Titre/Title :

Impact de contrôle en boucle fermé et battements auditifs sur l'attention

chez les patients en déficit d'attention /

Impact of closed-loop feedback and auditory beats on attention of attention-deficit patients

Motivation.

Attention-deficit/hyperactivity disorder (ADHD) is a neuropsychiatric disorder. It is characterized by, inter alia, inattention, hyperactivity and impulsivity. Visual attention reflects a certain degree of alertness and it has been shown experimentally in adult ADHD patients that pharmacological medication may well improve the ADHD patients' visual processing speed. Since pharmacological medication typically yields cognitive adverse side effects, an alternative non-pharmacological neurofeedback or performance feedback may represent an alternative light treatment. The current project proposes a combination of auditory stimulation and the performance feedback to demonstrate that non-pharmacological feedback may also improve visual attention deficits in ADHD. To this end, theoretical modeling, control feedback and experimental psychophysics will be employed.

Feedback schemes are well-known to improve visual attention. The most prominent approach is neurofeedback [1], which feeds back features of measured neural activity, such as the visualized spectral power distribution of brain activity or its power in certain frequency bands. Neurofeedback is known to entrain brain activity in certain frequency band and improve visual attention. However, such neurofeedback requests costly neural electronic devices capturing brain signals. These devices may be available to patients in experimental laboratories only or may be purchased privately for a high price. The aim of our project is to develop a computational feedback tool, that does not need specialized costly electronic devices but may be implemented as a software utility. A good candidate for a non-neural feedback is *performance feedback* [2], which feeds back the real-time behavioral performance. This performance may be the subjects reaction time or accuracy of performed trials. It is fed back to the subject synchronously with the experimental tasks. In such a setting, visual attention is reflected in the behavioral performance: for instance, the faster the subject responds to the stimuli, the higher is the subjects visual attention.

Moreover, it is well-known that auditory stimulation improves visual attention. We will employ binaural beats [3] which have been proposed to remedy visual attention deficits in adolescents and adults [4]. The optimal combination of performance feedback and auditory stimulation permits to improve visual attention optimally.

Neurofeedback targets to modulate a pre-defined set of frequency bands according to deficit or pathology of the subject. However, in practice not only these frequency bands are affected but also non-targeted frequencies [5] which may induce unwanted adverse effects. To control the impact of performance feedback, it is useful to capture brain signals during the experiment to supervise the impact on the brains rhythmic activity. A previous work [6] has shown that reward-based feedback enhances EEG activity in the beta-frequency range. Moreover, performance feedback in a reaction-time task has been shown to increase the amplitude of evoked potentials [7]. Since modifications of frequencies are important to control unwanted adverse side effects, the relation of performance feedback, auditory stimulation, resulting visual attention and brain activity is essential to understand in the development of a cost-friendly and save medical tool.

Objectives.

The project addresses deficits of visual attention in humans.

To study this (Task I), the student will start the project with the performance of different psycho-physical experiments capturing times of reaction triggered by simple visual stimuli presented on a computer screen. The reaction times represent the performance measure. Such simple experiments will be performed (i) under auditory stimulation only, (ii) with performance feedback only visualized in real time on the presentation screen and (iii) under auditory stimulation and with performance feedback. The experiments with tens of healthy deficit-free subjects serve to familiarize the student with the experimental setup and to provide insights into the impact/importance of auditory stimulation and performance feedback. A detailed statistical evaluation of the experimental results will permit the student to quantify the different impact of stimulation and feedback on the visual attention.

In a subsequent Task II, the student will study mathematical models of behavioral feedback [8] and link these models to the first quantitative experimental results obtained in Task I. Classical feedback models assume linear time-invariant systems. We may employ such systems while extending them by several features present in realistic experiments. The major extension will be the fact that the observation is taken from a system part which is not stimulated directly in the feedback but just indirectly via other system parts. For instance, in our psychophysical experiments human motor response is measured, while the feedback is visually presented. Moreover, the stimulation feedback signal, i.e. the performance, may be a nonlinear function of the observation. In addition, an additional stimulation (reflecting the experimental auditory input) may affect the feedback performance. Corresponding mathematical models will elucidate how much feedback and stimulation affect the observation and under which conditions they control the behavioral output. The behavioral output, i.e. the observations, reflects the degree of attention in human subject and hence such mathematical models describe the visual attention on a behavioral level.

In the final Task III, the student will transfer the gained insights from Task I and II to neurophysiological experiments with human subjects exhibiting deficits in visual attention. These experiments will be performed with assistance of the team of the collaboration partner Anne BONNFOND (INSERM 1114). The subjects in the experiments will be healthy (control group) and subjects with attention deficits . The experiment will capture multi-channel EEG signals measured during psychophysical experiments [9]. These experiments will be performed (i) without stimulation and feedback, (ii) with auditory feedback, (iii) in the presence of performance feedback and (iv) with auditory stimulation and performance feedback. In a first analysis step, the behavioral results will be evaluated and the impact of stimulation and/or feedback will be extracted. In a subsequent analysis step, the detailed spectral analysis of the EEG subjected to the stimulation condition and the performance will elucidate how both affects which brain rhythms. In a final model step, the student will attempt to describe the behavioral data by the mathematical models worked out in Task II and relate the stimulation and feedback impact of EEG spectral properties to the behavioral model parameters. This will provide insights for future work and indicates how future software implementations of the experimental setup can be optimized specifically for each patient.

[1] Ordikhani-Seyedlar et al. (2016) Neurofeedback Therapy for Enhancing Visual Attention: State-of-the-Art and Challenges. *Front. Neurosci*. 10:352.

[2] Mensen, et al. (2022) The effects of real-time performance feedback and performance emphasis on the sustained attention to response task (SART). *Psychological Research* 86 :1972–1979

[3]Chaieb et al. (2015) Auditory beat stimulation and its effects on cognition and mood states. *Front. Psychiatry* 6:70.

[4] Aparecido-Kanzler et al. (2021) Effects of binaural beats and isochronic tones on brain wave modulation: Literature review. *Rev Mex Neuroci.* 22(6):238-247

[5] Dessy et al. (2020) Train Your Brain? Can We Really Selectively Train Specific EEG Frequencies With Neurofeedback Training. *Front. Hum. Neurosci.* 14:22.

[6] HajiHosseini and Holroyd, (2015) Reward feedback stimuli elicit high-beta EEG oscillations in human dorsolateral prefrontal cortex. *Sci Rep* 5 :13021.

[7] Groen et al. (2007) Physiological correlates of learning by performance feedback in children: a study of EEG event-related potentials and evoked heart rate. *Biol Psychol*. 76(3):174-87.

[8] Hagger et al. (2020) The Handbook of Behavioral Change. Cambridge University Press.

[9] Chidharom et al. (2021) Investigation of electrophysiological precursors of attentional errors in schizophrenia: Toward a better understanding of abnormal proactive control engagement. *J Psychiatr Res.* 140:235-242.

Originality.

The project proposes to extend the current research on the cognitive impact of performance feedback to a pre-clinical application. Neurofeedback is known to improve visual attention in ADHD patients but requests the patient to visit an experimental lab due to extensive technological requests. Our project will combine experimental psycho-physical and electrophysiological attention studies with detailed and data analysis and computational behavioral modeling. The long-term aim of our project is to develop cognitive experiments with performance feedback that may replace electrophysiological neurofeedback and, in the future, may be applicable at home by installing a software.

Time schedule:

<u>Month 1 - Month 9:</u> (Task I) Literature study on visual attention, binaural beats, neurofeedback and performance feedback. Development and performance of psycho-physical experiments with healthy patients (performed in team MLMS) .

<u>Month 10 - Month 21:</u> (Task II) Mathematical modeling of behavioral feedback systems (in team MLMS). Summarizing experimental and modeling results and writing up manuscript for publication in peer-reviewed journal.

<u>Month 22 - Month 30:</u> (Task II) EEG-experiments in subjects with and without attention deficits (performed in team INSERM1114). Data analysis and statistical evaluation (MLMS). Summarizing results and writing up manuscript for publication in peer-reviewed journal.

Month 29- Month 36: Writing up results in thesis document.