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Short communication

The arm posture in children with unilateral Cerebral Palsy is mainly related to antero-posterior gait instability

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ABSTRACT

In this observational case-control study we aimed to determine whether altered arm postures in children with unilateral CP (uniCP) are related to gait instability in a specific direction.

Antero-posterior and medio-lateral Foot Placement Estimator instability measures and arm posture measures (vertical and antero-posterior hand position, sagittal and frontal upper arm elevation angle) were determined in eleven uniCP (7 years–10 months) and twenty-four typically developing children (9 years–6 months) at two walking speeds. Spearman-rank correlation analyses were made to examine the relationship between antero-posterior and medio-lateral arm posture and gait instability.

Arm posture in both planes was related to antero-posterior instability (e.g. sagittal and frontal upper arm elevation angle correlated moderately with antero-posterior instability; $R = 0.41$, $p < 0.001$, $R = -0.47$, $p < 0.001$). In uniCP, increased antero-posterior instability was associated with a higher ($R = -0.62$, $p = 0.002$) and more frontal position of the hemiplegic hand ($R = -0.58$, $p = 0.005$), while the non-hemiplegic upper arm was rotated more backward ($R = 0.63$, $p = 0.002$) and both upper arms rotated more sideways (hemiplegic: $R = -0.58$, $p = 0.004$; non-hemiplegic: $R = -0.55$, $p = 0.008$).

The altered non-hemiplegic (sagittal and frontal) arm posture in uniCP may be a compensation to reduce antero-posterior gait instability.

1. Introduction

The arms can be utilized to compensate for instability [1,2]. Therefore, it is not surprising that in pathology affecting balance, arm movements during gait are altered [3]. In Cerebral Palsy (CP) instability is a known cause of gait deficiencies [4]. Specifically, unilateral CP (uniCP) are known to walk with a decreased (increased) arm swing on the hemiplegic (non-hemiplegic) side [5–7], which impacts inter-limb coordination [8]. The hemiplegic arm is often held in a posture with a flexed elbow and reduced amplitude [6,7,9], likely caused by increased muscle tone [10]. They also show an altered non-hemiplegic arm posture. The elbow is flexed, and the hand is kept higher and more in front of the body during gait [7,11]. Increasing walking speed accentuated these altered arm postures in CP [11].

The arm posture in uniCP was found to be related to their step width [11]. As step width only provides information about medio-lateral gait stability, the resulting relation between medio-lateral gait instability and sagittal plane arm postures are biomechanically unexpected (as they are in different directions/planes). Nevertheless, uniCP are instable in both the antero-posterior direction and medio-lateral direction [12], using a gait stability measure that (unlike step width) takes into account center-of-mass movements with respect to the feet (Foot Placement Estimator [FPE]) [13].

Relating these FPE-measures to arm posture measures in the sagittal and frontal plane, will provide insights into the unexpected relation between step width and altered sagittal arm postures in uniCP. Therefore, we combined the results of two studies that calculated sagittal arm posture measures [11] and gait instability in two directions [12] in uniCP at two walking speeds, and added a frontal arm posture measure. We hypothesized that altered arm

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postures in the sagittal (frontal) plane in uniCP are associated to antero-posterior (medio-lateral) instability.

2. Materials and methods

We examined eleven uniCP and twenty-four typically developing (TD) children (4-12 years) from previous studies (Table 1) [11,12]. UniCP were recruited from the Clinical Movement Analysis Laboratory (UZ-Leuven). Children were excluded if they were unable to walk without walking aids, underwent Botulinum Toxin-A treatment within the last 6 months, or received lower limb surgery. Experiments were approved by the local ethical committee (UZ-Leuven) and performed with informed, written consent, conforming with the Declaration of Helsinki.

Three-dimensional total-body “PlugInGait” [14,15] kinematic data (100 Hz) were recorded with an eight camera Vicon-system (Oxford Metrics) during three walking trials. Preferred and fast walking were measured along a 10 meter walkway. Fast walking was included as altered arm postures and gait instability are more accentuated [11,12]. Marker coordinates were filtered and smoothed using Woltring’s quintic spline routine (predicted mean-squared error of 15).

Vicon Workstation and Polygon software (Oxford Metrics) were used to (manually) define gait cycles and determine spatio-temporal parameters.

Three (sagittal) arm posture measures were examined for each body side (hemiplegic/non-dominant & non-hemiplegic/dominant); (1) mean vertical hand position (Vertical_Hand_Pos), (2) mean antero-posterior hand position (AP_Hand_Pos), (3) and mean upper arm angular displacement with respect to the vertical (AP_UA_angle) over the gait cycle [11]. Vertical_Hand_Pos and AP_Hand_Pos were dived by participants’ heights.

One additional (frontal) arm posture measure was calculated; mean upper arm angular displacement with respect to the vertical over the gait cycle (ML_UA_angle).

Medio-lateral (FPE_ML) and antero-posterior (FPE_AP) FPE were calculated from total-body center-of-mass kinematics and angular momentum [12,13].

Data normality (Kolmogorov-Smirnov) and outliers (Grubbs test) were checked. All parameters between uniCP and TD were compared (hemiplegic vs non-dominant; non-hemiplegic vs dominant side) using Mann-Whitney U tests ($\alpha = 0.05$). To establish the relation between arm posture and instability, Spearman-rank correlations were determined for TD and uniCP separately, and combined. We focused on significant mild (R = 0.30–0.40), moderate (R = 0.40–0.60), or good (R = 0.60–0.80) correlations. As multiple comparisons were performed, False Discovery Rate (FDR) correction was applied.

3. Results

3.1. Summary of previous results: Instability

FPE_AP (FPE_ML) is increased (decreased) in uniCP compared to TD, and even more at fast walking speeds [12].

3.2. Summary of previous results: arm posture (sagittal)

UniCP show significantly increased Vertical_Hand_Pos (and more negative AP_UA_angle) compared to TD, especially on the hemiplegic side which increases (decreases) even more when walking fast [11].

UniCP show a significantly increased AP_Hand_Pos compared to TD [11].

3.3. Arm posture (frontal)

ML_UA_angle on the non-hemiplegic side was increased in uniCP compared to TD (median [interquartile range]; 17.45°[7.04] vs 12.31°[2.84]; U = 19, $p < 0.001$), while the ML_UA_angle on the hemiplegic side was not (12.15°[5.20] vs 11.74°[4.59]; U = 105, $p = 0.352$). When walking fast, ML_UA_angle on the non-hemiplegic (23.39°[10.77] vs 16.54°[5.25]; U = 17, $p < 0.001$) and hemiplegic side (20.39°[12.26] vs 14.41°[8.17]; U = 64, $p = 0.021$) were increased in uniCP compared to TD.

3.4. Relation between gait instability and arm posture

Arm posture measures were mainly related to FPE_AP. Step width showed moderate/good correlations to FPE_ML (Table 2A).

For TD, increased antero-posterior instability (decreased FPE_AP) was mildly associated with the dominant hand less in front of the body (AP_Hand_Pos), with increased abduction of the dominant upper arm (ML_UA_angle; Table 2B). In uniCP, antero-posterior instability was moderately/well related to a higher (Vertical_Hand_Pos) and more forward position (AP_Hand_Pos) of the hemiplegic hand, with the non-hemiplegic upper arm more in extension (AP_UA_angle) and both upper arms more in abduction (ML_UA_angle).

4. Discussion

The arm posture in uniCP was related to gait instability (as suggested by [6,7,11]). From a biomechanical point of view, we expected that medio-lateral instability is influenced by arm posture in the same plane. Strikingly we found no correlations between medio-lateral instability and frontal plane arm posture

Table 1
Characteristics of uniCP and TD children.

	TD	uniCP	Mann-Whitney U (p-value)
N	24	11	
Gender (M/F)	12/12	8/3	
GMFCS (I/II)	–	7/4	
Age (y: years, m: months)	9 y 6 m (3 y 6 m)	7 y 10 m (6 y 1 m)	89.5 (0.133)
Weight (kg)	29.50 (11.65)	22.90 (8.70)*	62 (0.012)
Height (m)	1.38 (0.20)	1.24 (0.32)*	61 (0.011)
Preferred speed step width (m)	0.80 (0.38)	0.86 (0.43)	217 (0.517)
Fast speed step width (m)	0.87 (0.22)	0.77 (0.32)	144 (0.077)
Preferred walking speed (m/s)	1.21 (0.24)	1.12 (0.25)	77 (0.052)
Fast walking speed (m/s)	2.00 (0.25)	1.63 (0.30)*	27 (<0.001)

Variables are presented as follows: median (interquartile range). TD = typically developing children, uniCP = children with unilateral Cerebral Palsy, N = number of subjects, M/F = male/female, GMFCS = Gross Motor Function Classification System.
* Significantly different from TD.