Enhancement of cognitive control for disorders treatment through BCI neurofeedback: an Integrated Review

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ABSTRACT

Context. The world of psychiatric disorders is vast and complex to unravel, as many layers need to be taken into consideration if we want to understand it profoundly. And this is essential in order to devise effective assessments and treatments for these disorders. That's the reason why some of the most relevant elements (from Shakespeare to cognitive neuroscience) needed to understand how it is possible to treat some mental disorders playing a videogame are presented in the introduction.
Aims. The aim of this report is presenting the study of a new BCI-based gaming application meant for training cognitive control using EEG neurofeedback in order to really understand whether this methodology and technology is valuable or not in the assessment of the disorder severity and in the treatment of patients.
Methods. In the study it was proposed the use of EEG signals to measure the focus level of some OCD patients on the UFO game displayed in front of them after being put under a stressful condition. All the different stages of the experiment have been linked to the theoretical elements given in the introduction. The idea is that this methodology can be used to assess the severity of the patient's disorder while helping in the medical treatment.
Results. The obtained results have been compared with a classical assessment test namely the YBOCS and found a good link between the score obtained in the game and the result of the questionnaire. Moreover this result also show therapeutic effectiveness in the case group of the study, however much more research is needed on a wider sample of subjects affected by various disorders to really assess the improvement in their quality of life.
Conclusions. The path traced by the study is positive as the technique of neurofeedback has been found to be slightly more effective than the classical ways of training. However, measuring the focus level on a fixed visual element is a task not easily assessable from EEG signals at the moment, so other types of games should be designed.

Key words. executive functions – psychiatric disorders – contamination OCD – EEG neurofeedback – BCI serious game

1. Introduction

If you read the following two obituaries and were asked to choose which one is referred to a person suffering from a mental disorder and which one is referred to an esteemed mathematics and logic professor, what would you say?

1. *"Regarded by some mathematicians as the world's leading logician, He died yesterday at the Medical Center in Princeton, N.J. He was 71 years old and lived at the 145 Linden Lane in Princeton."(1)*
2. *"Born in what was then Austria, on April 28 1906, He died in Princeton, New Jersey on January 14 1978, having developed a paranoia that he was being poisoned and, as a result, starving himself to death."(2)*

The right answer is that they are referred to the same person, his name was Kurt Gödel. I'm sure if his dearest friend Albert Einstein, during one of their many walks in Princeton, would have asked him *"Imagine, Kurt, the following situation:*

1. *A wants to survive,*
2. *A needs B to survive,*
3. *B can cause death,*
4. *A decides to renounce B.*

How would you define this simple situation?. He would have answered: *"It is a paradox, A should not renounce B".*
In his later years, Gödel only ate food prepared by his wife, so when she was hospitalized he renounced eating and died of starvation. So why, despite being a banal reasoning, wasn't he able to behave in accordance with it?

To be, or not to be, that is the question:
Whether 'tis nobler in the mind to suffer
The slings and arrows of outrageuos fortune,
Or to take arms against a sea of troubles
And by opposing end them.
..
Thus conscience does make cowards of us all
, And thus the native hue of resolution
Is sicklied o'er with the pale cast of thought,
And enterprises of great pitch and moment
With this regard their currents turn awry
And lose the name of action (3).

Hamlet, the son of the murdered King of Denmark, entitled by the ghost of the dead father himself to take revenge against his murderer, finds himself obsessively thinking of whether to face the sea of troubles taking revenge or to suffer in his mind brooding over his outrageous fortune. So, why wasn't Hamlet able to commit this right homicide? He wants to do that. He

knows it's the right thing to do. But in his mind the strength of his native enterprises is weakened by too much thinking, and so he finds himself incapable of turning it into action (*[...] And lose the name of action*).

1.1. Psychiatric disorders - ADHD and OCRDs

The content of this chapter is almost completely taken from the DSM-5: Diagnostic and Statistical Manual of Mental Disorders (4), please note that the content of this chapter is far from being exhaustive. It is aimed at giving the general idea of the main characteristics of these disorders. Among all the different psychiatric disorders, this report is specifically focused on the following ones:

1.1.1. Obsessive-Compulsive and Related Disorders

OCRDs are characterized by the presence of obsessions and/or compulsions.

1. Obsessions: recurrent and persistent thoughts, urges, or images that are experienced, at some time during the disturbance, as intrusive and unwanted, and that in most individuals cause marked anxiety or distress. The individual attempts to ignore or suppress such thoughts, urges, or images, or to neutralize them with some other thought or action (i.e., by performing a compulsion) (6).
2. Compulsions: repetitive behaviors(e.g., handwashing, ordering, checking) or mental acts(e.g., praying, counting, repeating words silently) that the individual feels driven to perform in response to an obsession or according to rules that must be applied rigidly. The behaviors or mental acts are aimed at preventing or reducing anxiety or distress, or preventing some dreaded event or situation; however, these behaviors or mental acts are not connected in a realistic way with what they are designed to neutralize or prevent, or are clearly excessive (6).

Many adults with the disorder have a lifetime diagnosis of an anxiety disorder (76%; e.g., panic disorder, social anxiety disorder, generalized anxiety disorder, specific phobia) or a depressive or bipolar disorder.

1.1.2. Attention-Deficit/Hyperactivity Disorder

Inattention manifests behaviorally in ADHD as wandering off task, lacking persistence, having difficulty sustaining focus, and being disorganized.
Hyperactivity refers to excessive motor activity (such as a child running about) when it is not appropriate.
Impulsivity refers to hasty actions that occur in the moment without forethought and that have high potential for harm to the individual (e.g., darting into the street without looking). Impulsive behaviors may manifest as social intrusiveness (e.g., interrupting others excessively) and/or as making important decisions without consideration of long-term consequences (e.g., taking a job without adequate information) (7).

1.2. Compulsivity and Impulsivity

In the previous chapter we encountered the concepts of two key features, namely *Compulsivity* and *Impulsivity*, which seem to be two opposite features, the first related to harm-avoidance while the second to risk-seeking.

1. The key characteristics of compulsivity are: (8):
   (a) impaired adaptation of behavior after negative feedback (contingency-related cognitive flexibility),
   (b) impaired switching of attention between stimuli (Task/attentional set-shifting),
   (c) impaired shifting of mental sets away from disorder-relevant stimuli (attentional bias),
   (d) lack of sensitivity to goals or outcomes of action (habit learning).
2. The key characteristics of impulsivity are: (8):
   (a) impaired ability to stop motor responses following environmental change (motor impulsivity),
   (b) difficulty weighing options and taking appropriate risks based on available information (decision-making impulsivity),
   (c) difficulty in delaying gratification and tendency to choose immediate small rewards despite negative long-term consequences (choice impulsivity),
   (d) insufficient information sampling before making a choice (reflection impulsivity).

Comparing this analysis with the profile of an OCD patient and an ADHD patient described in Chapter 1.1, the following qualitative considerations are taken:

1. the symptomatology of OCD patients is, as expected, completely in line with the description of compulsivity, as 1.a and 1.d motivate the compulsions, while 1.b and 1.c cause the obsessions. However 2.a is also a characteristic of OCD patients too and 2.c may have to do with the tendency of harm-avoidance typical of OCD patients,
2. ADHD patients are in line with the characteristics of impulsivity, in fact 2.a justifies hyperactivity, 2.b, 2.c and 2.d are referred to the impulsive behavior. However 1.a and 1.d are necessary to complete the profile and explain the inattentional and hyperactivity features of ADHD patients.

Impulsivity and Compulsivity have in common the feeling of *lack of control* and, rather than polar opposites, they may represent orthogonal factors each contributing at varying degrees to a person's behavior. (8).

1.3. Executive Functions

Executive functions (also called executive control or cognitive control) are a family of top-down mental processes defined by the National institute of Mental Health (NIMH) as the ability for top-down control on task relevant processes to coordinate thoughts and actions towards a particular goal (14). There is general agreement that there are three core EFs:

- Inhibitory Control: inhibitory control involves being able to control attention (selective attention), behavior (behavioral inhibition) and thoughts (cognitive inhibition) to do what's more appropriate or needed. Without inhibitory control we would be at the mercy of impulses, old habits of thought or action, and/or stimuli in the environment that pull us this way or that (10).
- Working Memory (WM): working memory involves holding information in mind and mentally working with it (or said differently, working with information no longer perceptually present) in order to guide the decision making (10).

– Cognitive Flexibility: cognitive flexibility is the ability to switch from a certain mental representation to another, so it involves changing perspective in the way we look at a certain situation (set shifting) and adjusting our behavioral response depending on past feedback or changed environmental conditions (task switching).

Comparing what has been said in *Chapter 1.2* with the concept of executive functions, we obtain the following qualitative consideration:

1. 1.a, 1.b and 1.d seem related to little cognitive flexibility, while 1.c may be related to little selective attention and cognitive inhibition.
2. 2.a could be caused by little capacity of behavioral inhibition and cognitive flexibility, while 2.b, 2.c and 2.d seem related to bad management of WM and by little cognitive flexibility.

1.4. Stress

Everyone intuitively knows what stress is: it is when you are playing your favorite videogame and someone tells you the dinner is ready so you has to stop playing, it is when your are laying on your bad and you start to think you will die some day so your heart starts to beat faster, it is when you find yourself dreaming of being alone in the Savana with a cutie, nasty lion pointing at you so you wake up sweating in your bed, it is when you are taking an exam and you achieve remembering everything you need to answer the questions faster than you expected, but it also is when you are taking an exam and you don't remember anything you studied the weeks before. Investigating the endocrinology of stress is far away from the aim of this report, but just know that stress is the perception of the *"fight or flight"* response mediated by the sympathetic nervous system (11). What is relevant here is the effect of stress on attention and task performance:

1. Attention shifts and lapses: one obvious response to a threatening or challenging stimulus is to shift attention away from the task at hand to search for the source of the stimulus. Decreased attention to a task favour responses which require less information processing and these may include execution of well-rehearsed, routine or "default" responses (12).
2. Attention narrowing: when a to-be-remembered event induces emotional arousal or stress in the observer the result is accurate memory of the features of the event at the expenses of memory of peripheral details (12).

The knock-on consequences of these features of stress may be poor performance of an ongoing task unless the threatening stimulus is part of the task itself.

1.5. Aims of the research

The aims of the presented study are:

1. helping medical practitioners treating psychological disorders by playing interactive games other than medication. To accomplish the goal, EEG-based BCI technology has been used to model and implement the system which is a culmination of medical and entertainment industry,
2. detecting severity levels of disorders with the help of BCI technology,
3. working on the cognitive control parameter to gather useful insight into enhancement of cognitive control function with the aim of helping people suffering from Psychiatric disorders.

In order to achieve these goals, a BCI-based gaming application was developed. A controlled application was also developed that was made free from the cognitive conflict present in the selected tasks. Twenty-one subjects fulfilling study criteria were randomly assigned for a clinic-based practice with either therapeutic application or control application. Individuals in case and control group were assessed for adherence to task assigned, disorder related clinical outcome (YBOCS, WHOQOL-BREF, CGI/GI) and performance on assigned tasks (UFO movement game score and reaction time). A well-recognized measuring index, YBOC, for checking the severity of the disorder has been used for comparison (13).

2. Materials and Methods

The content of this chapter is almost completely taken from the original study (13). The study explores the therapeutic effectiveness of a novel BCI-based gaming application for enhancing cognitive control in obsessive–compulsive disorder, predominantly contamination type (obsessions related to getting in contact with germs, viruses, etc. compulsions related to decontamination as excessive hand-washing, disinfection etc.) as a primary model for pilot study. The objective is to extend the experiment to patients suffering from any cognitive-dysfunction related disorder. The data is collected from the temporal region of the brain via two non-invasive dry non-spikey electrodes which mainly deal with a person's focus levels. This data that is collected is directed to the computer via Bluetooth module, and correspondingly alpha and beta wave frequency values are obtained. This stream of data is used as a parameter to move the object in our proposed game. This game is a 2-D game developed with the ability to operate in real time. It is aimed to not only find an alternative and exciting way to play games but also to serve the therapeutic application enhancing cognitive control. Implicit sensitization and training to control one's own cognitive performance by feedback EEG synchronization in EEG-based BCI interface is widely documented by various research (30).

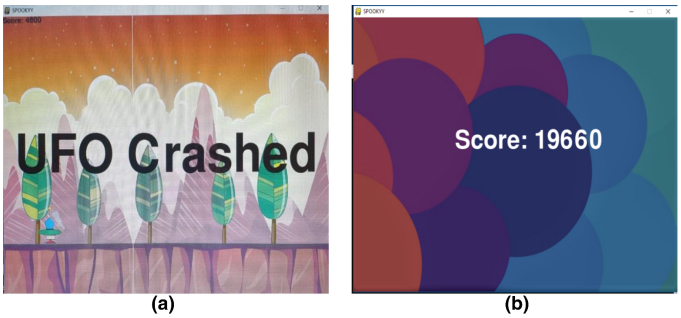
2.1. Severity detection for obsessive–compulsive disorder (OCD)

2.1.1. Subject

There were 34 clinic attendees (screened after obtaining appropriate consent), aged between 18–45 years fulfilling the criteria for diagnosis of OCD according to the International code of Diseases (ICD) 10 with prominent contamination-related obsessions and associated compulsions. Exclusion criteria were (a) colour blindness, (b) inability to read simple English, (c) history of head injury or neurological illness, (d) presence of comorbid Axis-I disorder including history of psychosis, bipolar disorder, substance abuse or dependence or mental retardation, (e) Yale–Brown obsessive compulsive scale (YBOCS) less than 16, (f) score of more than 17 on Hamilton depression rating scale—HDRS, and (g) score of less than 10 for contamination dimension in Dimensional Yale–Brown obsessive compulsive scale (DYBOCS). Selected subjects were assessed by pretested semi-structured demographic proforma. Severity of OCD was assessed with YBOCS (17).

2.1.2. Stimuli for symptom provocation

The package comes with openBCI kit, a 3D printed headset with electrodes placed, EEG machines and our dataset to store .CSV



(a) (b)

Fig. 1. Movement of UFO with brain signals **a)** UFO crashed due to lack of concentration **b)** raised up to maximum attentional score

files for the primary version of clinical trial applications. We choose a standard evaluation version, applied to all participants for assessment purpose. Home-based practice version for 'Case' population and for 'Control' population is in the development process. Stimuli for standard task assessment and individually tailored stimuli, primarily for clinic-based practice, has been developed till now.

Patients with OCD have characteristic bouts of symptoms precipitated by specific environmental or internal cues. Here, we opted for visual stimuli in the form of images. Two set of images were collected:

1. 30 images depicting contamination were adapted from the Maudsley Obsessive Compulsive Stimuli set (MOCSS) (18). In case an image was perceived as culturally inappropriate, it was selected for replacement with a similar picture from Indian background to increase cultural validity,
2. some neutral pictures were selected from the International Affective Picture System (IAPS) (19).

Selected OCD patients were asked to rate the picture for emotional distress on a visual analogue scale of 0–100 (0 for minimum distress). In the case group the pictures were hierarchically arranged in order to increase distress and enhance the symptom provocation. Every run of the experiment consists of the following phases:

1. the patient is ready to play the game and feels relaxed. *Hamlet is sleeping in his bed, Gödel is eating the food prepared by his wife*,
2. the images are shown, one by one, to the subject. To evoke emotional interaction, subjects had to respond to at least four questions related to the situation depicted by each picture: (a) what is happening, (b) what was happening before, (c) what will happen after, (d) how are you feeling. Then they had to rate their emotion on an on-screen visual analogue scale of 0–100 (0 for minimum distress). The patient feels distressed, parameter such as excitement, sweating, increased pulse rate, etc. are incorporated into the system. Even when the picture disappears, the phenomenon of attention shift leads the subject into the research of the cause of the distress, the image itself, so immediately attention narrowing occurs (more focus on the recalled image, less in the peripheral details). It becomes a persistent image, experienced as intrusive and unwanted. *The ghost of the murdered king appears and asks for revenge, Gödel's wife is hospitalized so he is left alone*,
3. the patient plays the game trying to focus on the UFO showed in the screen in front of him, the more he is focused on the visual stimulus of the UFO, the more the UFO goes up and the subject collects points, otherwise it goes down until it crashes on the ground. The subject needs to use his cognitive controls ability: cognitive flexibility to switch task (from thinking to the images in order to answer the questionnaire to playing the UFO game), inhibit the unnecessary images of the contamination and load into WM what is needed to perform the new task and so selectively put attention on the UFO on the screen. However, OCD patients shows in general attentional bias towards disorder-relevant stimuli and impaired attentional set-shifting so all these tasks turn to be very challenging for them. *Hamlet broods on his outrageous fortune without being able to commit the requested homicide, Gödel thinks of being poisoned starving to death without being able to prioritize the logic reasoning*.

The challenge is finding a correspondence between the disorder severity and the game points and ultimately helping patients improve their cognitive control.

2.1.3. Assessment with evaluation version for clinic-based practice

Assessment was done every week in a research setup for 12 weeks. It was done in all subjects of the control group first. Then all subjects in each disorder group were assessed with the symptom provoking standard evaluation version of the clinic-based practice module. Scale or parameter applied for assessment for each session is Yale–Brown obsessive compulsive scale (YBOCS) (17).

2.1.4. Outcome measures and plan for analysis

The primary outcome measure was to assess Adherence/Dropout rate to therapy. For assessment of intensity of practice, it was assessed (1) the level of cooperation from the subject in practice session per seating and (2) mean duration of session for which the tasks were practised.

The secondary outcome measure was the change in clinical variables, e.g. severity, change in disease status, Quality of Life.

An additional outcome measure was the change in performance in neuropsychological tasks. To accomplish that, it was initially recorded the game score by letting the patients enjoy the game. Then the game is played after stimuli provocation and the score decides the severity of OCD . Drastic change in the game score along with other erratic biological factors categorizes the stages of the disease. We planned to present data descriptively and to analyse with appropriate statistical tests, e.g. YBOCS and analysis of variance when applicable to study significance of association.

2.2. Data collection for BCI model

The methodology is categorized into three subsections for ease of understanding. The subsections can be described as: (1) acquiring relevant data, (2) processing and error management of the data, and (3) script to run game. Figure 1 describes the timeline followed during the project. The various subsections mentioned in the figure above have been elucidated hereafter (Figure 2).

2.3. Acquisition of relevant data

The open-source OPENBCI ULTRACORTEX MARK IV headset has been used in this project (20) that has been 3D printed.

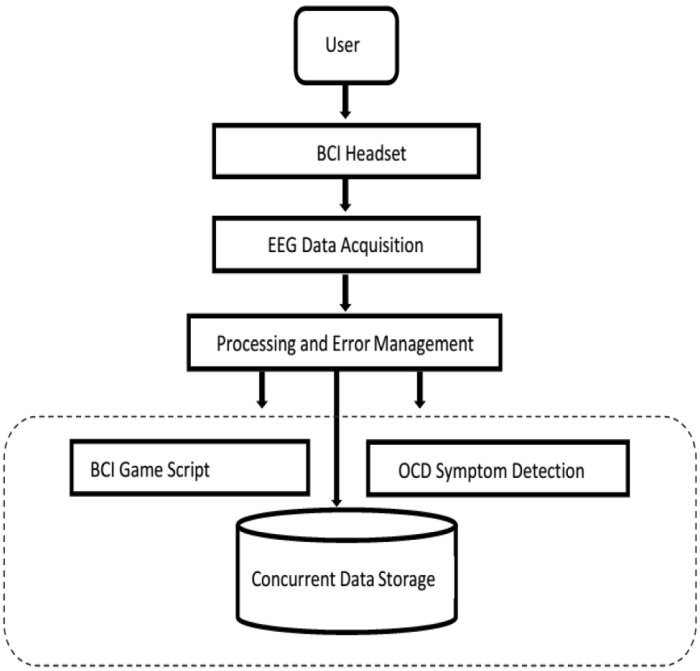


Fig. 2. Flow of the proposed system

Thirty-five electrode locations of the 10–20 system that has been considered as reference for the work are targeted. The version of the aforementioned OPENBCI ULTRACORTEX MARK IV headset that has been used in this project, is an 8-channel headset. A total of 8 electrodes (6 spikey dry electrodes and 2 non-spikey or flat electrodes) are present. The waveforms that showcase the cortical electrical activity are known as Electroencephalogram or EEG signals categorized as delta, theta, alpha, beta, and gamma waves based on frequencies of signals ranging from 0.1 to over 100 Hz (21). These EEG signals are acquired by the OPENBCI ULTRACORTEX MARK IV by the electrodes in the headset placed in correspondence with the 10–20 electrode placement scheme.

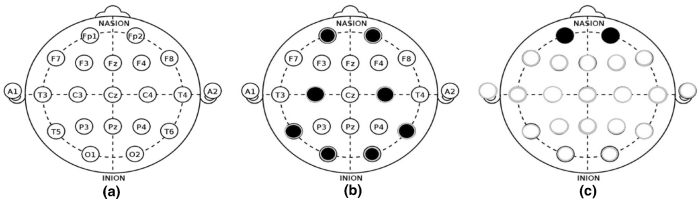


Fig. 3. 10–20 System of electrode placement b Electrode placement in this project c electrode placement in this project

The 10–20 system (Figure 3a) describes the relation between electrode placement and the portion of cerebral cortex (22). Each point in Figure 3a relates to one acceptable position of electrode placement. The letters F, T, C, P, and O stand for Frontal, Temporal, Central, Parietal and Occipital. Even numbers (2, 4, 6, 8) refer to the right hemisphere and odd numbers (1, 3, 5, 7) refer to the left hemisphere. The Z refers to an electrode placed on the midline (23). The electrode placement is described in Figure 3b. The electrodes in the headset are represented by nodes coloured in solid black. Utilizing the focus or concentration parameter is the primary objective of the study therefore only the beta and alpha waves are considered as they are mostly concerned with the conscious mind (24) (25) (26). To study the alpha and beta waves emitted by the brain at any instant, the nodes are highlighted in black (Figure 3c). OPENBCI provides an open-source GUI that is utilized to acquire and study the signals captured by the device. An inbuilt Focus Detection widget is also provided that assesses the alpha and beta waves captured by the device. A simple Fast Fourier Transform is performed to obtain the spectrum of the signals. In this FFT plot, the alpha band can be defined as frequency components between 7.5 and 12 Hz, and beta band defined as frequency components between 12.5 and 30 Hz (27). The final data is the readings of alpha and beta frequency range provided by channel 1 and channel 2 electrodes associated with the Fp1 and Fp2 region of the brain. Certain modifications were made in the GUI algorithm originally provided by the OPENBCI organization, in order to acquire the appropriate data in CSV format.

2.4. Processing and error management of the data

To access the data and classify as focused and non-focused state, an established and defined algorithm is then used. The algorithm, which is established in OPENBCI documentation (28), gives us the average alpha and beta value. At the same time, an error factor of ±0.1 is also introduced to counter balance any instrumentation or environmental error. A range of [0.7–4.0] for alpha average and a range of [<=0.7] for beta average are considered the optimum range for classifying an individual as truly focused on the visual stimulus in front of him (the UFO) as found by experimental study (27). The lower bound of alpha average and upper bound of beta average were also modified with an error factor of ±0.1. This change was made to cope up with the challenge of providing a streaming influx of data for the game which is discussed in the next section.

2.5. Script to run the game

An interactive game is designed that can actively access the final processed readings from other script and use it as an input to run the game engine. The objective of the game is to provide a visual medium for the user to interact and engage in cortical activity and also try to monitor any abnormality in cognitive skills. The game acts as a stimulus for the user to engage in an activity that targets the brain activity. Figure 4 displays a test user wearing the headset after which the data from the headset is ready to be cast and processed for the game.

2.6. Comparison: obsessive–compulsive test

Then in the study the result game scores are compared with a standard measuring index Yale–Brown OCD Scale (YBOCS). A standard OCD questionnaire for psychometric test is the YBOCS (17) (34). The goal of this study was to examine some hypotheses for OCD level measurement depending on 10 questionnaires. The rating is in the range of 0–4 for the parameters like none, 0–1 h/day, 1–3 h/day, 3–8 h/day, more than 8 h/day, etc. Table 1 shows the possible questionnaire set used as measuring index. Your Score: If you have both obsessions and compulsions, and your total score is; 8–15 = Mild OCD, 16–23 = Moderate OCD; 24–31= Severe OCD; 32–40 = Extreme OCD. The severity level of OCD was assessed depending upon the response time and game score. A score up to 500 is mild, 1000 is moderate and more than that is severe. A comparative analysis with YBOCS score found the result is commendable and comparable, Table 3.



Fig. 4. BCI Headset being worn by the user

	Questionnaire
1.	How much time do you spend on obsessive thoughts?
2.	How much do your obsessive thoughts interfere with your personal, social, or work life?
3.	How much do your obsessive thoughts distress you?
4.	How hard do you try to resist your obsessions?
5.	How much control do you have over your obsessive thoughts?
6.	How much time do you spend performing compulsive behaviours?
7.	How much do your compulsive behaviours interfere with your personal, social, or work life?
8.	How anxious would you feel if you were prevented from performing your compulsive behaviours?
9.	How hard do you try to resist your compulsive behaviours?
10.	How much control do you have over your compulsive behaviours?

Table 1. Obsessive–compulsive test—Yale–Brown OCD scale (YBOCS)

3. Result

Twenty-one patients were finally selected for clinical trial, and out of them, there were 14 female candidates. Age mean was 29.9 years (SD, 5.9 years), formal education mean was 11.4 years (SD, 2.9 years) and the patient's mean illness duration was 4.7 years (SD, 3.2 years; range, 1-15 years). The OCD severity was from moderate to severe (YBOCS total: Mean, 25.6; SD, 4.9) obsessions: Mean, 13.1 (SD, 2.9) compulsions: Mean, 12.3 (SD, 2.5). Dimensional YBOCS was applied for all subjects. The mean total score in the contamination dimension for the subjects was 13.7 (SD, 2.3). All the patients were on active psychotropic medicines, but none was undergoing any form of structured psychotherapy. Table 2 shows the data values that are used to control the object in the game (UFO). Both the columns in the above figure show the alpha average and the beta average values computed from the FFT plot used by processing the data obtained from placing the electrodes on the frontal region of the user's head. If the user is focused, the alpha-average value (the first column) should be within [0.6 to 4] and the beta-average value (the second column) should be less than 0.8. If both the values in the columns are within range, only then the individual is concluded to be in a focused state and the UFO within the game will fly (Figure 5a); otherwise, it will gradually decrease its altitude (Figure 5b) until it crashes (Figure 5a). The above data is being analysed by the game script simultaneously while the game runs. Figure 5a depicts a situation in which the UFO increases its altitude signifying that the user is in focused state. Figure 5b depicts that the user is in unfocused state. The UFO movements only depend on whether the data values from the user are within the specified range or not. The red line highlighted in Figure 5c denotes the crash line in the game. If the UFO descends below the red line, the game will consider it as a crash. This is implying that the user has lost concentration for a considerable amount of time. If the concentration of the individual falls below a particular delimiting value, it will be visually demonstrated by the crashing of the UFO. This mechanism provides an interactive environment between the user and the system to visualize the focus quotient of the individual for a given length of time in accordance with changing media in the game. During a game session, participant gets a visual feedback of real-time cognitive control status reflected by their performances. This principle of implicit sensitization and training to control one's own cognitive performance by feedback EEG synchronization in EEG-based BCI interface is widely documented (30). As per results shown in Table 3, subjects randomly assigned with the 'Case version' of practice application not only remained significantly more adherent to therapy ($p < 0.000$, p is probability, if < 0.05, significant), they were also engaged in more practice session every week compared to control. As most of the control population dropped out before completing 12 weeks, the analysis was done on results obtained at the 8th week. More engagement in a conflict task seems paradoxical, however this may be the therapeutic element contained in the tasks that is keeping the concerned subjects more engaged. It reflected in favourable outcome related to clinical parameters like significantly better YBOCS score ($p < 0.001$), better WHOQOL-BREF score ($p < 0.02$) and better CGI/GI outcome($p < 0.01$). There were some improvements related to neuropsychological tasks both in case and control group. This may be due to practice effect. Overall, this BCI game-based application showed some evidence of favourable adherence to the practice application and

Alpha Average	**Beta Average**
1.9190886	0.96383286
1.9487019	0.9791486
1.9785846	0.7969459
1.9815729	0.99744034
2.0065045	0.3142573
2.0272954	0.3306373
2.0377433	1.0462238
2.0366743	1.057771
2.027125	1.0462238
2.0261703	0.605094
2.0047317	0.7679742
1.9671408	0.8653191
1.9175301	0.7564997
1.8834324	0.4462542
1.8579422	1.0364553

Table 2. Subset of dataset obtained from BCI Headset

shown therapeutic effectiveness in this small sample of subjects suffering from OCD with predominantly contamination type.

Disorder/functional status	
YBOCS	**Proposed Method**
26.3 (± 4.9)	Severe (1678)
25.3 (± 4.1)	Severe (1978)
0.01 (± 5.1)	Mild (345
22.9 (± 4.8)	Severe (1678)
17.9 (± 5.8)	Severe (1912)
0.06 (± 6.4)	Moderate (978)
15.8 (± 4.9)	Severe (1738)

Table 3. Checking the results with standard YBOCS (these samples are randomly selected from 21 subjects)

4. Discussion

In this study as in the others that can be found in literature similar to this, the object of the neurofeedback modulation is not precisely the source of what we call cognitive control which is a high level brain function not easy to be reduced to a single source. Namely there are some different frequency bands at many brain sites whose neurofeedback training has been linked to improvement in executive functions performances (30) and still literature is not completely clear on this. In this case, for example, the object of the neurofeedback modulation was the focus on a visual stimulus placed in front of the patient (the UFO) and not cognitive control per sè which would have been far more complex. So the concept is, considering our knowledge of cognitive control, I can train it in a person as long as I describe a certain task and define a measure of performance on that specific task. *Focus on the UFO, so switch the content of your WM from the conflicting images to the image of the UFO*. So the question would be *"why is it the case of using EEG and neurofeedback for this training having to pay attention to long and uncomfortable calibration of devices and preparation of the experiment environment? Isn't it easier to use standard ways of training using measures of performance based on motor coordination and response rather than brainwaves feedback?"*. The answer is that there is moderate evidence EEG-based gaming neurofeedback produces better results than standard training especially due to enhanced engagement in the tasks (29) (31) (13). The number of serious games exploiting BCI neurofeedback is limited in literature, however the ones available show good results in both assessment and treatment of patients suffering from cognitive-dysfunction related disorders (29) (32) (33), especially ADHD(35). That's the reason why it is of fundamental importance to further investigate, with more precise and complete studies than the one presented, new ways of cognitive control training based on neurofeedback, linking them to disorders treatment.

4.1. Limitations

As it is said by the authors of the study, result from any new method of therapy should be judged with scepticism. The design of the study was drawn on intuitive reasoning rather than empirically based, so it needs to be verified on a larger and representative sample. It may not act on severe form of illness. Active participation from the individual is a prerequisite. Motivation to adhere to the therapy is an issue. But applying the therapeutic

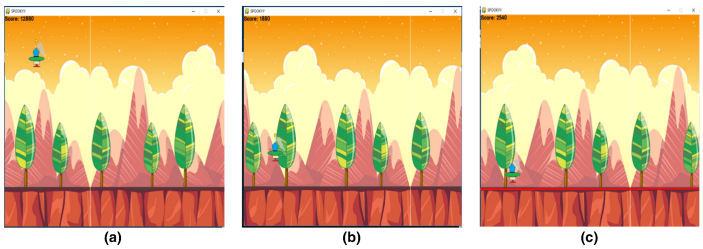


Fig. 5. Movement of UFO as a function of alpha and beta value

module by playing simple game was never seen as a difficulty for participants. Rather it was an issue dealt with enjoyment. Strength of the study design was its basic understanding of cognitive constructs and simplicity in design, minimal cost, minimal need for trained personnel, rendering its wider applicability across various psychiatric disorders (13).

4.2. Focus Detection

While considering the result of the study, the quality of the focus detection algorithm should be taken into account. A literature research on visual attention detection shows limited complexity of the algorithm used in the study and reveals contradictory result.

In the study, the in built Focus Detection widget provided by OPENBCI was used to perform an FFT on the signals coming from two electrodes at Fp1 and Fp2. The sampling frequency and the time window over which the FFT is performed are not specified. Moreover nothing related to artifact removal is performed before assessing the average value of alpha and beta bands. Artifact related to eyes or muscles movement have, in general, frequencies under the alpha band ($< 8Hz$), however the algorithm still remains very simple and based on the intuition that alpha waves are related to calm and focused states, while beta band can be associated to anxiety and tension.

Chiang et al. (36) developed an algorithm that used SVD to clean the EEG raw data than FFT, MEPA (minimize entropy principle approach) and an APN (associative Petri net) for the classification of the extracted features that showed good result in the detection of attention during learning exercises. Ling Li (37) comparing three different states: EC (eyes-closed), EO (eyes-open) and visual attention showed that the average alpha power over all the 128 electrodes is lower during the attentional state with respect to EC and EO states. Xiaowei Li et al. (38), using two different classifiers, namely KNN (K-Nearest-Neighbour) and NBC (Naive Bayes Classifier), showed the best group of features for Attention Recognition classification while reading or watching random content was mainly related to the power of alpha waves detected at F3, F4 and Cz. Matthias M. Müller et al. (39) found increase over the left and right parieto-occipital regions only in the frequency band from 35 Hz to 51 Hz when assessing visual attention, concluding gamma band is related to visual information processing.

Further studies are needed to understand properly how attention and in particular visual attention is related to brain waves.

5. Conclusions

The world of psychiatric disorders is vast and complex to unravel, as many layers need to be taken into consideration if we want to understand it profoundly. And I believe this is essential to devise effective experiments reasonably focused on the assessment and treatment of these various disorders.

The technology of BCI-based serious games is not the Holy Grail of cognitive rehabilitation, as similar training has been done for decades without the help of this technology yet with good result. However the use of games with the technique of the neurofeedback increases the patients engagement in the task, consequently reduces the treatment remission rate and enhance its effectiveness with respect to standard methods of cognitive training. Anyway we are very far from having effective systems and protocols which give generalized good result in the treatment of patients. The quality of the focus detection algorithms is crucial in this sense. A fundamental challenge is the simplification of the access to these type of treatment to guide patients toward this type of training, hopefully making the devices portable, allowing generalized studies to take place and devise new and more effective methods.

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