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Research article

Cortico-muscular coherence parallels coherence of postural tremor and MEG during static muscle contraction

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HIGHLIGHTS

- Corticokinematic coherence (CKC) can be measured during isometric hand activity.
- Cortico-muscular coherence (CMC) and CKC of the postural tremor resemble each other.
- The sources of CMC and CKC of postural tremor colocalize in the cortex.

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ABSTRACT

Corticokinematic coherence (CKC), i.e., coherence calculated between MEG and an accelerometer signal, recording movement kinematics, can be used for functional mapping of the sensorimotor cortex. Cortical sources of CKC, induced by both voluntary and passive movements, localize at the proximity of sensorimotor cortex. We tested the CKC during a static muscle contraction to compare it with simultaneously measured cortico-muscular coherence (CMC) estimated between MEG and surface EMG to study the role of postural tremor in CMC in ten healthy volunteers.

CKC was detectable also during this static task. CKC and CMC spectra had similar power distributions, and sources of CMC and CKC colocalized at the cortex in close proximity of the central sulcus. During the static hold task, the accelerometer signal originates from the postural tremor. The similarities between CMC and CKC indicate that postural tremor is related to CMC in healthy subjects.

1. Introduction

Physiological tremor is considered a general property of the neuromuscular system. It occurs during normal conditions, and is increased e.g., by stress [1]. Physiological tremor originates from complex interactions between neural events and limb-related mechanical properties [2]. However, it is unclear whether the neural or the mechanical properties are most prominent factors in the tremor. Synchronous oscillations in the central nervous system may play an important role in physiological tremor (e.g., [3]) or contribute to dominant peripheral resonance caused by the mechanical properties of the oscillating limb [4]. Nevertheless, synchronous central input may not be necessary for finger physiological tremor [5]. Physiological tremor can be enhanced by posture; this postural tremor appears during static maintenance of position against gravity [6]. Postural tremor is found in healthy controls, and is induced in the fingers with static tension of the wrist extensor muscles. Postural tremor differs from resting tremor which appears in a relaxed limb and attenuates with limb movement, and from kinetic tremor emerging during voluntary movement, as well as from isometric tremor which appears when the limb is contracted against a constant resistance [1].

Cortico-muscular coherence (CMC) is estimated between simultaneously measured magnetoencephalography (MEG) or electroencephalography (EEG) and electromyography (EMG)

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Table 1
The mean peak frequencies and maximum amplitudes of CMC and CKC (±standard deviation). Also the pooled values of CMC and CKC are shown.

The mean peak frequency (Hz) ± SD						The mean max amplitude ± SD					
CMC		CKC		Pooled CMC	Pooled CKC	CMC		CKC		Pooled CMC	Pooled CKC
Left hand	Right hand	Left hand	Right hand			Left hand	Right hand	Left hand	Right hand		
21.9 ± 7.9 p = 0.26	24.8 ± 7.4	18.0 ± 5.6 p = 0.049	23.6 ± 6.0	23.3 ± 7.6 p = 0.013	20.7 ± 6.3	0.088 ± 0.05 p = 0.953	0.111 ± 0.06	0.062 ± 0.04 p = 0.14	0.090 ± 0.04	0.099 ± 0.05 p = 0.059	0.075 ± 0.04

recordings. CMC at the 12–33 Hz frequency band has been found between motor cortex and different muscles during isometric contraction in healthy subjects (e.g., [7–9]). CMC is thought to reflect the interplay between cortex and muscle in motor coordination and to reflect central drive to the spinal motoneuron pool (e.g., [10]). More recent studies have emphasized both the efferent descending drive from the motor cortex to the muscle as well as ascending afferent drive from the muscles to the cortex in producing the CMC [11,12]. However, more detailed information about its physiological and pathophysiological mechanisms is lacking.

Conway et al. [7] and Salenius et al. [8] have observed coherence also at frequencies outside the beta band. The EMG spectra showed peaks roughly at 10 Hz (alpha), 20 Hz (beta), and 40–50 Hz (gamma band), and significant coherence was present at all three bands. However, alpha and gamma band coherence peaks were occasional findings, only present in a minority of subjects. Alpha band coherence has been associated with Parkinson's disease (PD) tremor [13], whereas gamma band coherence has been linked with very strong muscle contractions [14].

Corticokinematic coherence (CKC) was recently introduced as an alternative method for the functional mapping of the motor cortex [15]. CKC is estimated between MEG or EEG and a three-axis accelerometer signal recording the kinematics of movement. When subjects performed self-paced repetitive finger movements, a coherence peak was observed at the movement frequency and its first harmonic. The source of the CKC lies either close to the "hand knob" of the primary motor cortex or slightly posterior to it in the primary sensory cortex. As passive finger movements induce a similar CKC, it may reflect somatosensory, probably proprioceptive input to the sensorimotor cortex [16].

Sensitive accelerometers detect the slight postural tremor observed in healthy individuals. [2,4,17]. If postural hand tremor is involved in modification of CMC, the comparison between CMC and CKC during a hold task could potentially reveal a common cortical component. We measured CMC and CKC during wrist dorsiflexion, generating a sustained contraction of arm muscles in healthy controls. To our knowledge, no previous studies have compared CMC and CKC during static muscle contraction.

2. Methods

Ten healthy subjects (6 male and 4 female) aged between 22 and 58 years (mean age 30 years) were instructed to extend their wrist (dorsiflexion) for one minute at a time. The task was repeated five times with a pause of 20 s between each trial. The aim was to produce a sustained isometric contraction by using submaximal force. In a preliminary trial before the actual task the subjects extended their wrist with a maximal force to establish a baseline for the contraction force. The subjects performed the task first with the right and then with the left hand.

To obtain an EMG of the muscles activated in the motor task, a bipolar surface electrode was attached to the forearm on top of the extensor carpi radialis muscle. To record finger tremor related to muscle tension, an accelerometer (ADXL335 iMEMS Accelerometer, Analog Devices Inc., Norwood, MA, USA) was attached on the nail of the index finger in both hands. The accelerometers measured finger acceleration in three orthogonal directions.

The subjects were seated under a 306-channel neuromagnetometer (Elekta Neuromag®, Elekta Oy, Helsinki, Finland) to measure the brain activity during the task. The head position with respect to the MEG helmet was recorded continuously using the vendor-supplied head position indicator system. The recording passband was 0.03–330 Hz and the sampling rate 1012 Hz for MEG, EMG and accelerometers. The EMG signal was not rectified.

The spatiotemporal signal space separation (tSSS) [18] method implemented in MaxFilter™ software (Elekta Oy) with an 8-s time window and a subspace correlation limit of 0.9 [19] was applied to the MEG data to suppress the external and close-by artifacts before data analysis. Based on the singular value decomposition of the three orthogonal accelerometer channels, we extracted the signal corresponding to most significant singular value and used the resulting signal in subsequent analysis.

MEG and anatomical MRI were co-registered using the MRILab software (Elekta Oy). The matching provided a coordinate transformation between the head coordinates and the MRI coordinates. MR images were segmented to distinguish the brain from the surrounding tissues to provide volume for possible sources using the FreeSurfer software (MGH, Boston, MA) [20] or Seglab software (Elekta Oy).

Power spectral density (PSD) of MEG, accelerometer and EMG signals were estimated for each subject using Welch's method with 50% overlapping 1024-point Hanning windows, resulting in a frequency resolution of approximately 1 Hz.

The sensor-level coherence was estimated between the EMG or accelerometer signal and each MEG gradiometer pair in turn. Also the coherence between the EMG and the accelerometer signals were determined. The 50% overlapping 1024-point Hanning windows were used. The number of averaged segments used for

Table 2
The mean coordinates of x, y and z for CMC and CKC, and the mean differences between CMC and CKC coordinates and the confidence intervals of these differences.

The mean x-coordinate (mm)		The mean y-coordinate (mm)		The mean z-coordinate (mm)	
CMC	CKC	CMC	CKC	CMC	CKC
35.5 ± 9.0	37.2 ± 8.2	11.9 ± 8.7	12.0 ± 8.1	98.7 ± 6.0	98.4 ± 5.9
p = 0.345		p = 0.807		p = 0.701	
The mean difference					
−1.65 ± 5.2		−0.05 ± 4.4		0.24 ± 3.3	
95% confidence interval of the difference					
Lower	Upper	Lower	Upper	Lower	Upper
−4.1	0.8	−2.1	2.0	−1.3	1.8