Clinical Biomechanics 29 (2014) 381–386

Contents lists available at ScienceDirect

Clinical Biomechanics

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

Movement deviation and asymmetry assessment with three dimensional gait analysis of both upper- and lower extremity results in four different clinical relevant subgroups in unilateral cerebral palsy

Dan Lundh [a,*,1], Scott Coleman [b,1], Jacques Riad [c,d,1]

[a] *University of Skövde, Box 408, 541 28 Skövde, Sweden*
[b] *Motion and Sports Lab, Baylor University Medical Center, 411 N. Washington Ave Suite 2100, Dallas, TX 752 46, USA*
[c] *Orthopaedic Department, Skaraborg Hospital Skövde, 541 85 Skövde, Sweden*
[d] *Women's and Children's Health, Karolinska Institute, 171 76 Stockholm, Sweden*

ARTICLE INFO

Article history:
Received 10 September 2013
Accepted 27 February 2014

Keywords:
Unilateral cerebral palsy
Movement pattern
Gait
Gait analysis
Deviation
Symmetry

ABSTRACT

Background: In unilateral cerebral palsy, movement pattern can be difficult to define and quantify. The aim was to assess the degree of deviation and asymmetry in upper and lower extremities during walking.
Methods: Forty-seven patients, 45 Gross Motor Function Classification Scale (GMFCS) I and 2 patients GMFCS II, mean age 17.1 years (range 13.1 to 24.0) and 15 matched controls were evaluated. Gait profile score (GPS) and arm posture score (APS) were calculated from three-dimensional gait analysis (GA). Asymmetry was the calculated difference in deviation between affected and unaffected sides.
Findings: The GPS was significantly increased compared to the control group on the affected side (6.93 (2.08) versus 4.23 (1.11) degrees) and on the unaffected side (6.67 (2.14)). The APS was also significantly increased on the affected side (10.39 (5.01) versus 5.52 (1.71) degrees) and on the unaffected side (7.13 (2.23)). The lower extremity asymmetry increased (significantly) in comparison with the control group (7.89 (3.82) versus 3.90 (1.01)) and correspondingly in the upper extremity (9.75 (4.62) versus 5.72 (1.84)). The GPS was not different between affected and unaffected sides, however the APS was different (statistically significant).
Interpretation: We calculated deviation and asymmetry of movement during walking in unilateral CP, identifying four important clinical groups: close to normal, deviations mainly in the leg, deviations mainly in the arm and those with deviation in the arm and leg. This method can be applied to any patient group, and aid in diagnosing, planning treatment, and prognosis.

1. Introduction

In unilateral cerebral palsy (CP), even though the degree of involvement of the upper and lower extremities is variable, gait deviation and asymmetry is often noticeable (Riad et al., 2007; Winters et al., 1987). It is difficult to determine whether the movement deviations are directly related to the brain injury (primary), are secondary to changes developed in muscles and bone causing deformities, or are an expression of compensatory mechanisms (Gage, 2004; Miller, 2005). In addition movement deviations can be noted in the unaffected extremities (upper extremities in bilateral CP or the unaffected side in unilateral CP) and can be considered more or less primary, secondary, or compensatory. Separating unilateral and asymmetrical bilateral CP is an example of the complexity where deviations on the presumably unaffected side in unilateral CP could be a direct consequence of the affected side, or could represent asymmetrical bilateral CP involvement with primary- and possible secondary deviations, and/or compensatory mechanisms. The ability to distinguish between unilateral and asymmetrical bilateral CP is of clinical importance (Bax et al., 2005; Miller, 2005; Uvebrant, 2005).

Most existing classification systems for musculoskeletal impairments (e.g., the Gross Motor Functional Classification Scale (GMFCS) and the Manual Ability Classification System (MACS) (Carnahan et al., 2007; Damiano et al., 2006)) are based on clinical evaluation methods and typically subjective judgment (Damiano, 2007) which limit the possibility of identifying other general features of the patient's condition. Other features such as arm posturing during walking as well as stiff-knee gait and rotational malalignment of the hip are not identified within the MACS and GMFCS classifications. These classification systems are designed to address the functionality of a specific extremity. However for specific treatment, such as spasticity reduction with botulinum toxin injection in muscles and irreversible surgical intervention such as tendon lengthening and bony correction of deformity, it is important to define the movement deviation as clearly as possible. The use of each classification system on its own provides insufficient

---

* Corresponding author.
E-mail address: dan.lundh@his.se (D. Lundh).

[1] All authors were fully involved in the study and preparation of the manuscript. The material has not and will not be submitted for publication elsewhere.

http://dx.doi.org/10.1016/j.clinbiomech.2014.02.006

detail to describe distinct variability in other extremities. More detailed assessment with three dimensional GA provides the possibility of new measures of deviation and asymmetry, which give a more comprehensive assessment including movement pattern of both upper and lower extremities.

Deviation is defined as the amount/distance of the movement from normal (Baker et al., 2009; Riad et al., 2011) and the asymmetry the difference of deviation between extremities of the two sides (Dobson et al., 2007; Galli et al., 2010; Li et al., 2001; Toro et al., 2007). Symmetry implies symmetrical behavior of the extremities, measured between equivalent representatives (same angles in both sides), no matter what the actual movement is (restrained or increased motion) (Sadeghi, 2003). For example, the movement in the lower extremity on the affected side may be restrained (as in stiff knee gait; expressed as a deviation) and therefore asymmetry is noticed. On the other hand, the movement pattern on the contra-lateral unaffected side may be influenced by the stiff knee, with increased deviation (restrained or increased motion) rendering symmetry.

There are few studies on deviation and asymmetry with respect to body sides including the upper and lower extremities, as in rehabilitation and walking speed of adults (Kwakkel and Wagenaar, 2002), for example. Deviation in movement pattern and symmetry has also been used to address age and gender differences in adults' arm-swing and force (Li et al., 2001). Other studies have used deviation in movement pattern and symmetry to classify lower extremity gait patterns (Dobson et al., 2007; Galli et al., 2010; Toro et al., 2007) and to analyze upper extremity movement asymmetry during gait (Riad et al., 2011).

The aim was to develop a new, more comprehensive method to calculate deviation and asymmetry and to examine the deviation in movement pattern and asymmetry on the affected and the unaffected side in the upper and lower extremities during walking in teenagers and young adults with spastic unilateral CP.

2. Method

2.1. Study population

Forty-seven patients with unilateral cerebral palsy, mean age 17.1 years (range 13.1 to 24.0 years), 24 females and 23 males participated. All patients were classified according to the Gross Motor Function Classification Scale (GMFCS) (Palisano et al., 1997), with 45 being GMFCS I and 2 GMFCS II, meaning that all participants were independent ambulators with no need of assistive devices. Patients were also classified according to the modified Winter's classification based on sagittal plane kinematics (Riad et al., 2007; Winters et al., 1987). A total of 21 participants were classified as Type 0, 25 as Type 1, and 1 as Type 2. In 62% of the participants, the right side was affected and in the remaining 38% the left was affected. The patients' upper extremity was not classified according to any functional assessment instrument. Cerebral palsy is defined as an irreversible, non-progressive brain injury occurring before 2 years of age. The diagnosis is made by a neuro-pediatrician with a physical examination including assessment of spasticity. In unilateral CP typical upper-extremity positioning and lower-extremity positioning are noted and besides the physical examination typical gait deviations can be found in the kinematic and kinetic data from the GA (Cans, 2000; Rosenbaum et al., 2007). Inclusion criteria were spastic unilateral (hemiplegic) CP a current age of 13 to 24 years, and the ability to cooperate during gait analysis (1.5 h). The criteria for exclusion were any disease or previous injury affecting gait, substantial developmental delay, and previous lower extremity surgery other than calf muscle lengthening surgery or spasticity treatment (botulinum toxin) within the last year. The patients were matched by age and gender to a healthy control group of 15 individuals with a median age of 18.6 years (range 13.1 to 20.0 years), consisting of 8 females and 7 males. Ethics committee approval was obtained for the study. Written consent was collected from participants or a parent/caretaker if the participant was below 18 years of age.

2.2. Three-dimensional gait analysis

All participants (patients and controls) were examined by the same physiotherapist assessing passive range of motion from standardized positions of the upper and lower extremities using a goniometer (Livingstone, 1965). Spasticity measurement was performed over the elbow, knee and ankle joint (Bohannon and Smith, 1987).

Three-dimensional gait analysis including upper and lower extremities was performed using an 8-camera motion capture system with data recorded at 100 Hz (Vicon Motion Analysis System, Oxford Metrics, Oxford, UK). Retroflective markers were placed on bony landmarks or specific anatomical positions, according to the Vicon Plug-in-Gait marker placement for the lower extremity. Pelvic and hip angles were calculated in three planes, as well as knee flexion/extension, ankle dorsi/planar flexion and foot progression. Upper extremity variables of interest included shoulder flexion/extension, shoulder abduction/adduction, elbow flexion/extension, and wrist flexion/extension. The shoulder and elbow variables were performed in accordance with the clinical gait analysis software Orthotrak. Orthotrak does not include wrist flexion/extension, thus a custom LabView application was constructed to perform a set of Euler rotations between the hand segment and the forearm segment with flexion/extension being the primary rotation. The hand segment consisted of a medial and lateral wrist marker and a third marker placed on the dorsum of the hand just proximal to the metacarpals. The forearm segment consisted of the wrist markers and a lateral elbow marker. The participants walked bare feet at a self-selected speed on a 10-meter walkway during which the gait variables and speed and distance parameters were recorded. Data from several trials were collected and as many gait cycles as possible (5–20) used, which meant that no other than obviously distorted trials were avoided. We used a minimum of 5 gait cycles per subject to calculate an average kinematic profile.

2.3. Calculation of deviation

The gait profile score (GPS) (Baker et al., 2009) was used to describe lower extremity movement deviation during walking based on pelvis, hip, knee, ankle, and foot angles in several dimensions. The GPS is a collective measure of the total deviation from the different joints in three dimensions and is calculated as the distance (in degrees) from a normal reference group using the Root Mean Square Difference (RMSD). The arm posture score (APS) (Riad et al., 2011) describes the upper extremity movement deviation during walking, using shoulder sagittal and frontal planes and elbow and wrist sagittal plane angles. The APS is calculated the same way as the GPS, using upper extremity kinematic variables instead of lower extremity variables (Fig. 1).

The results of the GPS and APS for most of these individuals (44) have previously been reported in a PhD thesis (Riad, 2011) and are accepted for publication in Journal of Pediatric Orthopedics (Riad et al., 2013).

2.4. Calculation of asymmetry

The asymmetry between extremities (or joint variables) was derived as:

$$\mathrm{Asym\_RMSD}_{\alpha}^{v-u} = \sqrt{\frac{\sum_{k=1}^{N}\left(g_k^{v(\alpha)} - g_k^{u(\alpha)}\right)^2}{N}}.$$

The asymmetry (Asym_RMSD) for a subject is α's gait vector ($g^{v(\alpha)}$); the joint/extremity (v) on one side of the corresponding vector ($g^{u(\alpha)}$); the joint/extremity(u) on the opposite side. The index (k) is the vector