Brain-Computer Interface-Based Procedure for The Improvement of Autism

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Abstract. Brain-computer interface refers to the computer-based system that acquires neural signals in human brains, analyses and translates them into data and commands that can be further studies via algorithm. These features introduce new opportunities in the treatment of neuropsychological disorders, opening the door to many advances in the field. Although there have been many pharmacological and counselling therapies for psychological disorders over the last few decades, we are not aware of any complete cure programme that can cure some spontaneous neurological disorders such as autism (ASD). In contrast, there are new breakthroughs and significant advances in BCI technology, which uses external stimulation and guidance to treat internal neuronal problems. This paper highlights research conducted to provide knowledge on the application of BCI-based interventions for Memory, recognition, understanding, cooperation, correspondence, and emotional development. The application of non-invasive treatment of autism for BCI types is investigated based on representative, and latest research in the field. The paper also discusses the progress and further improvement of BCI research, while investigating different BCI paradigms, and the long-term effects of this technology. The future directions for researching BCI-based applications are discussed for reconstruction and mentoring of patients with ASD.

Keywords: Electroencephalogram (EEG), Brain-computer Interface, Autism

1. Introduction

Brain-computer interface is the one of the new technologies of Human Computer Interaction (HCI). It is a combination of neuroscience, computer science, and engineering, and its origins can be traced back to Delgado in 1969), who created an implantable chip that can stimulate the brain via radio while also sending electrical signals from it via telemetry, allowing the subject to wander independently [1, 2]. In 1973, Jacques Vidal form University of California, Los Angeles determined the name ‘brain-computer interface’ and investigated scalp-recorded brain signals in the human brain in order to establish a "visually potentials" based non-invasive BCI [3]. Therefore, in addition to the invasive form of BCI such as neurolink chip that is now the default for the public, there is also various non-invasive paradigm of it. There are three different categories under these two categories: active, reactive, and passive. where the passive BCI relies on non-voluntary user-regulated brain activity to assess mental states such as depression or even cognitive load. The BCI is always utilised with combination with other technology such as motor imagery (MI), electroencephalogram (EEG), virtual reality (VR), etc. [4].

The non-invasive BCI based on EEG is used to cure Autistic Spectrum Disorder (ASD), a neurodevelopment disorder with currently no cure. People with ASD exhibit deficits in interpersonal and interpersonal skills such as imitation, empathy, and joint attention from an early age, as well as comprehension of other aims based on gaze or other social attention cues [5]. There has been no single explanation for the wide and diverse characteristics of deficiencies in ASD until now [6]. In this paper, we will hypothesise that over- and under-connectivity in autistic children is based on research findings of elevated local coherence in the theta (3-6 Hz) center frequency in disciplines with Autism, predominantly in the left frontal and temporal regions, along with an overall reduction in consistency in the lower alpha spectrum (8-10 Hz) within the frontal region, and on neuroanatomical, functional, and electrophysiological evidence based on the spectrum, correlates with intellectual, emotional, and behavioural responses, particularly in the mirror neurone system.

According to this theory, specific electroencephalographic (EEG) frequency bands can be used to induce neuroplastic changes and lead to MNS normalisation [6].

The EEG studies are well combined with the application of BCI on improving individuals' cognitive performance, such as depression. However, there are still many technical issues for this technology to be widely used. In a fully implanted BCI system, its closed-loop on-board storage and computing resources are limited and decoding, and tracking is not possible for long periods of time [5]. It requires further multi studies on skills from different study areas including neuroscience, engineering, computer science, psychology, and clinical rehabilitation, which work together to provide a user experience that is both natural and productive.

2. Related works

2.1. The non-invasive EEG based BCI treatment for autism (ASD)

2.1.1 Introduction of non- invasive EEG based BCI treatment

People with ASD are unable to correctly interpret the intentions of others from their gaze or understand aspects of social attention cues, we try to use the JAAT, EEG and VR -based BCI technology to improve that issue. The ASD trial was conducted in Portugal, where 15 high-functioning adolescents and adults with ASD in the age range 16 to 38 years were invited to undergo seven BCI sessions over a period of four months. They must attend weekly training for the first four sessions and monthly training for the remaining sessions. Demographic characteristics, pharmacotherapy, and neurophysiological measures related to the ASD diagnosis are all part of the baseline visits. ADOS, DSM-5 and intellectual ability will be in the same day of BCI session 1 [2]. The result of treatment and improvement will be tested by the JAAT assessment.

2.1.2 Material and tools

1) JAAT**:** Participants are assessed both before and after intervention, as well as in a follow-up test, using a "Joint-attention task" as a tool to analyze reaction to executive function cues. A personalised ecologic 'Joint-attention assessment task' (JAAT) assesses the identification of initiation of joint attention cues—the number of instances of interpersonal interactions that the patient precisely determines using eye-tracking from the avatar's activity cues. The JAAT will be administered in four scenarios: café, classroom, zebra crossing, and zebra crossing [7].

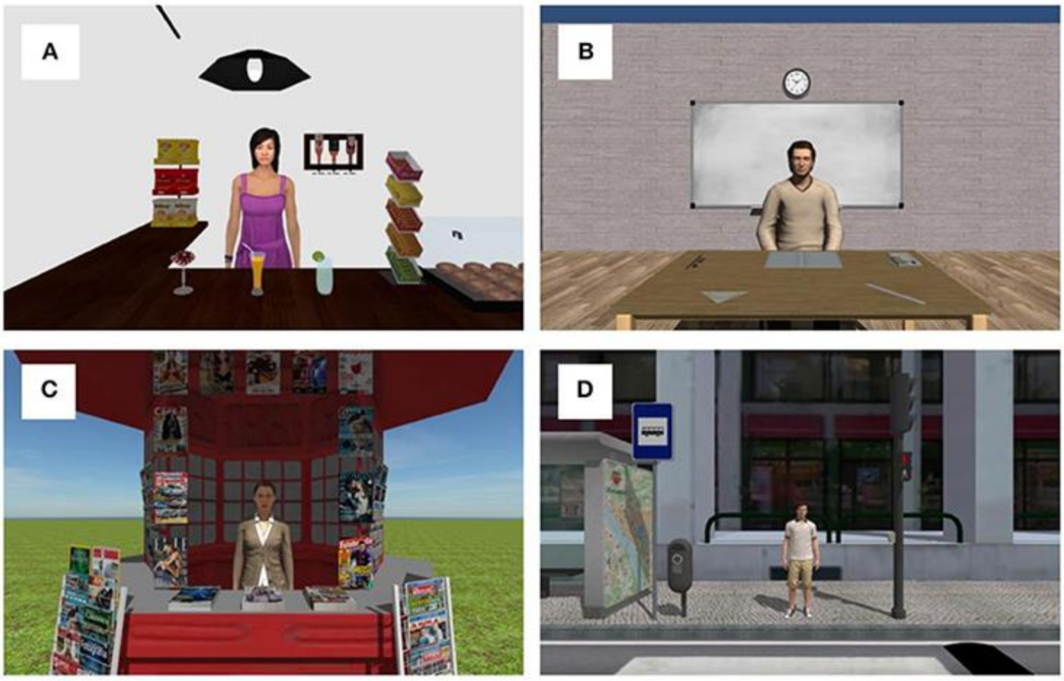

Figure 1. Cafe A, classroom B, kiosk C, and zebra crossing D [2]

The SMI Eye Tracking HMD package engrained in the Oculus Rift is used to disclose patients' eye movements. The using rate of sampling is 60 Hz, and accuracy is 0.5-1° Each scene is presented randomly. The task begins with 30 seconds of viewing freely, then a series of animations of the avatars at intervals of 2 to 2.5 seconds will be presented. The joint attention animations consisted of the avatar turning or pointing to an interested object in the scene

These animations are done exactly the same for twice in random order, totalling 18 in the cafe incident, 10 in the school picture, 16 in the kiosk, and 10 in the zebra crossing incident. Participants are told to do natural free movement. They are unknown that their eye actions are being collected. Number of social attention items that patients are able to accurately identify from the incarnation's movement cues.

The other secondary neuropsychological outcome directly relates to mood, anxiety and depression including Vineland Adaptive Behavior Scales (VABS), Profile of Mood States (POMS); Hospital Anxiety & Depression Scale (HADS). The Beck Depression Inventory (BDI) are also used to assess the result [2].

VR and EEG based BCI: The BCI paradigm based on VR P300 is utilised to present an immersive virtual environment by wearing Oculus VR which is Oculus Rift Development Kit 2 headset An EEG cap is placed in patients' heads, too. The equipment contains 16 active electrodes that collect EEG data without grinding the skin and are true wireless signal transmission. Signals will be collected using 8 electrode locations including C3, C4, P3, POz. [7]. The ground electrode is positioned at AFz, while the reference is situated at the right ear. It is set to sample at 250 Hz. We require EEG data. passband filters between 2 and 30 Hz, and a notch filter at 50 Hz [3].

2.2. Theory perspective

The BCI sessions are all operated in a empty and quite room which minimizes the electrical interference. The patients wear the headset that representing the virtual environment consists in a full-furnished bedroom such as bed and chair, and objects such as books, lights and radio.

The whole task is divided in 3 phases. The first two are training processes for the BCI, while the last one is real-time training. In the first stage, participants were explicitly ask to focus on an object or furniture to improve potential errors in recognising target objects related to the social attention deficit present in people with ASD. For second stage, participants are asked for viewing object that is picked by the avatar after it animated its appearance and selected an object, to guarantee the users' understanding of others' social joint attention cues and to successfully apply the information. In the third stage, participants are required to continuing responding to the avatar's head cue in the centre of the scene, following up in real time and looking at the object of cues. In all three phases of the BCI, the patient counts the number of blinks of the selected object in each experiment. All trials consist of 10 consecutive runs, and all 8 objects will flick randomly as green flicker. Each object is flashed at intervals of 200 ms and lasted 100 ms. The total number of flashes per trial was 80. Participants experience a 70 trials totally for 10 in the first and second phase and 50 in the online phase [2].

The first 20 measurement trials' data are used to store the P300 response, which occurs in people with ASD when objects flash, and statistical classification techniques are used to determine this response. These classifiers are then used for real-time training to determine whether participants are counting the flickers of automaton objects. If the participant does it correctly, the BCI gives a positive feedback - the selected object will turn green if process success and turn red if it is not. This can be seen in Figure 2.

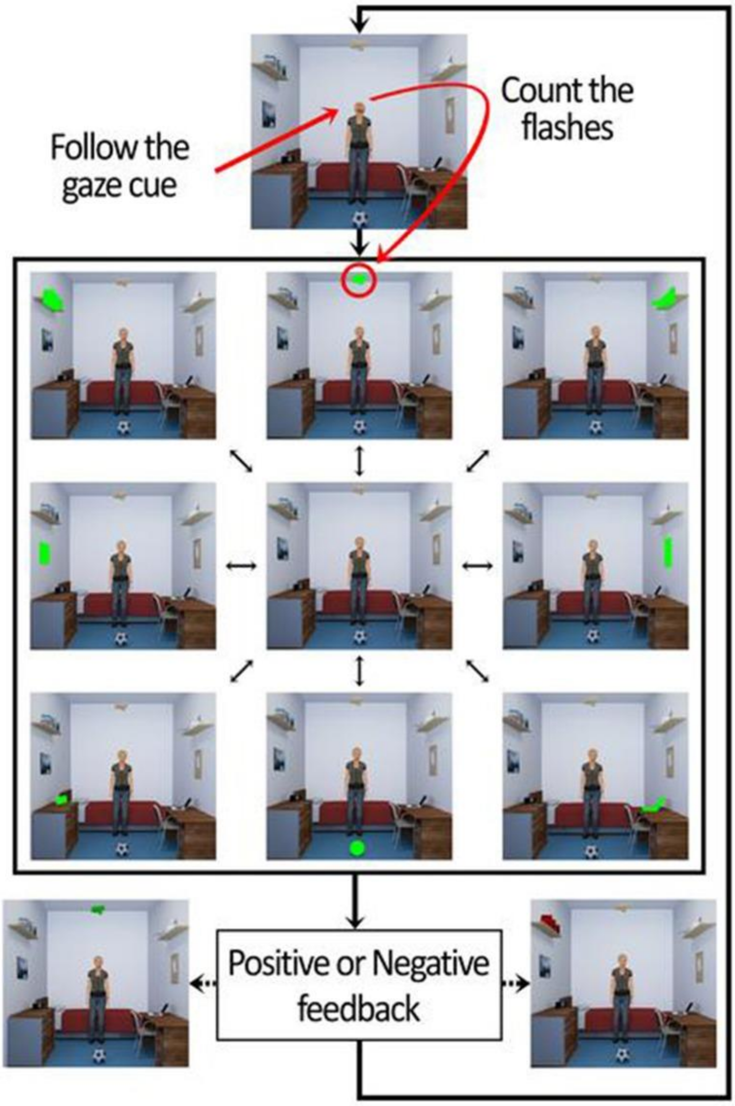

Figure 2. The exhibition of trials in BCI session [2]

3. Results

3.1. The outcomes of social abilities and JAAT results

The experiment's goal is to assess the practicability and impacts of using a vr technology P300-based BCI framework in ASD. During the period of February 2016 to January 2017, 15 patients with high-functioning ASD took part in the study. Although there was no significant effect in the main criterion of choice (JAAT), most supplementary indicators manifests a change (see table 1, table 2) [2].

Table 1. Core outcomes of POMS

Core outcomes	Mean (SD) before	Mean (SD) after
POMS-Tension	6.40 (3.23)	5.20 (5.51)
POMS-DEpression	7.53 (6.13)	3.80 (5.20)
POMS_Anger	4.00 (3.46)	2.93 (6.12)
POMS_Vigour	12.53 (6.80)	12.87 (7.97)
POMS_Fatigue	4.47 (3.96)	4.67 (5.92)
POMS_Confusion	6.80 (2.68)	6.07 (3.60)
POMS_Total	116.67 (18.54)	109.8 (25.77)

Table 2. JAAT outcomes

Study specific outcomes	Mean (SD) before	Mean (SD) after
JAAT_Noface	16.33 (9.36)	13.73 (8.19)
JAAT_Face	10.67 (9.35)	7.80 (8.77)
ATEC_Speech/language/communication	4.07 (1.82)	2.93 (1.64)
ATEC_Sociability	12.64 (6.20)	8.50 (5.30)
ATEC_Sensory/cognitive awareness	9.50 (5.13)	6.14 (4.93)
ATEC_Health/physical/ behaviour	9.36 (6.25)	6.57 (5.39)
ATEC_Total	35.57 (12.53)	24.29 (12.90)

According to Table 1, the core measure outcomes of social abilities has achieved great effect, especially in improvement of depression, the mean changes from 7.53 to 3.80, and the standard division decreases, showing the potential of p300 based BCI to the improvement of depression for ASD patients.

Table 2 compares medical outcomes for concluded baseline and JAAT. The main JAAT revealed that patients' levels of social competence, sensory or intellectual awareness, and wellbeing problems were declining. Overall ATEC decreased by an average of 32%, while autistic symptoms showed varying degrees of decline, even though there was no significant difference in the ability to accurately judge social attention items for action cues in the incarnation. (34% decrease in social skills; 37% decrease in sensory/cognitive awareness; 29% decrease in health/physical/behavioural awareness; 5% average increase in adaptive behavioural integration)

3.2. The signal stability of brain computer interface

In addition, the experiments examines the data stability of the brain-computer interface device. The reported study investigated whether the signal quality and performance of the BCI could be maintained over a variety of intervention periods. Figure 3 depicts the online classifier's session balance accuracy.

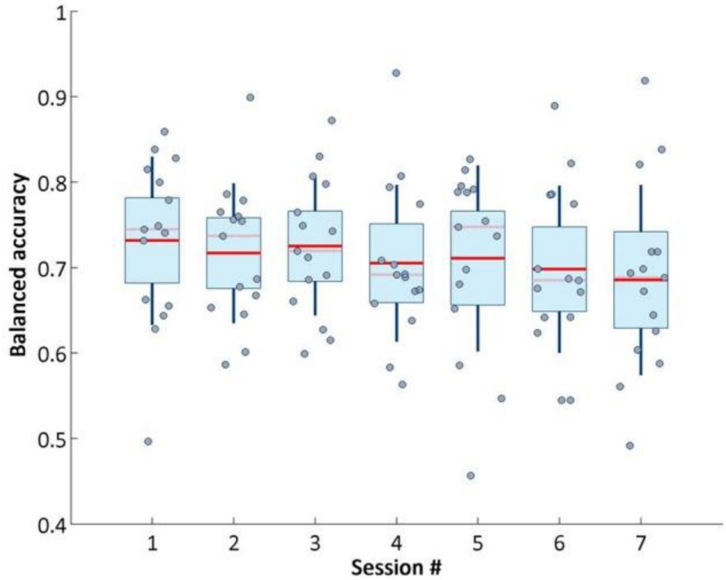

Figure 3. balanced accuracy of aim object detection on online phase [2]

3.3. Clinical outcomes for secondary follow-up in 6 months

Table 4 [2] shows the medical outcomes for the 6-month ancillary follow-up. The consistency of JAAT-No face and JAAT-Face scores between the standard and supplementary follow-up points of time is been determined. ATEC scores continue to produce some positive results across all subscales. As a result, the positive effect of the treatment continues to work even though the treatment ends after 6 months.

Table 3. The change of outcomes after 6 months

Study specific outcomes	Mean (SD)	Mean (SD) after 6 months
JAAT_Noface	16.33 (9.36)	15.00 (10.02)
JAAT_Face	10.67 (9.35)	7.53 (8.11)
ATEC_Speech/language/communication	4.07 (1.82)	1.79 (1.42)
ATEC_Sociability	12.64 (6.20)	6.57 (5.14)
ATEC_Sensory/cognitive awareness	9.50 (5.13)	5.21 (4.28)
ATEC_Health/physical/ behaviour	9.36 (6.25)	4.86 (4.35)
ATEC_Total	35.57 (12.53)	18.43 (11.77)

There is a natural imbalance in the data, but this makes balancing accuracy a more reliable metric for assessing classifier performance. The equation for balancing accuracy is (specificity + sensitivity)/2. According to Table 3, this value does not change significantly over time. The overall trend decreased slightly from Section 1 to Section 7, however, the system maintained a stable performance overall. And the Table 4 has represented that the effect of treatment is quite consistent within 6 months as the clinical outcomes does not have obvious difference.

4. Discussion

The study evaluates a P300-based virtual reality BCI in autism. The device provides a combination of interactive environment and the attentional features of the P300 brainwave as a cognitive training equipment for ASD patients.

Despite the fact that test equipment based on eye-track does not exhibit changes in the final amount of social attention items that patients are capable of correctly recognizing from the avatar's action cues, some improvements are observed (JAAT with/without face). However, the outcome data show that there is an effect on the total ATEC score, implying a reduction in the severity of autistic manifestations. (Particularly those in relatiion to social competence and sensory/cognitive awareness). The adaptive behaviour syndrome and skills for everyday living are enhanced. One of the most vulnerable fields in Autism is daily living skills.

The research suggests a long-term postive effect on the emotional/mental state of the patient. This effect is not clear at this stage as to the causal relationship between the mechanism of the intervention and the outcome. However, there are some positive observations about the intervention's structure, measurement methods, and equipment reliability [8].

As a strength, the signal stability data of BCI is evaluated and showing a stable result, the noise stability and decoding accuracy is high and consistent. Moreover, most of the supplementary improved clinical indicators such as ATEC and VABS need further research on. As limitations, the primary outcome assessment does not has any validation on clinical, it cannot provide solid results. While more social attention skills can be trained in various way, not only by providing VR environment and give stimulation [8]. If interaction between the technologies and patients can be provide, it will be more efficient, and the data recorded will have abundance. The long-term following up test for at least 1 year can be considered, too, which it can show the stability of this treatment for long term.

Furthermore, when viewed solely as a home or portable system, the BCI has limited on-board storage and computing resources to decode and track over long periods. Emotion decoders are thus caught in a dilemma: if they are programmed to respond to transient and intense events, they will overreact to natural and healthy mood changes. If they only focus on detecting and guiding long-term trends, transient and severe deterioration will go undetected and uncorrected, lowering the patient's quality of life. The large amount of data collection and operation also makes BCIs very laboratory based, heavy and professionally maintained equipment. For patients with severe ASD, even meeting researchers and wearing heavy test equipment can be a problem, the treatment can be maximised in a familiar environment, so home equipment is needed [9]. Long-term improvements in battery and handling technology may alleviate these issues. The road to this solution, however, is quite far away; government regulators necessitate thorough review of all new technology components, which implies that even if a new battery has been demonstrated repeatedly for non-implantable applications, it could take up to ten years to enter clinical use.

5. Conclusion

An EEG-based BCI system based on P300 visual reality is introduced in the study. This system is designed to improve deficits in interpreting others' intentions from gaze direction or other social attention cues with ASD patients. In addition, analysis of the recorded EEG resulted in the extraction of EEG data that contributes significantly to the extraction of clinical outcomes and JAAT. It is effective in reducing autism symptoms both during the experiment and in the post-follow-up survey, and the effect is long-lasting. This work is the begin step towards developing a real-time BCI system capable of working and enhancing on a widening range of social competence issues. We hope to add the ability to detect, stimulate, and receive activity-related brain responses in real time through EEG monitoring to the proposed BCI system now that we have demonstrated that EEG can reliably differentiate between objects of interest and certain noises. In addition, the EEG- based BCI also suffers from a large size and limited memory of the storage board, which does not allow for a balance between detecting short term mood swings and long-term issues, requiring technological improvements which may take a lot of time and regulatory understanding to achieve [10]. In conclusion, it is clear from this trial that EEG-based BCI can have a significant impact on the improvement of neuropsychological disorders, and that external technology is more acceptable and safer for patients than internal medication.

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