Assessment of Neurofeedback Training by means of Motor Imagery based-BCI for Cognitive Rehabilitation

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Abstract— **The age-related impairment is an increasing problem due to the aging suffered by the population, especially in developed countries. It is usual to use electroencephalogram (EEG)-based Brain Computer Interface (BCI) systems by means of the signal in order to assist and to improve the quality of life of people with disabilities. However, a parallel research line addresses the problem by the use of BCI systems as a way to train cognitive areas to achieve a deceleration of cognitive impairment or even an improvement. In this regard, a neurofeedback training (NFT) tool using motor imagery-based BCI, was developed. Training consists on imagery motor exercises combined with memory and logical relation tasks. In order to assess the effectiveness of the application 40 subjects, older than 59 years old, took part in this study. Our NFT application was tested by 20 subjects and their scores of a neuropsychological test were compared with the remaining 20 subjects who did not perform the NFT. Results show a significant improvement of three cognitive features after performing the NFT: visual perception, expressive speech, and immediate memory. Therefore, evidences show that the performance of a NFT tool based on motor imagery tasks could be a positive activity for slow down the aging effects.**

I. INTRODUCTION

A Brain Computer Interface (BCI) is a system that allows interacting with the environment without the involvement of peripheral nerves and muscles [1]. Thus, a BCI system creates a nonmuscular alternative which reflect the user's intents by means of the brain activity translation. Electroencephalography (EEG) is the method most commonly used for monitoring brain activity in BCI systems [2]. EEG is a non-invasive method that requires relatively simple and inexpensive equipment and it is easier to use than other methods [2].

Motor imagery-based BCI applications translate motor imagery activity into a movement of a cursor in a display. This type of BCI is endogenous systems since they depend on the user's control of the amplitude in a specific frequency band of EEG recorded over a particular cortical area, which is an endogenic electrophysiological activity [2]. These systems use motor imagery strategies to generate event-related desynchronization (ERD) and event related synchronization (ERS) in α and β frequency ranges of the EEG [3, 4]. Usually, these BCI systems are used for cursor control on computer screens, for navigation of wheelchairs, or for navigation in virtual environments [4].

Recent studies address the possibility of use BCI to restore brain function by inducing activity-dependent brain plasticity [5], for instance, demanding close attention to a motor imagery task which requires the activation or deactivation of specific brain areas. In this way, new methods based on neurofeedback training (NFT) application are proposed. But the reliability of the NFT effect has been questioned. Although Bauer [6] found increments in α band after NFT, several studies [7, 8] indicated that, sometimes, "no spectral effects could be found after NFT" [9]. Nevertheless, they did not conduct any test on the possible cognitive changes that may have been suffered the subjects after several sessions of NFT. Furthermore, although there are several studies that focus on neural changes due to NFT [7, 8, 9, 10], to the best of our knowledge, no study approaches the issue from the perspective of cognitive rehabilitation due to aging effects.

In this study, a new imagery-based BCI application was designed and developed. We checked whether it is possible to reduce the cognitive impairments associated with aging. To that purpose, different cognitive areas were evaluated before and after the performance of NFT. Forty subjects participated in the study: 20 of them performed the NFT (experimental group) and the remaining 20 subjects (control group) did not perform the NFT. The designed NFT consists of five different games controlled by motor imagery.

Our initial hypothesis claims that repetitive stimulation of endogenous brain activity of certain cortical areas improves brain plasticity, decelerating cognitive decline due to aging effects. This assumption is based on the fact that the aging is associated with a decline in cognitive function that can be explained by changes in neural plasticity [11]. Therefore, it stands to reason that continued training of the brain regions that have lost plasticity help to reduce cognitive decline.

The aim of this study consists of assessing cognitive changes produced by the NFT performed by users with the proposed BCI application. If there are cognitive changes then it should be checked whether NFT can be useful to prevent the effects of aging.

II. METHODS

A. Design of the experiment

For each subject, the experiment consisted in five sessions (once per week). They performed five types of NFT activities. Activities carried out in each session were different. Users started with the easiest activities and the

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difficulty was increased in the following sessions. Activities are briefly described below:

- NFT1. The aim of the first task consists in learning to image hand movements. Therefore, the proposed interface for this task is composed of two types of exercises. When a closed door is displayed on the screen, the user has to imagine repeatedly that he is moving the door's handle with his right hand. The visual feedback allows the user to know when he is executing suitably the proposed task so he can keep or change his strategy to achieve an open door. Likewise, when a closed window is displayed on the screen, the procedure is similar but the user has to imagine repeatedly left hand movements.

- NFT2. This second kind of task is aimed at moving a cursor in horizontal direction in order to reach a target randomly located on the right or the left of the screen. To that purpose, the user has to imagine right or left hand movements, depending of where he wants to move the cursor. The cursor is moved continuously over the screen. Thus, the user knows if he needs to keep or change his motor imagery strategy. The cursor and targets are represented by different pictures.

- NFT3. This task is very similar to the previous one. In this case, the difficulty is increased by showing two possible targets on the screen: a right one (related to the cursor) and a wrong one (not related to the cursor). Users have to do a simple logical relation to decide which the right target is and move the cursor towards it by means of motor imagery.

- NFT4. During this task a path crossing a park is shown to the user. The screen displays a person walking forward continuously. The user can control the horizontal movement trying to overcome different obstacles that appear across the path: puddles, trees, animals, etc.

- NFT5: This task combines hand motor imagery tasks with memory exercises. Firstly, two images are displayed on the screen during several seconds. Then, they disappear and the screen remains blank. Subsequently, two images are shown: a new image and a repeated image from the beginning. The user has to identify what of these images appeared at the beginning of the trial and move the cursor towards the right or the left in order to reach it.

Difficulty was increased across the sessions. As shown in Figure 1, session 1 and session 2 contain several trials of NFT1 activity in order to learn and practice motor imagery tasks. In the following weeks, the exercises were supplemented with other NFT tasks which are comprised of memory and logical relation exercises that have to be solved by means of motor imagery tasks. This increases the complexity of the training while various brain regions are activated.

In order to evaluate the influence of the NFT, experimental and control group performed a Luria Adult Neuropsychological Diagnosis (AND) test [12] at the beginning and at the end of the study. In this way, it is possible to assess potential changes in some cognitive abilities of the users who performed the training.

B. Participants

A total of 40 subjects participated in the experiment. All participants were older than 59 years, healthy, and without any neuropsychological disorder. They were all BCI-naive (without any BCI previous experience). The experimental group consists of 20 people (9 males, 11 females; mean age = 67.6 ± 3.3 years, range = 63–77) who received NFT. The remaining 20 subjects formed the control group (7 males, 13 females; mean age = 69.5 ± 5.5 years, range = 61–80) and they did not receive NFT. Nonsignificant differences were observed in the mean age or gender ($p > 0.05$, Mann–Whitney U-test) of both groups.

All participants (control and experimental group) were free of psychotropic medication and without previous history of psychiatric and neurological disorders or substance abuse. The study was approved by the local ethics committee. All subjects gave their informed consent for participation in the study.

C. EEG recordings

EEG was measured from 8 active electrodes (F3, F4, T7, C3, Cz, C4, T8, and Pz) placed in an elastic cap according to international 10–20 system [13]. Signals were amplified by a g.USBamp amplifier (Guger Technologies OG, Graz, Austria), filtered using an analog bandpass filter (0.1–60 Hz) and a notch filter in order to remove the power line frequency interference (50 Hz). Finally, signals were digitally stored at a sampling rate of 256 Hz. An electrode placed in the ear was used as reference and the ground electrode was located at AFz channel. EEG signals were recorded and processed in real time using the BCI2000 general-purpose system [14].

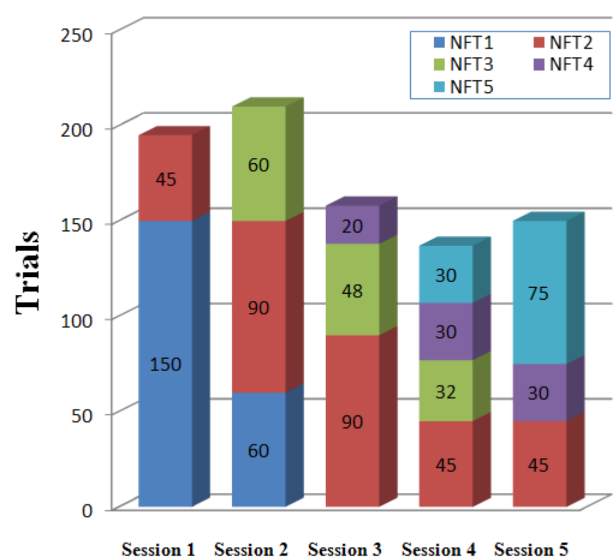

Figure 1. Experimental design of each session (once per week). Complexity is increased acrross sessions by means of including more logical relationships and memory tasks. The number of trials of each kind of NFT task is shown.

D. Statistical analyses

In order to assess the effectiveness of the proposed NFT, participants performed the Luria–AND test. This test includes nine subtests distributed in five different areas: visuospatial (visual perception and spatial orientation), oral language (receptive speech and expressive speech), memory (immediate memory and logical memory), intelligence (thematic draws and conceptual activity) and attention (attentional control). Control and experimental groups performed the Luria–AND test twice: at the beginning of the study (pre-scores) and at the end (post-scores).

Descriptive analysis was carried out in order to explore the distribution of the pre and post-scores. Kolgomorov–Smirnof test was applied to evaluate the normality of the distributions. In addition, Levene test was used to assess the homoscedasticity. We observed that the pre and post-scores did not meet the parametric assumptions. Hence, we used nonparametric tests in order to evaluate our results.

Scores of these tests were analyzed in two ways. Firstly, the nonparametric Mann–Whitney U–test was used to assess the statistical differences in the scores of each neuropsychological feature between both groups (statistical significance $p<0.01$). Secondly, in order to assess the statistical differences between the scores of pre and post-tests, the nonparametric Wilcoxon signed–rank test ($p<0.01$) was applied. Hence, a total of five p-values were calculated for each cognitive feature: pre-scores between control and experimental group, post-scores between control and experimental group, pre and post-scores only with experimental group, pre and post-scores only with control group, and the variation of experimental and control group between pre and post-scores.

III. RESULTS

Analysis of pre-scores suggests that both groups (experimental and control groups) presented similar distribution for each neuropsychological feature. Thus, there were no significant differences between experimental and control group before starting the NFT program. Nevertheless, in regard to the post-scores, there are significant differences between both groups for three features: visual perception, expressive speech, and immediate memory. Test scores of these features were increased for the experimental group after carrying out the NFT program. In order to check if these variations were significant, the increases between the pre and post-scores were evaluated. We found significant differences (p-value<0.01) between pre-scores and post-scores in the experimental group in all the measured features except for attentional control. No significant difference was found in the variations between pre-scores and post-scores for the control group. Finally, regarding the variations for experimental and control group between pre and post-scores, statistical differences were found in four cognitive areas: visual perception, receptive speech, expressive speech, and immediate memory. Results of the analysis of the significant differences are summarized in Tab. 1. These results are consistent with the differences showed in the post-test between both groups. Fig. 2 shows boxplots of the scores for immediate memory. This feature achieves the lowest p-value

TABLE I. STATISTICS ASSOCIATED TO THE MANN-WHITNEY U-TESTS FOR THE SCORES OF THE LURIA AND TESTS FOR EACH SPECIFIC NEUROPSYCHOLOGICAL FEATURE.
THE SIGNIFICANT VALUES (p-VALUE < 0.01) HAVE BEEN HIGHLIGHTED.

Neuropsychological area	**Feature**	**E vs. C Pre**	**E vs. C Post**	**E vs. C Post–Pre**
Visuospatial	Visual perception	0.330	**< 0.01**	**< 0.01**
	Spatial orientation	0.817	0.411	0.044
Oral language	Receptive speech	0.274	0.021	**< 0.01**
	Expressive speech	0.073	**< 0.01**	**< 0.01**
Memory	Immediate memory	0.234	**< 0.01**	**< 0.01**
	Logical memory	0.978	0.438	0.011
Intelligence	Thematic drawings	0.751	0.498	0.117
	Conceptual activity	0.087	0.016	0.333
Attention	Attentional control	0.459	0.434	0.342

E: Experimental group, C: Control group.

in the comparison between the increments of pre and post-scores of both groups. By means of the boxplots of Fig. 2, it can be noted that there is almost no variation in the mean of control group between pre and post-scores. However, considerable differences exist between the pre and post-scores in the experimental group.

IV. DISCUSSION

In line with our initial hypothesis, cognitive decline due to aging effects was reduced thanks to an endogenic repetitive stimulation of brain activity. Three cognitive features (visual perception, expressive speech, and immediate memory) showed improvements between experimental and control groups when the NFT was performed. By means of Wilcoxon signed–rank test, it was demonstrated that these increments has statistical significance. Therefore, receptive speech shows a significant improvement intra-group although this cognitive area did not show differences between control and experimental groups.

These results suggest that it is possible to reduce the cognitive decline by means of NFT. The performing of the NFT designed produces changes in Luria–AND test scores. Hence, the presented findings support NFT as a promising method for reduce the neuropsychological decline due to aging effects. Nevertheless, the precise functionality of NFT still remains unclear. Different studies [9, 15] suggest that if there are not any changes in the EEG measures before and after NFT, there was absolutely no effect in the neocortical dynamics. Hence, changes in EEG spectral or amplitude measures are worth investigating further. We think that the spectral distribution of EEG signal at rest changes when a user learns to control their own sensorimotor rhythms. This could be new evidence that would prove that cognitive changes are permanent. Changes in EEG at rest after completed the NFT would indicate that alterations in brain plasticity could have been produced.

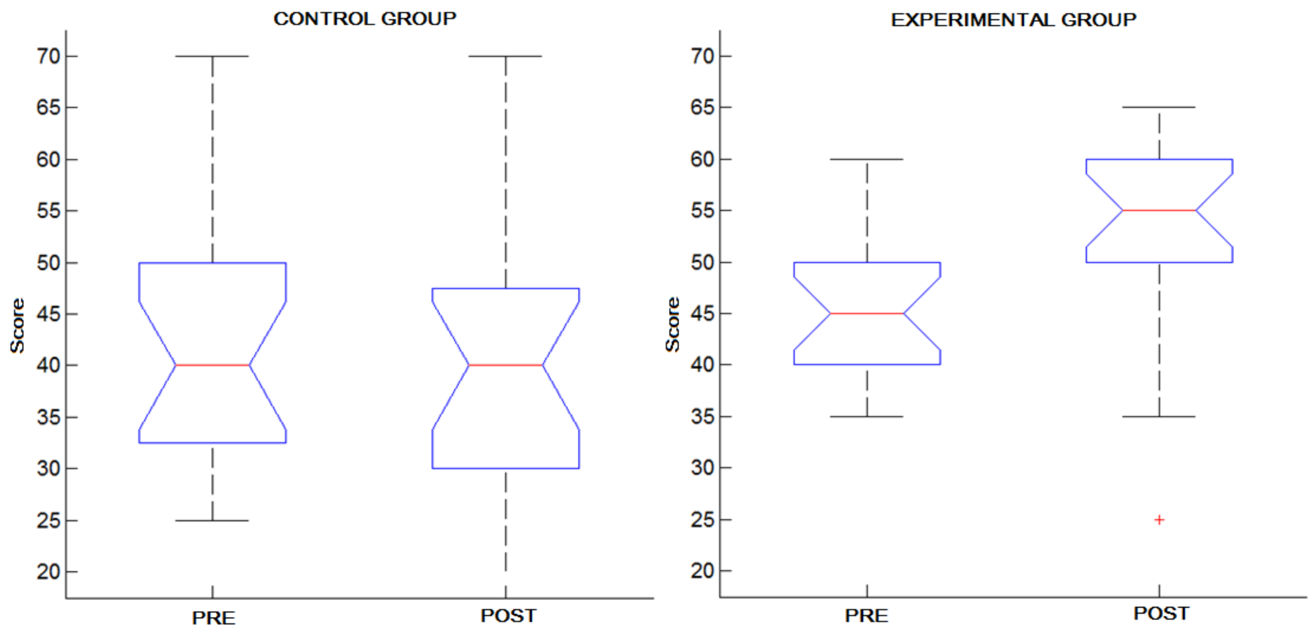

Figure 2. Notched boxplots showing the distribution of the scores in mean for immediate memory feature between control (left) and experimental group (rigth) in pre and post-measures.

The study has some limitations that must be noted. Firstly, it would be desirable to extend the population under study in order to check whether significant differences remain in the same cognitive areas when the population is larger. Furthermore, in future works, the acquired EEG recording could be analyzed in order to validate the results found by means of the neuropsychological tests. Finally, a follow-up measurement could be performed in order to verify if cognitive changes remain in time.

In summary, this study presented promising results about the usage of NFT to increase some neuropsychological features that it could be useful to slow down the cognitive effects of aging. Significant changes in brain plasticity were found when subjects performed NTF. Due to the cognitive improvements found, this study inspires further analysis in order to detect spectral changes in the EEG when users perform the NFT designed after performing NFT tasks.

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