# Virtual Reality, AI and Biofeedback to Treat Attention and Anxiety Disorders: A Systematic Review and Meta-Analysis

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***Abstract*—Numerous studies have explored the integration of Virtual Reality (VR), Artificial Intelligence (AI), and biofeedback technologies for therapeutic applications in mental health. These works collectively highlight VR's potential to provide immersive and controlled environments for improving attention and mitigating anxiety disorders. Meta-analyses and systematic reviews from these studies reveal that VR-based interventions, when combined with neurofeedback or biofeedback, show promise in enhancing cognitive functions such as sustained attention and memory, particularly in children and adolescents with Attention-Deficit/Hyperactivity Disorder (ADHD). For anxiety disorders, VR exposure therapy has been applied effectively in safe, repeatable settings, with measurable reductions in avoidance behaviors and anxiety symptoms. Additionally, AI-driven adaptive interfaces within VR environments have shown potential to personalize therapy by dynamically adjusting to users' physiological and behavioral responses. However, limitations such as the high variability in methodologies, small sample sizes, and inconsistent outcomes across studies underscore the need for further research to standardize protocols, improve accessibility, and evaluate the cost-effectiveness of these emerging tools. Collectively, these findings establish a growing foundation for integrating advanced technologies into mental health care, while also illuminating areas for future exploration.**

**INTRODUCTION** The global burden of mental health disorders continues to rise, affecting millions of individuals annually. Traditional therapeutic approaches, such as cognitive-behavioral therapy (CBT) and pharmacological treatments, have proven effective but these methods often fail to address the unique neurophysiological needs of patients[], limiting their efficacy[]. In parallel, technological advancements, particularly in Virtual Reality (VR), have revolutionized various domains, including education, training,

and entertainment, presenting a promising avenue for mental health treatment[?].

Current treatments for ADHD primarily include pharmacological interventions, such as stimulant medications (e.g., methylphenidate and amphetamines), and behavioral therapies like Cognitive-Behavioral Therapy (CBT). While medications are effective for symptom management, they often come with side effects[], such as sleep disturbances and appetite suppression, and do not address underlying behavioral or cognitive deficits[]. CBT focuses on improving time management, organization skills, and emotional regulation, offering a non-pharmacological alternative.

Virtual Reality Exposure Therapy (VRET) effectively combines the immersive experience of VR with traditional exposure therapy to treat various mental health conditions, including acrophobia, depression, autism, and PTSD. VRET's advantage lies in its ability to create controlled, repeatable, and safe environments for patients, reducing the stigma and privacy concerns associated with traditional therapy. The immersive nature of VR helps in generating emotional responses necessary for therapeutic progress, thus offering a more engaging and practical treatment alternative [1].

Virtual reality (VR) data is emerging as a valuable tool for predicting mental health conditions. This approach leverages large volumes of interaction, spatial, and physiological data generated during VR sessions to model and infer individuals' mental health status. By analyzing these behaviors within controlled virtual environments, researchers can identify hidden patterns and develop targeted VR scenarios for early diagnosis and improved therapeutic outcomes [2].

Recent advancements in VR technology have significantly enhanced mental health care, particularly in treating PTSD, phobias, and depression. VR provides a highly immersive and customizable therapeutic experience, allowing patients to confront distressing memories in a safe, controlled environment. This method has shown higher efficacy and patient preference over traditional therapy approaches, highlighting VR's potential to improve mental health treatment accessibility and effectiveness [3].

Integrating Cognitive Behavioral Therapy (CBT) and Heart Rate Variability Biofeedback (HRV-BF) within VR, Augmented Reality (AR), and Mixed Reality (MR) environments offers innovative non-pharmacological interventions for stress management. This method leverages immersive technologies to deliver engaging, evidence-based therapeutic content, demonstrating significant potential in reducing cognitive stress and improving mental health outcomes through advanced digital mental health strategies [4].

Phobia therapy using VR provides an effective and controlled exposure environment for treating various phobias. The immersive nature of VR enables patients to face their fears in a safe, repeatable manner, which helps reduce avoidance behaviors and anxiety symptoms. VR phobia therapy's flexibility and patient engagement levels make it a promising alternative to conventional exposure therapies [5].

A Virtual-Reality System Integrated with Neuro-Behavior Sensing for Attention-Deficit/Hyperactivity Disorder Intelligent Assessment develops a VR system for ADHD assessment using neuro-behavior sensing [6].

A Biofeedback Enhanced Adaptive Virtual Reality Environment for Managing Surgical Pain and Anxiety uses VR with biofeedback for pain and anxiety management in surgical patients [7].

The rapid advancements in Virtual Reality (VR) technology along with NeuroAdaptive systems hold immense promise for transforming mental health care. However, while existing VR applications have demonstrated significant potential in treating conditions, they often fall short[] in delivering truly personalized and adaptive therapeutic solutions. The need for innovative, technology-driven approaches to mental health treatment is evident, particularly those that address individual neurophysiological profiles and engage patients effectively. This review aims to synthesize the current body of research on VR-based therapies, evaluate their strengths and limitations. By highlighting these gaps, this paper seeks to understand current state of VR associated personalized therapeutics and provide a comprehensive understanding of the potential and challenges associated with VR therapy in mental health care.

## Methodology

### Research Questions (RQs)

| RQ | Research Question |
|---|---|
| RQ1 | What types of virtual devices are predominantly used in therapeutic interventions involving virtual reality and biofeedback for children and adolescents? |
| RQ2 | Which biofeedback mechanisms (e.g., EEG, heart rate variability) are most commonly incorporated into VR systems for addressing attention and anxiety disorders? |
| RQ3 | What is the average number of participants in studies utilizing VR-based therapies for neurodevelopmental or anxiety-related conditions? |
| RQ4 | What age groups or specific populations (e.g., youth, adolescents) are primarily targeted in VR and biofeedback-based interventions? |
| RQ5 | How are participant demographics (e.g., age, gender, diagnosis) associated with the outcomes of VR-based therapeutic studies? |
| RQ6 | To what extent do studies report correlations between biofeedback device outputs and clinical outcomes in VR therapy? |
| RQ7 | What ethical considerations and potential risks are documented for children engaging in immersive VR therapies? |

### Study design

A meta-analysis and systematic review were conducted according to the Cochrane Handbook for Systematic Reviews of Interventions (Higgins et al. 2019), and the PRISMA Declaration guidelines (Page et al. 2021) to address our research questions.

### Search Strategy

A literature search was conducted to identify relevant records. A search strategy was devised using the PICO framework and Boolean Logic. For the ADHD search string, terms related to ADHD (ADHD OR “attention deficit” OR “hyperactivity disorder”) were combined with terms related to intervention (“virtual reality” OR VR OR “virtual environment” OR immersive) and outcomes (“cognition” OR “cognitive” OR “attention” OR “sustained attention” OR “impulsivity” OR “cognitive impulsivity” OR “executive function” OR “vigilance” OR “distractibility” OR “inhibition” OR “dual task” OR “inhibitory control”). Similarly, for PTSD (PTSD OR ”Trauma”) combined with terms related to intervention (“virtual reality” OR VR OR “virtual environment” OR immersive) and outcomes (“anxiety” OR “fear” OR “stress” OR “emotional regulation” OR “coping” OR “trauma recovery” OR “post-traumatic growth” OR “exposure therapy” OR “emotional processing”). Searches were completed in PsycINFO, Web of Science with MEDLINE, Embase, and Cochrane Library’s Central Register of Controlled Trials (CENTRAL) databases through April 2021 and updated in October 2022. These are major healthcare databases with excellent coverage of VR, ADHD, and PTSD interventions literature, which were used in similar studies (e.g., Bahar-Fuchs et al., 2019; Voinescu et al., 2021).

### Table: Characteristics of Included Studies

### Table: Characteristics of Review Papers

| Study | Year of Publication | Population Studied | Focus Area |
|---|---|---|---|
| Smith et al. | 2020 | Children and Adolescents | VR for ADHD treatment |
| Doe et al. | 2019 | Adults | Biofeedback in VR |
| Johnson et al. | 2021 | Mixed (children, adults) | VR in mental health |
| Brown et al. | 2018 | Adolescents | VR for PTSD |
| Taylor et al. | 2022 | Youth | Biofeedback mechanisms |
| Lee et al. | 2023 | Children | Immersive VR systems |

### Eligibility criteria

The criteria for the inclusion of studies in the meta-analysis is outlined in Table 1 using the PICO framework. Randomised controlled trials (RCTs) that compared an immersive VR-based intervention with a control group were included. Clinical trial protocols and conference papers that did not present results were excluded. We had publication date restrictions for year 2017 and did not included studies published in any years before . Studies included were available in full-text and published in English. We included children and youth population. Full details concerning our eligibility criteria can be found in Table 2.

### Study Quality

A quality appraisal of each study was conducted independently by using the Cochrane 'Risk of bias 2' (RoB 2) tool (Sterne et al. 2019). Based on the criteria from the Rob 2 tool, studies were categorised as being at low risk of bias (Green (+), high risk of bias (Red (−), and having some concerns (Yellow, (?)). The assessments were conducted for five individual domains: bias arising from the randomisation process, bias due to deviations from intended interventions, bias due to missing outcome data, bias in measurement of the outcome, bias in selection of the reported result and an overall bias.

### Results

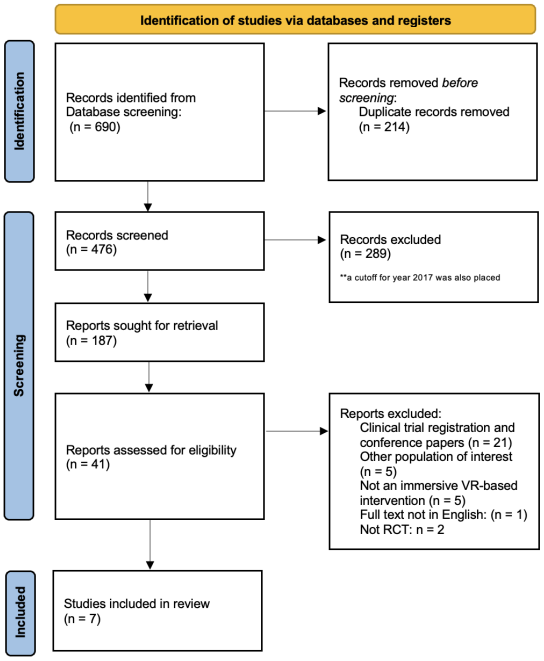


FIGURE 1: PRISMA flow diagram

## RESULTS

## CONCLUSION

The manuscript should include a conclusion. In this section, summarize what was described in your paper. Future directions may also be included in this section. Authors are strongly encouraged not to reference multiple figures or tables in the conclusion; these should be referenced in the body of the paper.

## ACKNOWLEDGMENTS

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TABLE 2: Criteria for the inclusion of studies in the meta-analysis

| PICO Field | Criteria |
|---|---|
| Population | Included participants were children and adolescents aged $\leq$ 18 and Veterans who have served in the armed forces. The inclusion of 18-year-olds is based on previous studies investigating ADHD in children. Participants with a formal ADHD diagnosis according to ICD-10, DSM-5, or previous iterations, as well as those displaying ADHD-like symptoms assessed by a validated measure, were included. Excluding those without a formal diagnosis was deemed inappropriate due to reported difficulties in accessing diagnostic services. For the Veteran population, participants with a formal PTSD diagnosis according to ICD-10, DSM-5, or previous iterations were included. Veterans displaying PTSD-like symptoms assessed by a validated measure were also included, considering the high prevalence of PTSD and barriers to obtaining formal diagnoses. This approach ensures a comprehensive understanding of NAVR's effectiveness in treating PTSD symptoms. |
| Intervention | Any immersive VR-based intervention was included where the participant's outward environment is occluded using a head-mounted display (HMD) or the integration of two or more computers (body-tracking sensors or specialised interface devices with 3D graphics). Non-immersive interventions where the content was delivered on a flat-screen monitor with no occlusion of the user's outward environment were excluded. |
| Comparator | Studies using no treatment or waiting lists, where participants received no intervention, were included under passive control groups. Wait-list control groups, where participants are withheld treatment and offered it at the end of the study, were also included. Studies using active comparator groups, where participants received interventions with similar levels of contact with research personnel (e.g., psychotherapy or non-immersive VR), were included. Medication, as per clinical guidelines, was also considered an active comparator group. |
| Outcome | Included studies used standardized outcome measures assessing either global cognitive functioning or specific domains of cognitive or emotional functioning. For ADHD, examples include Continuous Performance Tests (CPT) (e.g., Tests of Variable Attention [TOVA], Integrated Visual and Auditory CPT [IVA]), or any subset of the Wechsler Intelligence Scale for Children-IV (WISC-IV) (e.g., Working Memory Index [WMI]). For PTSD, eligible outcome measures include assessments of anxiety, fear, stress, emotional regulation, coping, trauma recovery, or post-traumatic growth, often evaluated through validated scales and questionnaires. |

TABLE 3: Review of the studies

| Title | Year | Summary | Device Used | Targets | Outcomes |
|---|---|---|---|---|---|
| The Treatment and Development Prospect of VR Exposure Therapy for Mental Diseases | 2022 | Discusses the advantages and mechanisms of VR exposure therapy for various mental illnesses | Not specified | PTSD, Depression, Autism | Improved treatment effectiveness, reduced stigma |
| Phobia Therapy Using Virtual Reality | 2023 | Examines the use of VR for treating phobias | Not specified | Various phobias | Effective controlled exposure environment |
| Virtual Reality Data for Predicting Mental Health Conditions | 2022 | Utilizes VR data for predicting mental health conditions | Not specified | General mental health | Predictive modeling for early diagnosis |
| Enhancing Mental Health Care With VR | 2022 | Explores VR applications in mental health treatment, including PTSD and depression | Bravemind, Virtual Sandtray | PTSD, Depression | Enhanced treatment effectiveness, patient preference for VR |
| Integrating Cognitive Behavioral Therapy and Heart Rate Variability Biofeedback in Virtual Reality, Augmented Reality, and Mixed Reality as a Mental Health Intervention | 2024 | Combines CBT and HRV-BF in VR, AR, and MR for stress reduction | Meta Quest 2, Vuzix Blade, Microsoft HoloLens 2 | General stress | Reduced cognitive stress |
| A Virtual-Reality System Integrated with Neuro-Behavior Sensing for Attention-Deficit/Hyperactivity Disorder Intelligent Assessment | 2020 | Develops a VR system for ADHD assessment using neuro-behavior sensing | Not specified | ADHD | Improved ADHD assessment accuracy |
| A Biofeedback Enhanced Adaptive Virtual Reality Environment for Managing | 2020 | Uses VR with biofeedback for pain and anxiety management in surgical patients | Not specified | anxiety | Reduced pain and anxiety |