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Coherence between magnetoencephalography and hand-action-related acceleration, force, pressure, and electromyogram

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ABSTRACT

Hand velocity and acceleration are coherent with magnetoencephalographic (MEG) signals recorded from the contralateral primary sensorimotor (SM1) cortex. To learn more of this interaction, we compared the coupling of MEG signals with four hand-action-related peripheral signals: acceleration, pressure, force, and electromyogram (EMG).

Fifteen subjects performed self-paced repetitive hand-action tasks for 3.5 min at a rate of about 3 Hz. Either acceleration, pressure or force signal was acquired with MEG and EMG signals during (1) flexions–extensions of right-hand fingers, with thumb touching the other fingers (acceleration; *free*), (2) dynamic index–thumb pinches against an elastic rubber ball attached to a pressure sensor (pressure and acceleration; *squeeze*), and (3) brief fixed-finger-position index–thumb pinches against a rigid load cell (force; *fixed-pinch*).

Significant coherence occurred between MEG and all the four peripheral measures at the fundamental frequency of the hand action (F0) and its first harmonic (F1). In all tasks, the cortical sources contributing to the cross-correlograms were located at the contralateral hand SM1 cortex, with average inter-source distance (mean ± SEM) of 9.5 ± 0.3 mm. The coherence was stronger with respect to pressure (0.40 ± 0.03 in *squeeze*) and force (0.38 ± 0.04 in *fixed-pinch*) than acceleration (0.24 ± 0.03 in *free*) and EMG (0.25 ± 0.02 in *free*, and 0.29 ± 0.04 in *fixed-pinch*).

The results imply that the SM1 cortex is strongly coherent at F0 and F1 with hand-action-related pressure and force, in addition to the previously demonstrated EMG, velocity, and acceleration. All these measures, especially force and pressure, are potential tools for functional mapping of the SM1 cortex.

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Introduction

Several hand-action-related signals, such as electromyogram (EMG) (Brown et al., 1998; Conway et al., 1995; Hari and Salenius, 1999; Mima and Hallett, 1999; Salenius et al., 1996, 1997), movement velocity (Jerbi et al., 2007) and acceleration (Bourguignon et al., 2011, 2012) are coherent with brain signals recorded with magnetoencephalography (MEG) and electroencephalography (EEG).

The corticomuscular coherence between MEG and EMG or EEG and EMG reflects modulation of motor-cortex drive to motor unit populations (Conway et al., 1995; Salenius et al., 1997). Corticomuscular coherence is typically observed during sustained isometric contraction (Conway et al., 1995; Kilner et al., 1999; Salenius et al., 1997), and it peaks at ~15–40 Hz depending on the exerted force (Hari and Salenius, 1999; Mima and Hallett, 1999). Corticomuscular coherence decreases during dynamic movements with respect to the steady isometric hold period (Hari and Salenius, 1999; Kilner et al., 1999; Salenius and Hari, 2003), and its sources display somatotopical order in the primary motor (M1) cortex contralateral to the contracted muscle (Murayama et al., 2001; Salenius et al., 1997).

The corticokinematic coherence (CKC), on the other hand, reflects coupling between primary sensorimotor (SM1) cortex MEG and kinematic (e.g. acceleration) signals of executed or observed hand movements (Bourguignon et al., 2011, 2013a; Jerbi et al., 2007). CKC is observed during fast repetitive dynamic executed or observed hand movements at the same frequency as the movements are performed, typically at 2–5 Hz

Abbreviations: CKC, corticokinematic coherence; F0, fundamental frequency of hand action; F1, first harmonic of hand action frequency; M1 cortex, primary motor cortex; MNI brain, standard Montreal Neurological Institute brain; S1 cortex, primary sensory cortex; SM1, primary sensorimotor cortex.

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(Bourguignon et al., 2011, 2012, 2013a; Jerbi et al., 2007). In addition to the hand kinematics, rhythmic modulation of EMG during repetitive voluntary hand movements is coherent with MEG at SM1 cortex at the movement frequency (~1.4–3.9 Hz) (Pollok et al., 2004, 2005a,b).

We have recently proposed CKC as a tool for functional mapping of the SM1 cortex (Bourguignon et al., 2011), but it is still unclear to what extent hand-action-related kinetic signals such as force and pressure are coupled with the cortical MEG signals.

The purpose of the current study was to compare coherence between MEG and four hand-action-related peripheral signals (acceleration, pressure, force, and EMG) during repetitive self-paced continuous dynamic or fixed hand-actions. The tasks were selected to vary in their range of motion to clarify whether the degree of hand movement is crucial for the coherence. We expected all these signals to be phase-synchronized with MEG signals as they all carry information about the fundamental frequency of the repetitive hand-actions. The coherence strengths and respective source locations were compared between the peripheral signals.

Materials and methods

Subjects

Fifteen healthy subjects (mean age 29.4 yrs, range 21–38 yrs; 8 males, 7 females) without any history of neuropsychiatric disease or movement disorders were studied. According to Edinburgh handedness inventory (Oldfield, 1971), 14 subjects were right-handed (mean score 92, range 67–100 on the scale from −100 to 100) and one subject was ambidextrous (−20).

The study had prior approval by the ethics committee of the Helsinki and Uusimaa hospital district. The subjects gave informed consent before participation. Subjects were compensated monetarily for the lost working hours and travel expenses.

Experimental protocol

During MEG recordings, the subjects were sitting with their left hand on the thigh, the right hand on a table in front of them. Earplugs were used to minimize concomitant auditory noise. A white paper sheet was taped vertically on the MEG gantry to prevent the subjects from seeing their moving right hand. Subjects were instructed to fixate a self-chosen detail in a picture (21×30 cm^2) on the wall of the magnetically shielded room, positioned 2.8 m in front of them, 11° to the left from the midline.

Subjects performed three hand-action tasks: (1) *free*: dynamic flexions–extensions of right-hand fingers, with thumb touching the other fingers (unrestricted ~10-cm range of motion between the thumb and other fingers); the acceleration of the right index finger was monitored with a 3-axis accelerometer (ADXL335 iMEMS Accelerometer, Analog Devices Inc., Norwood, MA, USA) attached on the nail of the index finger (Fig. 1), (2) *squeeze*: dynamic index–thumb flexions (pinches) against an elastic rubber ball (~1-cm range of motion) attached to a pneumatic pressure sensor (MPX5050DP, Motorola Inc., Denver, Colorado, USA), and (3) *fixed-pinch*: brief fixed-finger-position index–thumb pinches (minimal movement, fingers fixed to noncompliant force sensor) against a rigid load cell (1042, Vishay Precision Group, Malvern, PA, USA). During *squeeze* task, acceleration was also recorded correspondingly to the *free* task.

The subjects were instructed to perform repetitive, self-paced hand actions continuously for 3.5 min at comfortable but rather fast rate of their own preference (which turned out to be about 3 Hz) and at low intensity (to avoid muscle fatigue). The order of the four tasks was randomized for each subject.

Measurements

MEG

The measurements were carried out at the MEG Core of Aalto University. MEG signals recorded in a magnetically shielded room (Imedco AG, Hägendorf, Switzerland) with a 306-channel whole-scalp neuromagnetometer (Elekta Neuromag™, Elekta Oy, Helsinki, Finland). The recording passband was 0.1–330 Hz and the signals were sampled at 1 kHz. The subject's head position inside the MEG helmet was continuously monitored by feeding current to four head-tracking coils located on the scalp; the locations of the coils with respect to anatomical fiducials were determined with an electromagnetic tracker (Fastrak, Polhemus, Colchester, VT, USA).

Peripheral signals

The four peripheral signals (acceleration, pressure, force, and EMG) were low-pass filtered at 330 Hz and sampled at 1 kHz, time-locked to

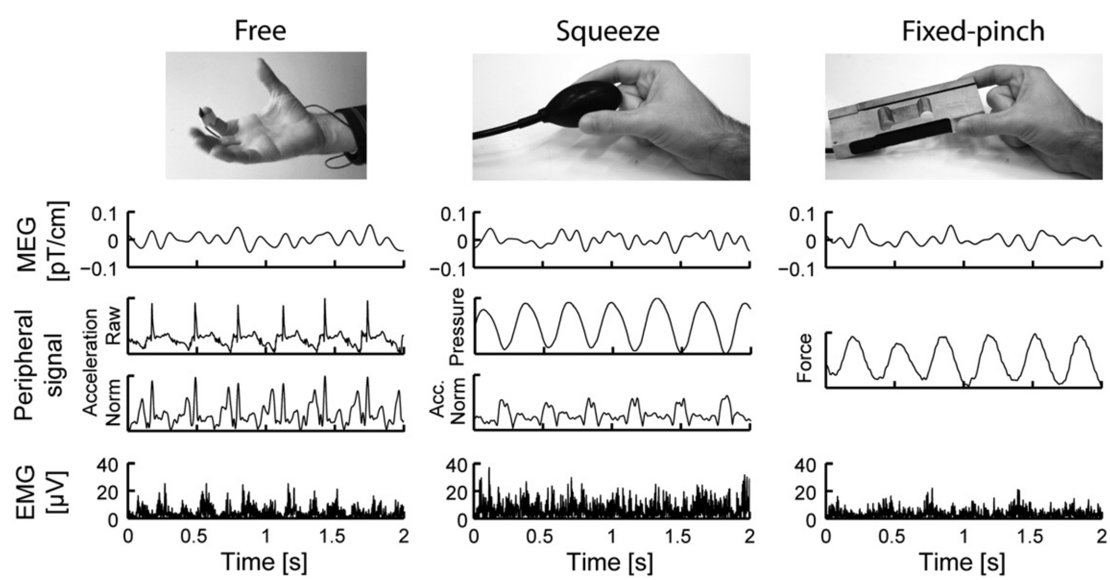

Fig. 1. Representative signals of one subject in *free* (left), *squeeze* (middle) and *fixed-pinch* (right) hand-action tasks. MEG signal from a single gradiometer channel (filtered 1–10 Hz) over the SM1 cortex. Acceleration signal is from one of the 3-axis accelerometer channels (raw), measured from the tip of right index finger during *free* task, and Euclidian norm of the three accelerations (norm). Pressure and force signals were recorded during *squeeze* and *fixed-pinch* tasks respectively. EMG signals from *flexor carpi radialis* muscle was measured during all three tasks.

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