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Is interlimb coordination during walking preserved in children with cerebral palsy?

Pieter Meyns [a,*], Leen Van Gestel [b], Sjoerd M. Bruijn [a], Kaat Desloovere [b,c], Stephan P. Swinnen [b], Jacques Duysens [a,d]

[a] Department of Kinesiology, Faculty of Kinesiology and Rehabilitation Sciences, KU Leuven, Heverlee, Belgium
[b] Department of Rehabilitation Sciences, Faculty of Kinesiology and Rehabilitation Sciences, KU Leuven, Heverlee, Belgium
[c] Clinical Motion Analysis Laboratory, CERM, University Hospital Leuven, Leuven, Belgium
[d] Department of Research, Development and Education, Sint Maartenskliniek, Nijmegen, The Netherlands

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A B S T R A C T

Arm movements during gait in children with cerebral palsy (CP) are altered compared to typically developing children (TD). We investigated whether these changes in arm movements alter interlimb coordination in CP gait. 3D gait analysis was performed in CP (diplegia [DI]: $N = 15$ and hemiplegia [HE]: $N = 11$) and TD ($N = 24$) children at preferred and fast walking speeds. Mean Relative Phase (MRP, i.e. mean over the gait cycle of the Continuous Relative Phase or CRP) was calculated as a measure of coordination, standard deviation of CRP was used as a measure of coordinative stability, and the sign of MRP indicated which limb was leading (for all pair combinations of the four limbs). In HE, coordination was significantly altered, less stable and a different leading limb was found compared to TD whenever the most affected arm was included in the studied limb pair. In DI, coordination deteriorated significantly when any of the two legs was included in the studied limb pair, and coordinative stability was significantly affected when any of the two arms was included. In almost all limb pair combinations, a different limb was leading in DI compared to TD. Increasing walking speed significantly improved coordination and coordinative stability of several limb pairs in DI. Coordination and limb-leading deficits were mostly linked to the affected limb. The compensating (non-affected) arm primarily affected coordinative stability, which underlines the importance of active arm movements in HE. Increasing walking speed may be used to improve interlimb coordination in DI.

1. Introduction

Cerebral palsy (CP) is a developmental disorder resulting from injury to the central nervous system in the immature brain (Aisen et al., 2011), often leading to persistent abnormal limb strength, muscle spasticity and motor control deficits. Different types of cerebral palsy are based on the topography of the affected limbs (Dabney, Lipton, & Miller, 1997). In children with hemiplegia (HE) one side of the body is affected while in children with diplegia (DI) the lower limbs are affected more than the upper limbs (Dabney et al., 1997).

* Corresponding author at: Department of Kinesiology, KU Leuven, Tervuursevest 101, Box 1501, B-3001 Heverlee, Belgium. Tel.: +32 16329065; fax: +32 16329197.
E-mail addresses: pieter.meyns@gmail.com, Pieter.meyns@faber.kuleuven.be (P. Meyns).

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A fundamental part of the rehabilitation strategy in children with CP is focused on sustaining or improving independent locomotion. The use of arm movements during gait seems to have a potential beneficial influence on gait rehabilitation. In patients with spinal cord injury, for instance, it was found that the natural reciprocating arm swing facilitated stepping. On the contrary, weight bearing on the arms inhibited rhythmic stepping (Behrman & Harkema, 2000). Additionally, the use of sliding handles on handrails that allows for reciprocating arm swing during walking, yielded promising effects for the gait rehabilitation in stroke patients (Stephenson, De Serres, & Lamontagne, 2010; Stephenson, Lamontagne, & De Serres, 2009). Moreover, even in healthy participants, the use of arm movements has been found to improve functional mobility test scores compared to when arm movements were not allowed (Milosevic, McConville, & Masani, 2011). In children with CP, the use of arm movements has not received much attention for this purpose.

However, we recently demonstrated that arm swing during gait in CP children is altered compared to typically developing (TD) children (Meyns et al., 2011). HE children exhibited a smaller swing of the hemiplegic arm compared to TD children. Such a smaller swing could be due to weakness, spasticity and/or deficient motor control (Rose, 2009). Additionally, we reported that the arm swing amplitude on the non-hemiplegic side was significantly increased (Meyns et al., 2011), both when compared to TD children and to the unaffected arm. The latter finding has been suggested to be a compensatory strategy to control total body angular momentum (Bruijn, Meyns, Jonkers, Kaat, & Duysens, 2011). DI children, on the other hand, do not show this asymmetry in arm swing during walking, and they are able to increase arm swing amplitude with increasing walking speed (in contrast to HE children) (Meyns et al., 2011). However, DI children show increased bilateral shoulder abduction and elbow flexion (Romkes et al., 2007) and hold their hands more elevated and anterior compared to TD children during walking (Meyns et al., 2012). These arm postures are thought to be a compensation strategy to maintain stability during walking (Meyns et al., 2012).

It is expected that these arm swing alterations during gait lead to changed interlimb coordination. Alterations in arm swing during gait have been shown to affect interlimb coordination in stroke and Parkinson's disease (Wagenaar & Van Emmerik, 1994), however, it has not been assessed before in CP. Studying interlimb coordination of gait allows for assessing pathology induced spatio-temporal movement deficits rather than spatial or temporal deficits only, as is the case with traditional measures (Krasovsky & Levin, 2010). So far, most studies on CP have not gone beyond these traditional spatial and temporal quantifications of gait. Still, it has been shown that coordination measures are an important determinant of gait quality, and they are considered a meaningful goal in rehabilitation (Donker & Beek, 2002). Therefore, in the current study, we aimed to investigate interlimb coordination during walking in CP in order to assess the movement deficits of this group in an integrated manner, combining all limbs and spatial and temporal characteristics of the movements.

When studying interlimb coordination, the frequency ratio between arm movements and leg movements is often described as well. At preferred walking speeds, one arm swing is typically associated with one leg swing (i.e. 1:1 arm-to-leg swing ratio). At low walking speeds, however, a 2:1 frequency ratio with respect to the leg movements has been reported (Van Emmerik, Wagenaar, & Van Wegen, 1998; Wagenaar & Van Emmerik, 2000). At higher walking speeds, healthy adults abandon the 2:1 arm-to-leg ratio, and adopt a 1:1 arm-to-leg ratio. In subjects with central neurological deficits (e.g. stroke and Parkinson's disease), however, this 2:1 arm-to-leg swing ratio persists at higher walking speeds (Wagenaar & Van Emmerik, 1994). Interestingly, in stroke patients the hemiplegic arm shows the 2:1 arm-to-leg swing ratio, while the non-hemiplegic arm shows a 1:1 arm-to-leg swing ratio (Wagenaar & Van Emmerik, 1994).

Changes in interlimb coordination could potentially be accompanied by an alteration of the limb that is leading the movement (i.e. leading limb) and the limb that is following this leading limb (i.e. lagging limb). Such alterations in the leading limb have already been described in patients with Parkinson's disease (Nanhoe-Mahabier et al., 2011). In an interlimb cycling study, it was shown that arm cycling cadence was altered when leg cycling cadence was changed but not vice versa (Sakamoto et al., 2007). This indicates that the legs lead the arms under these conditions. Whether this is also true for gait remains to be investigated, even in healthy subjects. However, it could be that in CP patients (especially DI children), where the legs are more affected, arm movements play a more prominent role, and thereby lead the leg movements.

Since interlimb coordination has not been studied before in CP gait, the aim of the current study was first to investigate whether interlimb coordination is altered in CP gait compared to TD children. In doing so, we focused on arm-to-leg swing ratio and the leading of limbs. Since walking speed influences arm swing differently in HE and DI children, we studied interlimb coordination for two walking speeds.

2. Material and methods

2.1. Participants

The same 26 CP (4–12 y) and 24 TD children (5–12 y) from a previous study (Meyns et al., 2011) were included in the current study. The CP group consisted of 11 HE children and 15 DI children. Participant characteristics are presented in Table 1. CP children were recruited from the Laboratory of Clinical Movement Analysis of the University Hospital Pellenberg (U.Z. Leuven) and included if they (1) were able to walk without walking aids (based on the Gross Motor Function Classification System or GMFCS), (2) were diagnosed with the predominantly spastic type of CP, (3) had sufficient cooperation to follow verbal instructions, (4) did not undergo Botulinum Toxin A treatment within the past 6 months or (5) did not previously receive lower limb surgery. The GMFCS is a five level classification system that describes the gross motor function of children with CP on the basis of their self-initiated movement with particular emphasis on sitting, walking, and wheeled mobility.