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Journal of Information Systems Applied Research

Integrating Virtual and Augmented Reality with Brain-Computer Interfaces for ADHD and ASD Management: A Preliminary Review

Maximus Streeter
mstre5@brockport.edu
SUNY Brockport
Brockport, NY 14420 USA

Zhigang Li
zli8@kennesaw.edu

Joy Li
joy.li@kennesaw.edu

Chi Zhang
chizhang@kennesaw.edu

Xin Tian
xtian2@kennesaw.edu

Selena He
she4@kennesaw.edu

Kennesaw State University
Marietta, GA 30060 USA

Abstract

To review current and past applications of brain-computer interfaces in combination with augmented or virtual reality technologies in the intervention of Attention-Deficit/Hyperactivity Disorder and Autism Spectrum Disorder, we reviewed the related literature during the past 13 years. The literature review was categorized based on the focus of the studies. While more investigation is needed to thoroughly investigate the results and impact of these experiments, it has been shown that the experiments tested in the literature are mostly successful in intervention and diagnosis. We discuss relevant observations that may help future studies and inspire collaboration among researchers and partitioners in the field.

Keywords: ADHD, ASD, brain-computer interface, virtual reality, augmented reality

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Integrating Virtual and Augmented Reality with Brain-Computer Interfaces for ADHD and ASD Management: A Preliminary Review

Maximus Streeter, Zhigang Li, Joy Li, Chi Zhang, Xin Tian and Selena He

1. INTRODUCTION

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurological condition with an array of symptoms, including challenges in sustaining attention, difficulties in behavior regulation, and hyperactivity (Reddy & Lingaraju, 2020). In 2022, the number of children aged 3 to 17 in the United States diagnosed with ADHD is estimated at approximately 6 million, constituting 9.8% of this age group (CDC, 2022). Additionally, Autism Spectrum Disorder (ASD) encompasses a range of neurobehavioral symptoms, such as struggles in social interaction and communication, and repetitive behavioral patterns (Arpaia, Bravaccio, et al., 2020). The reported ASD among children in the United States is about 2.8% of the same age group as of 2023 (CDC, 2023). While ADHD and ASD are two different neurological disorders, both have witnessed an increase in intervention approaches through brain-computer interface (BCI) and virtual or augmented reality (VR or AR), and the combination methods over the last decade. Through the utilization of BCI, the brainwave activity of individuals can be monitored for data collection or for neurofeedback processes. Neurofeedback is a technique for individuals to gain awareness of their own brainwave activity through external stimulants and to normalize irregular brainwave patterns (Arpaia, Duraccio, et al., 2020). However, the use of BCI alone sometimes falls short in terms of engagement, where the intervention process is extensive. However, incorporating VR/AR systems into intervention methodologies has shown that participants tend to become more engaged and involved with the intervention process (Reddy & Lingaraju, 2020). This is especially true for individuals with ASD, and it is a major reason for its popularity among the ASD community (Simões et al., 2012). The interest comes from it as an alternative to medications, as it causes fewer side effects, including anxiety, suppressed appetite, irritability, and insomnia (Reddy & Lingaraju, 2020).

In this paper, we aim to review the studies focusing on ADHD and ASD intervention through the BCI with VR or AR technologies, and discuss the challenges and accomplishments in this specialized area. We hope to provide valuable insights to researchers and practitioners with similar interests in this evolving field.

2. METHOD

To find the relevant studies, we searched databases including Web of Science, IEEE Xplore, Google Scholar, ACM, Scopus, and PubMed. We searched the databases using the query "brain computer interface" AND ("virtual reality" OR "augmented reality" OR "extended reality") AND (autism OR ASD OR ADHD). We narrowed our search to only include studies published between 2010 and 2023. This was done because results that are most relevant started to emerge around 2010. Most results before 2010 discussed virtual reality rehabilitation methods outside of a headset context, which is not part of the focus of this study. The last search for literature was done on June 26, 2023. The search results from all the databases included an initial screening process where the title and the abstract of the study were reviewed against inclusion criteria. The inclusion criteria follow the guidelines below:

- The study must have an ADHD or ASD rehabilitation focus.
- Rehabilitation methods must involve the use of brain-computer interfaces.
- Rehabilitation methods must involve virtual, augmented, or extended reality.
- The study must be available in full text or have a substantive abstract.
- The study must be a peer-reviewed academic journal or conference paper.
- The study must be in English.

If a study's title and details met two of the first three guidelines, its abstract was examined to see if the last guideline could be met. It was excluded if the studies did not meet the last three guidelines or if the VR environment used in the study was not immersive, i.e., a 3D environment displayed on a computer monitor. The initial screening process resulted in 39 studies. After removing duplicates, 19 results were examined with a more in-depth screening process. One result was excluded because the headset was not involved in their virtual reality experiment. Another one was excluded because it is a thesis instead of a peer-reviewed publication; three others were excluded because they were proposal-oriented and did not include relevant details. After the screening processes, 12 studies were included in the review. The complete screening process is presented in Figure 1.

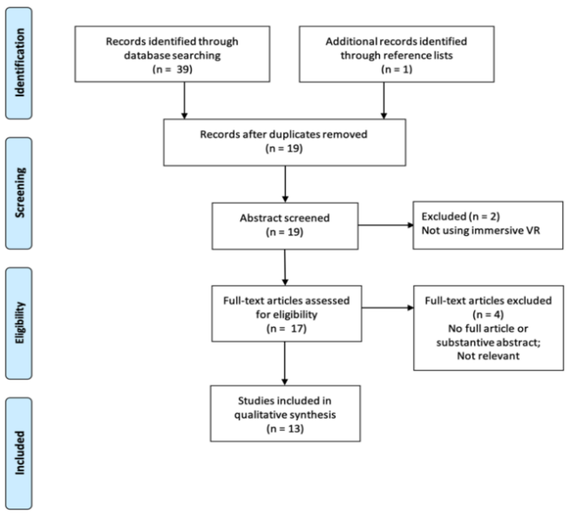

Figure 1. PRISMA (Page et al., 2021) flowchart of the search and screening process

3. REVIEW RESULTS

In this section, we describe the results of the search process and summarize the findings within the literature.

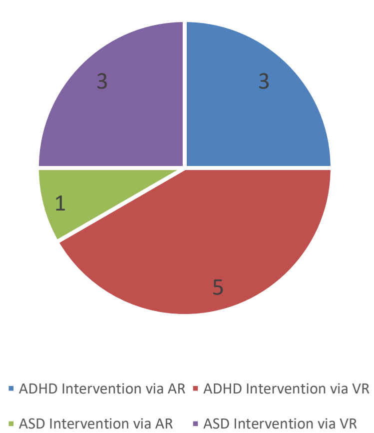

Figure 2. Number of papers per category

Overview of Search Results
Upon analyzing the search results, distinct patterns emerged within the topics covered in each paper, prompting the creation of well-defined categories to facilitate organization. The four categories are:

1. ADHD intervention through AR
2. ADHD intervention through VR
3. ASD intervention through AR
4. ASD intervention through VR

Figure 2 illustrates the distribution of papers in each category and the prevalence of specific research focus. It shows that ADHD intervention using VR emerged as the most prominent subject. In contrast, ASD intervention using AR constituted the least explored area, with only one study published in the year 2020.

A key aspect we kept track of while documenting details on the studies was the country of origin for each study. If it was explicitly mentioned in the paper as the country where that study took place, that country was designated for that particular paper. Otherwise, the country would be the authors' location at the time of publication, or the country of the university that the authors are affiliated with. The number of papers from each country is shown in Figure 3. The country that contributes the most papers is Portugal, with three papers, while China and Italy tie for the second most contributions with two papers each.

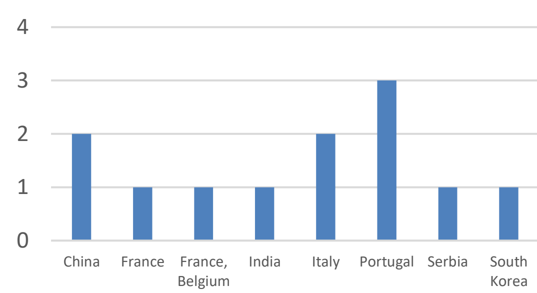

Figure 3. Number of papers per country

ADHD Intervention Through AR Methods
The articles collected that focus on ADHD intervention through AR used one of two approaches for intervention. The first approach involves transforming virtual objects through a process of regulating brainwave patterns. By allowing patients to transform a simulated world with their minds, this form of neurofeedback keeps the targeted children engaged with the intervention process. Rajshekar Reddy and G. M. (2020) discuss this form of intervention in their paper, where they developed two AR telekinetic

games. Both of their games work by collecting the brainwave information of an individual via electroencephalogram (EEG), sending the brainwave data over a network connection where they are classified and the features are extracted, then the results of the classified data are sent to the AR application where they responded with positive or negative feedback. By reaching a desired psychological state, the first AR game will respond with a virtual balloon that begins to inflate. Similarly, the second game requires reaching a desired psychological state to bend a spoon. While no study has been performed yet on children with ADHD in their paper, Reddy and Lingaraju expected that their games would work well for ADHD as gamified exercises, as the ADHD neurofeedback protocol they adopted to design the game has shown to help increase children's concentration, control, and memory.

A second approach to ADHD intervention through AR was explored recently by Arpaia et al. (2021; 2020). Both articles detail their experiment on two different groups of children with ADHD. They described the method of intervention by controlling a robot to move through BCI and blink detection applications. Arpaia et al. (2021) attempted to train patients to control their focus and drive the robot according to the indication provided, which lessened the symptoms associated with ADHD, such as attention deficit, hyperactivity, and impulsivity. The system works through various applications, beginning with a pair of AR glasses that emit a flickering stimulus superimposed onto the surrounding environment. The flickering stimulus is set to two frequencies on either side of the glasses. Arpaia et al. explained that steady-state visual evoked potentials (SSVEPs) are natural frequencies emitted by the brain when focusing on a visual stimulus flickering within a certain frequency range. By focusing on one of these frequencies in the AR glasses, the patient's brainwaves can respond by oscillating at similar frequencies. These frequencies are picked up by electrodes placed on the scalp of the patient and translated into one of two commands, either move left or move right. Blink detection was also used in the process to tell the robot to cycle between three different states: idle, change direction, and move forward. All together, these two systems allow a person to control a robot through thinking and blinking. The purpose of the experiments was to observe the accuracy of the signal classifier, assess the comfort level of the patients when interfacing with the headset, and confirm the effectiveness of the system when used in a therapy setting. Results claim that the classifier worked as intended and most children responded very well to the system.

ADHD Intervention Through VR Methods

Instead of focusing on intervention, many applications of VR with a focus on ADHD in the collected literature trended toward diagnosis. However, most researchers expressed their interest in exploring ADHD intervention using the processes like neurofeedback in future work. Regardless, diagnosis in every example collected follows a similar process, which begins by placing the patient into a simulated environment via VR headset. Within this environment, several tests can be conducted while data readings are taking place physically through EEG, eye-tracking, or head position-tracking devices. The simulated environment varies from study to study, while all tend to include some sort of distracting feature whether it is traffic driving by, a bug flying around the room, or some other distraction. Some studies opted for a classroom environment, as explored by Lee et al. (2017) and Tan et al. (2019), while others chose to let the patient choose their virtual environment as a stress-reducing precaution, as explored by Devigne et al. (2020; 2020). These studies all include a similar test known as a continuous performance test (CPT). A CPT, as described by Lee et al. (2017), "is a common method for detecting sustained and selective attention in the field of neuropsychology." Sustained attention is the ability to keep focus on a stimulus for a continued period while selective attention is the ability to focus on a specific stimulus while blocking others out. Both abilities are negatively affected by ADHD and this is why they are important abilities to be tested in the diagnosis. A CPT can take on many different forms. In Lee et al. (2017) and Tan et al. (2019), the CPT involves flashing the patient a letter at a time and when the letter X appears directly after the letter A, the patient is instructed to confirm through some method that the event just took place. Lee et al. (2017) and Tan et al. (2019) also incorporate another test into their diagnosis process known as the Wisconsin card sorting test (WCST). The WCST is a test of cognitive function where the test takers are asked to sort a pile of 128 cards where each card has a picture of an object with variations in color, shape, and graphic quality. The results of the WCST are the number of correct and incorrect placements and supports the diagnosis of ADHD. The results of these studies described had a high accuracy of correct diagnosis when all factors were combined, including the results of the virtual test and readings from the physical behavioral and mental monitoring.

A study by Oh et al. (2022) is the only study we found that focuses on intervention of ADHD through VR instead of diagnosis. Their study takes place over multiple sessions with multiple patients, both with and without ADHD. During each session, the patient is immersed in a virtual simulation where they were riding a roller coaster. While on the roller coaster, balloons taking the shape of different animals as well as other distractable objects will move across the environment. An announcer will instruct the patient on which balloon animal to pop with a virtual gun while avoiding all other animals and objects. The purpose of this task is to heighten the patient's sense of presence. After each session the patient is given a questionnaire where they describe their sense of presence by answering multiple questions on a scale from 1 to 10. The results of this study show that patients with ADHD had a statistical significant increase in overall sense of presence after the sessions were complete, while those without ADHD experienced no significant change in sense of presence.

A summary of the above-mentioned studies, including title, source, data source, description of participants, whether AR or VR methods are used, and findings of each study that focuses on ADHD can be found in Appendix A.

ASD Intervention Through AR Methods

Only one article was identified to focus on ASD intervention through AR methods (Arpaia, Bravaccio, et al., 2020). This study follows a similar, if not identical, approach to intervention as seen in (Arpaia, Duraccio, et al., 2020) and (Arpaia et al., 2021). However, the difference in this study is that the three participants in the case study all have diagnosable ASD. This intervention was applied by letting patients control a robot through the use of blinking and brainwave activity alone. In this case, the intervention is believed to work on both ASD and ADHD children, as both tend to respond well to computerized activity. The results of this study are provided by the response of the 3 case study participants, who all gave positive feedback on the intervention.

ASD Intervention Through VR Methods

All studies collected that cover ASD rehabilitation through VR methods were done in Portugal. These studies all focus on training the joint attention skills of individuals with ASD. Joint attention is a social interaction between two people where nonverbal actions such as gaze and gestures are used to indicate a reference point on where the individuals should focus their shared attention (Charman, 2003). The collected literature describes that having deficits in joint attention skills is a common characteristic of individuals with ASD and that by training these skills, especially at a young age, other negative characteristics of ASD can be improved as well (C. Amaral et al., 2018; C. P. Amaral et al., 2017; Simões et al., 2012). The joint attention skill training described in these studies is done through neurofeedback. The neurofeedback process works by taking advantage of the P300 signal, a well-known neural signal created by detecting a rare item in a stimulus series (C. Amaral et al., 2018). For example, in (Simões et al., 2012), a VR scenario is described where the patient is positioned in front of a group of people. Each person in the simulated group is animated to make a movement at different instants. When one of these characters makes a movement and the patient notices using their joint attention skills, a P300 signal can be elicited. All other studies describe using similar VR scenarios to elicit a P300 signal. The first two studies in chronological order (C. P. Amaral et al., 2017; Simões et al., 2012) experiment with refining the machine learning methods used to classify these P300 signals. By increasing the classification accuracy of these signals, the neurofeedback process becomes more effective. The last article (C. Amaral et al., 2018) describes a multi-session study where individuals with ASD are subjected to VR scenarios and their behavioral characteristics are monitored. At the end of the sessions, while the rate of P300 signals stayed stagnant, participants showed a decrease in ASD related symptoms, depression, and mood disturbance.

A summary including title, source, data source, description of participants, AR or VR methods, and findings of each article that focuses on ASD can be found in Appendix B.

4. DISCUSSION

Only ADHD in the observed experiments has been reported on diagnosis, but no study was found directly focused on the diagnosis of ASD. Overall, the methods tested in the collected literature for the diagnosis of ADHD were reported successful. All the methods used a combination of head tracking, eye tracking, and EEG devices for data collection. Each of these studies revealed an interest in using their devices for neurofeedback-based therapies in the future.

The intervention of ADHD and ASD in the collected literature shows successful results. This high level of success shows the potential of complementing or replacing the traditional intervention methods or medications that causes unwanted side effects (Reddy & Lingaraju, 2020).

Current research on the intervention of ADHD and ASD through AV/VR and BCI technologies has shown promising results. However, this area is still under-researched. Given the effectiveness of the therapies described above and the accessibility of current AR/VR technologies, it makes sense for practitioners and researchers alike to explore and experiment further in the area of healthcare. An obvious furtherment of this area of research is to study the long-term effects of these therapies. Most of the studies examined in this paper are pilot studies and many describe the need for a long-term observational study to examine the results of these therapies.

An added benefit in continuing this area of research is that more data will be provided to train machine learning models. The need for more data is expressed when researchers described using deeper learning models for their intervention (Delvigne, Ris, et al., 2020). However, this is not possible due to the lack of data. As more data is collected, more accurate models will be available, and therapies will become more effective.

5. CONCLUSION

In this paper, we reviewed past studies conducted on ASD and ADHD intervention using AV/VR and BCI technologies. We systematically collected papers for review and broke the literature into four categories (ADHD intervention using AR or VR, ASD intervention using AR or VR). Each study was reviewed and analyzed. We also discussed the challenges the researchers faced during the experiments and the significant achievements made by the researchers. Overall, VR and AR technologies have shown great potential in helping children with ADHD and ASD. This paper serves as a starting point for continuing further research in the technologies in helping the therapy for ASD and ADHD.

6. ACKNOWLEDGEMENTS

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APPENDIX A
Article Summary of ADHD-Focused Studies

Title / Source	Data Source	Participants	AR/VR	Findings
A Brain-Computer Interface and Augmented Reality Neurofeedback to Treat ADHD: A Virtual Telekinesis Approach (Reddy & Lingaraju, 2020)	Not Available	Not Available	AR	The authors developed a virtual telekinesis game in an AR environment for the treatment of persons diagnosed with ADHD. Further studies are still needed to evaluate the effectiveness of the game.
A Wearable AR-based BCI for Robot Control in ADHD Treatment: Preliminary Evaluation of Adherence to Therapy (Arpaia et al., 2021)	Commands used, errors, and accuracy of tasks completed from adult voluneteers. Initial reluctance and task completed from children participants.	10 healthy adults for preliminary testing and 18 children 5 – 10 years old (yo) with ADHD.	AR	Children aged 8 to 10 years were able to complete the tasks successfully. A few younger kids experienced difficulties concerning the usability of the devices and exhibited reduced levels of focus when the operation was being explained.
ADHD Assessment and Testing System Design based on Virtual Reality (Lee et al., 2017)	Test results along with head position, eye tracking, EEG, and smart watch data.	120 aged between 8 and 14. 60 children diagnosed with ADHD, 60 children without ADHD.	VR	The authors designed and implemented a VR based system for the diagnoistic and test of ADHD using data from a combination of sources.
Attention Estimation in Virtual Reality with EEG based Image Regression (Delvigne, Wannous, et al., 2020)	Model accuracy, EEG, eye-tracking, and head position data.	5 healthy individuals.	VR	By using the collected data, their CNN was able to outperform previous studies on the estimation of attentional state of individuals.
Effectiveness of the VR Cognitive Training for Symptom Relief in Patients with ADHD (Oh et al., 2022)	Sense of presence questionnaire and EEG data.	8 experimental subjects with ADHD and 8 control subjects without ADHD. 8 – 13 yo.	VR	The sense of presence underwent a notable transformation following VR cognitive training among the participants with ADHD. However, the control group did not experience any comparable alterations in their sense of presence after the VR cognitive training.
VERA: Virtual Environments Recording Attention (Delvigne, Ris, et al., 2020)	EEG, eye-tracking, and head position.	Not Available	VR	The study proposed a noval framework for evaluating attention in a VR environment. The framework demonstrated promising outcomes in terms of categorizing attention states.
Virtual Classroom: An ADHD Assessment and Diagnosis System Based on Virtual Reality (Tan et al., 2019)	EEG, eye-tracking and head position data along with audio test, CPT, and WCST performance data.	100 male children (6 – 12 yo). 50 children with ADHD in the experimental group and 50 without ADHD in the control group.	VR	By analysis of the performance and sensor data, researchers could conclude whether the subject had ADHD.
Wearable Brain–Computer Interface Instrumentation for Robot-Based Rehabilitation by Augmented Reality (Arpaia, Duraccio, et al., 2020)	SSVEP detection and eye-tracking data along with time to complete task, number of commands used, errors, and accuracy results.	10 healthy adult subjects for preliminary study, 4 untrained children (6 – 8 yo) with ADHD for case study.	AR	The SSVEP/Eye blink detection algorithm achieved an average accuracy of higher than 83%. The study on ADHD patients got positive feedback on device acceptance and attentional performance.

APPENDIX B
Article Summary of ASD Focused Studies

Title / Source	Data Source	Participants	AR/VR	Findings
A Feasibility Clinical Trial to Improve Social Attention in Autistic Spectrum Disorder (ASD) Using a Brain Computer Interface (C. Amaral et al., 2018)	Questionnaires, eye-tracking, EEG data	N =15 (mean age = 22 years and 2 months, 16-38 yo) with high-functioning ASD	VR	Positive effects in all subscales of the Autism Treatment Evaluation Checklist (ATEC) and in ATEC total scores, improvement in Adapted Behavior Composite, and in all subareas from the Vineland Adaptive Behavior Scale.
A novel Brain Computer Interface for classification of social joint attention in autism and comparison of 3 experimental setups: A feasibility study (C. P. Amaral et al., 2017)	Setup time, reported comfort	N=17 (13 healthy, 4 with ASD)	VR	g.Nautilus proved to be the best-performing system among 3 systems (g.Mobilab+, g.Nautilus, V-Amp with actiCAP Xpress dry-electrodes) in accurately detecting P300, preparation time, speed, and reported comfort.
Robotic Autism Rehabilitation by Wearable Brain-Computer Interface and Augmented Reality (Arpaia, Bravaccio, et al., 2020)	SSVEP detection, eye-tracking, errors, and accuracy results	N=10 healthy adults for preliminary study, 3 children on ASD (8-10 yo with different CGI scores) for case study.	AR	SSVEP/Eye blink detection algorithm shows accuracy higher than 83%, with a corresponding time response 1.5s for adults. Positive device acceptance and attentional performance for 3 children on ASD.
Virtual Reality and Brain-Computer Interface for joint-attention training in Autism (Simões et al., 2012)	EEG data	4 subjects with no developmental disorders, mean age =22	VR	90% accuracy by a classifier to identify the target object with P300 wave in the EEG, on high-level social animations performed by virtual characters.