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Altered corticomuscular coherence elicited by paced isotonic contractions in individuals with cerebral palsy: A case-control study

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ABSTRACT

The purpose of the study was to analyze corticomuscular coherence during planning and execution of simple hand movements in individuals with cerebral palsy (CP) and healthy controls (HC).

Fourteen individuals with CP and 15 HC performed voluntary paced movements (opening and closing the fist) in response to a warning signal. Simultaneous scalp EEG and surface EMG of extensor carpi radialis brevis were recorded during 15 isotonic contractions. Time–frequency corticomuscular coherence (EMG-C3/C4) before and during muscular contraction, as well as EMG intensity, onset latency and duration were analyzed.

Although EMG intensity was similar in both groups, individuals with CP exhibited longer onset latency and increased duration of the muscular contraction than HC. CP also showed higher corticomuscular coherence in beta EEG band during both planning and execution of muscular contraction, as well as lower corticomuscular coherence in gamma EEG band at the beginning of the contraction as compared with HC.

In conclusion, our results suggest that individuals with CP are characterized by an altered functional coupling between primary motor cortex and effector muscles during planning and execution of isotonic contractions. In addition, the usefulness of corticomuscular coherence as a research tool for exploring deficits in motor central processing in persons with early brain damage is discussed.

1. Introduction

Motor impairment in persons with cerebral palsy (CP) affects both muscular contractions and motor central processing. Previous research has demonstrated that children with CP display intrinsic muscle alterations (Mockford and Caulton, 2010) as well as reduced voluntary-contraction force, earlier fatigue and increased time to produce and relax muscular contractions (Barber et al., 2012; Moreau et al., 2012, 2008; Braendvik and Roeleveld, 2012; De Groot et al., 2012; Leunkeu et al., 2010; Downing et al., 2009; Tammik et al., 2008). Brain damage as it occurs in CP may also affects the neural connections between motor cortex and muscle, as well as the neural control strategy involved in performing muscle contractions in voluntary movements (Fang et al., 2009).

The correlation between oscillatory EEG (electroencephalography) and EMG (electromyography) signals in the frequency domain is called corticomuscular coherence, and is thought to reflect corticospinal coupling between motor cortex and muscle motor units during motor performance (Mendez-Balbuena et al., 2012; Kristeva et al., 2007). Moreover, it has been suggested that different motor processes could be associated with specific changes in corticomuscular coherence (Gwin and Ferris, 2012). Thus, for instance, corticomuscular coherence in alpha EEG band (8–12 Hz) seems to mirror pulsatile communication between brain and muscle (Gwin and Ferris, 2012), whereas coherence in beta EEG band (13–30 Hz) reflects the control of muscle force for producing efficient tonic and isometric contractions (Chakarov et al., 2009; Androulidakis et al., 2007; Omlor et al., 2007). In addition, corticomuscular coherence in the low range of gamma EEG band (30–45 Hz) reveals fast integration of sensory inputs required to produce self-paced phasic contractions (Schoffelen et al., 2011; Omlor et al., 2007). Moreover, static and dynamic force output has been associated with increased corticomuscular coherence in beta and low gamma EEG band, respectively (Omlor et al., 2007; Andrykiewicz et al., 2007). Finally, some studies have revealed that corticomuscular coherence is affected by changes in descending drive from spinal and cortical levels. Thus, for instance, corticomuscular coherence has proven to be altered in healthy

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individuals after inmobilization (Lundbye-Jensen and Nielsen, 2008) or in neurological conditions such as essential (Muthuraman et al., 2010) and neuropathic tremor (Weiss et al., 2010), Parkinson disease (Weiss et al., 2012), stroke (Graziadio et al., 2012; Fang et al., 2009) or pseudo-choreoathetosis (Timmermann et al., 2001). Nevertheless, there is currently no data about the effects of cerebral palsy on corticomuscular coherence.

In the present study, we compared corticomuscular coherence elicited by planning and execution of simple hand movements in individuals with CP and healthy controls (HC). The motor task consisted of opening and closing the hand (make one open and one closed fist) after a warning signal was presented. The task was chosen because it is simple and similar to natural human motion. Similar to other neurological conditions affecting the motor system, we expected that corticomuscular coherence would be altered in individuals with CP during the execution and planning of such motor task.

2. Methods

2.1. Participants

Fourteen persons with bilateral CP recruited in occupational centers of Mallorca (4 females, 10 males; mean age 29y 3mo, SD 12.7) and 15 HC (2 females, 13 males; mean age 25y 11mo, SD 8.1) were invited to participate in this study. Inclusion criteria were: (1) diagnosis of bilateral CP, and (2) appropriate cognitive level for understanding and performing task instructions. Cerebral palsy classification, gestational age at birth, mental retardation, presence of epilepsy and medication were obtained from individualś health history. The level of motor impairment was determined with the Gross Motor Function Classification Scale (GMFCS) (Palisano et al., 1997). Table 1 displays clinical characteristics of participants with CP.

Participants granted informed consent according with the Declaration of Helsinki. Healthy adults and adults with CP without legal tutors provided written informed consent. For participants under the age of 18, permission and written informed consent were also obtained from their parents or legal tutors. In the case of adults CP participants with mental retardation, parents or legal tutors provided written informed consent. Additionally, all individuals verbalized willingness to participate in the study. The study was approved by the Ethics Committee of the Regional Government of the Balearic Islands.

2.2. Hand movement task

Participants were seated in a dimly lit, sound-attenuated room in front of a computer screen, and keeping their forearms horizontally on the armchair in a mid-position between pronation and supination, and elbows at an angle of 90°. Participants were instructed to make one open fist with the right hand followed by one closed fist as fast as possible, and with the maximal possible range of motion when an acoustic and visual warning signal was presented. Each trial started with a closed fist and pacing signals were sent out every tenth second. A total of 15 trials were collected. Participants performed several practice trials before the experiment to ensure that the task was understood.

2.3. Data acquisition and preprocessing

Surface EMG signals were recorded with two 8 mm surface, silver–silver chloride (Ag/AgCl) cup electrodes placed above *extensor carpi radialis brevis* muscle (longitudinally over the mid-portion of the muscle belly) and with an inter-electrode distance of ¼ of the muscle fiber length. The site for electrode placement was prepared by abrading and cleaning the skin with alcohol to minimized skin resistance. The placement of EMG electrodes was performed according with SENIAM recommendations (Hermens et al., 2000). EMG was recorded with a sampling rate of 1000 Hz and a frequency band filter of 30–500 Hz by using one bipolar channel of an EEG/EMG amplifier (BrainAmp, Brain Products, Munich, Germany).

EMG data were integrated, rectified, and segmented off-line into epochs extending from 500 ms before to 8000 ms after the warning signal. The threshold for contraction onset and offset was individually defined as the time point when EMG activity yielded above (EMG onset) or below (EMG offset) two standard deviations above baseline (mean EMG activity before the warning signal). Following variables were calculated from the EMG data for each trial: *EMG onset latency*, time between warning signal and EMG onset; *EMG duration*, time between EMG onset and offset; and *EMG amplitude*, area under the curve between EMG onset and EMG offset. The average of these variables over the 15 trials was used for further statistical analyses.

EEG was recorded with Ag/AgCl electrodes from 64 scalp electrodes, including left and right mastoid. A nylon cap was used to place the electrodes following the international 10/20 system, and using Cz as reference. Vertical electrooculograms (EOG) were recorded bipolarly from the outer canthi of both eyes. Electrode impedance was kept below 10 kOhm. The sampling rate was 1000 Hz and a filter bandpass was set at 0.1–45 Hz. Synchronization of EMG and EEG signals was assured by recording both signals with the same amplifier, and using a trigger signal for the presentation of the warning signal.

Corticomuscular coherence between central electrodes (C3, C4) and EMG was determined at four time-windows for three EEG frequency bands (alpha: 8–12.99 Hz; beta: 15–29.99 Hz; gamma:

Table 1
Clinical characteristics of individuals with cerebral palsy (M = male, F = female, BS = bilateral spastic, D = dyskinetic, A = ataxic).

ID	Sex	Age	CP subgroup	Gestational age (weeks)	GMFCS	Mental retardation	Epilepsy	Medication
1	F	12	BS	36	2	No	Yes	Antiepileptic
2	F	12	A	40	4	No	No	No
3	M	12	BS	31	3	Mild	No	Antidepressants
4	M	21	A	40	1	Moderate	No	No
5	M	26	BS	40	1	Moderate	No	No
6	M	27	BS	40	1	Moderate	No	No
7	M	27	BS	40	3	Moderate	No	No
8	M	28	BS	40	1	Severe	No	Antidepressants
9	M	28	A	40	2	Severe	Yes	No
10	M	30	BS	30	3	No	Yes	No
11	F	35	BS	40	2	Severe	Yes	Antiepileptic
12	M	38	A	40	2	Mild	Yes	Antiepileptic
13	F	52	BS	40	4	No	Yes	Antiepileptic
14	M	54	D	32	1	Mild	No	Muscular relaxant