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Upper body movements in children with hemiplegic cerebral palsy walking with and without an ankle–foot orthosis

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ABSTRACT

Background: It has previously been discussed that treatment of the hemiplegic arm in patients with cerebral palsy can improve gait parameters in the lower body. Our question was whether improving the ankle rocker with an orthosis has an effect on the upper body during walking. The main aim was to investigate, which trunk and arm kinematics of toe walking children with hemiplegic cerebral palsy are changed by wearing a hinged ankle–foot orthosis, restoring an initial heel contact.
Methods: Specific parameters of the pelvis, thorax, and arm kinematics were investigated. Differences in the hemiplegic side between the barefoot and the orthotic condition were calculated by Students *t*-tests. Additionally, the 95% confidence intervals were used to explore clinically relevant differences between the controls and the patients and asymmetries within the patients' affected and unaffected sides.
Findings: Pelvic tilt range of motion (barefoot: 7.5° (6.1–9.0°), orthosis: 6.6° (5.1–8.1) $P = 0.040$) and mean shoulder abduction (barefoot: 14.3° (10.2–18.4°), orthosis: 12.1° (8.4–15.8) $P = 0.027$) were the only two parameters with statistically significant differences, although not clinically relevant, between the barefoot and orthotic conditions. Abnormalities in all three planes were explored between the patients and controls. The entire trunk was more externally rotated, the pelvis stood lower, and the elbow was more flexed on the hemiplegic side compared to the unaffected side.
Interpretation: A hinged ankle–foot orthosis, restoring the first ankle rocker, had no clinically relevant effects on trunk kinematics. None of the observed upper body gait deviations seemed to be secondary to or caused by toe walking.

1. Introduction

Patients with cerebral palsy (CP) are the most commonly observed patients in gait laboratories (Armand et al., 2006; Davis, 1997). Contrarily to patients with stroke, the brain damage in patients with CP occurs prenatally or in early childhood. Hemiplegic CP (hemi-CP) is one of the subgroups. These patients show involvement of the arm and leg primarily of one body side. The neuromuscular impairment is typically of a spastic nature.

Due to the unilateral impairment, hemi-CP patients demonstrate an asymmetric leg swing with a 5.5% (mean 0.47 SD 0.03 vs. mean 0.44 SD 0.03) increased amplitude on the sound side (Meyns et al., 2011). According to Wren et al. (2005), 64% of hemi-CP patients have an equinus gait, 56% a stiff knee, 54% show in-toeing, 48% have excessive hip flexion, and 47% show a crouch gait pattern.

Although, both the upper and lower body of the hemiplegic side are affected, studies on the trunk and arms during gait in hemi-CP patients are scarce (Riad et al., 2011). Hsue et al. (2009) observed the centre of mass sway to be increased in the medio-lateral and vertical amplitude in children with hemi-CP. This was supported by Galli et al. (2012), who found increased thoracic range of motion (RoM) in all three planes. Riad et al. (2011) reported a decreased RoM in the elbow and shoulder on the hemiplegic side, together with an increased flexion of the elbow. Their results are in line with Meyns et al. (2011) who found 22.9% (mean 0.13 SD 0.07 hemi-CP vs. mean 0.16 SD 0.07 controls) reduced arm swing on the involved side compared to healthy children. Further, they found the sound side to compensate by 53.3% (mean 0.27 SD0.11 sound side hemi-CP vs. mean 0.16 SD 0.07 controls) increased arm amplitude. This enhanced arm swing seemed to be driven by trunk rotation towards the unaffected side (Meyns et al., 2011). Galli et al. (2012) described a similar behaviour for the elbow, but they did

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not find a significant difference in the shoulder RoM in the sagittal plane. Nevertheless, they reported increased shoulder abduction in both arms, which they interpreted as a movement to maintain balance while walking.

As equinus gait and equinovarus gait are amongst the most typical gait deviations in hemiplegia, hinged ankle–foot orthoses (hAFOs) are often prescribed in these patients. A hAFO blocks excessive plantarflexion in swing while allowing dorsiflexion (Buckon et al., 2001). Numerous studies have confirmed the gait improving capabilities of hAFOs for the lower body in hemi-CP patients (Balaban et al., 2007; Brunner et al., 1998; Buckon et al., 2001; Romkes and Brunner, 2002). It was reported that patients can walk with increased speed (Balaban et al., 2007; Brunner et al., 1998; Romkes and Brunner, 2002), longer stride and step length (Balaban et al., 2007; Brunner et al., 1998; Buckon et al., 2001; Romkes and Brunner, 2002), and improved single support time (Balaban et al., 2007) when wearing a hAFO compared to the barefoot condition. Most importantly hAFOs were reported to be able to reduce plantarflexion, especially during mid-swing (Balaban et al., 2007; Buckon et al., 2001; Romkes and Brunner, 2002) and at initial contact, thereby restoring a heel–toe gait. At the knee hAFOs can decrease the flexion at initial contact (Balaban et al., 2007), and prevent hyperextension in stance (Buckon et al., 2001). When wearing a hAFO, the RoM at the hip was increased and adduction was reduced compared to barefoot gait (Brunner et al., 1998). Additionally, pelvic obliquity was more symmetric (Brunner et al., 1998).

While many studies have concentrated on the effect of hAFOs on the lower body in hemi-CP patients (Balaban et al., 2007; Brunner et al., 1998; Buckon et al., 2001; Romkes and Brunner, 2002), similar studies for the upper body are scarce. Patients walking with a posterior leaf spring orthosis revealed increased RoM of the relative angle between the thorax and the pelvis (spine angle) in both the frontal and transverse planes (Molenaers et al., 2006). Degelaen et al. (2013) gave indications of increased trunk motion when hemiplegic patients walked with an ankle–foot orthosis. However, the differences seem not to be tested statistically. Brunner et al. (1998) reported a visual trend of a less pronated arm and greater arm swing when walking with hAFOs.

Spasticity of the upper body seems to restrict the lower body when walking. Treating this spasticity in the upper body by means of botulinum toxin injections can improve gait speed (Esquenazi et al., 2008) and stride time of the paretic leg in stroke patients (Hirsch et al., 2005).

Treating the upper body has been reported to improve the gait parameters in the lower body. Therefore, one could hypothesise that inverse treatment of the lower body can improve movement parameters of the upper body. The main aim of this study was to evaluate the immediate changes in upper body movements when wearing a hAFO which restored the heel–toe gait in children with hemi-CP. The second objective was to identify the clinically relevant upper body parameters that differentiate hemi-CP patients from typically developing children. Additionally, it was explored which of the trunk and arm kinematics in the patients were asymmetrical. Trunk movements are considered as an essential component of effective gait (Tyson, 1999). To know which upper body angles are improved by a hAFO is clinically relevant as it may help to differentiate primary from secondary deviations.

2. Methods

2.1. Participants

For this retrospective study all hemi-CP patients in our gait database from 2006 to 2013 were considered. The patients had to meet the following inclusion criteria: hemiplegia of type CP, aged between 8 and 18 years, no botulinum toxin-A treatment within the last six months, full-body gait analysis data of barefoot walking and with a hAFO with shoes at the same visit in the gait laboratory, no other assistive devices

Table 1
Subjects' characteristics.
Reported are means, the standard deviation (SD), as well as the 95% confidence interval within the brackets unless stated otherwise. Significant differences (Wilcoxon signed-rank test) between the hemiplegic and the unaffected side are highlighted in bold. The *P*-values are listed in the last column. Arrows indicate where the confidence intervals do not overlap.
Knee extension (*at* 90° *hip flexion*): This is the popliteal angle. It is measured with the patient laying on his/her back, with one thigh held vertically (90° hip flexion). The shank is moved to knee extension. The angle between the shank and the vertical shows the length of the hamstrings. *Knee extension* (*at hip extension*): A therapist measures the knee extension angles when the patient is laying on his/her back with the hips and legs extended. *Dorsiflexion*, *knee* 90° *flexed*, *lower ankle joint fixed*: The patient is laying on his/her back, the thigh is vertical, and the shank horizontal (90° knee flexion). A therapist assesses the passive dorsiflexion in the foot, while holding the foot in supination. Thereby, the subtalar joint as well as the midfoot are locked and do not allow compensatory dorsiflexion. The measurement evaluates the length of the m. soleus. *Dorsiflexion*, *knee extended*, *lower ankle joint fixed*: Here, the dorsiflexion is measured with the foot in supination and the knee extended to evaluate the length of the mm. gastrocnemii.
Manual muscle strength (*MMS*) *knee flexion*: The patient is laying on his/her stomach with the hip and knees extended. He/she has to flex the knee through its entire range of motion against resistance of a therapist. *MMS knee extension*: While sitting on a bench (90° hip and knees flexed), the patient has to extend the knee through its entire range of motion against resistance of a therapist. *MMS active knee extension deficit*: In a sitting position, the patient is asked to maximally extend his/her knee. When maximum active knee extension is reached, the therapist tests if further passive knee extension is possible. The active knee extension deficit is the difference between the active and passive shank positions. *MMS active plantarflexion in standing*: The patient has to rise to its toes five times standing on one leg, keeping the knee extended at any time. *MMS dorsiflexion*: In a sitting position (knees 90° flexed), the patient has to lift the foot into dorsiflexion against the resistance of a therapist.

Parameter	Controls (n = 17)		Patients (n = 23)	
Age in years (range)	12.8 (8 to 18)		12.4 (8 to 18)	
Height [m]	1.59, SD 0.14 (1.51 to −1.66)		1.49, SD 0.12 (1.43 to −1.54)	
Weight [kg]	47.8, SD 10.7 (42.1 to 53.4)		42.1, SD 13.6 (36.1 to 48.1)	
Sex [female/male]	8/9		9/14	
Hemiplegic type [type 1/2/3]	–		15/5/3	
		Unaffected side	Affected side	*P*-value
Analysed side [left/right]	9/8	11/12	12/11	
Knee extension (at 90° hip flexion) [°]*	–	**−39, SD 11 (−44 to −34)**	**−46, SD 10 (−50 to −42)**	**.001**
Knee extension (at hip extension) [°]*	–	**6.5, SD 3.1 (5.1 to 7.9)**	**2.6, SD 4.4 (0.7 to 4.6)** ↓	<**.001**
Dorsiflexion, knee 90° flexed, lower ankle joint fixed [°]*	–	**17.2, SD 4.1 (15.4 to 19.0)**	**−0.4, SD 10.2 (−4.9 to 4.1)** ↓	<**.001**
Dorsiflexion, knee extended, lower ankle joint fixed [°]*	–	**8.0, SD 4.4 (4.3 to 11.8)**	**−8.0, SD 12.4 (−13.5 to −2.6)** ↓	<**.001**
MMS knee flexion	–	**5.0, SD 0.1 (4.9 to 5.0)**	**4.5, SD 0.6 (4.2 to 4.8)** ↓	<**.001**
MMS knee extension	–	**5.0, SD 0.1 (5.0 to 5.0)**	**4.7, SD 0.3(4.5 to 4.8)** ↓	<**.001**
MMS active knee extension deficit [°]	–	0.9, SD 3.2 (−0.5 to 2.3)	2.4, SD 4.7 (0.3 to 4.4)	.125
MMS active plantarflexion in standing	–	**4.9, SD 0.3 (4.8 to 5.0)**	**3.3, SD 1.4 (2.7 to 4.0)** ↓	<**.001**
MMS dorsiflexion	–	**4.9, SD 0.2 (4.9 to 5.0)**	**3.1, SD 0.9 (2.7 to 3.5)** ↓	<**.001**

Hemi type = Classification according to Winters et al. (1987).
MMS = Manual muscle strength in clinical testing (range 0 = paralysed muscle to 5 = normal muscle strength).
↑↓ = Affected side increased/reduced compared to unaffected side according to confidence intervals.
* Joint mobility measures. Negative values indicate a deficit to reach neutral zero position.