Perceptual Learning via Decoded-EEG Neurofeedback

A. Brandmeyer[1], M. Sadakata[1], L. Spyrou[1], J. M. McQueen[123], P. Desain[1]
[1]Donders Institute, Nijmegen, Netherlands; [2]MPI for Psycholinguistics, Nijmegen, Netherlands;
[3]Behavioural Science Institute, Nijmegen, Netherlands

Correspondence: A. Brandmeyer, Donders Institute, P.O. Box 9104, 6500HE Nijmegen, Netherlands. E-mail: a.brandmeyer@donders.ru.nl

Abstract. An experiment was conducted to determine whether decoding auditory evoked potentials during passive listening and providing the classifier output as a neurofeedback signal leads to the enhancement of auditory perceptual discrimination and/or brain responses related to auditory perception. Results indicate an enhancement of both behavioral discrimination and brain responses to frequency stimuli across four days of measurements.

Keywords: EEG, Mismatch Negativity, P3a, Neurofeedback, Perceptual Learning, Brain-Computer Interface

1. Introduction

BCIs are most commonly developed for use as communication devices for patients with motor impairments [van Gerven et al., 2009]. Recently, it has been shown that the same multivariate methods underlying many BCIs can be used to provide novel forms of fMRI-based neurofeedback (NFB) that induce visual perceptual learning in healthy users [Shibata et al., 2011].

An experiment was conducted to determine whether a similar approach is possible using NFB based on decoded auditory evoked potentials (AEPs) measured using EEG. Stimulus sequences containing high-probability ‘standard’ trials and low-probability ‘deviant’ trials were used. In a passive listening setting, deviant trials in these sequences are known to elicit both enhanced P3a responses and the mismatch negativity (MMN). We hypothesized that providing NFB on the differing pattern of AEPs to standards and deviants would lead to a relative enhancement of these components, along with an induced perceptual learning effect that would improve behavioral discrimination.

2. Material and Methods

2.1. Participants

Six participants completed four days of testing. All participants reported normal hearing.

2.2. Stimuli

Harmonic sinusoidal tones were used for the behavioral, offline EEG measurement and NFB portions of the experiment. During both the offline and NFB portions, so-called ‘optimal’ MMN sequences containing 5 types of deviant stimuli were utilized, as described in [Naatanen et al., 2004]. Two of these deviant stimuli served as NFB targets: duration (25 ms vs. 75 ms standard) and frequency (550 Hz vs. 500 Hz standard). Half of the participants’ NFB was based on single-trial AEPs measured for duration deviants and the standard stimuli immediately preceding them, while the other half received NFB on frequency deviants and the standard stimuli preceding them.

2.2. Procedure

At the beginning of the first day, participants completed measurements of their behavioral discrimination thresholds for both frequency and duration using a 2AFC staircase procedure. For the first three days, participants completed offline EEG measurements while watching silent films, followed by a NFB session. On the fourth day, participants completed a NFB session followed by the same behavioral measurements as on the first day.

2.4. Classification analysis and NFB parameters

On the first three days, individual data collected during the initial EEG measurements were used to train two quadratically regularized linear logistic regression classifiers. The fourth day made use of classifiers trained on the previous three days’ worth of individual data. A first classifier was trained on a binary problem consisting all standard trials vs. all deviant trials, and was applied during NFB sessions to the standard trials preceding the target deviants. A second binary classifier was trained on trials for the NFB target (frequency or duration deviant) vs. an equal number of trials in which the same stimulus was measured in an isochronous sequence. During NFB, this classifier was applied to the target deviant trials. The outputs of the two classifiers for the previous five trials were combined into a single value during the NFB sessions to control the amount of blurriness of the films viewed by participants during the NFB sessions.

3. Results

3.1. Behavioral

Behavioral results can be seen in Fig. 1a. Thresholds for frequency discrimination in the post-test were significantly lower than in the pre-test ($p < .01$), with 5 out of 6 participants showing reduced thresholds in the post-test. No effects were observed for duration thresholds, nor were any training group effects observed.

3.2. ERP measurements

ERP plots across the 4 days can be seen in Fig. 1b. For each day and measurement (offline vs. NFB), the mean amplitude of the MMN and P3a components in the individual grand average deviant – standard difference waveforms were computed in a 50 ms window around their peaks using the mean of nine fronto-central electrode locations where AEPs tend to be maximal. These results are plotted in Fig. 1c. For the P3a component, a significant effect of deviant type ($p < .05$) and an interaction of deviant type with measurement day ($p < .001$) were found, with higher P3a amplitudes for 5 out of 6 participants on the final two days (relative to the first day). No significant effects were found for the MMN component.

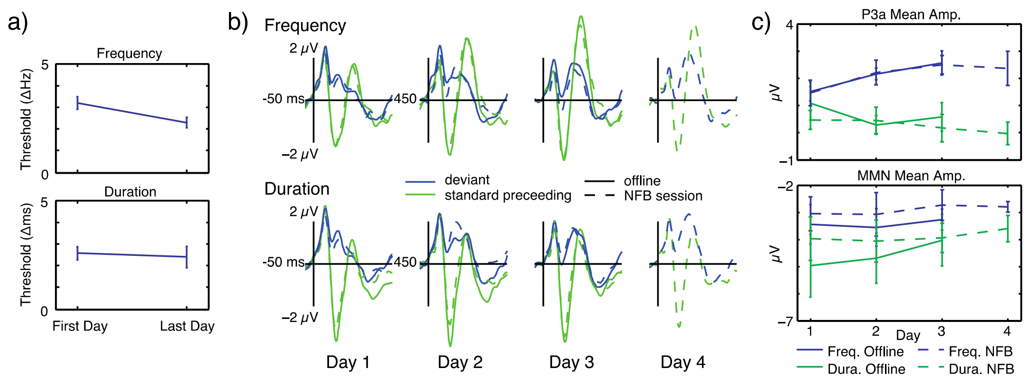

Figure 1. *Behavioral and ERP results. a) Frequency and duration discrimination thresholds on the first and last days for all participants. b) Grand-average ERPs at fronto-central electrode locations across days and deviant types. c) Mean amplitudes of MMN and P3a components across days, session and deviant types.*

4. Discussion

Regardless of which deviant was used to provide NFB to participants, a general enhancement of P3a responses to frequency deviants was observed along with an improvement in frequency discrimination performance. One possible explanation is that effortful control of the NFB mechanism leads to top-down modulation of perceptual processes related to the perception of deviant stimuli, and that this modulation is most apparent in responses to frequency deviants. While additional research is needed to clarify these effects, the present results suggest the potential for novel BCI applications for auditory perceptual learning in healthy users.

References

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