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Alpha and Theta Intensive Neurofeedback Protocol for Age-related Cognitive Deficits

J. Reis, A. Portugal, M. R. Pereira, and N. Dias, *Member, IEEE*

Abstract—**With the growing life expectancy, the number of elderly people is increasing tremendously worldwide. The progressive decrease of synaptic plasticity and neuronal inter-connectivity in the ageing brain, concomitant with alterations in key cognitive abilities such as working memory and attention, may be delayed, stopped or reversed by neurorehabilitation. Hence, current approaches used to modify cognitive capabilities are of utmost importance to contemporary society and often divided into behavioral training procedures and techniques for direct modulation of neural mechanisms. Neurofeedback (NF), which is based on electroencephalogram signals, is used to train individuals on learning how to influence brain function by modulating their own brain rhythms. However, the potential effects of rehabilitation through behavioral training, neuromodulation and even a combined methodology are poorly understood. Differently from the frequently reported longer protocols, an alpha and theta intensive neurofeedback protocol was applied on 14 subjects ageing more than 55. Although the herein presented results suggest that the proposed protocol succeeded to modulate alpha and theta rhythms and led to moderate cognitive improvements, no modulation was apparent on post-training resting state EEG rhythms.**

I. Introduction

Cognitive functioning in elderly is a wide research topic, providing clues about cognition itself and future interventions to age deterioration. The most documented cognitive changes with age are on processing speed, working memory and encoding of information into episodic memory [1] , and also executive functioning [2,3]. To support these findings, neurology and electrophysiology studies also found differences through aging. In adult stages, alpha frequency, in a range between 8 and 12 Hz, is the most prevalent EEG rhythm in general cortex, and its oscillations are related to psychological and cognitive performance [4,5]. In frontal sites, alpha activity might be caused by thalamic and anterior cingulate cortex functioning, which addresses to attentional and working memory processing. Theta band (4-8Hz) is also related to cognitive performance, especially during memory tasks, with a relative poor power during resting state, unless in sleepy stages [6], but enhanced during memory encoding and retrieval [e.g. 7,8,9], proving its relationship with hippocampus functioning [10]. The poorer cognitive performance with aging might be paired with some registered EEG differences, as a slower general EEG frequency [11,12,13], an enhanced parietal and temporal delta [13], and changes in coherence [11], mainly between frontal and parietal structures that share attentional and information processing pathways. Therefore, this relationship makes possible the association between a better cognitive performance and a specific EEG pattern in specific cortical sites.

Neurofeedback (NF) is a brainwave training technique that has been focused on improving cognitive and neurological functioning in several clinical conditions, as ADHD and epilepsy, by giving feedback to the subject about his electrophysiological state and directing it to the desired activity [14,15]. There is some literature dedicated to NF intervention in elderly, but most studies focus on alpha and theta training, as well as with healthy adult populations, stressing its effects in attention and working memory [16,17]. In terms of protocol duration, greater results are observed in longer NF protocols with 10 NF sessions on average [17] and with resting days between sessions. Therefore, the goal of this work is to assess the effects of both alpha and theta intensive no-interval training in EEG modulation and cognitive performance of older adults, especially in working memory tasks. To this purpose, a neuropsychological evaluation was done before and after the alpha and theta separate training in frontal sites. Improved attentional resources mobilization and enhanced memory performance are the main expected outcomes of this training, translating in better task results.

II. Methodology

A. Subjects

For this study, 14 right-handed healthy volunteers (6 males and 8 females) aged above 55 years, were recruited from a Health Care Centre from Braga, Portugal. Only participants without any diagnosed dementia, cerebrovascular or neurological pathology were invited to take part. At the beginning of the experiment they answered questions about their educational background, current or previous occupations as well as prescribed medication. The cohort was established in accordance with the principles expressed in the Declaration of Helsinki and the work was approved by the national ethical committee and by local ethics review boards. All the participants signed a voluntarily informed consent for the use of the collected data. The participant's cognitive profile was assessed using a battery of neurocognitive tests to measure cognitive flexibility, verbal fluency and processing speed. Additionally, psychological tests were also applied to access mood, anxiety, stress

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Joana Reis, Ana Maria Portugal, Mariana R. Pereira and Nuno Dias are with Life and Health Sciences Research Institute (ICVS), School of Health Sciences, University of Minho, 4710-057 Braga, Portugal and ICVS/3B's - PT Government Associate Laboratory, Braga/Guimarães, Portugal.

Nuno Dias is also with DIGARC, Polytechnic Institute of Cavado and Ave, 4750-810 Barcelos, Portugal.

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profile, personality, functional ability and quality of life and memory perception. Most notably, Geriatric Depression Scale (GDS) and the Mini-Mental State Examination (MMSE) were comprised in this battery. At the end of the study, all participants completed a questionnaire about their general opinion of the study.

B. Electroencephalogram signal acquisition

All EEG signals were acquired with the QuickAmp®, Brain Products, GmbH or the ActiCHamp®, Brain Products, GmbH. Both systems use the international 10-20 system with 32-channels standard electrode layout with ground and reference electrodes. The whole system was constituted by: Ag/AgCl active electrodes, a cap – actiCAP or EASYCAP (Brain Products, GmbH) – electrolyte and straps to keep the cap in place. Ground was located at forehead and reference was FCz channel when using QuickAmp equipment and Cz when using the ActiCHamp equipment. For each participant, the same equipment was used for all EEG data acquisitions. During recordings, all participants were instructed to not make any movements (beyond the required ones) and to always answer with the same hand.

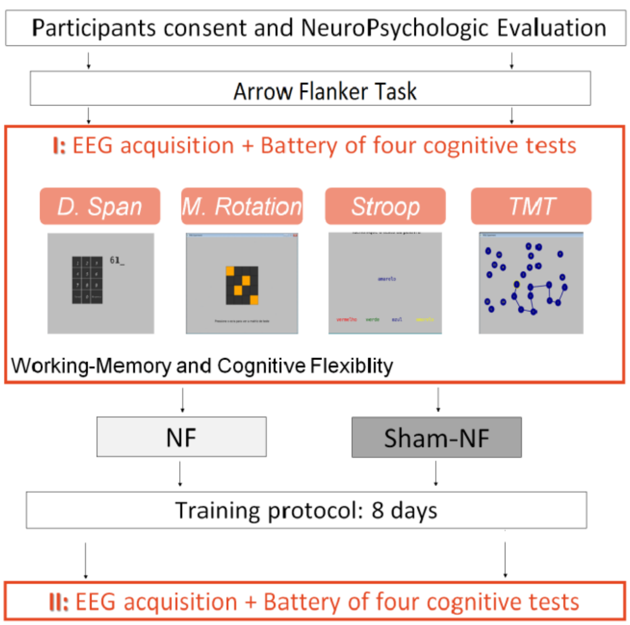

Figure 1: Representation of the implemented rehabilitation protocol.

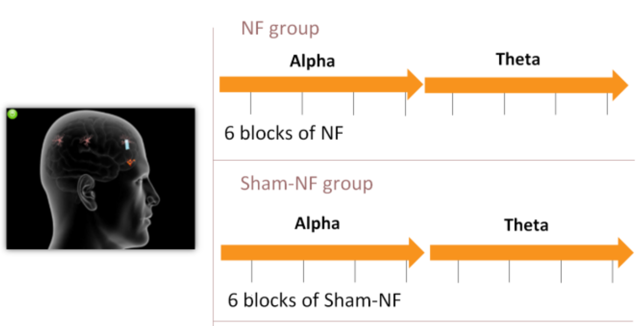

Figure 2: Graphical representation of the implemented intensive alpha and theta neurofeedback protocol.

C. Experimental design

All the participants followed a 12-day protocol accordingly to the diagram in Figure 1. During the intervention, participants were sited in an illuminated and acclimatized room, distancing 50-80 cm from a 17 inch computer screen with touch technology. All the moments of the study were conducted in Centro Clinico-Académico (C2A), Hospital of Braga. In order to guarantee that all participants presented a minimum attention level to perform the subsequent tasks, in the first 2 days all participants were submitted to the Arrow Flanker Test adapted from the Flanker Task in the PEBL (Psychology Experiment Building Language) [18].

All participants were cognitively characterized pre and post-training sessions. The EEG signals from 32 channels were acquired while participants performed 4 cognitive tasks (Stroop Test, Matrix Rotation Test, Trail-Making Test and the Auditory Backward Digit Span Test) also adapted from PEBL [18]. The EEG signals were acquired and synchronized with PEBL using OpenVibe software. All cognitive tests were preceded by a one-minute eyes-open baseline, where the participants were instructed to relax and minimize blinking while staring at the center of a grey computer screen. Participants were randomly allocated in one of the 2 experimental groups (according to Figure 2); neurofeedback (NF) group (n=8) or neurofeedback sham (Sham-NF) group (n=6). During the 8 days of training, participants were submitted to a 30-minute intervention protocol each day. At the beginning of each session the motivation and interest were self-assessed. Also, at the end of the session, concentration and training difficulty were also self-evaluated. Exceptional stress or tiredness observed by researchers was also documented for posterior analysis. During the training protocol, EEG signals were acquired continuously, sampled at 500 Hz, from the Fp1, Fp2, Fz and Pz channels. Alpha or theta feedback was calculated from the Fz channel and Fp1 and Fp2 channels were used for detection of ocular movements. Feedback data contaminated by ocular artifacts were excluded. All participants engaged in a 30 minute session each day and all sessions were preceded by a 3-minute active baseline.

D. Signal Analysis

All EEG data collected in this study was processed using an open-source Matlab toolbox, the EEGLAB. The EEG signals were acquired during the training sessions using the BCI++ [19]. The signals were filtered using high-pass (>0.2 Hz) and low-pass filters (<35 Hz), segmented in 1 second windows and separated according to baseline and activity in order to perform analysis. The methods implemented to detect artifacts were the maximum value (values above 50 µV and below - 50 µV were marked as artifacts) and also the maximum difference between the lower and higher point (this value in a segment could not exceed 60 µV). The PSD (Power spectrum density) was calculated for each non-marked segment in both activity and baseline. The frequency band of interest; theta and alpha were adjusted according to the participant's alpha peak (maximum amplitude between 8-13 Hz). Alpha was then calculated between alpha peak +/- 2 Hz and theta between alpha peak – 7 Hz and alpha peak -3

Hz. In order to extract the absolute PSD gradient for the 4 days of alpha and theta training the mean baseline for the 8 days was subtracted to the PSD of each NF block. For each day, the mean of the 4 best blocks was calculated and the gradient extracted as a linear regression of this measure across the 4 days of training, both for theta or alpha frequency bands. The relative PSD was calculated dividing the mean power of each band by the broadband PSD (0,2 – 35 Hz). This measure was corrected by subtracting the baseline's relative power to each band and the gradients were calculated as explained for the absolute PSD values.

III. RESULTS

Figure 3 represents the differences between pre and post intervention scores for both groups (NF and sham-NF) in Matrix Rotation Task and Digit Span Test. In the Mental Rotation test both groups tend to increase performance but only in the NF group the increase is statistically significant (non-parametric one-sample Wilcoxon signed ranked test p-value=0,049) . In the Digit Span test only the NF group tends to increase the score. There were no differences between groups when comparing the EEG acquired during the cognitive battery.

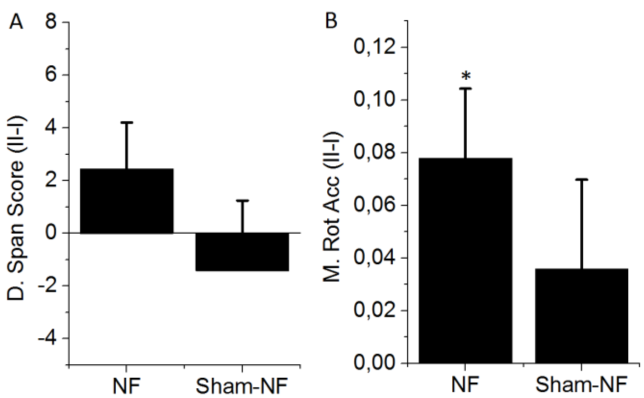

Figure 3: Representation of the difference between pre and post intervention scores for both NF and sham-NF groups in A) Matrix Rotation Test and B) Digit Span Test.

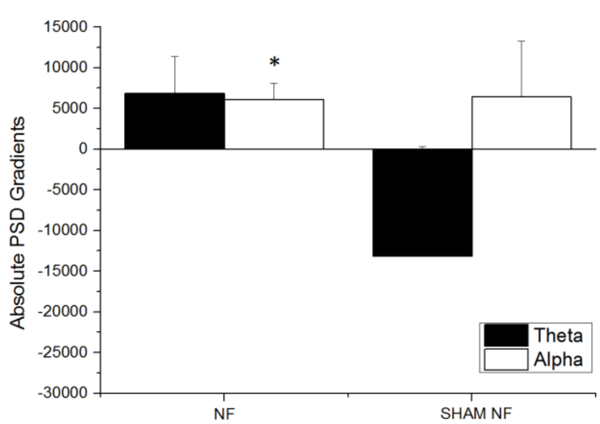

Figure 4: Representation of the absolute PSD slopes for both NF and sham-NF groups.

Figure 4 represents the training slopes for both groups NF and sham-NF across the four days of alpha and theta training. The positive slopes in the NF group for both bands indicate that this group was able to increase both frequency bands. However, only alpha band increased significantly (non-parametric one-sample Wilcoxon signed ranked test p-value=0,007). In contrast, in the NF-Sham group only the alpha band tends to increase, but not theta. Figure 5 represents the relative alpha and theta power gradients. The relative power of alpha and theta bands is increased in the NF group for both alpha and theta training significantly (non-parametric one-sample Wilcoxon signed ranked test p-value=0,021 and p-value=0,014 respectively), but not in the sham-NF group.

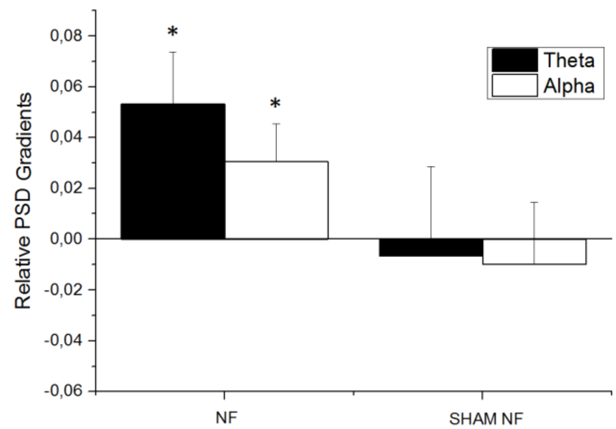

Figure 5: Representation of the relative PSD slopes for both NF and sham-NF groups.

IV. DISCUSSION

The goal of this study was to assess the effects of alpha and theta NF intensive no-interval training in working memory performance of an older population (above 55 years old). The results of the cognitive assessments before and after the neurofeedback intervention (Figure 3) show that, after the consecutive 8-session training, NF group shows improvement in both tasks, with significant results in Matrix Rotation. Although this succeeds both alpha and theta training, previous works have already found relationship between alpha oscillations and Matrix Rotation [20] and between upper alpha training and mental rotation enhancement [21].

Looking at the PSD gradients across the four days of training (Figure 4) it shows that the NF group increased both rhythms (significantly the alpha but not the theta). The sham-NF subjects, although not receiving a real feedback of their own EEG signals also tend to increase the alpha power, but not the theta power. This could be explained by the nature of the protocol and the engagement of attention processes often assigned to alpha rhythm. As the subjects must pay attention to the visual stimulus, it may explain why even the sham participants also increased their alpha rhythm. In contrast, the theta rhythms were only increased by the NF group. As alpha is a dominant rhythm in adult EEG [5], its evocation and later enhancement or suppression may be easier, especially when compared with theta, a slower EEG pattern, common in sleepy stages [6, 22], cognitive and mnesic demanding tasks [23, 24], making harder its modulation and elicitation with eyes open [5, 2]. On the other hand, sham-NF group shows a down-training of theta during the instructed sham up-training theta feedback and a non-significant alpha up-training. This last apparent enhancement is elucidated in Figure 5, comparing both bands relative PSD during their 4 training sessions. Therefore, it confirmed a power improvement of both frequencies during NF group's training comparably to the broadband, which indicates an energy improvement in the underlined bands during their training. Contrarily, the sham-NF group did not register any improvement of either frequency-range in terms of relative power, showing the inability of unspecific-feedback to effectively modulate EEG rhythms. The lack of EEG modulation on resting state after intervention may be partially explained by the number of sessions, as this protocol used fewer sessions than the numbers revealed by the literature. Additionally, the age of the sample seems to require more sessions, as neuroplasticity is slightly compromised with aging, although there is always a development of compensatory mechanisms [25].

V. Conclusion

In essence, the major conclusions of this study are, firstly, the positive results on EEG modulation during intensive no-interval 8 NF sessions and their outcome in terms of working memory, although there were some non-significant values. In future work, a larger population and a higher number of sessions might be considered.

Due to protocol intensity and population heterogeneity we were not able to observe training effects on post-training resting and activity EEG and only moderate cognitive performance improvements were perceived. In the near future we might further evaluate some protocol aspects, such as protocol length, neurofeedback EEG rhythms and their brain sources, and behavioral evaluation tools.

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