for their helpful comments.

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