

# Attention Training with an Easy-to-Use Brain Computer Interface

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**Abstract.** This paper presents a cognitive training based on a brain-computer interface (BCI) that was developed for an adult subject with an attention disorder. According to the neurofeedback methodology, the user processes in real time his own electrical brain activity, which is detected through a non-invasive EEG device. The subject was trained in actively self modulating his own electrical patterns within a play therapy by using a reward-based virtual environment. Moreover, a consumer easy-to-use EEG headset was used, in order to assess its suitability for a concrete clinical application. At the end of the training, the patient obtained a significant improvement in attention.

**Keywords:** Play therapy, Attention training, Rehabilitation, Brain-computer interface (BCI), Neurofeedback.

## 1 Introduction

In the last decades the development of new human-computer interaction technologies made possible to directly interface the human brain with digital devices in order to control them just using our thoughts. The brain-computer interface (BCI) through electroencephalography (EEG) arouse the attention of the scientific community thanks to its last improvements in terms of performance and applications [21] [7]. These cover a wide range of areas such as entertainment (e.g. video games) [18], military enhancement [13] and assistive technologies [15].

One of the most interesting area of investigation concerns clinical rehabilitation of physical and cognitive deficits. On one hand it is possible to enhance physical capabilities of disable patients with methodologies such as silent speech interfaces [17], thought-driven wheelchairs [9] and prosthetic devices [16]. On the other hand BCI can be exploited to rehabilitate patients with cognitive deficit. Within the neuropsychology field, one of the most successful application deals with attention disorders (as for ADHD syndrome [10][14][3]).

This paper presents an innovative and user-friendly way to apply consumer BCI technologies and play therapy with virtual reality in the neuropsychological research on attention disorders. Immersive virtual reality (VR) cognitive

training has been already confirmed to be effective with behavioural and attention problems [25]. In the neuropsychological rehabilitation field, previous research has generally used game-like training environments in order to increase motivation and participation in the patient [23][24]. In that regard, a good virtual reality-based rehabilitation has to deal with the usability of the employed human-computer interaction technologies. Therefore, within the BCI community, one of the challenges of the last years is to develop more advanced devices and experimental methodologies in term of cost for costumers and usability. This becomes further important in the rehabilitation field with cognitive or physical disabled patients, who typically have more difficulties to be comfortable with normal EEGs.



**Fig. 1.** The *Emotiv EPOC* and the electrodes location

In recent times, simplified consumer BCI EEG headsets were introduced, such as *Emotiv EPOC* [26] and *NeuroSky* [27]. So far, the research community still wonders about the accuracy and suitability of consumer BCI electronics in clinical environments [1]. However, although less clear and strong, *Emotiv EPOC*'s recording accuracy has been already assessed within the literature as having reasonable quality compared to a medical grade device [8]. The *Emotiv EPOC* device, makes possible to simplify the equipment set up, avoiding the practical difficulties related to the EEG operations, such as skin abrasion or the application of conductive gel on the subject, which represents a particularly valuable advantage in attention disorder rehabilitation with restless patients. Our study confirm that is possible to use this type of headset in a clinical context, where the usability of the device (i.e. wireless connectivity, saline solution instead of gel, fixed arrangement of electrodes) can positively influence the compliance of the subject.

Based on neurofeedback methodology, we performed a cognitive training on an adult subject suffering from a frontal syndrome. In line with this approach, the user was confronted in real time with his own electrical brain activity: by using a reward-based virtual environment, we trained the subject with a video game to actively self modulate his own electrical patterns. In line with this approach,

this study aims at further reduce problems of compliance and familiarity also with clinical equipments. Moreover the procedure has been embedded within a game-like environment to challenge the patient. Such a methodology aims to develop a training in which the subject is more motivated and involved than in a typical clinical context.

The first step of the cognitive training was to record specific electrical patterns with the *Emotiv* EPOC. These were used as input commands in the video game. The participant was then asked by the game to repeatedly recall various and specific patterns corresponding to different movements of an object in a 3D space with levels of increasing difficulty. Each correct move leads to a positive reinforcement stimulus appearance. In this case a slightly erotic kind of reward was chosen, since the frontal syndrome of the patient was characterized by a sexual disinhibition. During and after the training the subject's attention deficit has been assessed with three different neuropsychological tests (i.e. Posner, CPT-II, d2). It will be shown that with this combination of new BCI technology and play therapy one can obtain significant results: at the end of the training of this case study the subject was able to improve his attention skills.

## 2 Methods

### 2.1 Experimental Design

The method used in this study is an experimental protocol within the subject, a manipulated variable on and off. The experiment is in the alternation of two types of phases: a training phase with neurofeedback (A) and a resting phase (B) not subjected to any kind of experimental stimulus. These two phases are repeated twice in alternation and each have the duration of one month. The two training phases (A) are composed of five meetings of one-hour training. The cognitive performance of the subject is assessed at the beginning and the end of each phase, through the same neuropsychological tests. We expect to find significant performance improvements at the end of each experimental phase and no significant changes at the end of each resting phase.

### 2.2 Subject

The participant of this single case study is G.F. (male, age 36). In October 2003, due to a car accident, suffers a head injury. As a result he suffers from a frontal syndrome with character of medium-high severity, with outcome of cognitive and behavioural disorders: regarding to the cognitive profile, the previous neuropsychological assessments identify a "damage to the frontal lobes with impairments charged to attention and concentration, the ability to support a cognitive activity over time and switch from one line of thought to another". On the behavioural level the loss of spontaneous initiative (apathy), a depressive mood with a tendency to restlessness, irritability and aggression, and also the lack of awareness of his own cognitive disorders and sexual disinhibition were diagnosed as the symptom of his syndrome.

The subject has no prior experience with BCI and neurofeedback.

## 2.3 BCI Device and Software

For the signal acquisition an EEG recording device produced by Emotiv Systems is used: *Emotiv* EPOC. The device uses a set of electrodes placed with a fixed arrangement and localized on the International 10-20 System [12], with 14 channels (with CMS/DRL references in P3/P4 locations, see Figure 1). The sampling frequency is 128Hz. The EPOC filter is set from 0.2Hz to 43Hz. The application of the sensors is easy and requires few minutes: it is sufficient to wet with a saline solution small sponges that allow the passage of the electric signal on the scalp to the EEG electrodes (without any use of electro-conductive paste or abrasion of the scalp).

The computer acquires the EEG signal directly via wireless from the EPOC device. Processing occurs online through the Software Development Kit (SDK) of EPOC and is communicated to a graphic user interface developed for the experiment. This interface was developed by using the OpenGL library and the C++ language on a Windows XP machine with Visual Studio 2010 Express and displayed during the training on a 21-inch LCD monitor.

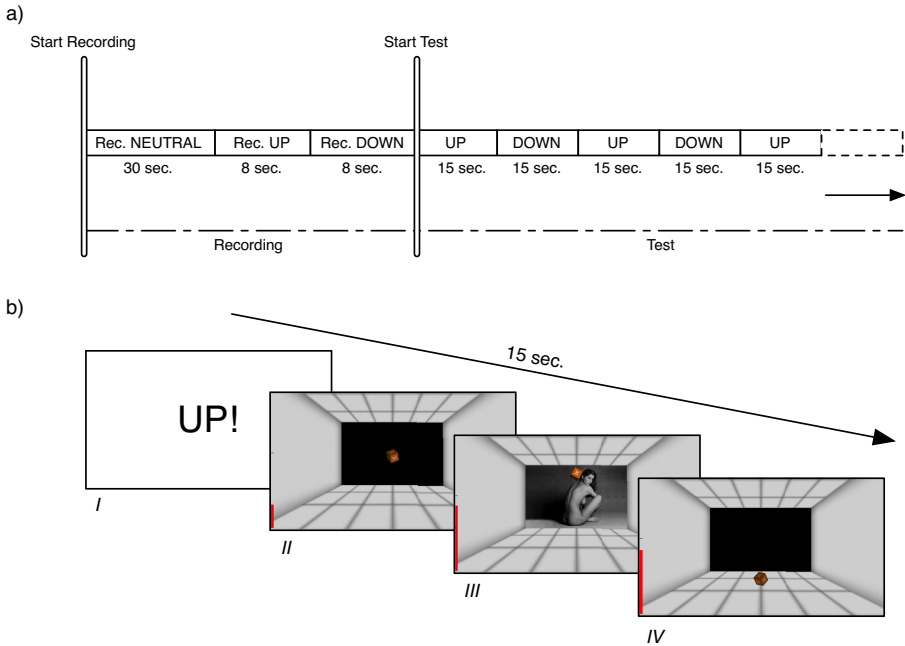
## 2.4 Task Structure

During the training the participant is requested to repeatedly recall and produce various and specific electrical patterns. These are used as input commands for the task. The feedback consists of two components: the corresponding movement of a cube in a 3D space and the appearance of a positive reinforcement stimulus.

The first step is the Recording of the EEG patterns. The subject begins by defining a baseline, through a 30 seconds EEG recording in a neutral state. Then, for every possible cube's movements, the corresponding patterns are recorded for 8 seconds each (e.g., one for UP, one for DOWN, one for LEFT and so on). Once these recordings are concluded the participant has organised the commands to meet the request of the Test phase.

The Test is composed by a block of 40 consecutive trials, 15 seconds each (Figure 2a). At the beginning of each trial a word at the centre of the screen indicates the direction to which the cube has to be moved within the next 15 seconds interval (Figure 2b I). The subject must recall from time to time the pre-recorded pattern associated with the requested movement. The different directions requests are randomized and equally distributed within the 40 trials block.

In each trial a red bar on the left side of the screen indicates the power of the recalled pattern (Figure 2b II). Upon exceeding the 65% intensity of production, the appearance of a positive reinforcement visual stimulus fades in (a slightly erotic image) progressively sharper until the 100% intensity (Figure 2b III). On the contrary, if the player moves towards the wrong direction, the reinforcement will not be shown (Figure 2b IV). This type of stimulus was chosen considering the sexual disinhibition of the subject.



**Fig. 2.** a) Task structure. b) Single trial.

## 2.5 Training Procedure

The two experimental phases (A) consist of five training meetings distributed with rate of once or twice a week during a month in a laboratory of the Department of General Psychology, Padua, Italy.

At the beginning of the whole training GF was told to think of distinct mental states, easy to recall, and that these thoughts would have been translated into electrical patterns detected by the EEG headset as commands for the cube movement in the game.

During each meeting, after 10 minutes of practice to become familiar with the task, the participant begins the training: two sessions composed each by a Recording and a Test phase. A short break separates the two equal sessions to give to the subject a time of recovery after the attention effort. The entire cognitive training is characterised by an increasing difficulty in the requests asked to the participant and the game is organised and divided into different levels. In the first level the player has to perform actively one movement with the cube in all the trials (e.g. UP); in the second level two movements are requested (e.g. UP and DOWN) randomly distributed in the trials block, and so on for the next levels increasing the number of movements.

To unlock the access to the next level, the player must reach the 95% accuracy rate of the requested movements, crossing the threshold of 65% of intensity indicated by the reward stimulus fading in, in both Test sessions of a meeting. This

criterion was set in order to be sure that once the level has been completed, the movement-skill was learned completely before adding another one to the next level. With this procedure the participant faces a sustained attention task from the very first level. In the later levels of the training the selective component of attention is also requested by switching between two or more movements. After the resting phase (B) of the entire cognitive training, in the subsequent training phase (A), the subject will start the game again from level 1.

## 2.6 Neuropsychological Tests

For the attention assessment an adaptation of the Posner's spatial cueing task [19], the d2 test [2] and the CPT-II [5] are used.

In this study, a computerized test on Posner's paradigm was chosen to assess mainly the intensive component of attention through the precise detection of the parameters of response accuracy (ACC) and reaction times (RT). The trials, divided into 8 blocks of 48 trials each, follow one another with a variable time between 50 ms and 150 ms and the time between the cue and the target (Stimulus Onset Asynchrony, SOA) can be 200 ms or 800 ms. The test has a total duration of 30 minutes.

The Continuous Performance Test consists of a visual test performed on the computer with an odd-ball paradigm. This test is used for the assessment of attention and vigilance, detection of the signal and the automatic response inhibition ability [4]. On this occasion Conners' version of this test is used (CCPT-II).

The d2 test is a barrage test characterized by the simultaneous presentation of visually similar stimuli. This test is presented as a standardized measurement method particularly accurate to detect individual abilities of selective attention and concentration [2].

The tests were administered at the beginning and end of every Training (A) and Rest (B) phases, at a distance of one month, for a total of five measurements taken at time  $t_1$ ,  $t_2$ ,  $t_3$ ,  $t_4$ ,  $t_5$ , corresponding to the start of the experiment, the first training's end, the first rest's end, the second training's end and the second rest's end respectively.

## 3 Results

### 3.1 Posner

In the results analysis of the test, the values of Accuracy (Acc) and Reaction Time (RT) are considered. The obtained values were analyzed using a paired samples t-test, comparing the performances recorded after the different phases (Figure 3). As a result of the training sessions (A) significant improvements were found. Regarding the Accuracy parameter, the t-test shows a significant difference between the beginning and the end of the first phase (A) of cognitive training ( $t(6) = -9128$ ,  $p < 0.001$ ); the analysis shows also a significant reduction of Reaction Times (RT) as a result of the first experimental session ( $t(6) = 42.965$ ,  $p < 0.001$ ) and the second one ( $t(6) = 8.916$ ,  $p < 0.001$ ). Following

the first rest phase (B), the  $t$ -test shows no significant differences compared to previous assessments in both parameters Accuracy and Reaction Times, while following the second rest phase the  $t$ -test presents a significant difference for both parameters (Acc:  $t_4 - t_5: t(6) = 2.661, p = < 0.05$ ; TR:  $t_4 - t_5: t(6) = -4,676, p = < 0.05$ ).

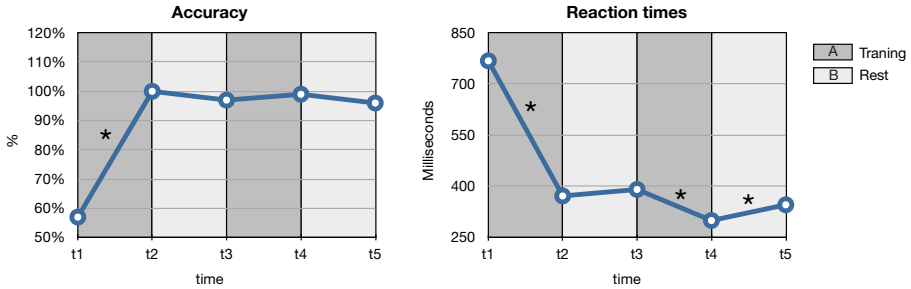


Fig. 3. Posner test results

### 3.2 CPT-II

The five assessments reveal a trend similar to the one detected by the Posner's test. The performance progression is analyzed looking at different parameters that are indicative of attention capacity and control of impulsivity: Confidence Index, Omissions, Commissions, Reaction Time, Variability of reaction times and capacity of Detectability. Except for the Confidence Index, the scores are converted to  $T$ -scores and the significance of the changes between the different performances in each parameter is calculated with the Reliable Change Index [11]. Clinically significant changes has been detected in the following parameters (see Figure 4).

*Confidence Index*: the percentage chance to present an attention disorder, if more than 50% is defined clinically at risk. The values show improvements after both the training sessions. A significant change after the second training phase in comparison with the first assessment has been recorded ( $t_1$ : 52.4%;  $t_4$ : 42.3%). It starts with a clinical classification of attention deficit in  $t_1$  (52.4%) to a non-clinical in  $t_2$  (49.9%) stable until the end of the study ( $t_5$ : 45.5%).

Regarding the parameters of *Commissions* (the subject responds to the non-target stimulus or responds too slowly); *Variability* (the degree of constancy of the speed of response); *Discrimination* (the value related to the ability to correctly identify the target stimuli): significant improvements are recorded after the first training phase, the performance is also assessed as "mildly atypical" (i.e.  $T$ -score  $> 60$ ) in  $t_1$  and within the average in  $t_2$ . This significant change, as a result of the first training, remains stable and within the average until the end of the study.

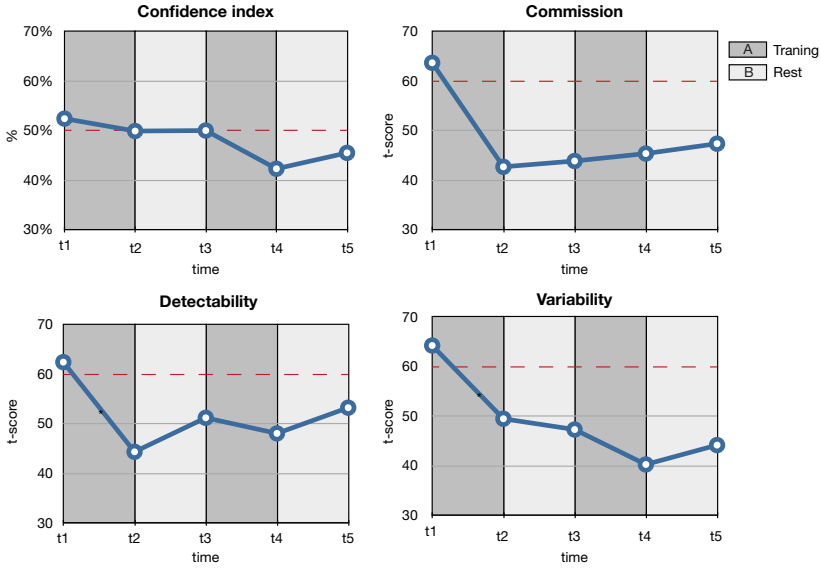


Fig. 4. CPT-II results

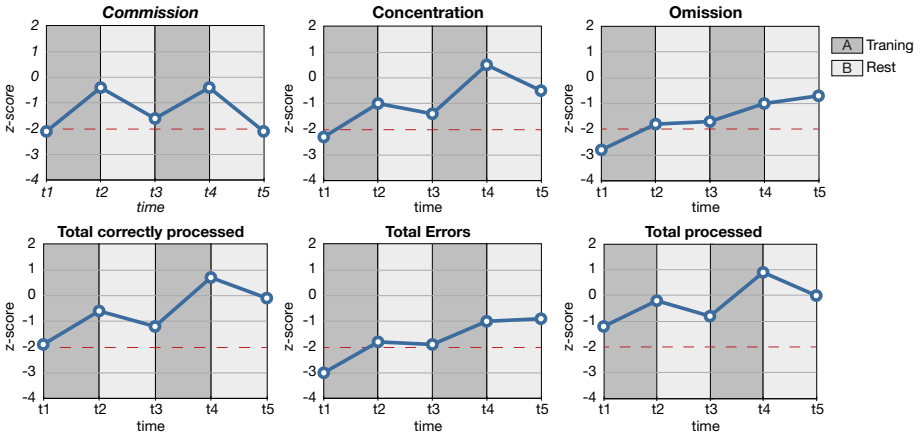


Fig. 5. d2 test results

### 3.3 d2

The raw scores obtained in the different categories were converted to *z-score*, showing an increase of the values as a result of both the training phases in every parameters. Furthermore, the first assessment is almost globally out of average ( $z\text{-score} > 2$ ), excluding the parameter of Total characters processed, while the last one is characterized by data within the average, with the exception of errors of Commission (see Figure 5).



## 4 Discussion

In the present study an attention training through neurofeedback has been developed. The subject's attention has been assessed during the different phases to measure the evolution of his performance over time in relation to the training. The expected *step trend* was recorded in the three tests: the results show significant improvements after the two training phases and a general enhanced performance at the end of the study.

The attention improvements are the results of the effort in self modulating the EEG patterns requested within the structured neurofeedback training. This subtended different higher cognitive abilities such as the strategic process to recall these patterns quickly and precisely; the ability to self control and regulate one's behaviour; the sustained and selective attention requested in the training.

In the last decades, the research on neurofeedback has shown significant results in terms of rehabilitation for attention disorders (e.g. ADHD [10][14][3]). Game-like trainings have been used to increase participation and motivation in the subjects. The key of the training was in fact to elicit motivation for the patient to stay focused and challenge himself further, since attention deficit and behavioural issues can be considerable opponents in a cognitive training.

Virtual reality-based play therapy appeared to provide a solution to this challenge [24][28][29]. By choosing a VR game, we aimed to develop an intervention tool that would have been challenging and appealing for the user. The game was designed by following a set of guidelines already assessed to be effective for cognitive rehabilitation [23][30]. We chose to develop a game that could feed-back the user with immediate rewards based on performance, in this case a slightly erotic kind of reward was chosen to increase the appeal of the therapy since the frontal syndrome was characterized by a sexual disinhibition. The game also provided the patient with quantitative performance data: a gauge representing his ability and precise rules to overcome the levels. In this way the patient was led to actively and responsibly engage in his own cure by self evaluating his performance online. The levels have been structured by trying to determine the right challenge to make the game fun (flow), with the purpose of gradually raise the complexity of the task and the requested attention effort.

Moreover, the evolution towards economical and easy-to-use headsets can be considered an essential step to achieve a new generation of user-friendly BCI training equipment [20]. In this study, with the use of the *Emotiv* EPOC device, was possible to simplify the equipment set up, avoiding the practical difficulties related to the EEG operations such as skin abrasion and adding conductive gel, especially with our type of restless patient. The simple usability of this headset (i.e. wireless connectivity, saline solution instead of gel, fixed arrangement of electrodes, etc.) influenced positively the compliance of the subject. So if on one hand the *Emotiv's* recording accuracy has been already assessed within the literature as having "reasonable quality compared to a medical grade device" [8][22], on the other, regarding its suitability in clinical environments, the results

of this study show the important potential of using this kind of device for concrete clinical applications. Not only significant positive results were obtained regarding the subject's attention deficit, but we could also confirm that similar technologies facilitate the creation of user-friendly training environments, and hence can improve the compliance rate of subjects. In our opinion, similar devices enable to develop a training and a play therapy in which the subject is more motivated and involved than in a typical clinical context.

## 5 Conclusion

In this paper a virtual reality-based play therapy with neurofeedback was used for a patient with an attention disorder. As seen in previous experiments and assessed in this single case study, the effort in self modulating one's electric patterns into a BCI has significant positive implications for attention disorder. In a clinical setting, create a user-centered training with an easy-fitting procedure for the patient can also be crucial. When opting for the experimental procedure, the right EEG device and reinforcements, our challenge was to find a trade-off between user's motivation and goals, and his health-mental state. Due to the patient's attention deficit and restlessness, we shifted the focus of our training on usability and appeal, in order to let the patient concentrate on the task without any environmental or technical distractions related to the EEG device, and trying at the same time to make his effort as pleasant as possible. A non invasive EEG device was used, since our priority was to develop a comfortable training system. Our experiment allowed us to eliminate complex procedures, which were deemed not feasible for this kind of patient. Moreover, play therapy has been an effective answer for the patient's motivation problem. Starting from the results of this case study, our aim is to extend the same procedure to a higher number of subjects, in order to confirm further our results.

In recent years the effectiveness of BCI therapy has been confirmed and the related technologies have become more commercially accessible and usable. However, it is impossible until now to carry out the neurofeedback training without the assistance of a therapist. The innovative aspect of this new kind of consumer equipment (provided with a well designed training and an adequate reinforcements) is that the patient should be able to eventually undertake his training independently. One could also think to promote a domestic therapy with home exercises and training programs (telerehabilitation), easy-to-use for the patient or for his caregiver. Therefore, the challenge for us is to further develop EEG devices enhanced in lightness and precision; create appealing and adequate training software; deepen the study of BCI and neurofeedback method for a more effective learning of the interface from the user. In order to achieve this much, a partnership is needed between engineering, computer science, neuroscience and psychology, through which virtual realities and related technologies can be better applied to healthcare and rehabilitation.

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