An ERP study reveals how training with Dual N-Back task affects risky decision making in a gambling task in ADHD patients

Sarah K. Mesrobian[1], Alessandra Lintas[1,2], Manon Jaquerod[1], Michel Bader[3], Lorenz Götte[4], and Alessandro E.P. Villa[1,2]*

[1] NeuroHeuristic Research Group
[2] LABEX, HEC Lausanne
University of Lausanne, Quartier UNIL-Dorigny, CH-1015 Lausanne, Switzerland
[3] Research Unit of the University Department of Child and Adolescent Psychiatry (SUPEA), CHUV University Hospital and Faculty of Biology and Medicine, University of Lausanne, CH-1004 Lausanne, Switzerland
[4] Institute for Applied Microeconomics, University of Bonn, 53113 Bonn, Germany
http://www.neuroheuristic.org

Abstract. Impaired decision making and Working Memory (WM) are among the characteristic symptoms of patients affected by Attention Deficit/Hyperactivity Disorder (ADHD). In order to investigate whether a WM training can affect the attitude towards risky decision making, we designed a study where participants had to perform a Probabilistic Gambling Task. Our study has demonstrated that WM training affects in a different way controls and ADHD patients, who showed an increased tendency towards a risk-taking attitude in case of the adaptive variant of the memory task. In ADHD patients, the frontal sites appeared the most affected, whereas global brain activity was likely to be affected in controls. This study shows also the benefits of cognitive training in ADHD patients and healthy subjects.

1 Introduction

Patients with a diagnosis of attention deficit/hyperactive disorder (ADHD) are characterized by Working Memory (WM) impairment, difficulties in concentrating and maintaining focused attention, high degree of impulsivity, as well as excessive level of activity and talking and a multiple range of associated disorders. Experimental studies have not clarified yet to what extent, if any, ADHD were characterized by impaired performances in risky decision-making tasks. In a double blind placebo experiment, using the Iowa Gambling task (IGT), no significant difference was detected neither in the selection of bad deck nor in the total net score between all groups [1]. Other studies have pointed out a riskier behavior using the Iowa Gambling Task, with ADHD disclosing a lower total score compared with a control group [2].

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* Corresponding Author: alessandro.villa@unil.ch

During decision making it is important to determine whether the subjects are sensitive to the frequency but blind to the magnitude of a penalty/reward. In order to investigate whether a WM training can provoke a neural response having an influence on risky decision making, we designed a study where participants had to perform a Probabilistic Gambling Task (PGT), modified from the original Gneezy and Potters' neuroeconomic game [3]. The protocol included a pre-training session in the laboratory, 20 days of WM training at home and a post-training session in the laboratory. During the WM training, half of the participants played the adaptive variant of the memory task and half played a baseline variant blocked at the first level of difficulty. We analyzed the effect of WM training on the behavior and on event-related potentials (ERPs). Preliminary results have been published in the PhD Thesis of SKM [4].

2 Experimental protocol

We selected 127 participants (22 yrs. old ±0.28 SEM, $N_{ADHD} = 43$ and $N_{CTRL} = 84$) for this study. All participants underwent a short structured diagnostic interview assessing psychiatric disorders. The session started by playing the PGT with an endowment of 20 points at the beginning of each trial, and requested to gamble 0, 4, 8, 12, 16, or 20 points with 1/3 chance to win [4]. The outcome of the gambling was either to win four times the chosen amount, with a probability $P_{win} = 1/3$, or to loose the entire amount with a probability $P_{loose} = 2/3$ with a uniformly distributed probability. If the participant selected 8 points, the outcome would be $12 = (20 - 8)$ in case of loss, or $44 = (20 - 8) + (8 \times 4)$ in case of win. The participants had the possibility to modify their initial choice during 4 seconds. The overall amount of points held by the participant was displayed every four trials. The whole session was composed of 10 games x 16 blocks, overall 160 trials. The duration of PGT was approximately 30 minutes.

Subsequently, the participants exercised the adaptive version of the Dual N-Back memory task [5], which consisted of 20 blocks of 20+N trials, composed of visual and auditory stimuli. Participants were asked to detect and to press a key if any of the current stimuli corresponded to the ones presented in the previous trial (Level 1). Participants pressed the "A" key to report the correspondence with a visual target and pressed the "L" key to report for the correspondence with an auditory target. In the adaptive variant, the level of difficulty was adjusted as follows: in case of less than 3 mistakes in both modalities, the difficulty was increased by 1, while 5 errors in any modality decreased the level by 1. Level 2 meant to recognize if any of the current stimuli corresponded to the ones presented two trials earlier, level 3 corresponding to 3 trials earlier, and so on.

During the entire duration of a session, ended with the Attentional Network Test (ANT) [6], EEG was continuously recorded using 64 active Ag/AgCl electrodes and referenced to the linked earlobes [7]. Epochs triggered by pressing the spacebar (event S) and by clicking on the selected amount to gamble (event I) were used for the analysis of ERPs from 500 ms before to 1000 ms after the triggering event. Following the removal of EEG's equipment, the participants

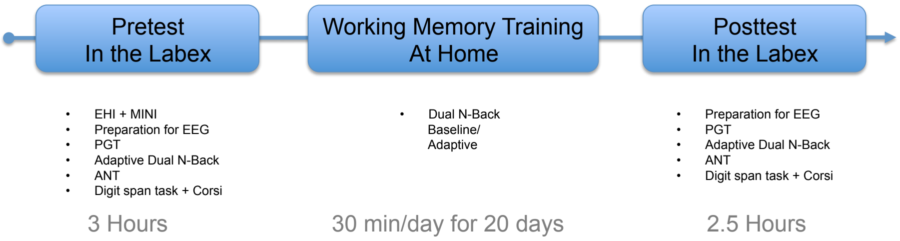

Fig. 1. Experimental procedure of the whole study.

performed the WAIS-IV digit span task [8] and the Corsi Block-Tapping Task [9]. The complete protocol of the study (Fig. 1) included a pre-training session in the laboratory (with all participants playing the adaptive version of the Dual N-back task), 20 days of WM training at home, and a post-training session in the laboratory (with all participants playing again the adaptive version of the Dual N-back task). During the WM training, half of the participants of each group (ADHD and controls) played the adaptive variant (trained participants), whereas the other half played the Dual N-Back blocked at the level 1 for the whole training period (baseline participants). Participants were required to complete at least 18 training sessions within a month. The Dual N-Back task played during each training session (composed of 20 blocks) was made available to the participants via a customized secured internet web site.

3 Results

Before WM training, all participants reached level 2 of the Dual N-Back task. No difference was observed between the baseline and trained participants of either group ($U_{CTRL} = 953.5$, $p > .05$; $U_{ADHD} = 335.5$, $p > .05$) neither between controls and ADHD ($\chi^2(1) = 0.74$, $p > .05$). After training, the performance on the Dual N-Back was enhanced in both controls ($Z_{CTRL-base} = -5.59$, $p < .01$; $Z_{CTRL-train} = -5.7$, $p < .01$) and ADHD patients ($Z_{ADHD-base} = -3.67$, $p < .01$; $Z_{ADHD-train} = -4.23$, $p < .01$. It is interesting to notice that in both groups, even a training with Dual 1-Back (baseline participants) improved the performance during the post-training session ($\chi^2(1) = 104.2$, $p < .001$, Fig. 2).

The WT training did not affect the total gains earned by all participants at the Probabilistic Gambling Task, irrespective of the group, ($\chi^2(1) = 1.8$, $p > .05$). The count of times a participant gambled a small amount (i.e., 0, 4, or 8 points), termed LIR, and the count of times a participant gambled a large amount (i.e., 12, 16, or 20 points), termed HIR, were used to compute an investment risk index $IRi = \frac{HIR-LIR}{HIR+LIR}$. Thus, the value of IRi is centralized within the range [-1 − +1]; an index closer to -1 characterizes a participant with risk averse strategy, an index closer to $+1$ characterizes a risk seeking participant. Hence, each individual was characterized by an investment risk index.

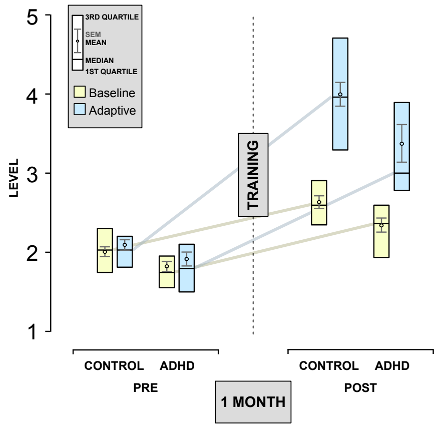

Fig. 2. Boxplot of the Dual N-Back performance of $N = 84$ controls and $N = 43$ ADHD participants before and after the WM training.

WM training affected the participants of the two groups in a very distinct way. Controls tended to centralize their attitude towards a risk neutral attitude after WM training and risky behavior was not affected by the training protocol ($t_{(70)} = -0.171$, $p > .05$). On the contrary, ADHD patients tended to maintain the same risk-taking behavior before and after WM training for the baseline participants. Moreover, ADHD patients who performed the adaptive training showed an increase in their attitude towards risk ($t_{(40)} = 3.516$, $p < .01$).

The analysis of the ERPs after WM training (Fig. 3) showed a N2-P3 complex triggered by the self-paced start of trial (event S). In controls we observed no differences due to the training variant. In ADHD we observed a larger N2 component in baseline, especially towards posterior sites, and a larger P3 component towards the frontal sites after the adaptive training. After the selection of the gambling (event I), the controls showed an increase in P3 amplitude close to central sites after the adaptive training, suggesting a localization towards the cingular cortex. In the ADHD after the adaptive training, we observed also an important secondary component, P3b, mainly localized towards the frontal sites.

4 Discussion

Several hypothesis have been suggested in order to explain the suboptimal decision making abilities characterizing ADHD patients [10]. The medial prefrontal cortex–posterior cingulate cortex circuitry is involved in the abilities to have a sense of self, and to pursuit specific goals. This circuitry has been shown to be less effective in ADHD, and might explain goal setting impairments, planing difficulties and intention deficits involved in the valuation and intention to take risks processes. Executive functioning deficits in ADHD associated with abnormal activity in the dorso-lateral prefrontal cortex postulates that WM deficits prevent

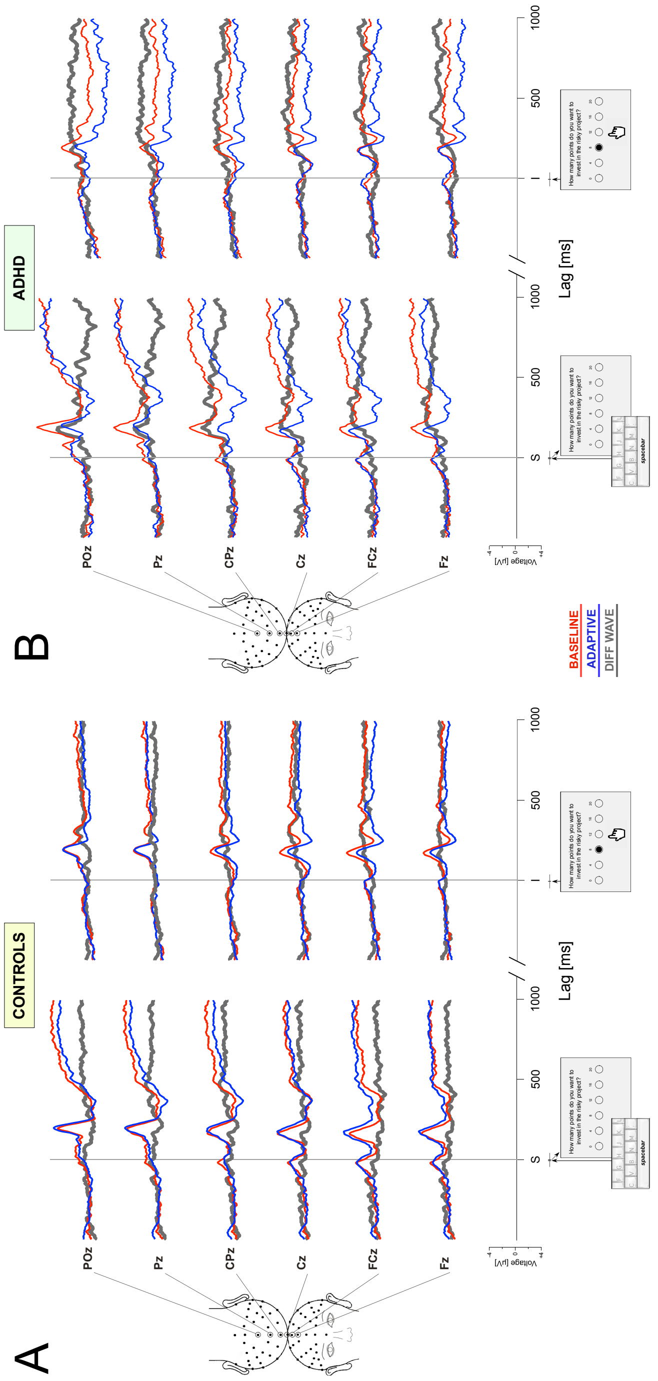

Fig. 3. ERPs: Grand average ERPs recorded after WM training at Fz, FCz, Cz, CPz, Pz and POz sites triggered by pressing the Spacebar (event S) and following the selection of the amount to gamble (event I) in Control (**A**) and ADHD (**B**) participants. ERPs of participants trained with Dual 1-back (the baseline variant, red curves) and trained with the adaptive variant (blue curves) are plotted with the differential curves (dark grey).

to hold informations in mind, resulting in poor economic decision-making capacities in ADHD. The last hypothesis involves dopaminergic dysregulation in ventral frontostriatal loops supporting outcome prediction and evaluation, and learning competences, that have been reported to be less efficient in ADHD individuals. Our study has demonstrated that WM training affects in a different way controls and ADHD patients, who showed an increased tendency towards a risk-taking attitude in case of the adaptive variant of the memory task. The inherent difficulty of this task is likely responsible of an increased activity of the frontal areas, observed in the ERPs after the selection of the gambling. We are undergoing further analyses of these results aimed at providing a more precise localization of the cortical areas that characterize altered brain activity in ADHD patients.

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