

## **Implementation of virtual reality (VR) in diagnostics and therapy of nonaffective psychoses**

Dawid Kruk<sup>1</sup>, Dagmara Mętel<sup>2</sup>, Łukasz Gawęda<sup>3</sup>, Andrzej Cechnicki<sup>2</sup>

<sup>1</sup> Association for the Development of Community Psychiatry and Care,  
Schizophrenia Research Unit, Krakow

<sup>2</sup> Jagiellonian University Medical College, Chair of Psychiatry,  
Department of Community Psychiatry

<sup>3</sup> Institute of Psychology, Polish Academy of Sciences

### **Summary**

Immersive virtual reality is a technology that allows the user to immerse in the virtual world in isolation from external stimuli. It enables the simulation of different social situations, often impossible to arrange in reality, with high control over the confounding variables. Thanks to the VR realism, the viewer of this reality behaves similarly and experiences similar emotions to those in natural conditions, which results in high ecological validity of this environment, making it useful for diagnostics and therapy. This review, conducted in a narrative way, presents the results of observational and interventional research using immersive virtual reality (VR) in exploration of mechanisms generating psychotic symptoms (mainly in the scope of paranoia), as well as cognition and social functioning (research with the use of virtual avatars) in persons diagnosed with nonaffective psychosis. The research included in the review has been divided by the authors into two categories, depending on their type and the related level of reliability of the results. Moreover, the authors discuss technological aspects of VR, including the most important ways of presenting it, the differences between VR technology and classical neurocognitive tests, and the use of this technology for diagnostic purposes. As far as the treatment of psychotic disorders is concerned, the authors discuss VR interventions focused mainly on delusions and auditory hallucinations. Finally, the prospects for further development and use of VR technology in psychiatry are discussed.

**Key words:** nonaffective psychoses, virtual reality

## Introduction

The aim of the study is to review the application of virtual reality (VR) in the diagnostics and therapy of nonaffective psychoses. The essence of VR is the experience of immersion in a computer-generated interactive 3D world. This allows for eliciting physiological and psychological reactions similar to real ones, which makes the virtual environment (VE) highly ecologically valid. Thanks to full controllability of VE, most of the confounding variables present in the natural social context are eliminated. In the Polish environment, interventions with the use of VR in the treatment of mental disorders are few in number, but in highly developed countries such as the United Kingdom, the Netherlands or South Korea there is at present a dynamic development of this field. In the English literature, there are already several reviews concerning the use of immersive VR in the diagnostics and therapy of psychotic disorders. It should be noted, however, that most of them also include, apart from papers with the use of immersive VR, research using non-immersive virtual reality, and what is more – due to the date of publication – they do not contain several major studies carried out on large samples and discussing, among others, the effects of CBT-VR therapy and avatar therapy, which are discussed in this review. So far, in the topic presented herein, there are no studies using augmented reality or mixed reality, although they will probably start to appear in the next few years.

One of the precursors, who made the greatest contribution to the application of this technology in the area of nonaffective psychoses, is a British psychologist Daniel Freeman. In 2008, in an article on the examination and treatment of schizophrenia, he distinguished 7 possible research areas using this technology in schizophrenia, such as symptom assessment, determination of symptom correlates (e.g., eye movement, heart rate), identification of predictive variables, differentiating variables and environmental predictors, determination of causal factors and treatment [1]. In our review, we distinguished several research areas using a narrative method. In the section dedicated to neuropsychiatric evaluation, we describe several studies that allow for a more comprehensive assessment of cognitive functions than paper versions of the tests. In the section on cognition and social competence, we focus mainly on studies exploring the subject of emotion recognition and emotion processing by people suffering from nonaffective psychoses. The last and most extensive section is devoted to studies on mechanisms and symptoms of psychosis, mainly concerning the issues of paranoia and persecutory delusions. These areas correspond with the first 6 points of Freeman's division. VR technology makes it possible to conduct both strictly observational research aimed at evaluating symptoms or determining their correlates, as well as interventional research on the effectiveness of therapeutic interactions in VR or identification of predictive factors of symptom severity. Therefore, in the last section of the review, the observational studies, and those in which the researchers used some kind of intervention in the VR environment, were discussed separately. The last section of the review refers to the possibility of VR use in the therapy of psychotic

persons and focuses mainly on paranoia and auditory hallucinations. The issues of safety in VR have been omitted, as the authors discussed them in more detail in their previous article [2]. In the Table, one of two categories has been assigned to all studies, depending on the strength of the evidence. It is worth noting, however, that some of the presented studies were not aimed at assessing the intervention or diagnostic method, but usually at showing the differences between healthy and ill people in the context of their reactions to simulated social situations.

### **VR technologies**

When selecting the papers, the authors focused mainly on research using immersive virtual reality (IVR), which usually entails use of HMD technology (head mounted display), commonly known as VR goggles. It consists of two small high-resolution screens and a headset. Nowadays, more and more often HMD sets also offer additional equipment such as hand tracking controllers, and in professional sets also gloves for perfect imitation of hand work, eye tracking system, shoes imitating leg movement, system of tracking the user's location in space and many others. Probably due to high costs, only four of the studies discussed in this review used a technology of a virtual cave, known also as CAVE (cave automatic virtual environment), which consists in projecting the image using a projector on the walls and floor of a small cubic room. The system user is wearing glasses for stereoscopic vision and the sound is played through the speakers in the room [3].

A summary table of the discussed studies can be found below.

Table 1. List of studies with the use of VR included in the review and broken down by subject of research

Authors (year, country)	Subject of research	Number of participants	age – mean (SD)	Tools (Allocation, Follow-up)	Task type in VR	Outcome/conclusions regarding the VR task
<b>Neurocognitive assessment</b>						
Ku et al. (2003) Korea [4]*	Motor memory, executive functions	13 – schizophrenia diagnosis 13 – control group	30.07 (2.65) 27.84 (2.43)	PANSS, SPM, WCST, K-MMSE, navigation and memory assessment in VR	WCST type test	Participants with schizophrenia obtained worse results (navigation, memory, latency) as compared to the control group
Sorkin et al. (2006) Israel [5]*	Working memory	39 – schizophrenia diagnosis 21 – control group	32.3 (7.9)	PANSS, 26 measurements within the program (working memory, navigation, perseverations, learning)	WCST type test, labyrinth	Participants with schizophrenia made more mistakes, had a longer reaction time and weaker strategy of navigation in comparison to the control group
Sorkin et al. (2008) Israel [6]*	Distorted perception of reality	43 – schizophrenia diagnosis 29 – control group	32.6 (8.5)	PANSS, distorted perception of reality assessment in VR	The task of the respondents was to search for audiovisual inconsistencies (barking cat, a tree with red leaves)	88% of people with schizophrenia had difficulty recognizing audiovisual inconsistencies (the greatest regarding sound)
<b>Symptom assessment – paranoia, auditory hallucinations, paranoia correlates, and psychotic mechanisms</b>						
Freeman et al. (2003) The United Kingdom [7]*	Paranoid ideation	24 healthy participants	26 (6)	BSI, PS, STAI, VR-Paranoia, Sense of Presence Questionnaire, SSI	A 5-minute stay in a library with several avatars VR presented in CAVE	Subjects attributed mental states to virtual reality avatars. Paranoid ideation is associated with interpersonal sensitivity
Freeman et al. (2005) The United Kingdom [8]*	Paranoid ideation	30 people with varying degrees of paranoid symptoms	22 (5)	PS, LSHS, SIAPA, NFC, DASS, IPSM, PSCS, Beads Task, SADS, VR-SAD, VR Questionnaire, Sense of Presence Questionnaire.	As above. The participants had to think about what they think about avatars and what avatars could think about them. VR presented in CAVE	The presence of hallucinations is a variable differentiating between persecutory ideation and social anxiety. The persecutory ideation experienced in VR correlates with the persecutory ideation in the real world

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Freeman et al. (2008) The United Kingdom [9]*	Paranoid ideation, social anxiety	200 persons from the general population	37.5 (13.3)	WASI, DASS, PSWQ, WDC, Catastrophizing Interview, BCSS, IPSM, Cognitive flexibility, Beads Task, CAPS, MAP, Life Stressor Checklist, SSQ, SELSA, SSPS, SADS, VAS	A 5-minute journey in a London underground train. Each avatar had its own movement pattern, some avatars smiled or looked towards the participant of the study	The presence of perceptual anomalies increased the risk of paranoid reactions, and their absence increased the risk of social anxiety
Freeman et al. (2010) The United Kingdom [10]*	Paranoid ideation and its predictive variables	Group 1 – 30 persons – mild paranoia Group 2 – 30 persons – severe paranoia Group 3 – 30 persons – persecutory delusions	44.2 (11.2) 36 (11.7) 44.2 (11.7)	G-TPS, SSPS, DASS, PSWQ, IPSM, Beads Task, CAPS, Life Stressor Checklist, SSQ, WTAR	Practically the same as above; the subway trip lasted 4 minutes	The evaluation in VR differentiated well between people from 3 groups. The jump to conclusion was present only in the clinical group. Positive correlation of paranoid symptoms with anxiety, worry, interpersonal sensitivity, perceptual anomalies and trauma history
Freeman et al. (2013) The United Kingdom [11]*	PTSD and paranoia	106 persons from Emergency Department after experience of physical assault	34.4 (11.6)	SSPS, PDS, PSSI, SCID-IV-PTSD, GPTS, VAS, PANSS, PSYRATS, and other (secondary measurements)	As above – a 4-minute underground train journey. The evaluation in VR as one of many elements of patient evaluation	Symptoms of paranoia and PTSD in VR correlated with interviewed symptoms and were also a predictor of paranoia and PTSD symptoms after 6 months
Valmaggia et al. (2015) [12]* The United Kingdom Valmaggia et al. (2015) [13]* The United Kingdom Shaikh et al. (2016) [14]* The United Kingdom	Paranoid ideation and social defeat, abuse and ethnic discrimination	64 individuals at ultra high risk for psychosis (UHR) 43 healthy participants	22.55 (4.01) 24.02 (4.07)	RBC, SSPS, PQ, CAARMS, Social Entrapment Scale, Defeat Scale, DASS, Social Defeat Composite Score, Social Comparison Scale, PEDQ-CV	As in Freeman (2010)	Perceived ethnic discrimination, experienced social defeat and bullying experience in childhood were higher in UHR group, and their higher levels were positively correlated with paranoia in VR

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Fornells – Ambrójo et al. (2015) The United Kingdom [15]*	Risk assessment in persecutory delusions	10 persons in a clinical group of persecutory delusions 10 healthy participants	24.2 (2.3) 23.8 (2.3)	PANSS, WTAR, STAI, SSPI, SSI (post-VR)	As in Freeman (2010)	Persons with persecutory delusions are more inclined to use their own affection as evidence of being persecuted and less inclined to actively test hypotheses
Stinson et al. (2010) The United Kingdom [16]*	Auditory hallucinations*	30 people experiencing daily auditory hallucinations in social situations	42.4 (9.7)	PSYRATS-AH, TVRS, HADS, LSAS, SSQ, CAS, ATQ, ASSQ,	As Freeman (2008), 4-minute VR session. The study group was asked to focus on thoughts preceding hallucinations. The control group was asked to focus on neutral thoughts	In both groups there were no significant differences in all aspects of auditory hallucinations. There was no correlation between the thoughts preceding the occurrence of a hallucination and auditory hallucinations in the social environment in VR
Brinkman et al. (2011) The Netherlands [17]**	Social environment, paranoid ideation and physiological stimulation	24 healthy participants 2 persons with delusional disorder	29 (9.2)	GSR, HR, distance to avatars, SUD	The participants were staying in the VE of a bar. During 4 sessions the population of the bar and ethnicity of avatars varied. The task of the participants was to find 5 avatars with consecutive numbers on their clothes	A higher population density and a higher number of avatars of a different ethnicity were associated with a higher fluctuation of physiological excitement, and the population density itself with a higher subjective distress
Broome et al. (2013) The United Kingdom [18]*	Paranoid ideation and environmental conditions	32 healthy participants	25.9 (4.2)	DASS, G-PTS, CAPS, SADS, PSWQ, Interpersonal Sensitivity Scale, SSPI	Participants spent 4 minutes at a bus stop in Handsworth, Great Britain, accompanied by avatars	A higher percentage of people experienced paranoid thoughts in VR in the outdoor street environment than in the indoor environment (Freeman 2008)
Aitherton et al. (2014) The United Kingdom [19]	Paranoid ideation and self-confidence	26 men from a non-clinical population with paranoid thoughts	43.4 ( 16.3)	GPTS-B, VAS (confidence), SCS, SSPI	Two sessions in VE of the London underground tube (6 min.). Before each session, self-confidence was manipulated (lowered or increased)	Low self-confidence led to more negative beliefs regarding the self (in relation to others) and to more intense symptoms of paranoia

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Freeman et al. (2014) The United Kingdom [20]**	Height and paranoid ideation	60 non-clinical women with paranoid thoughts in the last month	31 (13)	GPTS-B, SSPS, SCS,	Two 5-minute journeys in a London underground tube. During the second journey, a change in the perspective of a participants – their virtual height was reduced by 25 cm (head height)	In the condition of height reduction, the participants presented more negative evaluations of the self compared to others and showed higher levels of paranoia. Negative evaluations of the self fully mediated the effect of height on paranoid thoughts
Veiling et al. (2014) The Netherlands [21]**	Social environment, paranoid ideation and physiological stimulation	17 participants with the first-episode psychosis 24 healthy participants	27.3 (5.5) 29.0 (9.2)	GPTS, SIAS, DACOBS, SERS, SSQ, HR, GSR, IPQ,	Conditions as in Brinkman (2011)	People with the first-episode psychosis kept a shorter distance to avatars than healthy people. People with the first episode of psychosis, but not healthy, experienced stronger emotional excitement in response to avatars of a different ethnicity
Freeman et al. (2015) The United Kingdom [22]**	Effects of THC on paranoia symptoms	A non-clinical population with paranoid thoughts 41 placebo participants 41 THC participants 39 THC + awareness about THC participants	30.3 (9.6) 30.8 (8.5) 28.0 (6.8)	Paranoid VAS, SSPS, VAS – avatars hostility, PANSS, CAPE, and other (secondary measurements)	Conditions as in Freeman (2014) – single tube journey	THC triggers paranoid symptoms in sensitive individuals. The increase in paranoia was fully mediated by the intensification of the negative affect and the induction of anomalous experiences
Fomells-Ambrojo et al. (2016) The United Kingdom [23]*	Contingency in interpersonal relations and paranoid ideation	61 healthy men	25.3 (7.3)	PS, STAI, RQ, Sense of Presence Questionnaire, distance to avatars (within-VR measurement), avatars' trustworthiness	VE of a student apartment. Interview with the avatar about his apartment. High contingency – the avatar reacted immediately. Low contingency – the avatar reacted with a 20-second delay. VR presented in CAVE	Persons with an extremely high level of paranoia perceived a highly contingent avatar as more trustworthy than a low contingent avatar. Higher levels of paranoia and dismissive attachment style correlated with lower interpersonal distance

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<p>Veiling et al. (2016) The Netherlands [24]**</p>	<p>Social environment and paranoid ideation</p>	<p>55 FEP participants 20 UHR participants 42 siblings of persons with psychotic disorder 53 healthy participants</p>	<p>26.0 (4.7) 24.0 (4.5) 26.4 (4.8) 24.6 (4.4)</p>	<p>GPTS, SIAS, CAPE, SSPS, VAS (subjective distress)</p>	<p>VE of a bar. 5 sessions, 4 minutes each – task as above. Each session differed in population density, ethnicity and hostility of avatars (neutral/hostile facial expressions of avatars)</p>	<p>As the number of stressors increased, so did the number of paranoid thoughts about avatars and the perceived distress.  UHR and psychosis group participants felt more distressed and had more paranoid thoughts than healthy controls and siblings of the mentally ill</p>
<p>Spanlang et al. (2019) Spain [25]**</p>	<p>Fragmentation of self and evoked potentials</p>	<p>27 healthy participants</p>	<p>20.9 (data not available)</p>	<p>IMU, EEG, embodiment questionnaire</p>	<p>Induction of self fragmentation in VR. In one of three conditions, an embodiment with an avatar through visual – motor synchronization</p>	<p>In the conditions of visual- motor synchronicity with avatar, a significant decrease in ERP P300b was observed, probably due to the effect of fragmentation of the participant's self</p>
<p>Social functioning</p>						
<p>Jang et al. (2005) Korea [26]**</p>	<p>Social anxiety</p>	<p>15 people with schizophrenia 15 healthy participants</p>	<p>28.7 (7.1) 25.1 (1.6)</p>	<p>SAQ, PANNS</p>	<p>The participants were supposed to talk to an avatar – listen to him and then introduce themselves. The scenario was repeated 6 times, with each of the 2 avatars expressing positive, neutral or negative emotions during the conversation</p>	<p>In the healthy group, differences in the level of perceived anxiety were observed in each of the three emotions presented by avatars, and in patients with schizophrenia there was no difference between neutral and happy avatars.  The level of social anxiety positively correlated with negative symptoms</p>

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<p>Park IH et al. (2009) Korea [27]**</p>	<p>Dysfunctional emotional processing and social functioning</p>	<p>27 people with schizophrenia 27 healthy participants</p>	<p>28.5 (5.7) 26.5 (4.4)</p>	<p>Self-assessment Manikin, STAI-Y, PANSS, Social Anhedonia Scale, RPM, PANAS</p>	<p>As above</p>	<p>Schizophrenia patients felt lesser displeasure and weaker emotional excitement when talking to angry avatars and stronger anxiety state when dealing with happy avatars</p>
<p>Park KM et al. (2009) Korea [28]**</p>	<p>Social competences</p>	<p>1) 18 women with schizophrenia (10 receiving aripiprazole and 8 – risperidone) 2) 15 healthy women</p>	<p>30.2 (7.7) 29.3 (6.8) 28.1 (8.0)</p>	<p>SBS, RCS, PANSS, PANAS, BARS, SAS, Measurements in VR (visual contact, reaction initiation time, percentage of time spent watching avatar, distance)</p>	<p>6 social situations of talking with an avatar. Each scenario consisted of a phase of understanding skills (listening) and a phase of expressive skills (speaking)</p>	<p>Both groups differed significantly in each of the 4 measured factors in both phases. Virtual Reality Functional Skills Assessment (VRF-SA) was sensitive to changes in social competences of the respondents</p>
<p>Park SH et al. (2009) Korea [29]**</p>	<p>Personal space</p>	<p>30 people with schizophrenia 30 healthy participants</p>	<p>28.7 (5.5) 26.3 (4.3)</p>	<p>PANSS, easurements in VR: interpersonal distance, deviation of visual contact (angle of head orientation)</p>	<p>As above</p>	<p>The emotions of avatars had a lesser impact on the variability of the interpersonal distance of schizophrenic patients, who also maintained a larger distance and angles in visual contact than healthy people</p>
<p>Choi et al. (2010) Korea [30]**</p>	<p>Deficits of visual contact</p>	<p>26 people with schizophrenia 26 healthy participants</p>	<p>29.9 (7.9) 30.1 (6.9)</p>	<p>SAM, RAS, SES, PANAS, Presence Questionnaire, Copresence Questionnaire, measurements in VR, evaluation by raters</p>	<p>6 scenarios of conversation with an avatar – 3 that evoked positive emotions, and 3 that evoked negative emotions</p>	<p>Schizophrenia patients showed permanent deficits in visual contact and a smaller increase in visual contact in emotionally negative social situations</p>

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Han et al. (2012) Korea [31]**	Simulated auditory hallucinations and daily activities	36 people with schizophrenia: a) 18 without auditory hallucinations b) 18 with current auditory hallucinations 20 healthy people	26.0 (5.5) 30.9 (6.1) 28.9 (6.0)	RPM, PANSS, SSQ, VREQ, Barnes Akathisia Scale, SAS	The participants were supposed to find a few items of everyday use in the apartment. 3 sessions: 1) in silence 2) simulated auditory hallucinations 3) avatars + simulated hallucinations	In an auditory hallucination condition, patients with auditory hallucinations were more subjectively affected by simulated voices than non-hallucinating patients, but performed the task faster than non-hallucinating patients	
Han et al. (2014) Korea [32]**	Deficit of visual contact in a social situation	23 participants with a diagnosis of schizophrenia 22 healthy participants	28.9 (3.4) 27.0 (3.6)	RPM, TMT-B, PANSS, Presence Questionnaire, VREQ, eye tracking system	4 social situations of conversation with 2 avatars. In two of them avatars complain and in the other two avatars express gratitude	People with schizophrenia actively avoid eye contact during a triateral conversations	
Park S et al. (2014) Korea [33]*	Intimacy and social decision making	27 participants with a diagnosis of schizophrenia 30 healthy participants	33 (3.7) 31.7 (2.1)	PANSS, LSAS, RSES	First part – creating intimacy with avatars. The second part – making social decisions – responding to the requests of avatars	Patients showed a higher level of intimacy with distanced avatars and lesser acceptance for requests of more intimate avatars, which suggests deficits in emotional perception and social decision-making	
Therapeutic interventions							
Park KM et al. (2011) Korea [34]**	Social skills training	91 people diagnosed with schizophrenia: group 1 (n = 46) – VR training, group 2 (n = 45) – traditional training	Group 1 28.1 (7.7) Group2 31.2 (7.7)	Unstructured social skills tests: SBS, RAS, RCS, SPSHR, randomized allocation to groups	There were ten sessions, twice a week. In group 1 social skills training in VR. In the control group the same skills were practiced in the classic way	In the VR group there was a higher motivation and more interest in the training. The VR group achieved a greater improvement in conversation and assertiveness skills, and a smaller improvement in non-verbal and vocal skills	

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<p>Gega et al. (2013) The United Kingdom [35]*</p>	<p>Social phobia in psychosis</p>	<p>6 men with a diagnosis of schizophrenia</p>	<p>20-36 years old (no mean)</p>	<p>No control group; Follow-up: 6 months PANSS, GPT S, BCSS, SIAS</p>	<p>Practicing social interaction. A digitally edited film was displayed on the wall, in which the participant's figure was projected on the basis of a current camera image</p>	<p>The technique was characterized by a low sense of presence associated with a low immersion, which reduced its effectiveness</p>
<p>Leff et al. (2013) The United Kingdom [36]**</p>	<p>Avatar therapy – auditory hallucinations</p>	<p>26 people who have been hearing auditory hallucinations for at least six months and who have not reacted adequately to antipsychotic treatment</p>	<p>Data not available</p>	<p>Allocation: randomized a) TAU Group (antipsychotic treatment) b) research group Follow-up: 3 months PSYRATS, BAVQ-R, CDS</p>	<p>Non-immersive VE. The participants created a virtual representation of the dominant voice they heard. For this purpose, they selected and modeled the appearance of the persecutor's face, and adjusted the timbre and tone of the voice. During the following sessions, they conducted a dialogue with the avatar, in which the therapist played avatar's role</p>	<p>Compared to the TAU group, the frequency and intensity of auditory hallucinations, omnipotence and voice malevolence decreased in the research group. After 3 months, further improvement was observed in the above-mentioned areas and additionally in the depressive symptoms</p>
<p>Moritz et al. (2014) Germany [37]*</p>	<p>Persecutory delusions</p>	<p>33 participants with a diagnosis of schizophrenia</p>	<p>40.5 (9.9)</p>	<p>No control group PCL, OCI-R, ADS, PANSS</p>	<p>Non-immersive VE. Double walk through the VE street of the city, populated with avatars presenting different emotions. After the sessions, the participants were asked if they met specific avatars, and if so, what emotions they presented. They were also asked about the degree of certainty of the answers</p>	<p>The symptoms of paranoia have been reduced. The greatest decrease was observed in patients who answered with less certainty, which suggests a stronger effect for healthier people</p>

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<p>Freeman et al. (2016) The United Kingdom [38]**</p>	<p>Persecutory delusions</p>	<p>30 people with persecutory delusions randomly assigned to 2 groups: 1 – CBT therapy in VR, 2 – exposure in VR</p>	<p>Group 1 – 42.1 (13.4) Group 2 – 40.6 (14.4)</p>	<p>PANSS, PSYRATS, BDI, BAI, SBQ, VAS (distress and delusional conviction)</p>	<p>7 sessions 5 minutes each in the VE of the underground tube and elevator, with increasing difficulty. In the exposure group, the participants were encouraged to use their own safety behaviors and in the cognitive therapy group to use alternative strategies</p>	<p>In the CBT group, reduction of confidence in delusional beliefs and related distress – both on analog scales and in a behavioral test. No reduction of distress in the exposure group</p>
<p>Craig et al. (2018) The United Kingdom [39]**</p>	<p>Avatar therapy – auditory hallucinations</p>	<p>150 people with disturbing auditory hallucinations for at least one year, with a diagnosis of schizophrenia spectrum or affective disorders with psychotic symptoms</p>	<p>42.9 (11.2) avatar 42.5 (10.1) supportive counseling</p>	<p>Allocation: randomized. 75 people in avatar group and 75 in supportive counseling group. PSYRATS-AH, BAI/Q-R, VAAS, VPDS, SAPS, SANS, PSYRATS-DEL, DASS-21, CDS, MANSA, MAP, RSES Follow-up: 3 months</p>	<p>Non-immersive VE. Same as above. 7 sessions: avatar creation session and 6 sessions, 50 minutes each with an avatar. The therapist in a different room – once as an avatar and once as a therapist. Respondents received recordings of MP3 sessions with a recommendation to listen to them</p>	<p>After the completion of therapy in the avatar group, a greater reduction in omnipotence, frequency and distress caused by voices was observed. After 3 consecutive months from intervention, there were no statistically significant differences between the two groups</p>
<p>du Sert et al. (2018) Canada [40]**</p>	<p>Avatar therapy – auditory hallucinations</p>	<p>19 people with schizophrenia or schizoaffective disorder hearing persecutory voices resistant to treatment</p>	<p>42.9 (12.4)</p>	<p>allocation: randomized: 7 avatar therapy, 7 TAU, then cross-over Follow-up: 3 months PSYRATS, BAI/Q, PANSS, BDI, Q-LES-Q-SF, 10-point scales for presence, anxiety, fear</p>	<p>As above, but this time the dialogue with the avatar in the VR-Avatar therapy consisted of 7 sessions – one to create an avatar and six 45-minute therapy sessions</p>	<p>Reduction of voice hallucinations in the avatar therapy group – the most pronounced in the subscale of distress. Improvement in beliefs about voices – the most pronounced decrease in omnipotence and malevolence. Improvement in general symptoms, depression and quality of life. The effects persisted after 3 months</p>

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<p>Pot-Kolder et al. (2018) The Netherlands [41]**</p>	<p>Paranoid thoughts and social participation</p>	<p>116 people with psychotic disorders and active persecutory delusions (58 in the cbt group and 58 in the control group)</p>	<p>CBT Group 36.5 (10) Control group 39.5 (10)</p>	<p>Allocation: randomized Follow-up: 3 months ESM, GPTS, SBQ-PD, SIAS, MANSA, BDI, SOFAS; ISMI, BCSS, DACOBS, BARS, IPQ, SSQ</p>	<p>In the CBT group, the respondents participated in 16 VR-CBT sessions for 12 weeks. During the sessions, they practiced challenging suspicious thoughts, reducing safety behaviors and testing harm expectancies</p>	<p>After the treatment the level of momentary paranoia and anxiety in the VR-CBT group decreased and remained lower in the follow-up. No difference in social participation between groups (measured by ESM) – minimal difference in a 3-month follow-up.</p>
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Abbreviation list:

ADS – Allgemeine Depression Scale; ASSQ – Anxious Self-Statements Questionnaire; ATQ – Automatic Thoughts Questionnaire; BAI – Beck Anxiety Inventory; BARS – Brief Adherence Rating Scale; BAVQ – Beliefs about Voices Questionnaire; BAVQ-R – Beliefs about Voices Questionnaire – Revised; BCSS – Brief Core Schema Scales; BDI – Beck Depression Inventory; Beads Task – probabilistic reasoning test; BSI – Brief Symptom Inventory; CAARMS – Comprehensive Assessment of At-Risk Mental States; CAPE – Community Assessment of Psychic Experiences; CAPS – Cardiff Anomalous Perceptions Scale; CAS – Cognitive Assessment Schedule; CDS – Calgary Depression Scale; DACOBS – Davos Assessment of Cognitive Biases Scale; DASS – Depression Anxiety Stress Scale; EEG – Electroencephalography; GPTS – Green Paranoid Thoughts Scale; GSR – galvanic skin response; HADS – Hospital Anxiety and Depression Scale; HR – heart rate; IMU – Inertial Navigation System; IPQ – Igroup Presence Questionnaire; IPSM – Interpersonal Sensitivity Measure; ISMI – Internalized Stigma of Mental Illness questionnaire; K-MMSE – Korean Mini-Mental State Examination; LSAS – Liebowitz Social Anxiety scale; LSHS – Launay-Slade Hallucination Scale; MANSA – Manchester Short Assessment of Quality of Life; MAP – Maudsley Addiction Profile; NFC – Need for Closure Scale; OCI-R – Obsessive-Compulsive Inventory – Revised; PANAS – Positive and Negative Affect Schedule; PANSS – Positive and Negative Syndrome Scale; PCL – Paranoia Checklist; PDS – Posttraumatic Diagnostic Scale; PEDQ-CV – Perceived Ethnic Discrimination Questionnaire; PQ – Prodromal Questionnaire; PS – Paranoia Scale; PSCS – Private Self-Consciousness Scale; PSSI – PTSD Symptom Scale; PSWQ – Penn State Worry Questionnaire; PSYRATS – Psychotic Symptom Rating Scales; PSYRATS-AH – Psychotic Symptom Rating Scales – Auditory Hallucinations; PSYRATS-DEL – Psychotic Symptom Rating Scales – Delusions; Q-LES-Q-SF – Quality of Life Enjoyment and Satisfaction Questionnaire – Short Form; RAS – Rathus Assertiveness Scale; RBQ – Retrospective Bullying Questionnaire; RCS – Relationship Change Scale; RPM – Raven’s Progressive Matrices; RQ – Relationship Questionnaire; RSES – Rosenberg Self-Esteem Scale; SADS – Social Avoidance and Distress Scale; SAM – Self-Assessment Manikin; SANS – Scale for the Assessment of Negative Symptoms; SAPS – Scale for the Assessment of Positive Symptoms; SAQ – Social Anxiety Questionnaire; SAS – Simpson-Angus Scale; SBQ-PD – Safety Behavior Questionnaire – Persecutory Delusions; SBS – Social Behavior Scale; SCID-IV-PTSD – Structured Clinical Interview for DSM-IV-PTSD; SCS – Social Comparison Scale; SELSA – Social and Emotional Loneliness Scale for Adults; SERS – Self-Esteem Rating Scale; SES – Self-Efficacy Scale; SIAPA – Structured Interview for Assessing Perceptual Anomalies; SIAS – Social Interaction Anxiety Scale; SOFAS – Social and Occupational Functioning Assessment Scale; SPM – Standard Progressive Matrices; SPSP-R – Social Problem Solving Inventory – Revised; SSI – Semi-Structured Interview; SSQS – State Social Paranoia Scale; SSQ – Simulator Sickness Questionnaire;

SSQ – Social Support Questionnaire; STAI – State-Trait Anxiety Inventory; SUD – Subjective Unit of Discomfort; TMT–B – Trail-Making Test; TVRS – Topography of Voices Rating Scale; VAAS – Voice Acceptance and Action Scale; VAS – Visual Analogue Scale; VPDS – Voice Power Differential Scale; VR-SAD – Social Avoidance and Distress Scale – adapted to VR; VREQ – Virtual Reality Experience Questionnaire; WASI – Wechsler Abbreviated Scale of Intelligence; WCST – Wisconsin Card Sorting Test; WDQ – Worry Domains Questionnaire; WTAR – Wechsler Test of Adult Reading.

\* cross-sectional studies, uncontrolled before-after studies, case series, descriptive studies

\*\* randomized studies with a control group (cross-over or parallel)

### **Evaluation of neurocognitive functions in psychotic patients**

The use of VR methods to evaluate neurocognitive functions is useful for two reasons. First, psychotic disorders are associated primarily with higher-level cognitive deficits, such as integration or executive functions, while VR enables their evaluation in an ecologically valid environment with a high sense of presence, which gives a possibility of observing abnormalities of and interaction between various cognitive and sensorimotor processes [5]. Second, an engaging test form is an interesting alternative to the attention-intensive classic neuropsychological tests. This is particularly important in the case of people suffering from schizophrenia, due to a frequent lack of motivation, which may significantly affect the test outcomes [42]. It is also believed that classical neuropsychological tests have certain limitations in terms of generalizing their results. In contrast, it seems that results obtained by tests performed in a virtual environment may be extrapolated to actual functioning due to high ecological validity of the environment, while maintaining laboratory precision of measurements [43].

Sorkin et al. [5] attempted to create a model that would assign an examined person on the basis of his or her result profile of the performed tasks to a group of people suffering from schizophrenia or a group of healthy individuals, with a sensitivity of 85%. It seems, however, that without a control group with a different diagnosis, such a model is reliable, but not specific. In a subsequent study, the same authors tried to create a different tool for differentiating between healthy and schizophrenic individuals, based on their ability to perceive audiovisual inconsistencies [6]. People with schizophrenia had a particular difficulty in perceiving audiovisual inconsistencies – such as the sight of a civilian airplane with an accompanying sound of dropped bombs.

In all the studies included in the review, the authors managed to assess cognitive abilities of the subjects. Compared to classical tests, the studies described in this section included much more measurements of various variables and quantified more data, which in consequence allowed for a more accurate evaluation of specific cognitive domains [4].

### **Studies on mechanisms of psychosis, paranoia and auditory hallucinations**

One of the most important advantages of VR technology is its ability to objectively assess paranoid thoughts in the subjects. So far, in such studies, it could not be excluded that the perceived hostility and suspicion of malicious intent on the part of the others is in fact anchored in reality [10, 44]. Importantly, no participant's behavior, even strange or hostile, can cause hostile behavior in virtual avatars. For the first time, the VR paradigm enables high control over the behavior and emotions of the social interaction partners of the subjects.

In research on the mechanisms of psychosis, the main focus of interest was paranoia, understood rather as an attitude of distrust, suspicion, delusional or quasi-delusional conviction of being persecuted than as a structured system of delusions. So far, no studies have been published that would explore specific types of delusions, except for the most frequent persecutory delusions. Only one of the studies concerned mechanisms associated with auditory hallucinations. Other perception disorders has not been explored so far. In the study by Freeman et al. [44], 47.5% of the general population had paranoid thoughts in VE, which was associated with more than twice the risk of paranoid thoughts in everyday life. However, this may be related to the London metro attacks a year before the study. Interestingly, the predictive variable most strongly predicting the increase of paranoid thinking in VR was playing computer games – players are probably more inclined to perceive avatars as if they were real people. In another study by Freeman et al. [45], VR was used for the first time to predict future psychiatric symptoms, which gave positive results. The advantage of VR was certainly a higher degree of objectivity, compared to clinical history or self-report methods, which are highly dependent on circumstances, including unreliable memory. Two studies point to divergent results in terms of paranoia levels in the clinical and non-clinical population. In the study by Fornells-Ambrojo et al. [15], these levels were similar (SSPS = 15.6 and 14), whereas in the study by Freeman et al. [10], they were significantly different (several times higher odds of being in a higher SSPS category between groups). In both cases VE was practically the same. In the study by Fornells-Ambrojo [15], some participants emphasized that VE was safer than the cities in which they lived. Lack of anxiety, i.e., lack of emotional excitement, translated into lack of reasoning bias, therefore clinical group members did not present higher level of persecutory delusions than healthy controls. However, it is not known why similar results were not observed in the study by Freeman et al. [10]. The study by Broome et al. [18] showed that in the urban environment the subjects had paranoid thoughts much more often than in the closed-space environment (buildings, rooms). Such a conclusion can be accepted with a certain degree of skepticism, as two different groups in two environments of different quality were compared. However, this study sets a new direction for research that tests the impact of the external environment, including architecture, on various aspects of mental health. Another study in this trend showed that the stress response

in VR was stronger in a windowless room than in a room with windows [46]. This topic needs further exploration, as it is likely that the incidence of psychosis in urban environments is also influenced by physical environmental factors, including architecture and urban planning [47].

In several studies, participants were exposed to different levels of social stress, depending on their psychosis liability, associated with current symptoms [17, 21, 24]. An increase in distress and paranoia was observed in groups with higher liability. Such a result suggests the possibility of developing a future tool to assess psychosis liability based on the response to social stressors in VR. In the absence of a control group with a different diagnosis, it cannot be excluded that a tool based on users' responses to social stressors would still have low specificity.

A study in which the height of participants was manipulated is an example of an intervention impossible to carry out in natural conditions. It opens up a completely new area of research, related to the change of the VR user's perspective [20]. Probably, lowering of the social status of participants, mediating an increase in the level of paranoia and associated with the lowering of their height, was similar to the Proteus Effect described by Yee and Bailenson [48], who also manipulated the height of participants in VR. Even greater possibilities arise from embodiment with a virtual avatar, all the more so because the strength of the Proteus Effect probably depends on the strength of the sense of embodiment [49]. Embodiment with avatar was used only in one of the discussed studies, in which the authors examined the impact of controlled fragmentation of the self on reduction of P300b – an evoked potential that is considered one of the best biological markers of schizophrenia [25]. By reducing this potential in healthy subjects, the authors most likely confirmed the hypothesis that lower P300b values in schizophrenic patients are associated with the fragmentation of the self. The authors suggest that this technique may be able to help patients understand the fragmentation of their self that they are experiencing and then integrate some of its fragments.

The authors of the only study on the mechanisms underlying auditory hallucinations have not observed an impact of thoughts preceding hallucinations on the occurrence of these hallucinations [16]. This was probably due to the lack of activation of affect that is mediating the role of these thoughts, heterogeneity of auditory hallucinations or excessive concentration of the subjects on new VE. However, ecological validity of the environment was confirmed – the same number of respondents heard voices in VE and in reality.

### **Social cognition and functioning**

The results of the reviewed studies indicate some dysfunctions in processing emotions in patients with schizophrenia. The emotions presented by avatars had no or lesser impact on their level of anxiety, person-to-person distance or visual contact [26, 29]. Their reactions were also opposite to healthy people – they felt weaker emotional



stimulation in conversations with angry avatars and stronger fear of joyful ones [27]. The *Virtual Reality Functional Skills Assessment* (VRFSA) tool, described in one of the papers, is probably much more sensitive to changes in social functioning and may be more objective than a specialist's assessment [28].

Experiment of Han et al. [31] showed differences in the objective and subjective impact of simulated auditory hallucinations on people experiencing these hallucinations. Such people were less able to ignore auditory hallucinations and thus felt more affected by their presence, while doing their task better than those who did not have auditory hallucinations. Their better performance was probably due to their habituation to and ability to deal with auditory hallucinations. In another study by Han et al. [32], systems for tracking eyeball movement, which had already been available for some time, were used to directly assess visual contact in social interactions with avatars rather than indirectly, based on head movements, as in several other quoted studies [26, 27, 29]. Thanks to this system, the authors were able to observe a deficit of visual contact in people with schizophrenia, who stared at the space between avatars more often than healthy people. There was also a significant difference in the length of time before persons with schizophrenia – as compared to healthy subjects – started to speak to avatars, which was not noted in the previous study of the same authors [30], in which participants spoke to only one avatar. On this basis, it can be concluded that social situations with more avatars better reveal social deficits of people with schizophrenia.

In conclusion, it seems that VR enables realistic simulation of social interactions, compared to traditional methods of examining personal space (using photographs or abstract verbal stimuli), or to traditional methods of assessing emotions based on role-playing tests, where the effect depends on the individual's imagination and the tester [29].

### **VR in the treatment of psychotic disorders**

Virtual reality was also used for therapeutic purposes in the group of patients with schizophrenia in the few studies conducted in the Netherlands and in the United Kingdom. However, for the most part, the sample sizes in these studies were small (except for the study by Craig et al. [39], which is largely a replication of the studies by Leff et al. [36] and Pot-Kolder et al. [41]), which suggests the need to be very careful in assessing the effectiveness and persistence of VR interventions in psychotic disorders. The disadvantage of the study by Gega et al. [35], apart from a very small study group, was low immersion and consequently low presence. An obvious drawback of this study was also pointed out, which resulted from the similarity of the technique of viewing oneself in a film to the out of body experience, which is a condition often experienced in anxiety or psychosis. The cognitive intervention of Freeman et al. [38] was the first attempt at therapy in VR environment of social anxiety in psychosis. The results indicate that patients feel safer in social situations

after intervention. Prospects for the development of this type of intervention include arranging scenarios that are difficult to control in natural conditions. In the study by Freeman et al. [38], for example, patients could gaze without fear into the eyes of avatars they met. This was made possible by avatar reaction control, which would have been difficult to achieve under natural conditions. The VR-CBT Therapy by Pot-Kolder et al. [41] is, with the exception of avatar therapy, the only published long-term (i.e., consisting of several 1-hour sessions) therapeutic intervention in VR so far. It is emphasized that its effects require further exploration in order to determine the most important factors responsible for the positive effect, such as subjective variables – immersion, sense of reality and affective reactions – or objective variables – avatars' behavior [50].

In the study by Park et al. [34], apart from certain advantages of social skills training in VR, such as a probably better transfer of acquired skills to the real world, attention is drawn to the impact of this technique on the motivation of patients who were much more willing to participate in it than in the classic version. This means that an increase in motivation may translate directly into an improvement in social functioning, therefore social skills training that strengthens this motivation will be more effective than a training that has no impact on it. Psychotic disorders usually originate in young people, and they usually feel good in the world of new technologies, which may have an additional positive impact on their motivation for treatment.

The results of Moritz et al. [37] suggest that delusions are susceptible to change as a result of short-term interventions. It has not been determined what could have been the main therapeutic factor – a general error feedback, the need to establish certainty of response or a specific social environment. On the basis of these preliminary conclusions, the authors have developed further studies, already using immersive VR, but so far only two case studies have been published [51].

The authors of all three described studies using avatar therapy managed to reduce the frequency of auditory hallucinations, distress associated with them and their omnipotence. In addition, du Sert et al. [40] managed to achieve also the reduction of voice malevolence. The authors suspect that this is the effect of higher immersion of their VE, which enables the patient to enter into a deeper relationship with the personified voice and evoke stronger emotions. It is worth noting that the average duration of hearing voices among the participants of this study was 18 years. The inclusion criterion in the study by Craig et al. [39] was at least a one-year history of hearing voices, whereas in the study by du Sert et al. [40], the criterion of resistance to pharmacological treatment was applied – half of the patients were resistant to treatment with clozapine. The outcomes of avatar treatment give hope for going beyond the present-day treatment schemes, in which for antipsychotic drug resistant patients, a further treatment offer is significantly limited. However, it is worth waiting for the results of studies using avatar therapy in VR with a control group, as although Leff et al. [36] and du Sert et al. [40] observed a difference in relation to the control group (especially pronounced in a follow-up), in the study by Craig et al. [39] no significant

differences between the groups were found in a 3-month follow-up. This observation may result from the fact that the control group benefited from supportive counseling, while in other studies it was TAU (treatment as usual – standard treatment procedures). In the study by du Sert et al. [40], the patient's sense of presence was also measured, with an average score of 7.5/10. However, it cannot be compared with the results of Leff et al. and Craig et al. because they did not measure subjects' sense of presence. In Poland, avatar therapy is no longer a complete novelty – one case using this technique has been described. The authors are in the process of conducting a pilot study on a larger group of patients [52].

In the group of VR therapeutic interventions, the subject of the studies were therefore either auditory hallucinations or persecutory delusions. The interventions proved to be effective, which resulted in a reduction in the severity of symptoms. In the case of delusions, they probably did not significantly affect the entire delusional system, but they did reduce the distress associated with these delusions and decreased the certainty of delusional beliefs. This was not necessarily directly associated with the improvement in social functioning. Pot-Kolder et al. [41] did not succeed in increasing social participation of patients during the several-week CBT-VR intervention, despite the decrease in the level of anxiety and in the intensity of paranoid thoughts.

### Summary – main conclusions

Summing up the topic of treating psychotic disorders with the use of VR methods, it seems that this is now a promising direction for the development of this technology in psychiatry. VR enables observation and modification of one's own emotions, cognitive processes and behavior at the moment they appear [53]. The question is whether the improvement observed in the virtual environment can be generalized to daily functioning of patients. So far, improvements have been observed in several areas, such as social functioning [40, 41], self-stigmatization [41], assertiveness, and conversation skills [34]. In some part of the papers on therapeutic interventions in VR, no aspects of everyday life were measured. However, taking into account the results of meta-analysis of studies on exposure therapies in anxiety disorders, where no statistically significant differences between *in vivo* and VR therapies were observed, it can be assumed that the effects achieved in VR will correspond with the effects in natural conditions [54].

It is believed that it would also be beneficial to consider an additional physiological feedback from the VR user, e.g., in the form of heart rate, blood pressure, or galvanic skin reaction measurements [53]. This could increase self-efficacy, especially in relation to tasks in the natural environment. It has been observed that manipulation of the speed of heart rate presented to the user causes intensification of emotions such as fear or excitement, while presenting the actual heart rate facilitates controlling strong emotions [55].

Every user of the virtual world knows that everything presented in it is not true. At the same time, their minds and bodies act as if it was real. Thanks to this, it is easier for people to face difficult situations or to test new therapeutic strategies [56]. A feature of exposition therapies in VR is the ability of the therapist to continuously adjust the parameters of the environment to the actions and feelings of the patient. This allows the therapist to adjust the level of difficulty to an individual patient, thus providing a highly personalized therapeutic program.

Freeman suggested using VR to educate patients through experience [56]. For example, the mood of patients could be influenced and then, by exposing them to a social virtual environment that triggers hallucinations, they could be shown how the mood influences their hallucinations. There are already programs based on augmented reality that simulate changes in perception, similar to the patient's pathological sensations in the phase of active psychosis [57]. Such devices help to understand the experience of a person suffering from schizophrenia, which can be useful in educating the families of patients and in training medical staff.

It is not certain whether an immersive 3D environment is really necessary to achieve the appropriate degree of immersion [58]. An example is avatar therapy [39], where in the original version immersion was achieved by manipulating an avatar's voice on a classic computer display. However, bearing in mind the results of the avatar therapy conducted by du Sert et al. [40], it can be assumed that the effect of immersive virtual environment will generally be higher than the effect of non-immersive virtual environment, which is confirmed by studies showing that higher immersion is associated with a stronger sense of presence, and often also with more pronounced emotional reactions [59].

Potentially, VR can be useful in educating young people about early symptoms of mental health problems, as well as in breaking the barrier between a treatment centre and everyday life of patients, using a combination of VR and mobile applications [60]. To quote Veling et al. [61], 69% of schizophrenic patients worldwide do not receive treatment. Future VR applications could partially solve the problem of high costs and lack of sufficient therapeutic staff, even completely eliminating the need for constant supervision of the therapist, at least for some disorders [56]. The first research on VR therapies involving only a virtual therapist is in progress [62]. The question of to what extent certain therapies could be delivered without the therapist being present, and whether virtual avatars could replace a human being in his role as a traditional psychological interventionist is still relevant [56].

In the diagnostics area, most of the studies assessed a certain aspect of symptoms or cognitive functioning rather than carried out manipulations and observed changes in participants' feelings and behavior, thus providing evidence for causal associations. According to certain researchers, VR has the potential to become a gold standard for diagnosis, including psychotic disorders [56].

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Address: Andrzej Cechnicki  
Department of Community Psychiatry  
Chair of Psychiatry, Jagiellonian University Medical College  
31-115 Kraków, pl. Sikorskiego Street 2/8  
e-mail: andrzej.cechnicki@uj.edu.pl