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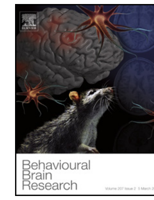

Evaluating low-resolution tomography neurofeedback by single dissociation of mental grotation task from stop signal task performance

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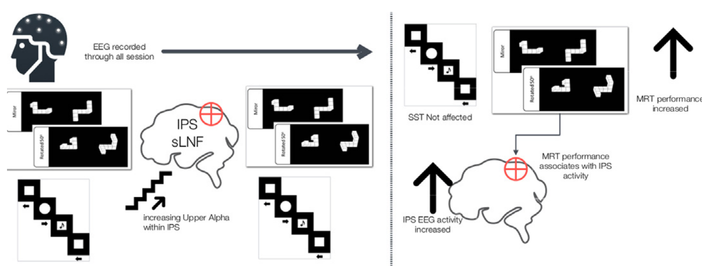
HIGHLIGHTS

- All participants were involved in a single session sLORETA neurofeedback.
- Practicing single brain area differentiates performance of one task from another.
- Changes in the trained area were found following practice compared to baseline.

GRAPHICAL ABSTRACT



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ABSTRACT

Electroencephalography source localization neurofeedback, i.e Standardized low-resolution tomography (sLORETA) neurofeedback are non-invasive method for altering region specific brain activity. This is an improvement over traditional neurofeedback which were based on recordings from a single scalp-electrode. We proposed three criteria clusters as a methodological framework to evaluate electroencephalography source localization neurofeedback and present relevant data.

Our objective was to evaluate standardized low resolution EEG tomography neurofeedback by examining how training one neuroanatomical area effects the mental rotation task (which is related to the activity of bilateral Parietal regions) and the stop-signal test (which is related to frontal structures).

Twelve healthy participants were enrolled in a single session sLORETA neurofeedback protocol. The participants completed both the mental rotation task and the stop-signal test before and after one sLORETA neurofeedback session. During sLORETA neurofeedback sessions participants watched one sitcom episode while the picture quality co-varied with activity in the superior parietal lobule. Participants were rewarded for increasing activity in this region only.

Results showed a significant reaction time decrease and an increase in accuracy after sLORETA neurofeedback on the mental rotation task but not after stop signal task. Together with behavioral changes a significant activity increase was found at the left parietal brain after sLORETA neurofeedback compared with baseline.

We concluded that activity increase in the parietal region had a specific effect on the mental rotation task. Tasks unrelated to parietal brain activity were unaffected. Therefore, sLORETA neurofeedback could be used as a research, or clinical tool for cognitive disorders.

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1. Introduction

Neurofeedback has been used for the last 40 years as a therapeutic method for a range of clinical conditions such as epilepsy, attention deficit hyperactivity disorder, and to optimize cognitive function in healthy subjects [8]. Participants can experience their real-time brain activity in the form of animated visual or auditory stimuli. The feedback co-varied with a specific property of the recorded activity. By being reinforced for obtaining clearly defined goals participants learn to modulate their brain activity. The feedback, continuously and reliably, represents brain activity with a delay of only a few tens of milliseconds.

During neurofeedback training brain activity data is collected from one or several surface sensors. The data recorded from these sensors represents an inseparable summation of brain activity from the entire brain. Practicing the control of brain activity, therefore, using these protocols could result in nonspecific and unpredicted changes to brain activity and participant behavior.

Source localization neurofeedback correlates the physiological signal with a continuous feedback signal. The physiological signal has been defined as the current density in a specified brain location calculated by algorithms such as low-resolution tomography (LORETA) and standardized LORETA (sLORETA). sLORETA is a widespread standardized linear, discrete, instantaneous, inverse solution proximity for brain electromagnetic measurements [17,18]. Whereas electroencephalography (EEG) is a measure of electric potential variations on a two-dimensional surface, the sLORETA algorithm estimates the current density in a three-dimensional space that results in the potential divergence on the scalp. sLORETA allows the continuous feedback to become a function of the intracranial current density and to co-vary with it [7].

There is only a handful of research using neurofeedback with source localization algorithms. In an early LORETA neurofeedback (LNF) study designed to assess the possibility of using this protocol on healthy subjects, [7] recorded the current density activity in the anterior cingulate of three participants and feedbacked it continously as a moving scatterplot and discretely as a beep tone accompanied by a color flash on the screen. The study showed that participants altered the ACC current density in the predefined direction between sessions. Furthermore, participants gained the ability to intentionally alter their own current density within the ACC at will without being feedbacked for their success. [7]. In another study, 14 healthy participants were trained to increase brain activity in the 14–18 Hz frequency band in the anterior cingulated gyrus (ACG) as well as in the right and left dorsolateral prefrontal cortices. A specific region effect was observed after training within the trained frequency spectral band. This effect was accompanied with performance enhancement which was seen in two indexes of the WAIS-III scores. Although well validated the WAIS-III is a multi-domain psychological test and its general score, as well as the sub-tests score, cannot account for activation in a distinct brain region. Changes, therefore, in WAIS-III scores after LORETA neurofeedack, cannot be applied to the treatment of a specific defective cognitive ability [5]. In a recent published study, a mixed psychiatric and normal population trained their alpha band frequency within the precuneus, a posterior parietal region implicated in the default mode network. The participants in this study performed neurocognitive tests and completed a clinical symptoms questionnaire before and after twelve training sessions. The results of this study suggests an effect of the training of both clinical symptoms of the diagnosed sample as well as cognitive changes that were interpreted by the authors as reflecting a general improvement of integration processes Baldwin, [4].

The aforementioned studies established an initial proof of concept for the application of source localization neurofeedback. In this work we address the shortcomings of these studies. First, we will propose a set of validating criteria for source localization neurofeedback treatment that we have built on previously described criteria for surface neurofeedback [26]. We will then try to follow these rules thereby validating sLORETA neurofeedback (sLNF) training.

A set of three validating criteria for single surface electrode neurofeedback has been proposed [26]. According to these criteria all neurofeedback protocols should influence the brain activity at the predefined direction within the trained frequency band (trainability). Furthermore, the neurofeedback training should impact only the attended frequency bands and not affect other untrained frequency bands (independence). Finally, the changes in brain activity resulting from the neurofeedback practice should be correlated with changes at some related cognitive performance (interpretability). These are powerful criteria for validating neurofeedback protocol based on one surface electrode and a power spectra goal. For the validity of other neurofeedback protocols, specifically source localization neurofeedback, a more elaborate approach should be considered.

As opposed to surface-neurofeedback, while practicing source localization neurofeedback, the participants' efforts are directed at changing brain activity of a specific brain region and at a specific frequency spectral band. Therefore, the validation criteria described above are not good enough for this method. Altering brain activity should normally have specific functional objectives such as improving cognitive, perceptive or motor performance. For the adaptation of the above validation criteria to source localization neurofeedback, we propose an extension of these three criteria, clustered into three main groups. The following described criteria are somewhat overlapping. However, for convenience and clarity, we describe them separately.

1.1. Neurophysiology validity

1.1.1. Neurophysiology trainability

From the electrophysiology perspective we propose that every neurofeedback should affect the brain activity metric involved in the protocol at the predefined direction. Considering sLNF, we used current density (CSD) as the brain activity metric, and we expected to observe changes at the specific frequency of training.

1.1.2. Neurophysiology specificity

The protocol should affect the chosen metric with no specific, anticipated effect on other metrics. While performing sLNF we expected to observe an effect on the trained frequency compared to other frequency bands with no theoretical predictions for change.

1.1.3. Neurophysiology

Regional task dependence – given the interaction anticipated between electrophysiological metric spatial location and the cognition (or other brain functions) performance, electrophysiological changes will be considered valid if measured while the participant is engaged in the relevant task and not at resting state which is as traditionally measured. We will further discuss this issue later.

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