WS11. Clinical Neurorehabilitation Based on Neuromodulation Interventions

Upper-Alpha Neurofeedback Training for Cognitive Enhancement: A Single-Session Study*

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Abstract. This paper reports on a single-session neurofeedback (NF) training procedure on the user-specific upper alpha band for cognitive enhancement of healthy users. A double-blind study was designed using a NF group and an active control group. Control group performed as the NF group but received sham feedback, minimizing the non-specific factors of training. Results of EEG analysis show the key role of the feedback: only the NF group enhanced upper alpha during the training, and it led to a desynchronization increase during the execution of a cognitive task. Regarding the behavioral results, a strong learning effect was observed, with the NF group performing better in almost all measurements but many of them without statistical significance.

1 Introduction

Alpha activity is characterized by a peak in the range $[7.5 - 12.5]$ Hz and has been traditionally linked to cognitive performance [1]. It has been recently hypothesized that alpha rhythm may act in the cortex as a mechanism to inhibit unnecessary or conflicting processes to the task being performed, thus facilitating attention by actively suppressing distracting stimuli [2]. Neurofeedback (NF) has emerged as a potential technique to allow users to modulate their brain rhythms using an operant control paradigm, which could increase cognitive performance.

This study reports on a single-session NF training procedure on the upper alpha (UA) frequency band. It has been designed in a double-blind fashion using a NF training group and an active control group, where the control group performed as the

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NF group but received sham feedback. The main objectives were to (i) investigate UA as a NF parameter, (ii) evaluate the effects on UA band during the execution of a cognitive task, and (iii) evaluate the effects on cognitive performance by means of a cognitive task.

2 Methods

Nineteen subjects participated in the study, who were randomly assigned to either to a NF group (ten subjects) or to an active (placebo-based) control group (nine subjects).

EEG signals were recorded from 16 active electrodes placed at FP1, FP2, F3, Fz, F4, C3, Cz, C4, P7, P3, Pz, P4, P8, O1, Oz and O2 $(10/10$ system). Ground and reference electrodes were placed on FPz and the left earlobe, respectively. EEG was amplified using a commercial gTec system at a sampling rate of $256Hz$, power-line notch-filtered at $50Hz$, and $[0.5-60]Hz$ bandpass-filtered. Signal acquisition, processing and feedback presentation were developed using *Bit&Brain Technologies* software.

The experimental setup consisted of a single-session NF training. An EEG screening and a cognitive task were interleaved immediately pre-post the training to assess EEG and behavioral changes.

a) NF Training: Training focused on the enhancement of UA power over parieto-occipital areas (P3, Pz, P4, O1 and O2, referred to as feedback locations). UA was individually defined as [IAF, IAF+2] Hz range [1]. 5 trials of 5 min each were executed. Feedback was provided visually by a square on a screen, either red or blue according to whether the UA power was higher or lower than the baseline, respectively.

b) EEG Screening: The screening was a 3-min recording in an open-eyes active task to challenge subjects cognitively. Averaged UA power during the screening was considered as the baseline for NF training.

c) Cognitive Assessment: A mental rotation task of solid figures was performed to measure behavioral changes, and to evaluate the NF effects on the EEG during its execution. The task consisted of 50 trials. In each trial one item consisting of two figures, a target and a test figure, arranged one above the other, was presented. Subjects were asked to indicate whether the test figure was a rotated target or not, by pushing a corresponding switch.

3 Results

3.1 UA Progress in EEG Screenings and NF Trials

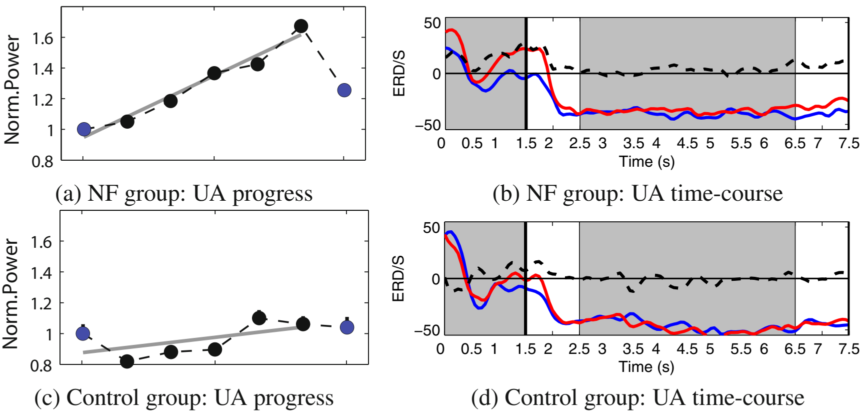
UA power results are displayed in Figure 1. Due to the large inter-user variability in absolute power, results are normalized with the UA power in the pre-screening.

Training progress was measured by the tendency of UA power in the pre-screening and training trials. The training progress was reflected by a significant positive tendency in that metric: the gradients of a fitted regression line for each subject of the NF group were significantly greater than zero ($t(9) = 2.52, p = 0.016$). This metric was not significant for the control group, and the difference between groups was not significant. The UA increase between the pre-screening and the last trial was also measured to assess training progress. This increase was 67% for the NF group (significantly greater than zero, $t(9) = 2.65, p = 0.013$), and 6% for the control group (not significant). The difference between groups was significant ($t(17) = 1.97, p = 0.032$). Functional changes in the EEG were measured using the pre-post screenings. UA pre-post increase was 25% for the NF group (significantly greater than zero, $t(9) = 4.12, p = 0.001$), and 4% for the control group (not significant). The difference between groups was significant ($t(17) = 2.42, p = 0.013$).

The results show a significant training progress only for the NF group, which was significant between groups in one of the two metrics used. Functional changes measured immediately pre-post the training were significant for the NF group in comparison with the control group.

3.2 UA Time-Course during the Executions of the Mental Rotation Task

The assessment was composed of two intervals: (i) rest interval, where the user was waiting for the item presentation; and (ii) task interval, where the user was



(a) NF group: UA progress

(b) NF group: UA time-course

(c) Control group: UA progress

(d) Control group: UA time-course

Fig. 1 Left side figures show the UA progress in EEG screenings and NF trials: blue dots denote screenings and black dots NF trials, the grey line shows the tendency of the pre-screening and trials. Values are normalized per user to the UA power in the pre-screening. Vertical bars indicate sem. Right side figures show the UA time-course ERD/S for each group in the mental rotation task: blue and red lines show the ERD/S pre-post the NF training, respectively; the difference between them is represented by the dashed black line. Grey colored areas denote the rest and task subintervals.

mentally rotating the figures. Complete rest and task intervals lasted 1.5 s and 6 s, respectively. For each group a modification of the event-related desynchronization (ERD) metric [3] was computed: the baseline for pre-post NF executions was set to the averaged UA power in rest interval of the pre NF execution to allow for pre-post visual comparison. Results are shown in Figure 1.

The results show that only the NF group presented a significant increase in power (17%) during the rest interval $(t(9) = -3.44, p = 0.003)$. The increase of this measurement was significant between groups $(t(17) = -2.09, p = 0.026)$. The power in the task interval remained constant for both groups and no significant differences were found between groups.

3.3 Behavioral Results of the Mental Rotation Task

Only responses in the complete task interval (6 s) plus 2.5 s (inter-trial interval) were taken into account. Reaction times were computed only for correct responses. Regarding the correct responses, both groups significantly improved performance. This increase was greater for the NF group, but was not significant between groups. Similar results were obtained in the reaction times measurement. Both groups significantly reduced reaction time, with the NF group performing better, but the difference between groups was not significant. These results show a strong learning effect that may have masked the changes in performance due to NF training. Furthermore, initial scores were 82.4% and 78% for the NF and control groups, respectively. The high initial scores suggest that the assessment was too simple for the participants of the study, which could be considered a methodological limitation.

4 Conclusions

This paper presented a single-session NF training procedure of the individual upper alpha frequency. The double-blind nature of the study with a placebo-based control group allowed for minimization of non-specific factors. Training progress and functional changes were obtained in the EEG only for the NF group, thus showing the importance of the feedback in the NF procedure. These changes in the upper alpha power for the NF group led to an increase in the upper alpha desynchronization during the execution of the cognitive assessment (not visible for the control group). Note that this desynchronization is suggested to be related to cognitive performance [2, 4]. Regarding behavioral effects, the NF group performed better in the two scores of the cognitive assessment, but no significant differences were found with the control group.

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