

Real-time OPM-MEG motor control of stroke patients before BCI implantation

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Introduction

Ischemic stroke is a leading cause of long-term motor disability, and conventional rehabilitation protocols often yield limited benefits for many patients. The prevalence of upper limb impairment is approximately 73-88% in the acute phase and 55-75% in the chronic phase (Coscia *et al.*, 2019). Brain-computer interfaces (BCIs) offer promising therapeutic opportunities, yet patient responsiveness remains highly variable. To identify patients most likely to benefit from BCI-assisted rehabilitation (Mestais *et al.*, 2015; Lorach *et al.*, 2023), this study evaluated motor imagery-based BCI control using real-time magnetoencephalography (MEG) with a novel system based on optically-pumped magnetometers (OPMs).

Material and methods

A patient was enrolled in the PRELUDE clinical trial (NCT05698810) as part of the preparatory investigations for the BCI4Stroke clinical trial (NCT07477613). The patient suffered left subcortical stroke (internal capsule) 18 months prior to the experiments, resulting namely in a right-hand motor deficit. The objective of PRELUDE was to assess the feasibility of the experimental procedures and optimize the acquisition protocols, including the comparison between optically pumped magnetometer-based magnetoencephalography (OPM-MEG) and conventional SQUID-MEG recordings.

The MEG system utilized zero-field OPMs operating in the spin-exchange-relaxation-free (SERF) regime (Hedscan, Fieldline), comprising 44 OPM sensors (88 channels). These sensors were positioned using a dedicated helmet (SmartHelmet, Fieldline), ensuring direct contact with the patient's scalp for optimal sensor localization. Sensors were arranged along a band centered on the sensorimotor sulcus, with correct positioning verified through an initial finger-tapping task to adjust the antero-posterior alignment of the helmet.

During two OPM-MEG sessions, the patient performed motor control tasks including visually cued right- and left-hand finger tapping (1 s-long visual cues, ITI = 3.5 ± 0.5 s) and 2 min-long resting state measurements were performed. Finally, real-time brain-computer interface (BCI) control was evaluated using a three-state motor paradigm (idle, left- and right-grasp – real movement for left hand and attempted movement for right hand). To do so, data were transmitted in real-time to the BCI software via LabStreamingLayer. Environmental noise was mitigated on-the-fly by applying band-pass (1-120 Hz) filtering, notch filtering (50 Hz) and a signal-space projection (SSP) calculated from the previous resting-state measurement.

Neural activity was decoded online using a REW-NPLS classifier integrated within a hidden Markov model framework, providing continuous state predictions at 10 Hz (Moly *et al.*, 2022). The classifier is linear multiclass: it distinguishes left hand from right hand movement from rest (idle). The classifier was incrementally updated every 15 s during 360 s, starting from a blank model. Labels were inferred from the visual cues, assuming the patient's intention to move aligned with each cue, thereby treating them as ground truth. Testing was conducted for an additional 360 s. and model performance was assessed using a sample-wise confusion matrix and balanced accuracy.

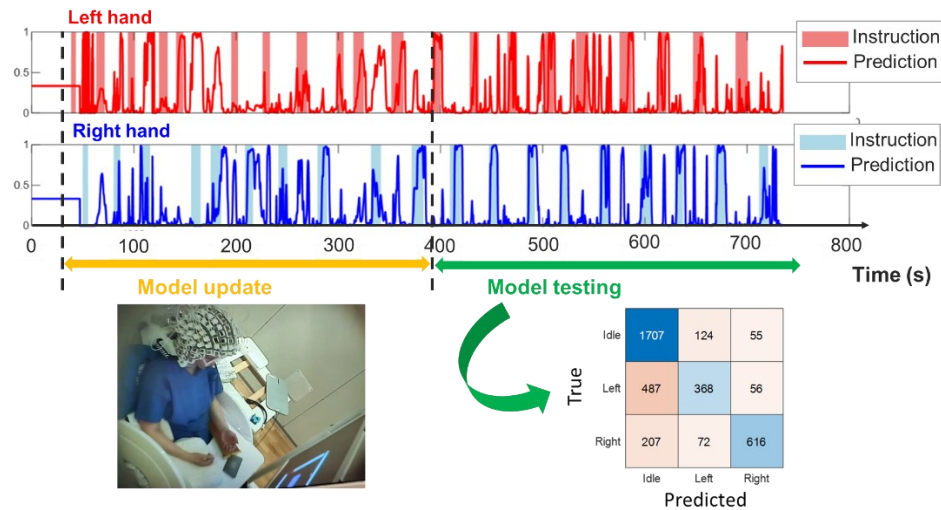


Figure 1: Real-time OPM-based BCI task: (upper) time-course of model instructions/predictions for both hands (impaired hand: right), (lower left) experimental setup and (lower right) confusion matrix.

Results and conclusion

The BCI algorithm efficiently detected motor intention for both the healthy and impaired hands: results indicated a balanced accuracy of 0.67 (chance: 0.33), with a by-class specificity of 0.61, 0.93 and 0.96, and a by-class sensitivity of 0.91, 0.40 and 0.69 for the idle state, the left hand, and the right hand respectively. The idle state was the most frequently predicted class, regardless of the cue. Left- and right-hand movements were rarely confused but were not always detected.

Preliminary results show promising conclusions to assess stroke patient BCI ability thanks to a MEG system based on optically-pumped magnetometers (OPMs). This preliminary study warrants further investigations based on this novel MEG-OPM approach as a viable alternative to conventional SQUID-MEG for BCI applications.

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