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Research Report

Cortical representation of rhythmic foot movements

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ABSTRACT

The cortex is involved in rhythmic hand movements. The cortical contribution to rhythmic motor patterns of the feet, however, has never been evaluated in humans. In this study we investigated EEG activity related to rhythmic stepping and tapping movements in 10 healthy subjects. Subjects performed self-paced fast bilateral anti-phase, in-phase and unilateral rhythmic foot movements as well as an isometric cocontraction of the calf muscles, while being seated as relaxed as possible. Surface EMG from the anterior tibial muscles was recorded in parallel with a 64 channel EEG. Power spectra, corticomuscular coherence and corticomuscular delay were calculated. All subjects showed corticomuscular coherence at the stepping frequencies in the central midline region that extended further to the frontal mesial area. The magnitude and the topography of this coherence were equal for the right and left anterior tibial muscle and all movement conditions. During cocontraction there was coherence in the 15–30 Hz range which was refined to the central midline area. EEG-EMG delays were significant in 9 subjects with values between 14 and 26 ms, EMG-EEG feedback was only found in 6 subjects with delays between 25 and 40 ms. We conclude that rhythmic motor patterns of the feet are represented in the cortex, transmitted to the muscles with delays compatible with fast corticospinal transmission and fed back to the cortex. A similar cortical contribution may be important also for gait control in humans.

1. Introduction

In a recent study voluntary rhythmic hand motor patterns have been shown to have a cortical correlate (Pollok et al., 2004). This is compatible with the strong and in large parts monosymptomatic corticospinal projections to the motoneurons of the distal forearm and hand muscles (Lawrence and Kuypers, 1968a,b). For proximal arm and leg muscles the corticomotoneuronal interaction is more indirect via spinal interneuronal circuits, and these interneuronal pathways differ significantly between the forearm and leg segments (Baldissera et al., 1981). This difference in corticospinal connectivity is thought to be one basis for the more delicate and fine motor capacities of the hands as compared to the feet (Boczek-Funcke et al., 1998; Hultborn and Illert, 1991). Thus the question arises whether the cortical involvement in the generation of rhythmic motor patterns is unique to the distal upper limbs or may play a role in cyclic foot movements as well. There is emerging evidence in non primate mammals that rhythmic gait movements of the lower limbs are paralleled by rhythmic changes in motor cortical activity (Armstrong and Drew, 1984). However, a cortical representation of cyclic foot movement patterns as for rhythmic hand movements has never been shown in humans. Since movement and muscle artefacts usually preclude a recording of cortical (EEG) activity during actual locomotion in humans we asked ten healthy volunteers (6 male, 4 female; age-range: 25–

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38 yrs.) to perform rhythmic foot stepping movements while seated, and investigated coherent rhythmic modulations of EEG activity in relation to rhythmic calf muscle (EMG) activity at the frequency of the stepping movements. The topography of this coherence on the scalp was analysed by constructing isocoherence maps based on a 64 channel arrangement. In order to differentiate between pure reafference and corticomuscular projection we estimated the delay between the EEG and EMG signal at the movement frequency using a new method (maximising coherence method) for estimation of delays between narrow band coherent signals (Govindan et al., 2006, 2005; Muthuraman et al., 2008; Raethjen et al., 2007).

2. Results

All subjects showed a significant coherence between the anterior tibial muscles on both sides and the EEG at the stepping frequency that is the frequency of muscle bursts or its first harmonic. This coherence was present for all recording conditions (see below). An example of EEG and EMG raw data with the corresponding power spectra and corticomuscular coherence spectrum is shown in Fig. 1. In 2 of the subjects we also found a weaker 15–30 Hz coherence during the rhythmic movements as displayed in the example of Fig. 1. During isometric cocontraction of the calf muscles 7 out of 10 subjects showed significant corticomuscular coherence in the 15–30 Hz range and 2 of them only with the right or left sided muscle. This 15–30 Hz coherence is the physiological coupling that is well-known for isometric contractions of hand and forearm muscles (Brown, 2000; Mima and Hallett, 1999; Salenius and Hari, 2003) and has recently also been described for leg muscles (Hansen and Nielsen, 2004). As expected, these coherences were mainly found in EEG electrodes located in the central midline. This is displayed in the isocoherence maps for the right sided muscles in 4 representative subjects in Fig. 2. The 15–30 Hz coherence was mostly restricted to the central area whereas the coherence at the stepping movements extended further to frontal mesial regions. Fig. 2 demonstrates examples from recordings with bilateral anti-phase stepping movements. The topography of the coherence was comparable to the other stepping modalities regardless whether they were unilateral or bilateral, slow or fast and in-phase or anti-phase movements and looked very similar for left sided and right sided muscles. However, there only was a small number of subject in which all conditions could be analysed. The frequencies of the movements and of the corticomuscular coherence and the midline electrodes showing this coherence are given in Table 1 for all subjects. For comparison the midline electrodes involved in the 15–30 Hz coherence during isometric cocontraction of the calf muscles are given on the right.

Corticomuscular delays are given in Table 2. The delays are given for the bilateral anti-phase stepping trials and for the

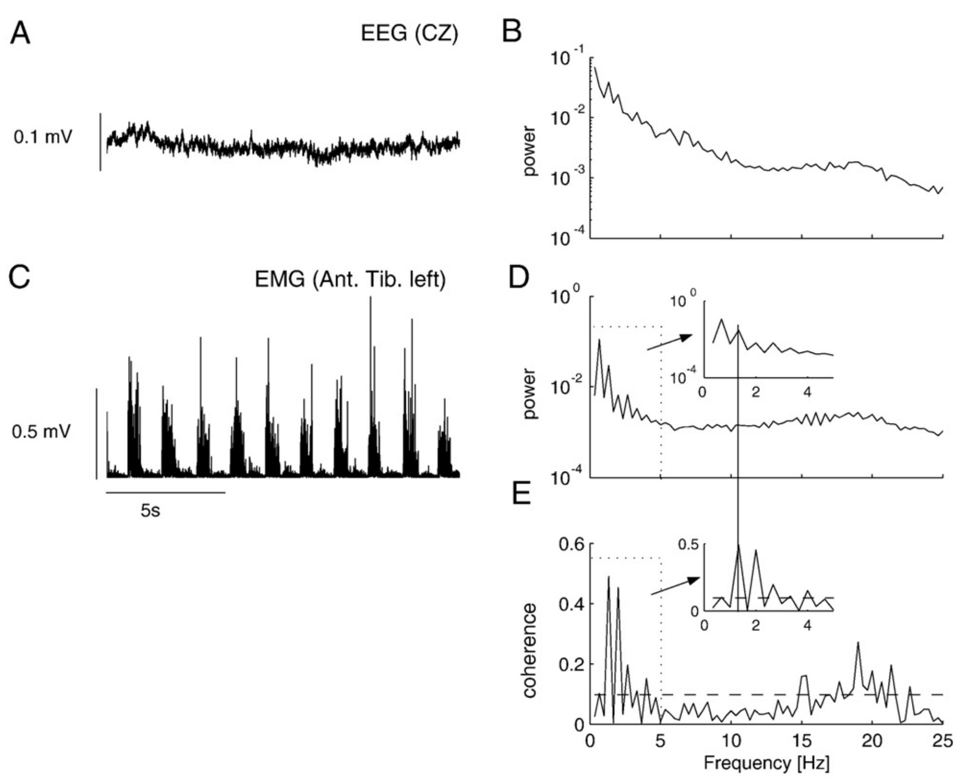

Fig. 1 – Representative example of EEG and EMG raw data (A, C), power spectra (B, D) and coherence between EEG and EMG (E). This example displays data recorded from electrode CZ in subject 6 from Table 1 during bilateral anti-phase stepping movements. Note the strong coherence at the first harmonic of the stepping frequency. In this case there was an additional coherence in the 15–30 Hz band which was typical for the isometric (co)contraction. It was only seen in two subjects in single recordings during stepping movements.