Can amputees control a brain-computer interface with their missing hand?

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Introduction: One of the main goals of brain computer interface (BCI) research is providing disabled patients with some levels of communication, control of external devices, and mobility. For such patients to use BCI we need to address two major questions: i) can motor brain circuits that have been deprived of input following trauma still be used for controlling BCI? and ii) if so, what happens to these neural circuits after BCI training? We suggest that our real-time functional magnetic resonance imaging (fMRI) BCI paradigm is most suited to address these questions. Unlike electroencephalogram (EEG), or even invasive methods, fMRI provides a highly detailed anatomical mapping of the brain activity, which allows us a quantitative investigation of brain activity during BCI in both healthy and patient population. In this study we addressed the first question by conducting a BCI experiment using real-time fMRI on arm amputees, comparing their brain activity and performance with healthy patients, as well comparing brain activation and BCI performance used to control the amputated arm versus the intact arm.

Material, Methods and Results: Three male upper limb amputees (all 1.5-2 years after amputation) performed cue-based BCI as well as free choice BCI (a complex navigation task) with four classes: left hand, right hand, feet, and rest (null class), and their results were compared with four able bodied subjects. BCI was based on our system for whole brain machine learning classification in real time, described elsewhere [1]. A univariate statistical analysis taking into account subject, condition, and accuracy, indicated that both groups had a very high degree of BCI control (amputees – 95.8%, control – 97.2%), and the difference between the groups was not significant ($p = 0.176$, $F=7.1$). The classification accuracy of the intact hand was the same as that of the missing hand; taking into account the repetition time (TR) with maximum classification yields exactly the same mean accuracy for both groups (96.7%, based on 3 subjects, two runs each). In addition, all subjects controlled an avatar along a trajectory and there was no significant difference between the performances of both groups. Performance was computed by time to reach targets, as compared with navigation of the best run by an experienced healthy subject from a previous experiment; the control group was slower by 38% and the amputee group by 48%.

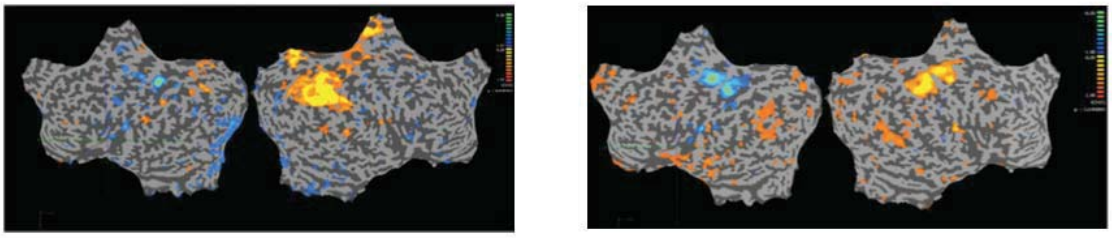

Fig. 1*: Right>left brain activation contrast, during cue-based BCI. Left: Right-hand amputee subject. Right: control subject.*

Discussion: Amputee subjects were able to control a BCI with very high performance, using their missing hand, in both cue-based and free-choice BCI. Their performance with the missing hand was identical to their performance in their missing hand, and their overall performance was nearly identical to that of able bodied control subjects. This performance is possible despite a reduction in the corresponding brain activation; Fig. 1 shows an example from one amputee subject; two others had similar activation patterns.

Significance: The study shows successful BCI, including a complex navigation task, using cortical networks of body parts following amputation. Our real-time fMRI method allows studying residual brain activations systematically in clinical populations, in the context of actual BCI performance.

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References

[1] O. Cohen, M. Koppel, R. Malach, and D. Friedman, “A generic machine learning tool for whole brain classification from fMRI,” in *6th Int’l BCI Conference*, 2014.