Neurofeedback video games in the rehabilitative treatment of Hyperactivity and Attention Deficit Disorder for attention enhancement and hyperactivity reduction

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Abstract

In the field of special education, and in particular, in the rehabilitation treatment of patients with Attention Deficit Hyperactivity Disorder, a multidimensional neurodevelopmental disorder characterized by a mixed pattern of inattention and hyperactivity and/or impulsivity, virtual reality integrated with neurofeedback produces an intensive neurocognitive training capable of enhancing long-term attentional capacity and, at the same time, reduce hyperactivity and/or impulsivity.

Research has shown that learning enhanced by technology and, in particular, by neurofeedback combined with cognitive training based on video games produces better therapeutic effects than other common therapeutic approaches, such as conventional therapies and pharmacological proposals, as the playful component greatly increases the motivation to learn by the patient / player, providing the opportunity to live not only an immersive and fun experience, but also therapeutic in terms of symptomatic reduction.

Keywords

Attention Deficit Hyperactivity Disorder, video games, neurofeedback, information and communication technologies

1. Introduction

The recent development of the role of information and communication technologies (ICT) in the field of disability and special education has promoted the development of a better and more accurate knowledge in the areas of special needs, with positive effects in teaching-learning processes and in improving the quality of life [1].

"When we think of disability, we spontaneously refer to a condition, physical or psychological, that prevents a person from performing independently, in whole or in part, the normal functions of life (studying, working, traveling or simply washing, dressing, driving). We focus, in essence, on the deficit (i.e., the impairment, whether sensory, motor or mental) and the limitations it entails. Disability, however, is not the deficit itself, nor that which prevents one from doing, but rather the result of the interaction between the deficit itself and a context capable of welcoming it, treating it and valuing it [...]. It is the environment, in fact, that determines the level of severity and the consequences of a certain state of health. In particular, the factors that the WHO considers as "facilitating" elements are those capable of reducing the consequences of a disability; on the other hand, it considers as "barriers" those elements that amplify the negative effects of the disability condition. One of these elements, placed by the WHO in first place, is represented precisely by "products and technologies": the availability or lack of technological tools contribute to determining the degree of disability of a person affected by a certain health condition" [2].

Digital innovation, therefore, provides solutions capable of responding to the particular needs and requirements of people with disabilities, translating into reasons for social inclusion [3].

In the last decade, numerous studies have demonstrated the benefits, in terms of learning and symptom reduction, of various forms of technological tools (augmentative alternative communication, assistive or enabling technology, Internet applications, virtual environment, and technology integration) for individuals with Attention Deficit Hyperactivity Disorder [03], a neurodevelopmental disorder generally characterized by poor attention skills and hyperactive and/or impulsivity behaviors [4].

This disorder is usually treated from three different perspectives: psychology, education, and pharmacology. An important part of the psychological treatment focuses on cognitive-behavioral intervention, counseling the parent training to manage the difficulties related to this disorder. On the other hand, the most widely used pharmacological treatment in both children and adults with ADHD is done with the administration of psychostimulants. However, the use of the drug reaches an efficiency of 70 to 80% and the patient may present side effects such as decreased appetite, dry mouth and irritability.

Therefore, 10-20% of cases with drug treatment do not improve. This demonstrates the need for different and alternative treatments [5].

A possible alternative to this type of pharmacological treatment concerns the use of the neurofeedback technique, formerly called electroencephalographic biofeedback and sometimes referred to as neurotherapy, which extends to the training of the electrical activity of the brain the biofeedback concepts, strategies and techniques previously established as useful in some medical disorders, especially cardiovascular [6].

The present contribution aims to highlight the positive therapeutic effects of neurofeedback related to video game-based cognitive training in terms of fun. The fun experience leads to a reduction in the treatment dropout rate, since the immersion of neurofeedback training in a virtual reality not only allows the enhancement of attention and the reduction of hyperactivity (typical symptoms of ADHD), but also promotes an emotional involvement and an increase in the interest and motivation of the patient, vital lymphs in the learning process [7].

Aiming to improve the quality of life through these technological solutions, patients with Attention Deficit Hyperactivity Disorder, can, therefore, benefit from an alternative and complementary therapy to traditional cognitive-behavioral and pharmacological therapies, to regulate their brain waves and, consequently, reduce the hindering and disabling symptomatology [8].

2. Effects of virtual reality integrated with neurofeedback

According to the Diagnostic and Statistical Manual of Mental Disorders, Attention Deficit Hyperactivity Disorder reflects an executive dysfunction that generates a difficulty in behavioral inhibition, a lack of persistence and weakness of interference control mechanisms, impaired motor modulation, poor attentional skills and impulsivity inconsistent with the level of development [9].

This complex of cognitive and behavioral problems is remarkably stable over time. In fact, 60-85% of children diagnosed with Attention Deficit Hyperactivity Disorder, continue to exhibit symptoms into adolescence [9] and between 2% and 46% into adulthood [10].

Usually, the onset of this disorder coincides with the period of early childhood and more specifically before the age of seven, the age at which a diagnostic assessment is made. All these difficulties are related to their relational interaction problems and discipline problems that normally damage social development, causing significant disruption of social, educational and vocational activities [11].

With respect to the etiopathogenesis of this disorder, it is still not firmly established, but the preponderance of evidence suggests that Attention Deficit Hyperactivity Disorder, is a highly heritable disorder, with abnormalities in neuroanatomy (reduced cortical volume of white and gray matter), neurochemistry (dopamine and serotonin); neurophysiology (dysfunction of frontostriatal structures), which result in electrophysiological under-excitation of the central nervous system [12].

In this regard, neuroimaging studies confirm a pathophysiological background in the presence of cortical hypoexcitation in Attention Deficit Hyperactivity Disorder, associated with smaller and, indeed, underexcited frontal lobes and other brain regions responsible for sustained attention, behavioral planning, and motor control [13].

More specifically, positron emission tomography (PET) and single-photon emission computed tomography (SPECT) studies have reported reduced blood flow and metabolism suggesting electrophysiological underexcitation over frontal and midline cortical regions in approximately 80%-90% of Attention Deficit Hyperactivity Disorder, patients, which causes impaired attentional capacity in children with ADHD [14].

Attentional capacity refers to a wide range of cognitive skills, processes, and situations that allow one to concentrate on processing specific information and focus on a particular action, thought, or object [19]. Information that receives attention from the individual is selected and processed, while input that does not receive attention exits consciousness [15].

Several physiological markers can be used to indicate levels of attention: regional cerebral blood flow, which increases during attention tasks such as reading, naming, etc.; pupillary diameter and blink rate, which increase or decrease, respectively, as attention increases; and, finally, markers derived from electroencephalographic activity, detected through the use of the neurofeedback technique [16].

Neurofeedback, also known as electroencephalogram (EEG) biofeedback, has been used as a treatment strategy for attention deficit hyperactivity disorder since 1976. Lubar and Shouse were the first to report on symptomatic changes in a hyperkinetic child following theta/beta neurofeedback treatment, which aimed at reducing theta waves associated with a state of inattention and increasing beta waves associated with a state of attention [17].

Neurofeedback was first used to train children with ADHD in the 1970s after researchers noticed improvements in the academic performance of children with seizure disorders treated with neurofeedback. Early single case studies showed behavioral and academic improvements among children who had ADHD [18].

Neurofeedback is a type of biofeedback based on operant conditioning of brain activity that measures brain activity in real time and aims to teach the user/patient with ADHD to regulate his or her brain activity and "modify" his or her symptomatology by intervening, through continuous feedback for reinforcement of correct responses, in enhancing attentional skills and reducing hyperactivity/impulsivity [19].

First measured in 1924 by the Austrian psychiatrist Hans Berger, it was seen that the electrical activity of the brain, shown as brain waves on the electroencephalogram (EEG), changes depending on the functional state of the brain during wakefulness or sleep, or in brain diseases such as epilepsy (Berger, 1929) [20].

EEG is described in terms of rhythmic activity measured in hertz (Hz), the number of waves per second. EEG activity is typically divided into specifically named frequency bands. Up to 4 Hz is called delta (e.g., slow-wave sleep state), 4 to 8 Hz theta (e.g., drowsy/disattentive state), 8 to 12 Hz alpha (e.g., awake/relaxed state), and 12 to 30 Hz beta (e.g., active/attentive state) [21].

Research has suggested that people with Attention Deficit Hyperactivity Disorder, have higher theta brain wave activity (especially in the frontal area) and lower alpha and beta activity than normal people [22].

In other words, ADHD patient consistently show brain activity dominated by low-frequency waves, such as theta waves (4-7 Hz), especially in the frontal area, and decreased power of fast-frequency waves, such as alpha (812 Hz) and beta (9-22 Hz) waves [23].

In addition, more specific wave patterns, so-called event-related potentials (ERPs), can be observed in the EEG. ERPs are electrical representations of the underlying sensory and cognitive processes that occur in the brain in response to a stimulus or event [24].

A specific group of ERPs are slow cortical potentials (SCPs), first observed by Walter, Cooper, Aldridge, McCallum, and Winter in 1964. They are slow DC shifts correlated with EEG events that reflect the excitation threshold of large cortical cell complexes. Shifts in the negative direction, called negative contingent variation (CNV), indicate a reduction in arousal threshold and are thought to be related to cognitive preparation and increased cortical activation of a network, whereas shifts in the positive direction reflect an increase in arousal threshold and a corresponding inhibition of activation [25].

Research on these SCPs has suggested that “failure to engage specific cortical networks in children with ADHD contributes to decreased performance” [26].

Theoretically, then, this slow-wave activity or reduced cortical negativity or underexcitation is associated with the core ADHD symptoms of inattention, hyperactivity, and impulsivity [27].

In this context, the assumptions underlying neurofeedback fit consistently with theories of brain plasticity and models describing ADHD as a disorder of neural regulation and brain underexcitation, which highlight the insufficient production (or utilization) of neurotransmitters, causing inefficient communication between neurons [28].

The efficacy of neurofeedback emerges by "solving" this gap: relying on operant conditioning of bioelectric neuroregulation, patients receive reinforcement when neurons communicate or activate more rapidly [29].

Therefore, the goal of neurofeedback is to train the individual to normalize abnormal EEG frequencies and increase awareness of how a normalized EEG pattern "feels" through immediate feedback of brain electrical activity, leading to learning how to self-regulate one's mental states. By placing sensors on patients' bodies, their brain activity is measured, and through some computer output device (screen, audio, or touch devices) they are shown what is happening inside their bodies. In this way, the ability to regulate cortical activation over time is improved, as represented by decreased activity in the theta band and increased beta activity. Once this mechanism is learned, ADHD symptoms decrease and neurofeedback, therefore, helps people to be "more attentive to being attentive" [30].

3. Neurofeedback games for ADHD treatment

More challenging and interesting is the use of virtual reality and video games integrated with neurofeedback. These are “special” games interfaced with neurofeedback devices, designed to detect the electrical brain activity (EEG) in real time during the game, which is controlled directly by the patient with his mind and not with his hands (through, for example, the use of controllers, mouse, keyboard, etc.). So, the patient/player controls the elements of the game (characters, actions, etc.) and obtains, during the course of the game, the various rewards through his brain activity, i.e., when he produces the EEG activity underlying the state of attention, i.e., when he shows attention [31].

The working principle of the video game integrated with neurofeedback is, therefore, the following: when the child is attentive, he produces specific EEG activation patterns; the neurofeedback tool detects them and "transmits" them to the game, thus allowing the child to control the game (achievement of goals, increase in scores, obtaining rewards, etc.) through his mind, and, in particular, through his attentional function; the child, unconsciously and, above all, while having fun, learns to remain attentive for longer and longer periods of time even during the most boring tasks [32].

In other words, the child learns by playing: he learns in a carefree way to produce brain activity corresponding to the cognitive state of attention.

Therefore, the risk of attention lapse, in a typical neurofeedback session, can be avoided thanks to the fun and playful activity of the video game, as it progressively enhances attentional capacity while performing specific tasks [33].

The ADHD patient, once he or she enters virtual reality, wears a special visor and has the impression of really being in an alternative reality of any kind, from the most verisimilar to the most imaginative (e.g., Neurofeedback Space game that is set in a space since

the EEG cap can be compared to a space helmet used by pilots); after sitting down, a psychophysiologist places the EGG sensors on the patient's head, a hygienic cap, a hygienic eye mask and the virtual reality helmet. At this point the neurofeedback-guided virtual reality experience begins, during which the individual in order to play must engage maximally on the attentional level and control hyperactivity for as long as necessary [34].

It is evident how the playful component of the game (and the immersive experiences that derive from it), allows on the one hand, to achieve better cognitive performance and in a shorter time with consequent positive effects on motivation, performance and, consequently, on the overall effectiveness of therapeutic treatment; on the other hand it promotes high levels of cognitive performance, such as prolonged concentration, impulse control, inhibitory capacity and control of interference [35].

4. Conclusions

Information and communication technologies (ICT), and, more specifically, neurofeedback, facilitate the creation and implementation of emerging technological solutions for the treatment of Attention Deficit Hyperactivity Disorder, that complement conventional treatments such as psychotherapy, behavioral therapy, support groups, pharmacotherapy, and parenting skills training [36].

Neurofeedback enables the training of physiological self-regulation skills by providing feedback (mostly visual) to users about their performance on specific tasks [37].

As argued by Holtmann and colleagues, humans have the inherent ability and inclination to regulate their physiological processes. If the patient receives informational feedback, their body processes it in the correct form. This ability is applied to video game-associated neurofeedback treatment where the target physiological function must be monitored in real time and information about the function must be presented to the patient so that he or she perceives immediate changes in the parameter. In addition, the feedback information should also serve to motivate the patient to be attentive to the training task [38].

This technology intends to unite the mind and body to make one aware of what the body is doing using real-time physiological sensing and to train physiological self-regulatory abilities.

The use of these Brain-Computer Interface (BCI) systems and neurofeedback video games in the treatment of ADHD has been shown to be effective in modifying ADHD symptoms in children (reduced hyperactivity, increased attention and concentration) as they provide a motivating method to encourage children with Attention Deficit Hyperactivity Disorder, to push their limits by providing them with highly stimulating, dynamic, and interactive experiences [39].

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