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Across-muscle coherence is modulated as a function of wrist posture during two-digit grasping

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HIGHLIGHTS

- EMG–EMG coherence of hand muscles is modulated as a function of wrist posture.
- EMG–EMG coherence tends to be larger in extrinsic than intrinsic muscle pairs.
- The present results suggest task-dependency of across-muscle coherence.

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ABSTRACT

The purpose of this study was to investigate the extent to which correlated neural inputs, quantified as EMG–EMG coherence across intrinsic and extrinsic hand muscles, varied as a function of wrist angle during a constant force precision grip task. Eight adults (5 males; mean age 29 years) participated in the experiment. Subjects held an object using a two-digit precision grip at a constant force at a flexed, neutral, and extended wrist posture, while the EMG activity from intrinsic and extrinsic hand muscles was recorded through intramuscular fine-wire electrodes. The integral of z-transformed coherence computed across muscles pairs was greatest in the flexed wrist posture and significantly greater than EMG–EMG coherence measured in the neutral and extended wrist posture ($P < 0.01$ and 0.05, respectively). Furthermore, EMG–EMG coherence did not differ statistically between the extrinsic and intrinsic muscle pairs, even though it tended to be greater for the extrinsic muscle pair ($P \geq 0.063$). These findings lend support to the notion of a functional role of correlated neural inputs to hand muscles for the task-dependent coordination of hand muscle activity that is likely mediated by somatosensory feedback.

1. Introduction

Dexterous manipulation requires coordinated activity of multiple hand muscles to produce fingertip forces. As several muscles insert into each digit, a given fingertip force vector can be produced through a large number of feasible muscle coordination patterns [17]. Besides the issue of muscle redundancy [2,14], our understanding of neuromuscular control of the hand is further challenged by the fact that a given fingertip force vector is the result of the combined action of extrinsic and intrinsic hand muscles, where only the former cross the wrist joint. Thus, changes in wrist joint angle change the length, and therefore force-generating capabilities, of the extrinsic but not the intrinsic muscles [1,10].

Previous evidence has suggested that the central nervous system (CNS) might simplify the control of redundant systems such as the hand by constraining the modulation of multiple hand muscles to act as a unit [6,15–17]. A study by Johnston et al. [6] indicated that extrinsic and intrinsic hand muscles were coordinated in a synergistic fashion when subjects were asked to exert a constant force during a precision grip task (thumb and index finger) at different wrist joint angles. Specifically, these authors found that electromyographic (EMG) amplitude of intrinsic and extrinsic muscles scaled uniformly with changes in wrist posture. Such a finding is not obligatory as neural activation of intrinsic muscles does not have to be modulated – their length does not change with wrist posture – as it should for extrinsic muscles. Based on these findings, Johnston et al. [6] suggested that neural inputs to hand muscles are shared across the two hand muscle groups, rather than being selectively targeted to each of the two muscle groups studied.

A complementary means through which task- or posture-dependent modulation of neural drive to hand muscles can be assessed is across-muscle coherence [3,7,8,15]. Across-muscle

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coherence between EMG signals (EMG–EMG coherence) recorded from two muscles denotes the correlation of periodic neural inputs to that muscle pair. As such, the information provided by across-muscle coherence can complement, and is non-redundant with, that provided by analysis of EMG amplitude covariation [6]. Therefore, the purpose of this study was to determine the extent to which correlated neural inputs to intrinsic and extrinsic muscles, quantified by EMG–EMG coherence, varied as a function of wrist joint angle during a constant force precision grip task.

Poston et al. [15] observed that EMG amplitude from intrinsic and extrinsic hand muscles increased with higher forces exerted through a precision grip, whereas EMG–EMG coherence did not change. However, to our knowledge there are no studies that have examined whether EMG–EMG coherence changes as a function of muscle length. Therefore, two alternative outcomes can be envisioned: (1) EMG–EMG coherence is invariant with respect to changes in EMG magnitude that accompany changes in wrist joint postures [6], or (2) EMG–EMG coherence significantly changes as a function of EMG amplitude modulation associated with changes in wrist joint angle. The results of Poston et al. [15] would suggest that changes in EMG magnitude would not be accompanied by changes in EMG–EMG coherence when fingertip forces are modulated at the same hand posture. However, it is conceivable that the neural drive necessary to maintain a given force at different muscle lengths might require a modulation of the strength of the coupling with which the same or newly recruited motor units are coordinated.

2. Materials and methods

Eight adults (5 males; mean age 29 years, range 22–45 years) participated in the experimental procedures. Subjects were without neurological and orthopedic disorders and gave written informed consent before participating in the study. The experimental procedures were approved by the Institutional Review Board at Arizona State University and were performed in accordance with the Declaration of Helsinki.

The experimental procedures have been described in detail in Johnston et al. [6]. Briefly, subjects held a grip device using the thumb and index finger tips. The device was held at three different wrist joint angles: neutral, flexed, and extended. The neutral wrist angle was set at 180° and then adjusted by ~5° to an angle that was comfortable and natural for the subject. The flexed and extended wrist angles were defined as 50% of the angle between neutral and the maximum flexed and extended wrist angles that subjects were capable of producing, respectively. Participants were required to maintain the same digit posture at all wrist angles to ensure constant intrinsic muscle lengths.

Three six-dimensional position/orientation (P/O) sensors (Polhemus Fastrak, Colchester, VT) were used to determine invariance of digit posture across wrist joint posture, as well as to measure wrist joint angle (Fig. 1). One P/O sensor was placed on the back of the hand between the first and second metacarpals. Two other P/O sensors (S2 and S3) were placed at the base of the grip device below the thumb and the index finger, respectively. S1–S3 define the vertices of a triangle denoting the digit configuration and the object orientation (see Fig. 1D in Johnston et al. [6] for more details). We rendered S1–S3 as 3-D dots on a computer monitor as feedback to subjects to help them in maintaining the same grip posture at all wrist joint angles. The target wrist joint angles and the position of the sensors at each angle were calculated as a rotation angle relative to the neutral wrist joint angle that was derived from the angular deviations of S1 in the transverse plane. Subjects were required to maintain a wrist angle within ±2° from the target wrist angle in the transverse plane (Fig. 1). Trials were repeated if subjects failed to maintain the target postures within the tolerance level throughout the recording period.

Each experiment began with the assessment of subject's two-digit maximal voluntary grip force (MVF). Subjects were asked to increase isometric grip force from rest to maximal over a period of 3 s and maintained the maximal force for 5 s. Subjects performed two MVF trials separated by approximately 60 s of rest. The total force from each maximal contraction was defined as the sum of thumb and index finger normal force and the greatest force of the two trials was defined as the MVF for normalization purposes. The experimental session consisted of five 5 s trials per wrist angle, in which the subjects held the grip device while producing a total grip force of 10% of MVF. Digit normal forces and normal to tangential force ratios were not significantly different across wrist joint angles (see Johnston et al. [6] for details on digit force analyses).

Multi-unit EMG activity was recorded from three extrinsic and two intrinsic hand muscles using intramuscular thin wire bipolar electrodes. The extrinsic muscles we recorded EMG from were the Flexor Pollicis Longus (FPL), and the index finger compartments of the Flexor Digitorum Profundus (FDP2) and Extensor Digitorum Communis (ED2). The intrinsic muscles we recorded EMG from were the First Dorsal Interosseous (FDI) and First Palmar Interosseous (FPI). EMG was sampled at 2 kHz and digit forces were sampled at 1 kHz. The EMG signals were amplified (1000×) and band-pass filtered (1–1000 Hz; grass instruments). Position data were recorded at approximately 25 Hz.

We first assessed stationarity (see below) in pairs of EMG signals to determine which signals were useable across subjects. Lack of stationarity for some muscles prevented the comparison of all muscle pairs across all wrist postures. Therefore, pooled EMG–EMG coherence was computed across the following six muscle pairs from

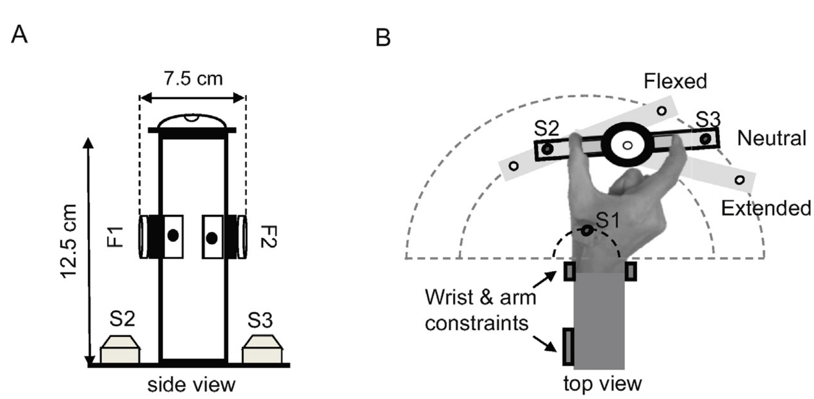

Fig. 1. Experimental setup. (A) Side view of two digit precision grip device. F1 and F2 indicate the 3-D force/torque transducers. (B) Top view of experimental setup. Subjects grasped the device in a flexed, neutral and extended wrist posture. Position orientation sensors S1–S3 are located on the device and hand to measure wrist joint angle, and ensure the invariance of digit postures across wrist joint angles (see Section 2 for details).