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Neurophysiological, behavioural and perceptual differences between wrist flexion and extension related to sensorimotor monitoring as shown by corticomuscular coherence

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HIGHLIGHTS

- Our inter-antagonistic corticomuscular coherence (CMC) comparison between wrist flexors and extensors accentuates an inverse relationship between CMC and precision, as opposed to the direct relationship found in a previous intra-muscle study.
- Functional suitability, long term usage adaptation and lower perceived difficulty of wrist flexion may explain this inverse relationship.
- We add to the debate around the contradictory literature relating CMC and precision by positing the confounding effect of perceived difficulty.

ABSTRACT

Objective: To investigate the effects of neurophysiological, behavioural and perceptual differences between wrist flexion and extension movements, on their corticomuscular coherence (CMC) levels.
Methods: CMC was calculated between simultaneously recorded electroencephalography (EEG) and electromyography (EMG) measures from fifteen healthy subjects who performed 10 repetitions of alternating isometric wrist flexion and extension tasks at 15% of their maximum voluntary contraction (MVC) torque levels. Task precision was calculated from torque recordings. Subjects rated the perceived difficulty levels for both tasks.
Results: Flexors had significantly lower; peak beta CMC, peak frequency, frequency width, normalised EMG beta power, torque fluctuation (<5 Hz and beta band) and perceived difficulty ratings; but higher MVC and precision compared to extensors. EEG alpha and beta powers were non-different between flexion and extension.
Conclusions: An inverse relationship between CMC and motor precision was found in our inter-muscle study, contrary to the direct relationship found in a prior intra-muscle study. Functional suitability, long term usage adaptation and lower perceived difficulty of wrist flexion may explain the results.
Significance: We extend the CMC literature to include the clinically different, antagonistic wrist flexors and extensors and add to the debate relating CMC and motor precision by positing the confounding effect of perceived difficulty.

1. Introduction

The antagonistic wrist flexor–extensor muscle sets are distinctive as present evidence reveals that there are neurophysiological, behavioural as well as clinical differences associated with their

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motor functionality. There is sufficient evidence in humans (Palmer and Ashby, 1992; Yue et al., 2000; Vallence et al., 2012) as well as primates (Phillips and Porter, 1964; Cheney and Fetz, 1980; Mink and Thach, 1991; Keifer and Houk, 1994) to suggest that overall, upper limb flexors are more facilitated compared to extensors. This tendency is supported by the behavioural differences found by Salonikidis et al. (2011), who reported higher precision (lower coefficient of variation of force) for isometric wrist flexion compared to wrist extension; as well as Mavvidis et al. (2010) who reported faster learning and higher accuracy of forehand strokes (primarily involving flexors) compared to backhand strokes (primarily involving extensors) in Tennis. Furthermore, clinical observations have been reported such as faster motor recovery of wrist flexion compared to extension in stroke patients (Lieberman, 1986; Duncan and Badke, 1987; Little and Massagli, 2007) and greater impairment of wrist extensors in Parkinson's disease (Pfann et al., 2004).

Electrophysiological changes related to motor control can be investigated at the central and peripheral levels of the nervous systems, by using the non-invasive electroencephalogram (EEG) and the electromyogram (EMG), either independently, or in conjunction, in the form of corticomuscular coherence (CMC). CMC measures the degree of synchronisation between the oscillatory activity of the sensorimotor cortex (measured by EEG) and muscle (measured by EMG), and is prevalent in the beta band for weak to moderate isometric contractions (Halliday et al., 1998; Kristeva-Feige et al., 2002). However, this primarily phase sensitive process is deemed to be independent of other movement related amplitude changes observed in the EEG beta band (Baker and Baker, 2003; Riddle et al., 2004). In Baker's study, 20 Hz EEG power over the sensorimotor cortex doubled after administration of diazepam but no significant change in CMC was reported; conversely in Riddle's study, after administration of carbamazepine, a significant increase (89%) in beta band CMC was reported with no associated significant increase in 20 Hz EEG power. The functional role of CMC is still not fully understood; although proposed theories associate it with promoting of the existing steady motor state (Gilbertson et al., 2005); and facilitation of efficient sensorimotor monitoring of the peripheral system (Baker, 2007). CMC therefore appears to indicate an independent efferent phase adjustment process that operates in parallel with fundamental motor control processes, for the purpose of monitoring the state of the muscle through subsequent phase-synchronised afferent feedback (Witham et al., 2011). These proposed functional roles seem to match the results of Kristeva et al. (2007), who reported a direct relationship between beta CMC and motor precision, in a study involving a single muscle, where the higher precision periods had significantly higher CMC as well as EEG beta band spectral power compared to the lower precision periods.

The direct relationship between motor precision and CMC found by Kristeva et al. (2007), whilst being true for a single muscle (motor unit pool), may not necessarily hold true for comparisons between different muscle sets with varying neurophysiological properties e.g. wrist flexors-extensors. Indeed, inter-muscle CMC comparisons have been studied in the past, for example, between the upper limb vs lower limb and between proximal and distal musculature (Ushiyama et al., 2010). However, no study has investigated the relationship between motor precision and CMC of the equally distal, antagonistic, wrist flexors and extensors. We hypothesise that an inverse motor precision vs CMC relationship may exist between wrist flexors and extensors; i.e. isometric wrist flexion would be carried out at higher motor precision levels, but with lower flexor CMC levels, due to a reduced need for their sensorimotor monitoring by the cortex for stabilisation, as they are better facilitated and possibly better adapted to isometric force production compared to extensors.

We therefore aim to compare CMC (peak CMC, peak frequency, peak frequency width), as well as associated variables related to cortical activity (normalised EEG alpha and beta powers), muscle activity (normalised EMG beta power) and behaviour (motor precision) between wrist flexion and extension tasks in a high precision experiment, in order to explore this inter-muscle precision vs CMC relationship. Additionally, we will investigate any possible correlation between perception (task perceived difficulty) and beta-CMC, as we theorise that wrist flexion would be performed with greater ease (less perceived difficulty) than extension. This CMC comparison between the antagonistic wrist muscles may help to improve our overall understanding of the functional role of EEG–EMG synchronisation and also provide insight into the underlying causes of the functional differences (clinical and normative) reported between wrist flexors and extensors.

2. Methods

2.1. Subjects

Fifteen healthy male right-handed subjects (23.5 ± 2.7 years), without any history of neurological disease, participated in the study. The handedness was verified according to the Oldfield questionnaire (Oldfield, 1971). Subject participation followed approval by the university human ethics committee with written informed consent according to the declaration of Helsinki (World Medical Association, 2008).

2.2. Experimental paradigm

Subjects were seated in a dimly lit room. The right forearm was rested on a wooden support and the right hand was inserted through a perspex splint to prevent movement of the fingers relative to the hand (Fig. 1A). The wrist angle was thus maintained at 180°. The forearm was then strapped down to prevent any movement relative to the wrist. The forearm was positioned mid-way between pronation and supination to equalise the effect of gravity during extension and flexion. The MVC for each task (extension, flexion) was measured as torque about the wrist joint prior to the experiments. During a task, subjects were prompted to either hold a wrist extension (task 1) or flexion (task 2) at a target Torque (TT) of 15% MVC for 45 s. This was achieved by providing visual feedback of the actual Torque (AT) represented by a moving white indicator which was to be kept coincident to a fixed black reference marker representing the TT. To enforce high precision, additional boundary markers were placed at 15 ± 1% MVC creating an allowable window, which was not to be crossed. Indicator sensitivity was set such that an application of 1% MVC torque would result in a displacement of 10 mm in the corresponding direction (right or left, extension or flexion). The visual feedback described above

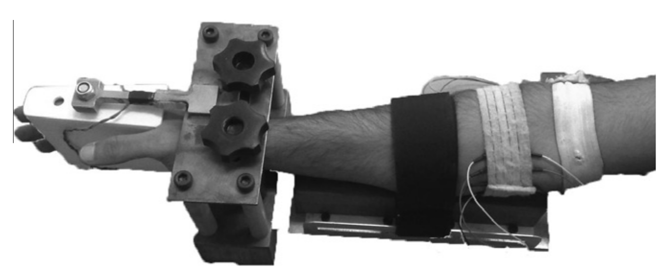

Fig. 1A. Subject carrying out isometric force maintenance task. The forearm is strapped to restrict movement; the hand is inserted into a splint to restrict finger movement with respect to the palm. Bipolar EMG electrodes are placed over corresponding flexor and extensor muscle bellies.