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PAPER

Combination of Virtual Reality (VR) and BCI & fMRI in Autism Spectrum Disorder

Angeliki Sideraki,
Athanasios Drigas(✉)

Net Media Lab Mind – Brain R&D, Institute of Informatics and Telecommunications, N.C.S.R. 'Demokritos', Athens, Greece

dr@iit.demokritos.gr

ABSTRACT

The combination of virtual reality and fMRI is an innovative methodology that is used to make inferences about the neurological stimulations that take place in the brain of the person with ASD during the use of the VR tool. At the same time, the use of the Brain-Computer Interface (BCI) will be important, as it can be used to achieve direct interaction between the person with ASD and the computer. Still, equally important conclusions can be arrived at through the EEG electroencephalogram, also establishing the neurological processes that are carried out during the use of the VR tool. The use of the two technologies mentioned above contributes to presenting in-depth conclusions and data about the emotional state experienced by children with ASD throughout the experimental process and their interaction with the virtual reality tool.

KEYWORDS

ASD, Virtual reality, virtual environment, BCI, fMRI, EEG, emotional intelligence

1 INTRODUCTION

Functional MRI (fMRI) and Brain Computer Interface (BCI) are powerful research tools to understand the neural foundations of human brain activity. The growing body of research on MRI incorporating virtual reality is answering critical questions regarding the development of human mnemonic capacity and the cultivation of emotional intelligence through the interaction of the person with ASD with the virtual reality tool. All of these studies adopt a variety of approaches and focus on spatial or navigational memory and behavioral intervention. The combination of fMRI and BCI with virtual reality contributes to many research areas and facilitates research in clinical disorders.

2 VIRTUAL REALITY VR & METACOGNITION

Virtual reality (VR) can be defined as an interactive 3D "imaginary system" that replaces the real environment with a virtual one. Through VR, the individual is

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enabled to organize his/her internal and external experiences and manage emotions that cause the emotions [1]. Emotions often stem from traumatic events and the use of the virtual environment can help to focus the individual on the present experience in order to overcome negative emotions [1]. At the same time, the use of VR helps to cultivate new skills such as communication and social skills [4]. In people with ASD, it activates neurological processes, and in this way, contributes to the development of higher cognitive skills such as working memory and other executive functions [2]. In addition, according to the analysis of Drigas, Bravou et al. (2020), on the importance of VR for people with ASD, it is evident that VR contributes to the improvement of emotional skills and abilities related to communication and social interaction in the school context.

According to the study conducted by Drigas and colleagues (2022) [102], virtual reality hypnosis (VRH) is a promising intervention that contributes to the development of the 8 pillars of metacognition. Specifically, a clinical virtual VR environment is created through which the patient is guided by a 3D technology to generate imaginary stimuli guided by verbal cues provided by the therapist [103].

The VRH Clinical Virtual Environment helps participants to apply hypnosis strategies by creating imaginary situations to deal with stressful situations and to change misperceptions [97]. This is achieved through the following metacognitive processes:

Self-observation: VRH helps participants, especially those who have difficulties focusing their attention on specific stimuli, to improve their concentration of attention and to assess themselves according to their learning goals.

Self-regulation function: According to [104], the use of VRH improves attentional distraction and regulates individuals' fatigue levels. At the same time, Teeley and colleagues (2017) [105] found that the use of VRH helps to regulate the feeling of pain. This is achieved by the fact that the patient during the procedure was able to take their attention away from the pain-inducing stimuli, resulting in the pain they felt being bearable.

Adaptation: During this procedure, the use of VRH virtual reality gradually exposes the patient to fearful situations using systematic desensitization. Patients become familiar with the feeling of fear for a condition (e.g., a flight), and are progressively exposed to stimuli that are increasingly associated with fear in a simulated reality environment. In this way they are able to overcome the phobia caused by the stimuli used in the simulation.

Recognition: VRH helps patients overcome the intense emotions associated with painful experiences by emphasizing feelings of calm and enhancing positive experiences during their interaction with the virtual reality environment

Distinction: According to Drigas (2022), exposure to virtual reality environments depicting situations that cause intense fear in participants helped patients become familiar with the face-to-face exposure to fear [4].

Mnemosyne: According to Mitsea et al. (2022), through hypnosis, the individual is immersed in a virtual world and is able to listen to their presence within it. In this way, the participant is able to understand the emotions he or she is experiencing and then the sense of his or her own presence helps him or her to overcome feelings of anxiety and depression [4].

Then, a pilot study with 86 children evaluated the effectiveness of DEEP, a virtual reality video game that provided deep breathing training in a virtual environment that promoted calmness. DEEP provided the opportunity for mild exposure to stressful situations (such as dark caves) to provide opportunities for participants to self-regulate their emotional responses. During this process, the participant is asked to breathe deeply as they move through the game. The results showed that internal control increased as the individual improved their attention levels through breath regulation, thereby contributing to the development of their metacognitive skills. Therefore, virtual reality and clinical hypnosis can guide subjects to overcome various cognitive and behavioural difficulties by capturing and intensifying their attention, minimising distraction and enhancing imagery, especially in the case of subjects with low imagination [1–10].

3 COMBINING VIRTUAL REALITY WITH THE COMPUTER-BRAIN INTERFACE BCI & EEG

The researchers, in this research, present a new paradigm of BCI based on virtual reality using social cues to guide attentional focus. They combined interactive virtual reality (VR) technology with the properties of P300 signals in a training tool that can be used in people with BCI [24]. The researchers tested the virtual reality tool for social attention training on 13 typically developing participants, using 3 different electroencephalographic (EEG) waveforms. Statistical accuracy was evaluated based on the detection of P300 signals. Using the following EEG systems: Naïve-Bayes, they compared: 1 – g.Mobilab+ (active dry electrodes, wireless transmission), 2 – g.Nautilus (active electrodes, wireless transmission) and 3 – V-Amp, together with actiCAPXpress dry electrodes. In all systems, significant statistical classification was achieved [25]. From the results, the g.Nautilus system proved to be the best performing system in terms of P300 localization accuracy, preparation time, speed and reported comfort. Still, in participants with ASD, this setting was found to be feasible and effective for training skills involving joint attention focus. Furthermore, the g.Nautilus system is best suited to be combined with the BCI human-computer interface system [24]. Subsequently, the tool created in the following research by El-Shehaly and colleagues (2013) was developed in a 3D virtual environment (CAVE) where users with ASD can interact and behave in the same way as in the real world [19]. The present research focuses on the construction of a suitable virtual reality tool that can be used by people with ASD and promotes their social skills as well as the expression of emotions. The main aim of the researchers was to formulate a tool that enables the user to benefit from the repetitive social interactions through a scenario-based system, without being hindered by social pressures or constraints to exist in realistic time [19].

Specifically, the researchers with the CAVE system emphasized on simulating real-life scenarios, ease of interaction and immediate feedback. From the results, it appeared that the central theme of the scenario was familiar to the users, so we can assume that they did not experience any particular stress or pressure in this condition and thus it is likely that they expressed their real thoughts and feelings during the process [19]. Still, according to El-Shehaly and colleagues (2013), the ability to recognise and understand emotions can be achieved through the use of BCI (human-computer interface) and virtual reality device in people with ASD. When the person enters the virtual environment, they are able to interact with the avatar. The other avatars are virtual bots that communicate with the user using various expressions (including facial expressions) [19]. The fMRI scanner can be used as a complementary tool to improve the accuracy of the BCI device data. There is a trade-off between high quality, accurate brain signal measurement (fMRI) and economy/mobility of the BCI devices used. BCI devices have an integrated MindSet system and over a dozen (Emotive) sensors/data points, and this data model is relatively low dimensional [19]. In addition, the high dimensional single user model (created from high quality fMRI data) can be used to improve the accuracy of the findings (Figure 1).

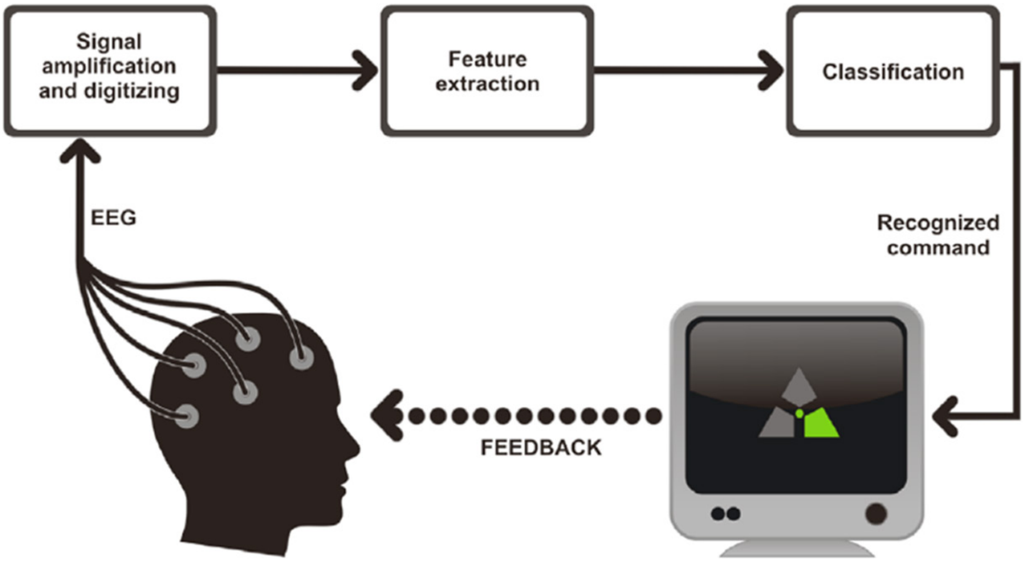

Fig. 1. BCI computer-brain interface

4 COMBINATION OF VIRTUAL REALITY AND MRI—FMRI

Although MRI has been and still is a powerful tool for the research of human memory, it requires the participants/examinees to be placed in a context that is far from naturalistic, with the consequence that there is often some confusion in the memories [26]. Virtual reality in turn provides the possibility of eliminating this problem, allowing the creation of memories using immersive, navigable, visuospatial contexts. This can enhance validity while ensuring that researchers maintain experimental control over critical aspects of learning and experience [20–26].

The inclusion of virtual reality in MRI memory studies provides researchers with the ability to use immersive and navigable contexts to present the stimulus. In particular, it provides researchers with a way in which they are able to conduct experiments that are both replicable and controlled in nature. In addition, the virtual environment enables the individual to expand his or her imagination more easily than in a real environment, as the virtual environment is designed with appropriate stimuli. [25].

Virtual reality technologies also enhance the ecological validity of the MRI scanner for both researchers and clinicians, as they provide the ability to collect objective diagnostic measurements for specific patient populations. Head-mounted display HMD (a virtual reality system that is placed on the head and contains glasses and headphones) is used for participants who are unaware of real-world environmental cues. In addition, compared to many real-world tasks, VR-based experimental techniques can be conducted in a shorter timeframe as it does not require transporting the subject to a physical environment [25].

Functional MRI shows findings that result in a function of the nervous system called the hemodynamic response function (HRF). During the hemodynamic response, many different brain regions experience perfusion due to oxygen concentration. This variability of brain areas that exhibit stimulation is a result of neural and non-neural parameters. Marked alterations in the underlying neurochemical mechanisms that control the HRF pattern have been reported in individuals with delayed auditory feedback (DAF) [25]. HRF can be influenced and modulated based on neural and non-neural factors. Non-neural factors include vascular differences, baseline cerebral blood flow, hematocrit, alcohol/caffeine/lipid ingestion, partial venous volume imaging, global magnetic sensitivities, incision timing differences, and pulse or respiration differences. These factors cause changes in HRF both in brain regions and in the individuals themselves. On the other hand, the systemic changes in HRF observed between individuals with ASD and typical individuals are much more frequent in individuals with ASD [26].

Nerve activity is associated with changes in blood-flow through signaling pathways controlled by various neurochemicals that directly or indirectly mediate vasodilation or vasoconstriction. HRF is a mathematical transfer function that represents this coupling and therefore could be modified as a consequence of changes in any of these neurochemicals. Specifically, glutaminergic and GABAergic endoneurons affect HRF by releasing neuromodulators that control local cerebral blood-flow. In brain regions with low GABA concentrations, higher, faster than hemodynamic HRF responses have been previously observed. Also, local activation of brain regions causes dilation of blood vessels, which is mediated by glutaminergic actions on N-methyl-d-aspartate (NMDA) receptors. Nerve activations as well as neurotransmitters could contribute to altered effects of the hemodynamic HRF response [26].

In this study, we tested the hypothesis that HRF is more altered in individuals with ADF compared to typical individuals, and studied whether this could lead to alterations in immunoglobulin FC receptors of individuals with ADF in a resting state. To confirm this hypothesis, the researchers calculated HRF in each voxel using a blind decomposition technique. From the results, significant changes in the HRF and FC characteristics were obtained in a resting state Therefore, in order to mitigate the uncertainty introduced by the variability of HRF, it is necessary to perform a resting state analysis of FC in the neural space. Therefore, changes in FC as a potential biomarker for imaging ADF, combined with changes in HRF, are a critical and important parameter for clinical trials [26]. Regarding the choice of decomposition technique of Yan and colleagues (2018), in this study, several methods for decomposition were evaluated and it was concluded that this technique is the most suitable for investigating voxel-level HRF changes among subjects. Still, the shape of HRF can be greatly influenced by blood vessels [26].

Then, using repeated measures NOVAs, the researchers investigated whether the brain regions that experienced stimulation from the experimental procedure showed significant differences by comparing the data obtained from the group of children with ASD and the control group. Specifically, based on the data, it was found that the bilateral angular gyrus and middle frontal gyrus showed higher positive connectivity in the control group consisting of typical subjects, compared to the group of individuals with ASD. Specifically, the right middle temporal gyrus showed little connectivity with the part of the brain called the precuneus in subjects with ASD. Still, lower connectivity of the procuneus with the superior temporal gyrus, and the right supraorbital gyrus, was observed in people with ASD (Figure 2). These negative correlations shown in individuals with ASD were described by the researchers as "anti-correlated" as they are not consistent with the correlations shown in typically developing individuals [26].

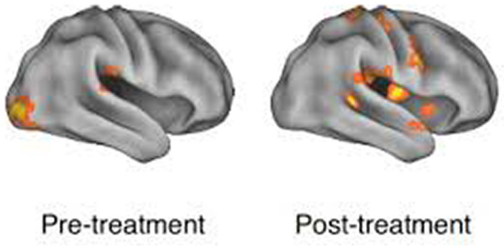

Fig. 2. Before treatment–after treatment

5 CONCLUSIONS

Concluding, we underline the importance of digital technologies in education and intervention domain for ASD. They are very productive and successful, facilitate and improve assessment, intervention and educational procedures via mobiles, provide access to educational activities anywhere [31–36] through various ICT applications that are the core medium of education [37–65], AI, STEM & ROBOTICS that raise educational, assessment and intervention procedures into new levers of performance [66–70], and games which deliver education in a very friendly and enjoyable interaction [71–75]. Additionally, the enhancement and combination of ICTs with theories and models of metacognition, mindfulness, meditation and emotional intelligence cultivation [76–102] as well as with environmental factors and nutrition [27–30], accelerates and improves more over the educational and intervention practices and results in ASD rehabilitation domain.

More specifically, according to the study by El-Shehaly et al., (2013), the fMRI model can be used to improve the accuracy of BCI data. There is a trade-off between high quality, accurate brain signal measurement (fMRI) and economy/mobility of the commodity BCI devices we use. BCI commodity devices have between one (MindSet) and over a dozen (Emotive) sensors/data points. The corresponding data model is relatively low dimensional, but can be used in intervention tools [20]. In addition, the high dimensional single user model (created from high quality fMRI data) can be used to improve accuracy [20–26].

Based on the aforementioned literature, it was concluded that these two methods can be combined. Methodologically, it was a combination of BCI &fMRI, which requires more complex analysis methods. Through the BCI computer-brain interface, improved emotional regulation of people with ASD will be achieved through the identification of changes occurring in points in the brain during the process of using VR [10–18]. At the same time, fMRI will yield specific statistical findings through the creation of a brain mapping (a multidimensional map) of the stimulation that specific brain points show during the process of using VR. Likewise, findings will also be obtained by using BCI in the form of a report (Electroencephalographic report), about the areas of the brain that may be activated by the interaction with the VR tool. In this way, findings and results will be obtained in two different methods, which will be analysed and compared by observing the neural activity both by BOLD and EEG methods.

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7 AUTHORS

Angeliki Sideraki, Net Media Lab Mind – Brain R&D, Institute of Informatics and Telecommunications, N.C.S.R. 'Demokritos', Athens, Greece.

Athanasios Drigas, Net Media Lab Mind – Brain R&D, Institute of Informatics and Telecommunications, N.C.S.R. 'Demokritos', Athens, Greece.