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Impact of muscle activation on ranges of motion during active elbow movement in children with spastic hemiplegic cerebral palsy

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ABSTRACT

Background: Children with spastic hemiplegic cerebral palsy are restricted in their daily activities due to limited active ranges of motion of their involved upper limb, specifically at the elbow. Their impaired muscles are frequently targeted by anti-spastic treatments that reduce muscle tone. But these treatments do not necessarily improve the limb function. There is a lack of comprehensive knowledge of the quantitative relations between muscle activation and joint active ranges of motion. Consequently, the objective of this study is to quantify the impact of muscle activation on the elbow active ranges of motion.

Methods: During voluntary elbow pronation/supination and extension/flexion movements, kinematic and electromyographic measurements were collected from the involved upper limb of 15 children with spastic hemiplegic cerebral palsy (mean age = 8.7 years, standard deviation = 2.2) and the dominant upper limb of 15 age-matched children who are typically developing. Representative indicators of the muscle activation, such as the muscle co-activation, were extracted from the electromyographic measurements.

Findings: Muscle co-activation in the involved upper limb accounted for 78% and 59% of the explained variance of the supination and extension limited active ranges of motion respectively. The agonist and antagonist muscle activations were both longer in the involved upper limb.

Interpretations: This study succeeded in quantifying the impact of longer antagonist muscle activation on decreased elbow active ranges of motion in children with spastic hemiplegic cerebral palsy. Longer agonist muscle activation suggests that strengthening agonist muscles could increase the extension and supination ranges of motion, which constitutes a perspective of future clinical studies.

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1. Introduction

Spastic hemiplegic cerebral palsy (SHCP) is the most common form of cerebral palsy (Himmelmann et al., 2010). Children with SHCP are restricted in their daily activities due to limited active ranges of motion (AROM) of their involved upper limb (IUL) (Levitt, 2010; Steenbergen and Gordon, 2006). Specifically, the IUL presents reduced extension (Steenbergen et al., 2000) and supination (Kreulen et al., 2007) AROM.

In clinical practice, the IUL limited elbow AROM is often associated with muscular impairments like spasticity, mostly affecting the pronator and flexor muscles. The impaired muscles are therefore targeted by anti-spastic treatments that successfully reduce muscle tone (Levitt, 2010). But these treatments do not necessarily improve the limb function (Gracies et al., 1997; Ward, 2008).

In this context, an analysis with objective measurements of the impact of muscle activation on the elbow AROM would give a more accurate indication of the causes of reduced elbow AROM in the IUL of children with SHCP. This analysis would help target the muscles with specific treatments to improve the limb function. 3D motion capture and surface electromyography are increasingly used for upper limb movement analysis in children with SHCP. They indeed provide non-invasive and objective measurements of the AROM and muscle activation. However, there is still a lack of comprehensive knowledge of the

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Abbreviations: AROM, Active range(s) of motion; CAI, Co-activation index; DUL, Dominant upper limb; EF, Extension/flexion; EMG, Electromyography; IUL, Involved upper limb; MACS, Manual Ability Classification System; MAS, Modified Ashworth Scale; PS, Pronation/supination; SD, Standard deviation; SHCP, Spastic hemiplegic cerebral palsy; TD, Typically developing.

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quantitative relations between muscle activation and upper limb joint AROM.

To our knowledge, the impact of muscle activation on the elbow AROM in the IUL of children with SHCP has never been thoroughly studied. Only de Bruin et al. (2013) briefly addressed this issue. They found a lack of correlation between the extension AROM and the average activation of the biceps brachii at maximal extension. However, no other correlation was reported for any other muscle indicator or for any other movement.

To analyze the impact of muscle activation on the elbow AROM, quantitative indicators of the global muscle activation are necessary. Two interesting indicators of muscle activation extracted from EMG signals emerge from the studies on upper limb movements of children with cerebral palsy:

- Muscle activation expressed as a percentage of the overall movement time (Feltham et al, 2010) gives an indication on the duration of muscle activation and can highlight an increased muscle tone.
- Co-activation value (de Bruin et al, 2013) gives an indication of the amount of simultaneous activation of antagonist muscles (Ikeda et al., 1998). In healthy participants, co-activation typically provides joint stability and movement accuracy, both in the upper limb (Gribble et al., 2003; Humphrey and Reed, 1983) and the lower limb (Bowsher et al., 1993; Detrembleur et al., 1997). The interest of this indicator lies in the fact that co-activation is known to be excessive in the lower limb of children with SHCP during walking (Ikeda et al., 1998; Unnithan et al., 1996), affecting their gait. Although de Bruin et al. (2013) found no excessive biceps/triceps co-activation during reach and grasp tasks in the IUL of children with SHCP, this issue deserves further analysis.

In children with SHCP, our objective is to evaluate the impact of the activation of six key muscles on the elbow AROM during voluntary elbow pronation/supination (PS) and elbow extension/flexion (EF). The studied muscles are the biceps brachii, the triceps brachii, the brachialis, the brachioradialis, the pronator teres and the pronator quadratus. Our research hypothesis is that impaired flexor and pronator muscles limit the extension and supination AROM respectively. Specifically, longer activations of flexor and pronator muscles and excessive co-activation values are expected during these movements, with an important impact on the elbow AROM.

2. Methods

2.1. Experimentation

2.1.1. Participants

The study included 15 children with SHCP (eight boys, seven girls, mean age = 8.7 years, Standard Deviation (SD) = 2.2, range 5.9–12.5). Their medical records indicated that five children had an upper limb function score at level I, eight at level II and two at level III on the Manual Ability Classification System (MACS) (Eliasson et al., 2006). An experimented occupational therapist evaluated the spasticity levels of the IUL, using the Modified Ashworth Scale (MAS) (Bohannon and Smith, 1987). Inclusion criteria for the SHCP participants were: unilateral spastic cerebral palsy, age between 5 and 12 years. Exclusion criteria for the SHCP participants were: inability to understand or perform the tasks, botulinum toxin injections within six months before measurements or previous orthopedic surgery at the upper limbs. Table 1 lists the participant characteristics.

Fifteen typically developing (TD) children (nine boys, six girls, mean age = 9.3 years, SD = 2.0, range 5.9–12.9) were recruited as control group. The inclusion criterion for the TD children was: age between 5 and 12 years. The exclusion criterion for the TD children was: no previous orthopedic surgery at the upper limbs. The study was approved by the Research Ethics Board of Ste-Justine Hospital. Written informed consent was obtained from the child parents or guardians, and informed assent was obtained from all children.

Table 1
Demographic and clinical data for the children with SHCP. The Ashworth scale was used to evaluate the spasticity [0: none, 4: severe] and the MACS levels for classification of their manual ability (1: quite good, 5: very impaired). Abbreviations: F — Female. IUL — Involved upper limb. L — Left. M — Male. MACS — Manual ability classification system. R — Right. SHCP — Spastic hemiplegic cerebral palsy.

Participant	Age (years)	Gender	IUL	Ashworth for the IUL			MACS score
				Flexors	Pronators	Extensor	
1	8.3	F	R	2	1	0	2
2	6.8	M	R	0	0	0	1
3	5.9	M	L	0	0	0	2
4	6.2	F	R	0	1	0	1
5	7.5	M	L	1+	1+	1	2
6	9.1	F	R	1	1	0	1
7	9.3	M	R	1+	1+	0	2
8	11.3	M	R	1	1	0	1
9	8.9	M	L	1+	1	1+	3
10	6.2	F	L	0	0	0	1
11	8.2	M	R	1+	1+	0	3
12	10.8	F	L	1	1	0	2
13	12	F	L	0	1	0	2
14	7.8	F	L	1	1+	0	2
15	12.5	M	R	1	2	0	2

2.1.2. Experimental set-up

2.1.2.1. Kinematics. Kinematics was recorded by a 12-camera 3D motion analysis system (*T40Sx VICON*, Oxford) at a sampling frequency of 100 Hz. Twenty-nine retro-reflective markers were mono-laterally placed on anatomical landmarks of the hand, forearm, arm, shoulder, and thorax (Fig. 1a). See Laitenberger et al. (2014) for more details.

2.1.2.2. Electromyography. The activation of superficial muscles responsible for extension (triceps brachii longus), flexion (biceps brachii brevis, brachialis, brachioradialis), pronation (pronator teres, pronator quadratus) and supination (biceps brachii brevis) (Basmajian, 1982) was recorded using a wireless FreeEMG300 system (BTS, Milan, Italy) (Fig. 1b). Disposable self-adhesive surface Ag/AgCl electrodes with a recording diameter of 10 mm (Covidien, Mansfield, MA, USA) were placed according to the SENIAM guidelines (Hermens et al., 1999).

2.1.3. Participant instructions and measurements

The experiment was conducted according to the following six steps:

1. The dominant upper limb (DUL) of TD children and the IUL of children with SHCP were equipped with the markers and electrodes.
2. The participants sat on a height-adjustable bench, both feet flat on the floor and knees bent at 90°.
3. They were asked to relax and let their arm hang loosely for several seconds, to record a baseline signal from each EMG recording site.
4. They performed four consecutive cycles of eight distinct randomized tasks: maximum active EF and maximum active PS at three different movement frequencies (2 × 3 tasks); then two multidimensional tasks consisting in hand-to-mouth and hand-to-back, at self-chosen movement frequency (2 × 1 tasks). The experimental conditions were as follows:
    - The participants were asked to keep the shoulder, wrist and finger joints as motionless as possible during each trial. They had to keep their forearm in neutral PS position during EF tasks and their upper limb in neutral EF position during PS tasks.

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