Somatosensory Attenuation as a marker for Embodiment of Supernumerary Robotic Limbs

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Introduction

Human motor augmentation tackles the challenge of relaying somatosensory feedback, which encodes the status of supernumerary robotic limbs (SRLs), to improve their motor control (*Eden et al. 2022*), but also to increase their embodiment, thanks to multisensory integration (*Pinardi et al 2020*). Embodiment is often assessed through subjective questionnaires (*Botvinick et al. 1983*) or behavioural protocols that requires dedicated experimental setups (e.g., proprioceptive drift or intentional binding).

Here we propose to exploit somatosensory attenuation as an objective, implicit and non-invasive method to assess embodiment of SRLs, capitalizing on the presence of supplementary somatosensory feedback from the SRL.

Somatosensory attenuation (SA) is the decreased intensity of the sensory experience of a stimulus when it is self-delivered compared to an externally generated one. This is thought to be generated by a null error between predicted and real feedback and it is an important mechanism to underline the salience of external stimuli while "silencing" self-generated ones. Moreover, SA has often been linked to embodiment, since body ownership determines the perceptual attenuation of self-generated tactile sensations (*Kilteni et al., 2017*).

We investigated the features of self- and externally generated somatosensory evoked potentials (SEP) in terms of amplitude and latency to validate the feasibility of SA as an electrophysiological marker of SRLs embodiment.

Methods

8 dyads (half males, aged 23±2y) pressed a button with the right, hidden hand, following a a go-signal (LED) presented randomly. The buttonpress generated a median nerve stimulation (MNS, twice the sensory threshold) on the left hand of both participants simultaneously. We compared *Self* (SEP evoked by participant who pressed the button) vs *External* (SEP evoked in the other participant) condition.

500 SEPs per condition were recorded through a 64 channels EEG (Figure 1).

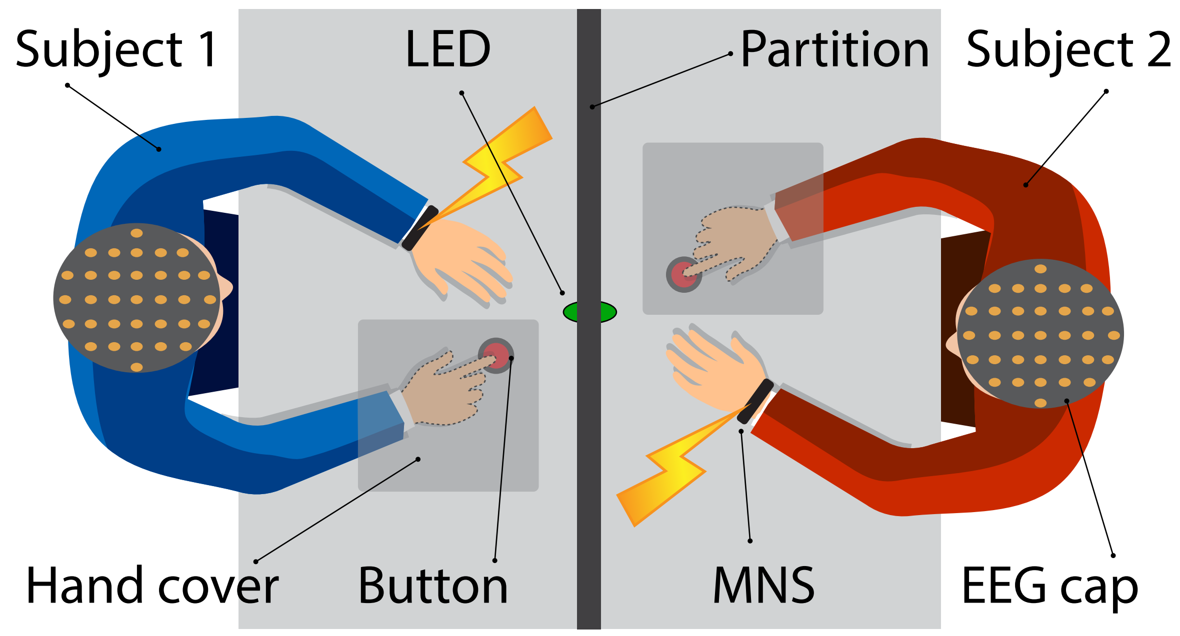

Figure 1. *Experimental setup. The partition kept other participant's hand and LED out of view.*

Results

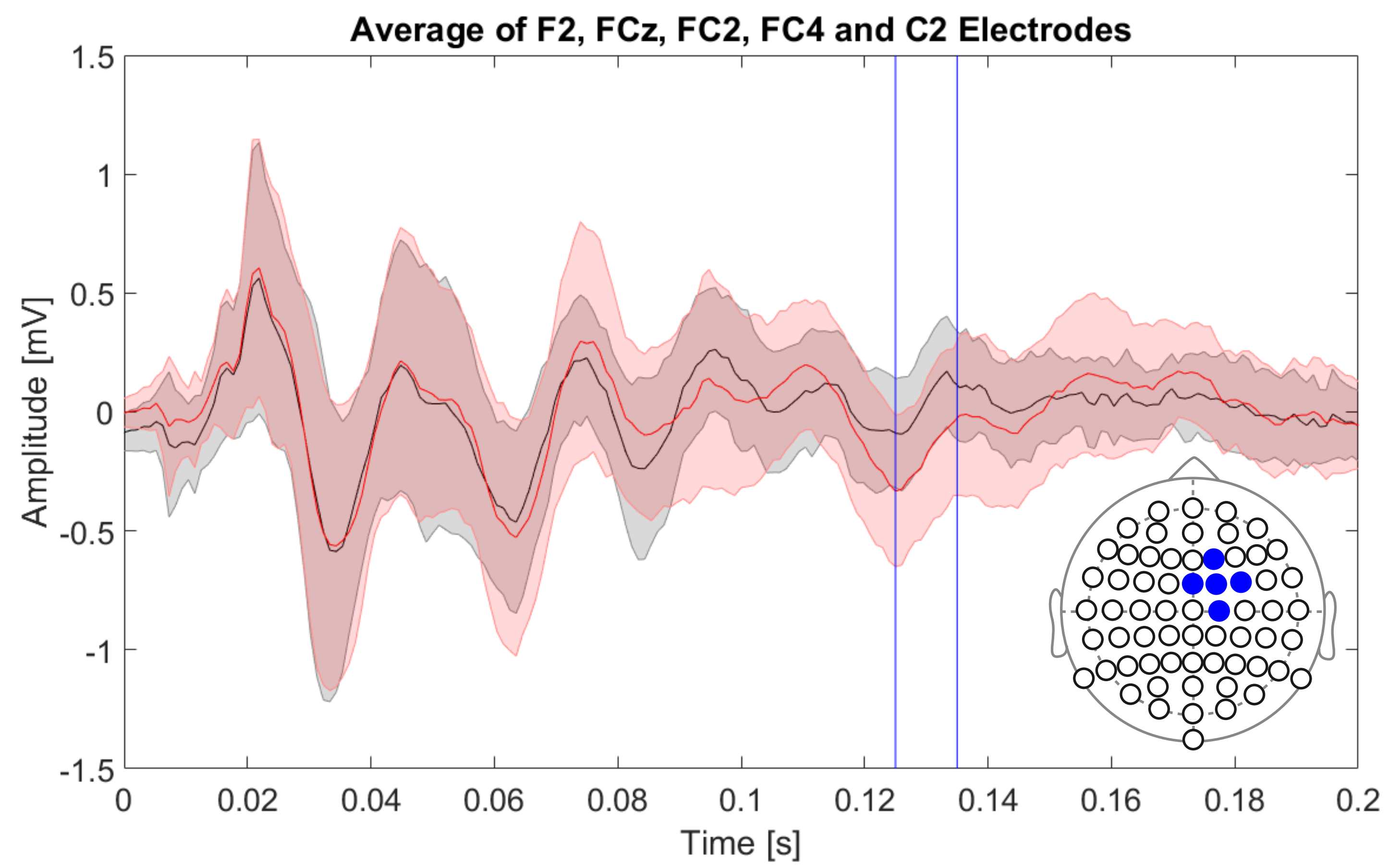

Figure 2. *Grand average of electrodes (blue dots) which showed a significant SEP attenuation. Red line marks External condition, Black marks Self condition. Blue vertical lines indicate time range containing the significant attenuation. Shades show standard deviation. Signal was evoked through MNS, delivered at time point 0.*

We observed a significant ($p=0.021$) attenuation of SEP between 125-135 ms, in electrodes F2, FCz, FC2, FC4 and C2, in *"self"* compared to *"external" condition* (Figure 2). The attenuation was maximal over the right fronto-central area.

Discussion and Perspective

The significant SEP attenuation in the self condition over right fronto-central area can be related to the activation of sensorimotor areas (i.e., premotor, motor and somatosensory cortex), which are known to be involved not only in sensorimotor processing but also in self-awareness (Tsakiris, 2010).

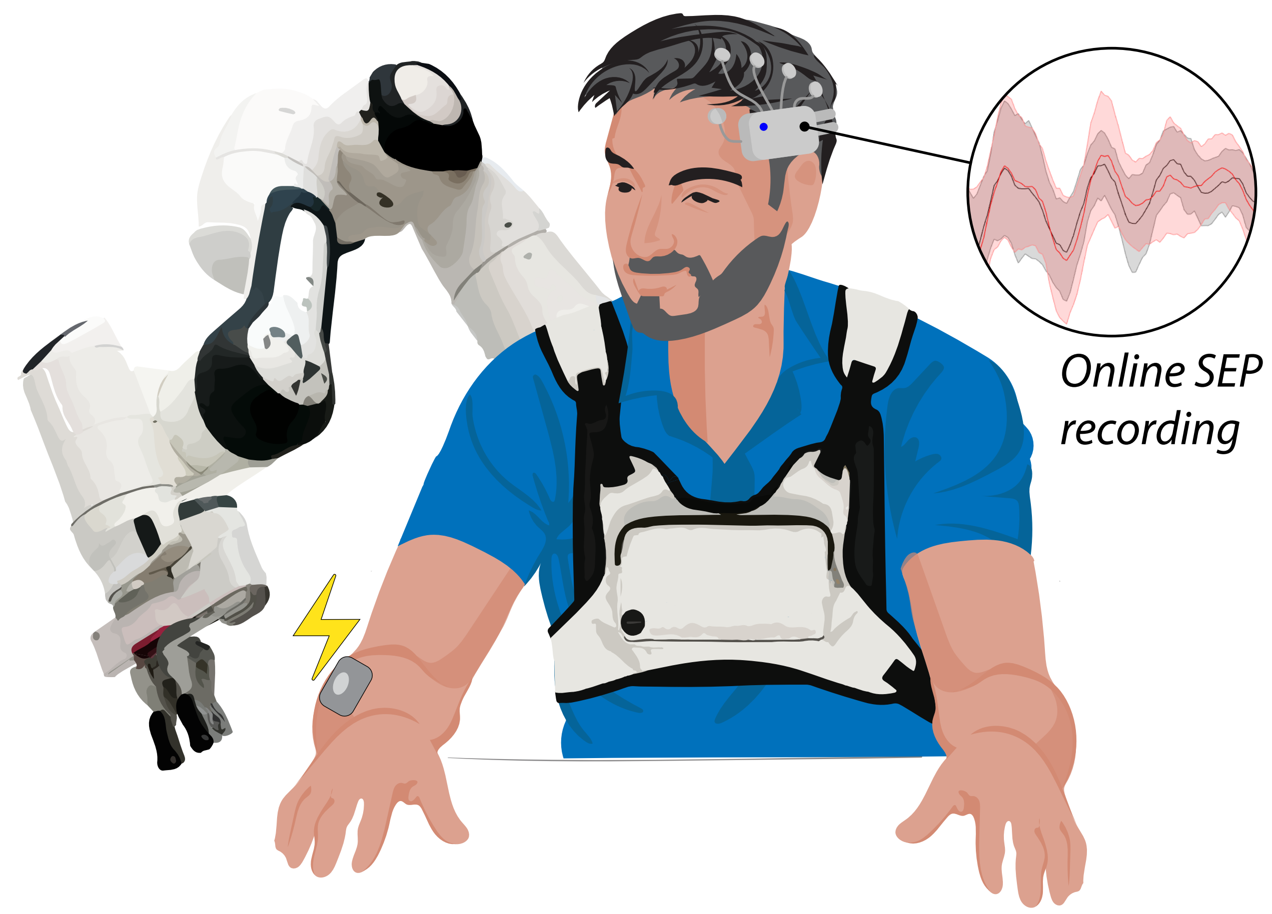

Figure 3. *Conceptual setup for testing embodiment of SRL through SEP attenuation. The somatosensory feedback encoding the SRL status is exploited to elicit a measurable SEP that can provide an online marker for embodiment.*

Hence, we deem that sensory attenuation could be a particularly useful objective marker of embodiment thanks to how easily it could be integrated in an SRL sensory feedback interface. Exploiting the feedback which encodes SRL status as an SEP generator would allow for an online assessment of embodiment, highlighting any possibile link between modulation of embodiment and motor control performance.

Eden, J., et al. "Principles of human movement augmentation and the challenges in making it a reality." Nature Communications (2022).
Pinardi, M., et al. "Doublecheck: a sensory confirmation is required to own a robotic hand, sending a command to feel in charge of it." Cognitive neuroscience (2020).
Botvinick, M., and Cohen, J., "Rubber hands 'feel' touch that eyes see." Nature (1998).
Kilteni, K., and Ehrsson, H.H., "Body ownership determines the attenuation of self-generated tactile sensations." PNAS (2017).
Tsakiris, M., "My body in the brain: a neurocognitive model of body-ownership." Neuropsychologia (2010).