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Review

# Biosensor-Integrated Virtual Reality (VR) System Assisted CBT and the Alteration of Delusional Perceptions in Psychosis

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**Abstract:** Introduction: The aim is to investigate the possibility of altering the delusional perceptions of psychotic patients by exposing them to a cognitively flexible virtual environment. A flexible virtual reality (VR) environment could challenge and enhance the ability to adapt to changing situations and generate novel solutions to core psychotic symptoms. Materials and methods: A systematic review was conducted using different combinations of keywords in different databases. This study was conducted using the PRISMA statement. Results: There is a growing literature on the use of VR to manipulate and normalise perceptual distortions in psychosis. Over the last decade, the number of published studies on VR in mental health has increased 14-fold. Conclusions: A cognitive flexibility virtual environment can alter delusional perception by exposing the person to different scenarios that require them to question their assumptions, test their hypotheses, and revise their beliefs. Commonly used biosensors measure heart rate, skin conductance and body temperature in relation to different emotional states. Recently, there has been a major shift towards the use of neuroimaging techniques to better understand the pathophysiology of mental disorders. This is where the new wave of biosensor-integrated virtual reality (VR) systems comes in.

**Keywords:** virtual reality (VR); biosensors; psychosis; hallucinations; delusions; cognitive behavioural treatment

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## 1. Introduction

Psychosis is a serious mental illness characterized by a disconnection from reality. People experiencing psychosis may have delusions, which are false beliefs that are not based in reality, and hallucinations, which involve seeing, hearing, or feeling things that aren't there. These experiences can be distressing and cause significant impairment in daily functioning. Psychosis can occur as a symptom of several mental disorders, either chronic such as schizophrenia, bipolar disorder, or major depression, or acute and can be brought on by substance use, sleep deprivation, or certain medical conditions. The delusional perceptions experienced by psychotic patients often have a significant impact on their social and occupational functioning, ultimately reducing their overall quality of life. These delusions can disrupt and even destroy the interpersonal relationships that individuals have built with others. A classic example is the patient's constant belief that he or she is being threatened by others [1]. The social impact of psychosis is exacerbated when the onset occurs at a younger age, as this doesn't allow the patient to cope with the core psychotic symptoms that could potentially lessen the impact of the disorder.

In essence, patients suffering from psychosis have lost the ability to create functional thought patterns and have replaced them with negative thoughts and maladaptive behaviors. Cognitive Behavioral Therapy (CBT) is a psychotherapeutic approach that focuses on identifying and modifying these dysfunctional thought patterns (cognitions) and behaviors. It is based on the premise

that our thoughts, feelings, and behaviors are interrelated and that by changing our approach, our emotional well-being and functioning can be dramatically improved. CBT is typically structured and goal-oriented, using specific techniques to challenge and reframe negative thoughts, develop coping strategies, and change behavior patterns. CBT is often delivered in a time-limited format and focuses on teaching clients skills they can use independently to manage their symptoms and improve their overall quality of life. Individuals learn to identify and challenge distorted beliefs, develop coping strategies, and prevent relapse by learning to recognize early warning signs of psychosis. CBT for psychosis (CBTp) is the gold standard, as it appears to alleviate key symptoms and dramatically improve the patients' social functioning [2]. The main drawback for patients is their difficulty in adapting to exposure-based social training, inaccurate self-report due to cognitive biases, and limited implementation in traditional therapeutic settings [2,3].

Various studies over the years have shown that patients in mental healthcare have substantial difficulty in accepting who they are and in differentiating their view of the self and how others perceive them. We can take the example of a person with depression who holds strongly negative beliefs about themselves. Self-discrepancy theory states that any discomfort a person feels is related to the difference between their actual self and their idea of an ideal self or their perceived self in situations involving others. This is also true in Markowitz's theory of self-awareness, by maximizing returns over a calculated risk. Any disturbances of awareness of the self like false beliefs, thoughts, or stimuli interpretations, can strongly affect a person's emotions, and integrated responses. This is a good point made to relapse prevention from changing these emotional responses to prevent the person from slipping back into previous habits. If a method can be developed to assist at this cognitive level, it would be a major stride in a technologically innovative method to assist people with mental illnesses [4–6].

The technological healthcare industry has grown considerably and has a vast scope in making advances to improve the lives of people with mental illnesses. That being said, any further work on improving treatment methods will significantly benefit the healthcare industry and, most importantly, patients. It is shown that the majority of mental healthcare patients own a smartphone. If not, technology is generally well received and user-friendly to people. Given that reality, what would be a better solution than to integrate modern technology into a treatment method for mental illnesses? An experimental study tested the first VR social environment used for a drug-dependent population, and it is considered to be a successful study as real-time data can be gathered in a realistic simulation without risks to patients in social situations of the real world. This could be further developed with modern technology to monitor biometric changes in real situations of the real world. With the intent to maximize cost-efficiency, this method would have the potential to replace traditional face-to-face methods of monitoring, only if there are no significant differences in the monitored data [7].

Virtual Reality (VR) is a relatively old technology, invented by Morton Heilig in 1957, although the term was coined by Jaron Lanier 30 years later. VR describes a computer-generated 3D environment that the user can explore, interact with, and modify by performing certain actions. VR is characterized by its immersiveness, control, and flexibility, making it potentially valuable in the assessment and treatment of patients with psychotic disorders. The sense of reality induced by VR has been shown to elicit physical and psychological responses similar to real-life experiences, but unlike traditional assessments conducted in controlled laboratory or clinical settings [8]. The market for Virtual Reality (VR) in healthcare is growing rapidly. The global Augmented Reality (AR) & Virtual Reality (VR) in healthcare market size was valued at USD 2.5 billion in 2022 and is expected to expand at a compound annual growth rate (CAGR) of 18.8% from 2023 to 2031. The global market for Virtual Reality (VR) In Healthcare estimated at US\$1.6 Billion in the year 2022, is projected to reach a revised size of US\$12 Billion by 2030, growing at a CAGR of 29.2% over the analysis period 2022-2032. The global virtual reality (VR) in healthcare market size was valued at USD 3.12 billion in 2023. The market is projected to grow from USD 4.18 billion in 2024 to USD 38.46 billion by 2032, exhibiting a CAGR of 32.0% during the forecast period. These technologies have wide applications in healthcare including surgeries, diagnostics, treatment, rehabilitation, training, and education [9].

While CBT is commonly thought of as a treatment for depression and anxiety, it is also used to address the cognitive and behavioral aspects of many of the symptoms associated with psychosis, including paranoia, delusions, hallucinations, and social anxiety. Gega and colleagues [10] conducted a proof-of-concept study of adding VR social training to a CBT program in 6 patients with social anxiety and paranoia. Participants' video was projected onto a scripted video in which they acted out a variety of social situations ranging from benign to hostile. The researchers found significant improvements in social anxiety and paranoia scores at the 24-week follow-up, but not at the end of the 12-week training. Similarly, Pot-Kolder and colleagues [11] used VR assisted CBT to treat 58 patients with psychosis with paranoid ideation and/or social avoidance and compared this treatment to control patients who received usual care. The VR assisted CBT sessions involved a virtual social environment, such as a supermarket, in which the number of virtual human characters and their reactions to the participant varied according to the patient's paranoia. The study found that the intervention did not increase the amount of time spent with other people, but significantly reduced momentary paranoid ideation and anxiety. Another study compared the effect of VR-assisted cognitive therapy in patients with persecutory delusions. The main task was to expose the patients to a social environment with a gradual increase in the number of people in the virtual environment. They found that VR cognitive therapy produced a significantly greater reduction in delusional beliefs than VR exposure therapy [12]. In a single-blind, randomized controlled trial, patients created avatars of a being they believed was talking to them. Patients who engaged in dialogue with these avatars had a significant reduction in auditory hallucination scores compared to controls who received supportive counseling [13].

Thus, combining VR with CBT seems to eliminate the above difficulties, as studies show that Virtual Cognitive Flexibility Environments (VCFEs) are successful in training social skills, reducing paranoid ideation, and improving social functioning. Cognitive flexibility is the ability to switch between mental processes to produce appropriate behavioral responses. This ability is severely impaired in patients with psychosis and is essential for socialization. A cognitive flexibility virtual environment is a virtual reality (VR) environment that challenges and improves the ability to adapt to changing situations and generate novel solutions. Patients can retrain their cognitive flexibility through repetition without consequences [14–16].

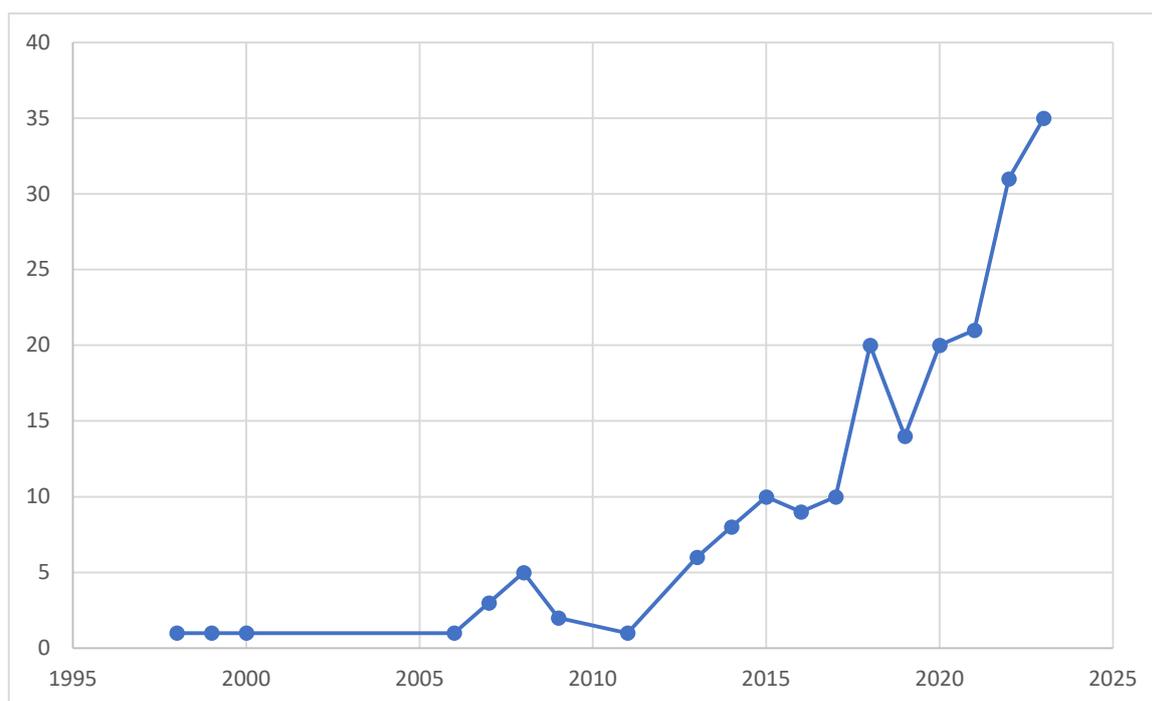
However, in the case of schizophrenia and other psychotic disorders, current VR simulations are mainly aimed at improving cognitive, social and interview skills. They are fixed scenarios in which patients are encouraged to perform tasks to improve their skills and reduce the burden of cognitive impairment. However, the severity of psychotic symptoms, such as delusions, hallucinations, or lack of motivation, makes VR treatment difficult, complex, and potentially unsafe. More controlled VR simulations are needed. Based on eye-tracking sensors inside the VR goggles, in addition to non-invasive electrophysiological sensors such as heart rate, respiration, and electroencephalogram, can provide better control of the treatment by adapting the virtual environment in real-time based on the specific goal of each treatment. Furthermore, much more sophisticated sensors can alleviate discomfort along with an improvement in the outcome [8,15].

## 2. Materials and Methods

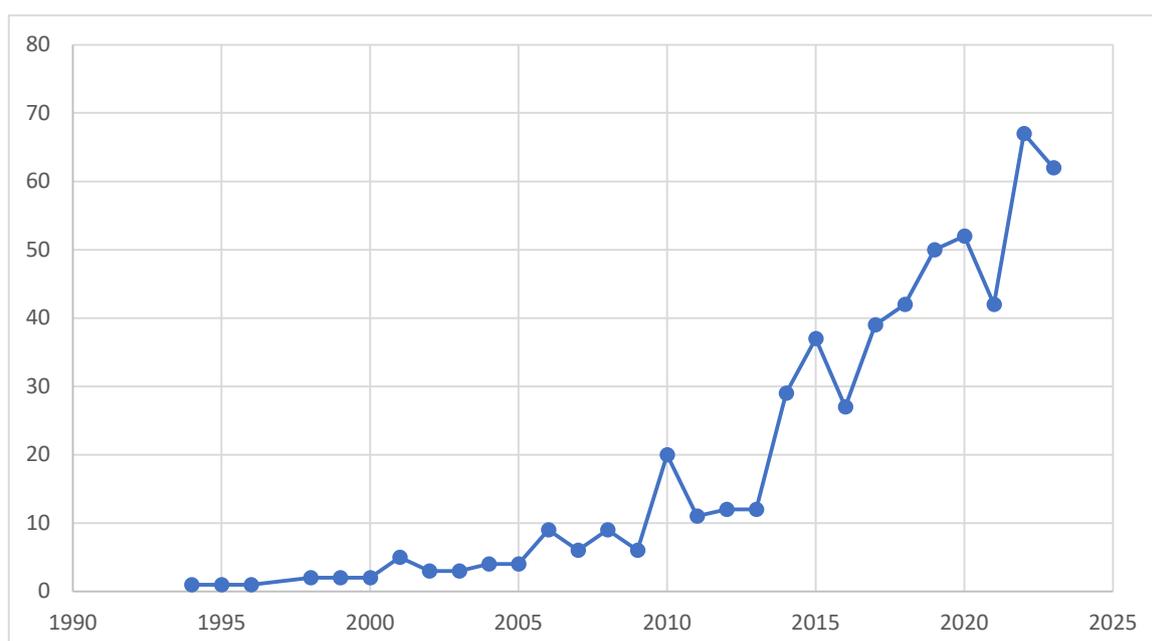
A systematic review was performed using different combinations of keywords. Database search: PubMed/Medline, Web of Science, PsycINFO, Embase, Google Scholar, and CINAHL with the keywords "virtual reality", "bio-sensors", "computer simulation", "computer-assisted therapy", "psychosis", "delusions", "hallucinations", "cognitive dissonance", and "CBT treatment- therapy-intervention". We also searched for systematic reviews on the topic by checking the reference lists of the papers we found. We also used citation tracking tools to see who had cited the papers we found. Finally, we looked at the publication lists of researchers active in the field. We also found papers by checking the references of the papers that appeared in our initial search with the above keywords and their combinations. There were no publication dates or country exclusions. All papers reviewed were in English. This review was conducted according to the PRISMA statement - Preferred Reporting Items for Systematic Reviews and Meta-analyses [18].

### 3. Results

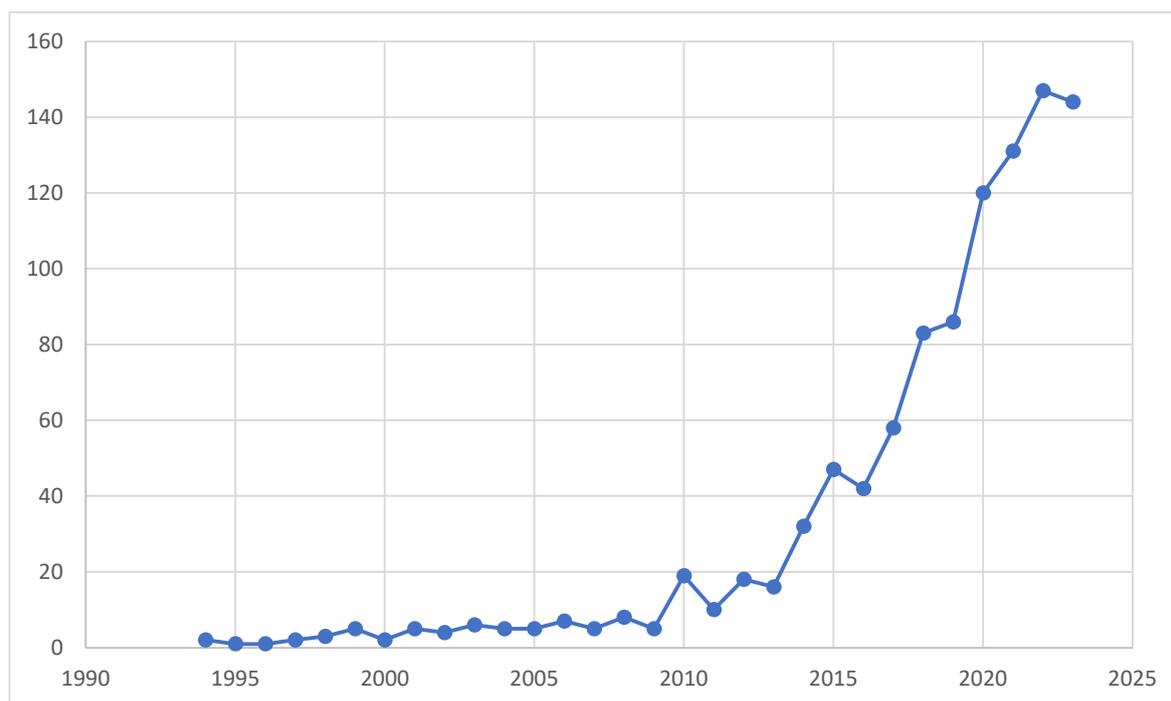
There is a growing literature on the use of VR to manipulate and normalise perceptual distortions in psychosis. (Figure 1). As shown in Figure 1, there has been a significant increase of 1400% over the last decade. This increase is seen in both diagnostic studies and studies of VR-assisted therapy (Figures 2 and 3). By region, North America dominates augmented reality (AR) and virtual reality (VR) in the healthcare market, accounting for the largest revenue share of 49.64% in 2022. Other countries with significant research activity in this area include China, Japan, India, Australia, and New Zealand [19–21].



**Figure 1.** The number of unique papers in the searched databases that include the keywords 'Virtual Reality' and 'Psychosis' from 1998 up until 2023.



**Figure 2.** Studies regarding VR-assisted diagnosis in psychiatry. From 1994 to 2023.



**Figure 3.** Studies regarding VR-assisted treatment in psychiatry, from 1994 to 2023.

#### 4. Discussion

Our study confirms the growing interest in using VR systems to diagnose and treat core symptoms of psychosis, such as hallucinations, delusions, and psychotic thinking. Biosensor data can also be used to create closed-loop systems where VR environments respond to the user's emotions in real time. For example, in a virtual reality social anxiety test, a user with high social anxiety in response to psychotic symptoms can be placed in a virtual environment with several computer-controlled virtual alleged perpetrators. If the user's biosensor data indicates high levels of anxiety, the virtual human perpetrators can change their dialogue to be more positive, thereby reducing the situations that cause the user the most anxiety. This type of system can automate exposure therapy and can be carefully controlled by clinicians to ensure optimal therapeutic outcomes. In a study comparing stress levels in a real and virtual environment, participants showed no significant difference in subjective stress, but those in the virtual environment had lower cortisol levels, suggesting a potential suppression of stress. By integrating biosensors into VR headsets, psychiatrists can measure the user's anxiety level in any situation. Knowing a user's anxiety triggers and the level of anxiety experienced in a virtual environment can provide invaluable data that can help identify the nature of a person's anxiety. These findings suggest that stress and anxiety levels experienced in virtual environments closely simulate real-world levels, making it essential to measure anxiety in virtual environments and making VR a powerful tool for exposure therapy [22].

As CBT is a highly evidence-based non-pharmacological intervention for the treatment of psychosis, the combination of CBT and VR can synthesise and extend the efficacy of both methods. The ever-increasing amount of information being added to the field of neuroscience, together with new algorithms driven by AI, can help clinicians to focus on specific brain areas and neuropathological pathways that are highly involved in core psychotic symptoms, resulting in a tailored combination of pharmacological and non-pharmacological treatments.

The field of VR-assisted treatment is an ever-growing area of psychiatry. Currently, most research is focused on anxiety disorders, particularly PTSD [23]. More recently, reports have emerged suggesting that VR may also be successful in the treatment of depressive disorders. In 2021, a meta-analysis was carried out on distributions that utilised VR-based computer distractions to advance disposition. By and large, distributions including 5,644 members of different ages were examined.

The discouragement treatment utilised computer recreations that induced a feeling of relaxation within the members, empowered physical movement, or combined the psychoeducational strategy [21]. Valmaggia et al. [24] dissected 24 distributions including 1,305 members with mental clutter such as discouragement, eating disorder or post-traumatic push clutter. They concluded that by using immersive VR, one can achieve comparable treatment to ordinary medication for these types of clutter. VR can produce circumstances that can be remedially supportive if carried out in the right way but remain close to outlandish to reproduce in genuine life. VR enables rehearsed and immediately accessible treatment input. With VR, patients with mental disorders can enter reenactments of troublesome circumstances and be coached into appropriate responses based on the best hypothetical understanding of the psychiatric condition. Because the reenactments can be replayed and re-experienced until the correct learning is achieved, patients will confront troublesome circumstances much more easily in VR than in real life. In addition, VR offers individuals with psychiatric analysis the opportunity to implement unused helpful strategies [25].

The use of VR-supported CBT treatment to control and reduce psychotic symptoms in psychosis is a relatively new approach compared with traditional approaches, as reflected in the published literature. A bibliometric analysis of research trends in people at high risk of psychosis from 1991 to 2020 identified 5,601 studies, including 1,637 original articles [25]. A review of psychological interventions for young people with psychotic experiences identified 1,449 publications [26]. Our analysis identified 177 papers on VR and psychosis and only 17 papers on the combination of VR, hallucinations, delusions and CBT.

One of the great advantages of using VR devices in treatment is that researchers can have almost unlimited combinations of data from other body and brain functions in real time. Incorporating additional sensors into a study using avatars in VR-assisted treatment of hallucinations can provide a wealth of data that can enhance understanding of patient responses and treatment effectiveness [26,27]. Some of the sensors that can be used and the additional information they can provide include heart rate monitors, which can provide data on the patient's heart rate, which can be an indicator of stress or anxiety levels. This can help to understand how the patient is responding to VR therapy in real time. Galvanic skin response sensors measure the electrical conductance of the skin, which can change with sweat secretion due to stress or anxiety. This can provide another measure of the patient's emotional state during therapy. Eye tracking devices, which can provide data on where the patient is looking during the therapy session. This can help understand what aspects of the VR environment the patient is focusing on. Motion sensors that track the patient's movements and provide data on how they are physically responding to the VR therapy. For example, they may move away from the avatar representing their hallucinations. EEG sensors can measure, in real time the brain activity. This can provide insight into what is happening in the brain during therapy sessions, although interpreting this data can be complex. Using machine learning algorithms, facial expressions can be analysed to understand the emotional state of the patient during therapy [28].

In addition to the sensors mentioned above that can be used in relative studies, several other, much more sophisticated sensors can be added to a VR device to improve the information collected. The most useful techniques are listed below. Functional Magnetic Resonance Imaging (fMRI) is a neuroimaging technique that measures brain activity by detecting changes associated with blood flow. This technique could provide insight into which areas of the brain are activated during VR therapy [29]. Magnetoencephalography (MEG) is a non-invasive technique that measures magnetic fields generated by neural activity in the brain. It can provide real-time information about brain activity at the millisecond level [30]. Near-infrared spectroscopy (NIRS) is a non-invasive optical technique that can measure oxygen levels in the cortex of the brain. This can provide information about cortical activation during VR therapy [31]. Electromyography (EMG) measures muscle response or electrical activity in response to nerve stimulation of the muscle. It can be used to detect any muscle response that may occur during VR therapy [32]. Skin temperature sensors, which measure skin temperature as an indicator of stress or emotional arousal. These sensors could provide additional data on the patient's emotional state during therapy [33]. Finally, VR devices can be combined with respiration rate monitors to assess breathing patterns as an indicator of stress or

anxiety. Breath rate monitoring could provide another measure of the patient's emotional state during therapy [34].

There are also combined treatments that can be given simultaneously while the patient is in the VR-CBT session. Transcranial magnetic stimulation (TMS) is a non-invasive method of stimulating small areas of the brain. During a TMS procedure, a magnetic field generator (or "coil") is placed near the head of the person being treated. TMS could be used in combination with VR therapy to enhance its effects [35].

The use of these sensors should be clearly explained to participants and their consent obtained. The data collected should be stored securely and handled according to ethical guidelines to protect participants' privacy. In addition, the use of these sensors should be relevant to the research question and genuinely contribute to the understanding or improvement of VR therapy. It's also important to consider the comfort and safety of participants when using these sensors. They can provide a wealth of data, but also require sophisticated techniques for data analysis and interpretation [36].

VR-based treatments are a relatively new area of interest in medicine. One of the major limitations in expanding its use is ethical. This becomes much more complicated when the subjects are psychotic individuals. When designing a trial, such as those identified and reviewed in our study, there are certain considerations. Trials should be conducted in accordance with ethical guidelines for human research. However, there are no definitive guidelines for the use of VR [37]. All participants must give informed consent and their privacy and confidentiality must be protected. This is a difficult task when dealing with people with schizophrenia. This is a basic outline and may need to be adapted based on specific research questions, resources, and ethical considerations. It's also important to note that this type of study should be conducted by qualified professionals from a variety of scientific backgrounds. It is also important to quantify the risks and benefits of such a procedure. The potential benefits of the trial should outweigh any potential risks to participants. Any potential risks or discomfort (such as distress during VR sessions) should be minimised. Participants should be informed of any potential risks and how they will be managed. The literature has identified certain risks of exacerbation of psychotic symptoms when a patient is exposed to virtual environments [38,39].

An often-overlooked consideration is the comfort and aesthetics of the system for the end user. Traditional EEG equipment and wires can be cumbersome and somewhat unsightly. The idea of using this in conjunction with a VR system could be a further deterrent to the patient. This may not be a significant challenge as the rapid development of technology continues to provide smaller and less intrusive biosensors. In our laboratory, we have developed an occipital lobe EEG device integrated into a VR system that causes minimal distress to end users (data in preparation). Finally, the cost of developing and implementing such a system should not be underestimated. Given the level of expertise and equipment required, it would be difficult to currently make such multifunctional systems available at a cost that would be affordable to many patients and care providers. However, a dramatic reduction in the cost of equipment is expected soon [28].

The nature of the data that the biosensors will collect presents a further set of challenges. For example, EEG data typically requires specialist knowledge to interpret, and using this data to directly manipulate the VR environment could be quite complex. Issues of patient confidentiality and data security may arise. As the sensor data will be shared with a third party (the clinician), the system will need to comply with strict medical data laws to ensure that no data leaves the system without consent and remains anonymous and confidential. This is often not an easy task with modern computing systems and would require careful consideration from the early stages of system design [40].

During the development of such systems, several other challenges were encountered that are specific to the integration of biosensors with VR technology. The first challenge is to achieve reliable signal and data processing, as there are known problems with biosensor signal corruption in the presence of electrical equipment. Secondly, as VR technology becomes more complex, the need for multiple separate devices, and before wireless biosensor technology becomes available, poses a problem for both the user and the developer in terms of cost and set-up time. Perhaps the most difficult challenge is to provide real-time feedback to the user. The concept of biosensors can often be

misrepresented as a means of monitoring the patient during therapy in VR. In fact, it is much more useful as a means of assisting the patient in self-diagnosis and self-management. It's therefore important to ensure that participants have access to appropriate support and care, including mental health services, during and after the study, and of course researchers need to be aware of long-term side effects or symptom changes after the procedure [41–43]. These are some of the ethical considerations that may need to be adapted according to the specific context and regulations in different locations.

In summary, the potential to tailor a bio-sensor integrated VR environment to a patient and deliver CBT or other psychotherapy in their home greatly increases the scope of treatment available. This is particularly important in mental health, where the stigma of mental illness can act as a barrier to treatment and many patients are unwilling to travel to psychiatric clinics due to the embarrassment associated with mental illness.

Biosensors have the potential to revolutionise the field of psychiatry, and their integration into VR technology is a promising innovation. Biosensors can measure biological responses to conscious and even unconscious thoughts, feelings, and behaviours. They provide an objective measure of how a patient is feeling or whether a particular treatment is working. They also allow continuous monitoring of symptoms. The potential for 24/7 monitoring in any environment is particularly important in mental health, and VR-assisted treatments can provide alternative options to prevent and control relapse, thereby improving treatment outcomes.

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**Conflicts of Interest:** The authors declare that this research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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