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Research Report

Motor-related cortical activity after cervical spinal cord injury: Multifaceted EEG analysis of isometric elbow flexion contractions

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ABSTRACT

Electroencephalographic (EEG) studies have well established that motor cortex (M1) activity ~20 Hz decreases during muscular contraction and increases as soon as contraction stops, which are known as event-related desynchronization (ERD) and event-related synchronization (ERS), respectively. ERD is supposed to reflect M1 activation, sending information to recruited muscles, while the process underlying ERS is interpreted either as active cortical inhibition or as processing of sensory inputs. Investigation of the process behind ERD/ERS in people with spinal cord injury (SCI) would be particularly relevant since their M1 remains effective despite decreased sensorimotor abilities. In this study, we recorded net joint torque and EEG in 6 participants with cervical SCI and 8 healthy participants who performed isometric elbow flexion at 3 force levels. Multifaceted EEG analysis was introduced to assess ERD/ERS according to their amplitude, frequency range and duration. The results revealed that net joint torque increased with the required force level for all participants and time to contraction inhibition was longer in the SCI group. At the cortical level, ERD/ERS frequency ranges increased with the required force level in all participants, indicating that the modulation of cortical activity with force level is preserved after SCI. However, ERS amplitude decreased only in SCI participants, which may be linked to delayed contraction inhibition. All in all, cortical modulation of frequency range and amplitude could reflect two different kinds of neural communication.

1. Introduction

One open question in sensorimotor control is the significance of ~20 Hz modulation of electroencephalographic (EEG) activity recorded over the motor cortex (M1) during and after the completion of motor tasks (Houdayer et al., 2012; Muthuraman et al., 2012). These modulations are known as event-related desynchronization (ERD) and event-related

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synchronization (ERS), respectively (Pfurtscheller and Lopes Da Silva, 1999). ERD is a decrease of cortical spectral power in the ~20 Hz frequency range relative to baseline resting state. ERD occurs during contraction and increases as force level or task difficulty is amplified (Stancak et al., 1997; Mima et al., 1999; Dal Maso et al., 2012). It is well-established that ERD reflects M1 activation, sending information to recruited muscles (Pfurtscheller and Lopes Da Silva, 1999). ERS is an increase of cortical spectral power in the ~20 Hz frequency range relative to baseline resting state. It occurs at the end of contraction and increases with force level and task difficulty (Stancak et al., 1997). On the one hand, given that ERS appears when no further information is sent from the M1 to the recruited muscles, it has been associated with cortical idling or active M1 inhibition (Salmelin et al., 1995; Stancak and Pfurtscheller, 1995; Pfurtscheller et al., 1996; Pfurtscheller and Neuper, 1997). On the other hand, ERS also appears after passive movement in healthy people and is decreased in patients presenting sensory deafferentation, indicating that ERS could reflect somatosensory processing from the M1 (Cassim et al., 2001; Houdayer et al., 2006; Reyns et al., 2008).

EEG studies of spinal cord injury (SCI) individuals have provided interesting results concerning the processes underlying ERD and ERS. For example, Gourab and Schmit (2010) observed unchanged ERD in participants with SCI who attempted, but failed to attain, muscular contractions. Furthermore, participants with cervical SCI show ERD modulation with force level comparable to that of healthy controls whether they succeeded or failed to produce contraction at a required force level (Cremoux et al., 2013). This suggests that ERD is more likely to be associated with the intention of undertaking a motor task rather than with its actual realization. At the end of contraction, SCI participants do not manifest any ERS after attempted motor tasks or passive movement (Müller-Putz et al., 2007; Gourab and Schmit, 2010). This absence of ERS in people with SCI is thus attributed to loss of sensory inputs (Gourab and Schmit, 2010). However, these results cannot rule out the possibility of a lack of active inhibition since contractions were only attempted and not actually performed. The objective of this study was 2-fold. First, we aimed to assess ERD and ERS modulation during isometric elbow flexion contractions actually achieved at different force levels by cervical SCI participants and healthy controls. We hypothesized that ERD and ERS would evolve differently with force level in both groups. ERD modulation would be preserved and ERS modulation would be reduced – or even canceled – in cervical SCI participants compared to controls (Gourab and Schmit, 2010). Second, we postulated that, if decreased ERS reflects lack of active inhibition, cervical SCI participants would present longer time to contraction inhibition (Pfurtscheller et al., 2002).

From a methodological point of view, ERD and ERS are usually quantified by their modulation in amplitude, but some studies have also highlighted modulation in frequency and duration (Clochon et al., 1996; Foffani et al., 2004; Gwin and Ferris, 2012; Hsu et al., 2012). Investigation of modulation in amplitude, frequency range and duration would help us to gain knowledge about changes in cortical activities during and after muscular contractions at different force levels actually achieved by SCI and healthy study participants.

2. Results

2.1. *Force production*

Regarding force production, analysis of variance (ANOVA) of Group (SCI vs. controls) × Force Level (25% relative maximal voluntary contraction (rMVC), 50% rMVC vs. 75% rMVC) disclosed a Group effect on net torque variability ($F_{1,\ 12}$=4.95; $p<0.05$; partial eta-squared (η_p^2)=0.29) and a Force Level effect on mean net torque ($F_{2,\ 24}$=203.15; $p<0.05$; $\tilde{\varepsilon}$=0.70; η_p^2=0.94) and its variability ($F_{2,\ 24}$=11.20; $p<0.05$; $\tilde{\varepsilon}$=0.61; η_p^2=0.48). For all participants, mean net torque was 11.74±2.28 Nm, 21.02±3.64 Nm and 32.35±6.09 Nm at 25%, 50% and 75% rMVC, respectively (Fig. 1A). Fig. 1B shows that net torque variability increased from 0.85±0.53 Nm at 25% rMVC to 1.49±0.98 Nm at 75% rMVC in the SCI group while it rose from 0.46±0.18 Nm at 25% rMVC to 0.79±0.19 Nm at 75% rMVC in the controls group.

ANOVA of Group (SCI vs. controls) × Force Level (25% rMVC, 50% rMVC vs. 75% rMVC), conducted on contraction duration, revealed a Force Level effect ($F_{2,\ 24}$=66.20; $p<0.05$; $\tilde{\varepsilon}$=0.69; η_p^2=0.85). For all participants, contraction duration decreased from 5.46±0.28 s at 25% rMVC to 4.74±0.40 s at 75% rMVC. ANOVA of time to contraction inhibition revealed a Group effect ($F_{1,\ 12}$=21.01; $p<0.05$; η_p^2=0.64) and a Force Level effect ($F_{2,\ 24}$=10.37; $p<0.05$; $\tilde{\varepsilon}$=0.88; η_p^2=0.46). In the SCI group, mean time to contraction inhibition decreased from 0.51±0.05 s at 25% rMVC to 0.45±0.11 s at 75% rMVC. In the control group, mean time to contraction inhibition declined from 0.41±0.04 s at 25% rMVC to 0.33±0.03 s at 75% rMVC.

2.2. *Mean ERD and ERS amplitude*

ANOVA of Group (SCI vs. controls) × Force Level (25% rMVC, 50% rMVC vs. 75% rMVC) × Epoch (during vs. after contraction), conducted on mean ERD and ERS amplitude, revealed a Group effect ($F_{1,\ 12}$=5.42; $p<0.05$; η_p^2=0.31), an Epoch effect ($F_{1,\ 12}$=91.85; $p<0.05$; η_p^2=0.88) and Epoch × Group interaction ($F_{1,\ 12}$=5.10; $p<0.05$; η_p^2=0.30). In the control group, mean ERD and ERS amplitude was −46.45±5.35% and 129.40±57.77%, respectively. In the SCI group, mean ERD amplitude was similar to that in the control group, averaging −47.26±7.69%, while mean ERS amplitude was lower than in the control group, averaging 61.52±71.60%. Fig. 2A and D illustrate mean ERD and ERS amplitude in both groups at each force level.

2.3. *Mean ERD and ERS frequency range*

Concerning frequency range, ANOVA disclosed a Force Level effect ($F_{2,\ 24}$=5.29; $p<0.05$; $\tilde{\varepsilon}$=0.73; η_p^2=0.31) and an Epoch effect ($F_{1,\ 12}$=18.33; $p<0.05$; η_p^2=0.60). In both groups, ERD and ERS frequency ranges averaged 8.31±3.07 Hz and 3.15±3.56 Hz at 25% rMVC, and 10.73±4.69 Hz and 3.99±3.40 Hz at 75% rMVC. Fig. 2B and E report the mean ERD and ERS frequency ranges in both groups at each force level. ERD and ERS frequency ranges were centered on similar mean values (21.15±1.49 Hz for ERD and 21.48±3.30 Hz for ERS).