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Neurofeedback via intracranial depth electrodes

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Introduction: The use of deep brain stimulation (DBS) devices in a clinical setting for treating various neurological and psychiatric disorders is developing [1], which provides the opportunity to explore new BCI concepts, by using the stimulating electrodes as deep recording electrodes. As a test case, we focus on intracranial recording from the amygdala of patients with epilepsy that undergo intracranial mapping for the localization of the epileptogenic zones. In this preliminary study we demonstrated that subjects can learn to volitionally regulate the amygdala signal amplitude in a Neurofeedback (NF) setting while interacting with a complex multimodal environment.

Material and Methods: Our NF setting is a based on a visually realistic environment (implemented with the Unreal Development Kit game engine), which aims at supporting user engagement through a well-defined task, as well as maintaining arousal through multimodal output. Fig. 1 depicts the experimental overview.

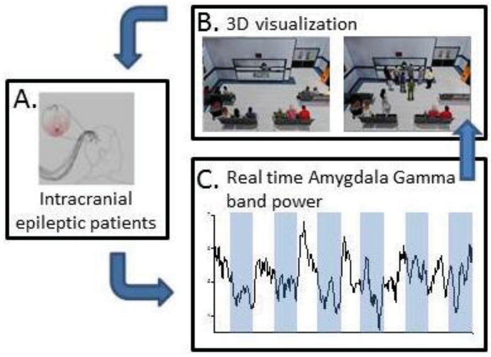

Figure 1. System Overview and Experimental Setting: the user is instructed to appease the situation in the waiting room. NF is based on a Gamma band amygdala iEEG power: the level of unrest in the waiting room matches the subject's amygdala's activation. C, The amygdala activity is plotted during several short NF trials (white-baseline blue-NF).

The NF task consists in controlling the level of unrest of a virtual crowd composed of characters in the waiting room of a hospital. Unrest is defined as the ratio between characters waiting and those protesting at the front desk, and is further emphasized by a matching soundtrack. Amygdala activity acquired through the depth electrode is mapped in real-time to the level of unrest, using a statistical distribution of virtual characters between waiting and protesting states.

Valid data were obtained from 3 patients with epilepsy (2M, 1F) implanted with Behnke-Fried depth electrode (AD-TECH). iEEG was sampled at 2 kHz and recorded using Neuroport (Blackrock microsystems). Each of the NF sessions included six to eight baseline epochs of passive viewing of the waiting room environment (60 sec each) and equivalent number of active NF blocks (60 sec each). The participants were instructed to "appease the waiting room using their brain activity" No preferred cognitive strategy was suggested to the subjects.

Results: Preliminary analysis of the iEEG recordings suggests that participants acquired the ability to down-regulate their amygdala's gamma band activity, even with little training. A successful relaxation session was defined as a block during which the probe values were significantly lower than those recorded in the baseline blocks (two-tailed Student's t-test; $p < 0.05$). Success was found in 50% of the relaxation sessions. We show that the response is specific to the Amygdala, i.e. other electrodes do not show correlated alterations to the gamma band activity. It is also specific in terms of band, as other frequency bands in the amygdala do not exhibit correlated activity with the Gamma band.

Discussion: Our preliminary results demonstrate that it is possible to train subjects to directly and specifically modulate their Amygdala's activity using depth electrodes as a signal acquisition device. Results obtained are encouraging, in particular the relatively high success rate considering minimal training received by subjects.

Significance: We presented a proof of concept of volitional control of local limbic activity recorded by depth electrodes in the Amygdala. This opens the way for further investigation of DBS electrodes for BCI applications. The NF setting we presented also supports various levels of personalization, or tailoring to specific conditions.

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