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BCI-NMES therapy enhances effective connectivity in the damaged hemisphere in stroke patients

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Introduction: In stroke rehabilitation, one of the key components for motor improvement is brain plasticity and, in particular, the reestablishment of cortical and subcortical networks [1] that can be studied with connectivity analysis. Despite recent advances in brain-computer interface (BCI)-driven stroke therapy [2], it is still unclear what are the underlying changes that lead to a clinical improvement.

Methods: During a controlled randomized clinical trial 18 chronic stroke patients received 10 sessions of neuromuscular electrical stimulation (NMES) triggered by the BCI (N=9) detecting EEG correlates of movement intention (modulation of the sensorimotor rhythm in the contralateral motor cortex), or a sham (N=9) therapy during which the NMES activation was not correlated with the brain activity. Subjects were asked to attempt to open their paretic hand with the aim of activating the NMES upon detection of suitable brain patterns. We studied neuroplastic reorganization within the lesioned hemisphere by computing the effective connectivity (estimated via the short-time direct directed transfer function, SdDTF, in the mu frequency band) from the resting state activity of the brain before and after the whole treatment.

Results: Inside the damaged motor cortex, in the mu frequency band, the connectivity significantly increased for patients who were using the BCI-NMES therapy compared to the sham group (mixed ANOVA, group x time interaction, $p<0.01$, see Figure 1). Moreover, the connectivity increase inside the damaged motor cortex is significantly correlated ($r = 0.57$, $p<0.01$) to the improvement of motor function of the upper limb for the chronic stroke patients. Similar results were found in the beta frequency range ($r = 0.53$, $p < 0.05$).

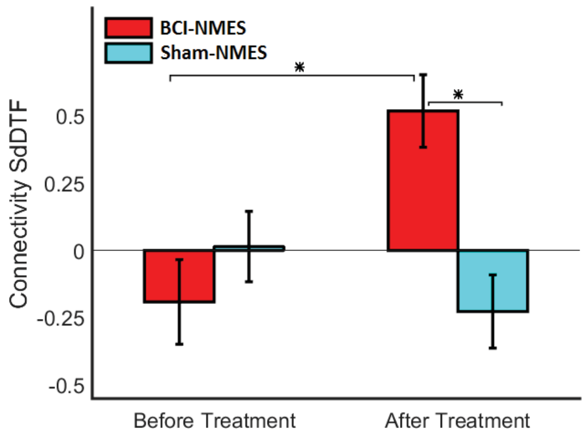

Figure 1. *Connectivity before and after treatment in the damaged motor cortex in th mu rhythm.*p<0.05, Bonferroni corrected post-hoc t-tests*

Discussion: Based on our results, we hypothesize that functional improvement of the upper limb has been achieved as a result of the congruence between the BCI detection and the NMES stimulation. Rewarding of expected brain activity patterns can be thought to be responsible for the plastic enhancement of connectivity within the damaged motor cortex. Future connectivity analyses will allow us to further understand which areas and neural networks are involved in the motor improvement for stroke patients using BCI therapy.

Significance: Our study showcases that BCI effectively enhances brain plasticity, as shown recently also with connectivity analysis [3], and could be used to counteract the natural decrease of brain connectivity in the affected hemisphere that is known to occur after stroke [1] thanks to a closed loop between the efferent intention of movement and the congruent rich afferent feedback of movement.

References

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