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REVIEW ARTICLE

Virtual reality in the assessment and treatment of psychosis: a systematic review of its utility, acceptability and effectiveness

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Over the last two decades, there has been a rapid increase of studies testing the efficacy and acceptability of virtual reality in the assessment and treatment of mental health problems. This systematic review was carried out to investigate the use of virtual reality in the assessment and the treatment of psychosis. Web of Science, PsychInfo, EMBASE, Scopus, ProQuest and PubMed databases were searched, resulting in the identification of 638 articles potentially eligible for inclusion; of these, 50 studies were included in the review. The main fields of research in virtual reality and psychosis are: safety and acceptability of the technology; neurocognitive evaluation; functional capacity and performance evaluation; assessment of paranoid ideation and auditory hallucinations; and interventions. The studies reviewed indicate that virtual reality offers a valuable method of assessing the presence of symptoms in ecologically valid environments, with the potential to facilitate learning new emotional and behavioural responses. Virtual reality is a promising method to be used in the assessment of neurocognitive deficits and the study of relevant clinical symptoms. Furthermore, preliminary findings suggest that it can be applied to the delivery of cognitive rehabilitation, social skills training interventions and virtual reality-assisted therapies for psychosis. The potential benefits for enhancing treatment are highlighted. Recommendations for future research include demonstrating generalisability to real-life settings, examining potential negative effects, larger sample sizes and long-term follow-up studies. The present review has been registered in the PROSPERO register: CDR 4201507776.

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Key words: Hallucinations, neuropsychology, paranoia, psychosis, schizophrenia, social functioning, systematic review, virtual reality.

Introduction

Virtual reality (VR) enables researchers and clinician to design realistic scenarios that can be used to assess the individual real-time cognitive, emotional, behavioural and physiological response to an environment (Slater, 2004; Eichenberg & Wolters, 2012). Computer-generated images are synchronised with the movements of the user, with the aim of creating a virtual world, which feels immersive and realistic (Rizzo *et al.* 2013). In VR, users can move and interact with the virtual world using head movements, full body turning and/or a joystick. Sounds are presented using speakers or a headphone, and in some VR environments, the user can experience haptic feedback (Yeh *et al.* 2014).

The last two decades have seen an exponential increase of publications about the use of VR in mental health (Valmaggia *et al.* 2016*b*), and recent studies employing VR with schizophrenia and other psychoses suggest that utilising VR methodology can be useful: whether to recreate social events in a laboratory environment; to enhance the understanding of psychosis; to assess psychotic symptoms or to treat these disorders (Freeman, 2008; Veling *et al.* 2014*b*; Valmaggia *et al.* 2016*a*).

The aim of the present study is to conduct a detailed review of the main applications of VR as an assessment tool and adjunctive technique for treatment in psychosis. A secondary aim is to review and critically evaluate the quality of the selected studies.

Methods

A systematic synthesis review was conducted of VR studies. The present review has been registered in the PROSPERO register: CDR 4201507776.

Selection procedure

Literature search

The databases used were Web of Science, PsychInfo, EMBASE, Scopus, ProQuest and PubMed. Unpublished

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dissertations, conference proceedings and abstracts without locatable full texts were excluded. The search was limited to studies available from selected databases up to 1 June 2016.

Inclusion and exclusion criteria

The primary criteria for inclusion were that the studies used immersive and interactive VR environments in three-dimensional (3D) graphics presented with a head-mounted display, or that they used 2D graphics on a computer screen but were interactive, meaning that participants could navigate through the environment using either a joystick or mouse/keyboard and where they would find sufficient elements in to interact with and had some feedback from (as a response of the interaction). The included studies had been designed for assessment or treatment purposes.

Papers were included in the review if they: (a) were written in English; (b) used empirical methods and published in a peer-reviewed journal; (c) included human participants presenting a psychosis spectrum disorder diagnosis, participants with at ultra high risk for psychosis or assessed psychosis symptoms in participants from the general population; (d) met the criteria above for immersive and/or interactive VR.

Search criteria

Studies for review were identified following a keyword search for the terms 'virtual reality' OR 'VR' AND 'psychosis', OR 'schizophrenia', OR 'severe mental illness', OR 'voices', OR 'positive symptoms', OR 'negative symptoms', OR 'hallucination', OR 'delusion', OR 'paranoia' OR 'paranoid ideation'. Appropriate truncations and wild cards were used to identify mutation of the terms searched, e.g. psychos* to search for psychosis, psychoses.

Quality assessment

The Evaluation of Public Health Practice Project Quality Assessment Tool for Quantitative Studies (QATQ) was used to assess the quality of all studies included in the systematic review. The QATQ has been evaluated and it has shown good content and construct validity, as well as inter-rater reliability (Thomas *et al.* 2004). The QATQ rates studies across six general domains: selection bias, study design, confounders, blinding, data collection and withdrawals. A global rating for the paper is described as follows: Strong = no weak ratings; Moderate = one weak rating; Weak = two or more weak ratings on the subscales.

Results

Information extraction

Information extraction was carried out by the first author and independently rated by the third author. The literature search identified 638 articles, from which 369 potential studies were identified for screening. Of these, 50 were included in the review (see Fig. 1). While all studies assessed the safety and acceptability of the VR environment, three studies focussed specifically on the safety and acceptability of VR with a psychosis population. Eleven studies focussed on neurocognitive evaluation; nine on the assessment of functional capacity, social cognition and social competence; 19 on the assessment of psychosis symptoms; and eight on the use of VR in the treatment of psychosis.

Quality assessment

Independent ratings were carried out by the first and last authors, resolving disagreements by consensus. As shown in Tables 1–5, the majority of studies received a QATA global rating of strong. It is however important to point out that the QATA defines a paper with no weak ratings as 'strong', even if the individual score on several subscales is moderate. Despite achieving an overall rating as 'strong', several papers had a score of moderate on one of more subscales reflecting small sample sizes and some methodological issues discussed below.

Safety and acceptability

Demonstrating the safety and acceptability of using VR with people experiencing psychosis has been an essential area of research in establishing the feasibility of using VR in this context. All studies reviewed in this manuscript addressed this important issue in their design, but three studies specifically reported results about safety and acceptability of this technology. Qualitative assessment showed that the patients' attitude towards using a virtual environment was positive, and they reported completing tasks by using computers to be engaging (da Costa & de Carvalho, 2004). Participants at ultra high risk for psychosis, healthy controls (Valmaggia *et al.* 2007) and individuals with persecutory delusions (Fornells-Ambrojo *et al.* 2008) did not report raised levels of anxiety or simulator sickness either during the VR exposure or in the week following the experiment.

Neurocognitive evaluation

Neurocognitive evaluation can be described as a method through which data about a participant's

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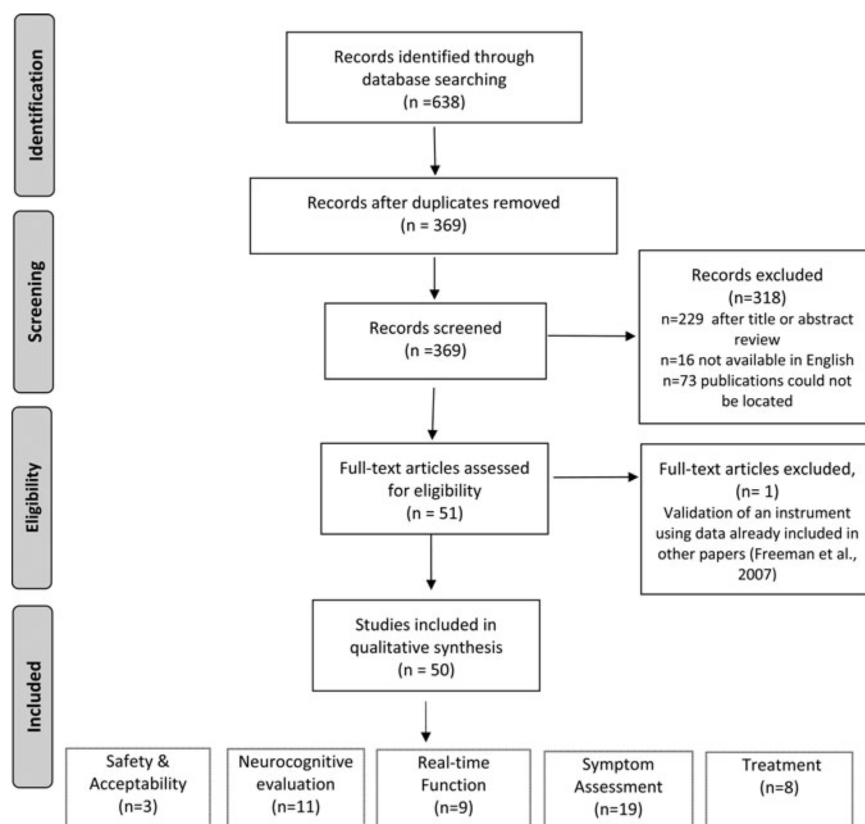

Fig. 1. PRISMA flow diagram.

cognitive, motor, behavioural, linguistic and executive functioning are acquired. The majority of the studies reviewed investigated the use of VR in the assessment of memory (Ku *et al.* 2003; Sorkin *et al.* 2006; Weniger & Irle, 2008; Spieker *et al.* 2012; Wilkins *et al.* 2013*a*, *b*; Fajnerova *et al.* 2014), while others investigated the use of VR in assessing executive functioning (Josman *et al.* 2009), self-perception (Landgraf *et al.* 2010; Synofzik *et al.* 2010) and reality distortion (Sorkin *et al.* 2008). Details of the reviewed studies are listed in Table 2. Taken together, the studies show that VR enables the multimodal assessment of cognitive functioning in ecologically valid environments.

Spatial working memory enables us to integrate various types of information about our environment and to orientate ourselves in it (Olton *et al.* 1979). Researchers have used multimodal virtual environments to measure objectively navigation ability, response time and navigation strategy (Ku *et al.* 2003; Sorkin *et al.* 2006). The studies used virtual complex environments (e.g. a courtyard or park) presenting different objects placed in specific areas and instructing the participants to learn and or memorise locations and scenes, with the possibility of controlling and manipulating the neurocognitive task with high reliability. Results are consistent across the studies, showing that participants with schizophrenia spectrum disorders: performed worse than healthy controls (Weniger & Irle, 2008; Wilkins *et al.* 2013*a*); made more errors and needed a longer time to locate targets than controls (Spieker *et al.* 2012; Wilkins *et al.* 2013*b*); had more difficulties in pointing and navigating accuracy; and more difficulties in recalling spatial sequences (Fajnerova *et al.* 2014).

Executive functioning is involved in planning, problem solving and the execution of an action or task (Chan *et al.* 2008). Impairments in executive functioning are associated with poor social functioning and less participation in activities in individuals with schizophrenia (Green *et al.* 2000). Josman *et al.* conducted a study aimed to examine the validity of a VR Supermarket in the assessment of executive functions (Josman *et al.* 2009). Results showed that the VR task had the ability to distinguish between people with schizophrenia and controls and that the group of participants with schizophrenia performed worse on the executive functions associated with the shopping task.

Other neurocognitive domains that have been investigated using VR technology are *self-agency* and *egocentric perception* of participants with a diagnosis of schizophrenia (Landgraf *et al.* 2010; Synofzik *et al.*

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Table 1. *Studies assessing safety and acceptability of VR in people with psychosis*

Study	Area explored	No. of participants	VR equipment	Experimental task	Main measure	Main findings	QATA global rating
da-Costa & de-Carvalho (2004)	Acceptability and safety	Four participants with schizophrenia Three males and one female Mean age: 45 (s.d. 8.6)	HMD (I-glasses)	Participants were asked to navigate a VR city and carry out a number of tasks: e.g. read the time on a clock; buy products in a supermarket	Specially designed questionnaire and interview	Participants described the VR city as enjoyable and found it easy to navigate it. They did not experience cyber sickness	Moderate
Fornells-Ambrojo *et al.* (2008)	Acceptability and safety	20 participants with persecutory delusions 17 males and three females Mean age: 23.5 (s.d. 3.1) 20 non-clinical controls 19 males and one female Mean age: 25.5 (s.d. 4.4)	CAVE Immersive projection system and Crystal Eyes shutter-glasses	Participants boarded a virtual underground train in which they met neutral characters who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking)	SSQ and STAI	VR experience did not cause any undesirable effects during the study or at the 1-week follow-up	Strong
Valmaggia *et al.* (2007)	Acceptability and safety	21 participants with at-risk mental state 13 males and eight females Mean age: 25 (s.d. 4.7)	CAVE Immersive projection system and Crystal Eyes shutter-glasses	Participants boarded a virtual underground train in which they met neutral characters who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking)	VAS for level of anxiety and comfort	The virtual environment did not increase levels of anxiety or cause any negative experiences during the study and at the 1-week follow-up	Strong

HMD, head-mounted display; s.d., standard deviation; SSQ, Simulator Sickness Questionnaire; STAI, Spielberg State-Trait Inventory; VAS, Visual Analogical Scale; VR, virtual reality.

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Table 2. *VR studies of neurocognitive evaluation in people with psychosis*

Study	Area explored	No. of participants	VR equipment	Experimental task	Outcome measures	Main findings	QATA global rating
Ku *et al.* (2003)	Working memory	13 participants with schizophrenia Eight males and five females Mean age: 30.1 (S.D. 2.6) 13 non-clinical controls Six males and seven females Mean age: 27.8 (S.D. 3.4)	HMD: i-visor DH-4400VPD	Participants experienced a virtual environment in which they had to play a game following a set of rules	Assessment of working memory, integration and navigation were embedded in the VR task SPM, WCST, K-MMSE, PANSS	The VR was effective in measuring multimodal stimuli integration and working memory abilities Patients had poorer performance on all the measures VR performance was comparable to the one traditional assessment measures (WCST and SPM)	Weak
Sorkin *et al.* (2006)	Working memory	39 participants with schizophrenia 21 non-clinical controls All males Mean age of the entire sample was 32.3 (S.D. 7.9)	HMD (no details given)	Participants' sensory integration was assessed by navigating through virtual maze. The maze was inspired by the WCST. Each door in the maze was associated with up to three features: shape, colour and sound. Two factors were manipulated during the experiment: the number of features to open a door and the presence of distractors	Measures of working memory, integration, navigation, strategy, learning and perseveration were embedded in the VR task PANSS	VR allowed the assessment of multiple measures, while participants were performing a complex task. Participants with schizophrenia performed worse on the virtual maze than controls in terms of their errors, strategy, response time and navigation ability	Moderate
Spieker *et al.* (2012)	Spatial memory	33 participants with schizophrenia 23 males and 10 females Mean age: 40 (S.D. 11.9) 39 non-clinical controls 20 males and 19 females Mean age 40.5 (S.D. 11.4)	Computer screen and joystick for navigation	Participants were presented with 10 virtual maze trials. The length of time that took to complete each trial, number of errors and rewards discovered were recorded	Assessment of spatial memory was embedded in the VR task BPRS, SANS, RBANS	Participants with schizophrenia demonstrated impaired spatial learning compared with non-clinical controls; also, longer trial completion time, distance travelled and more errors than non-clinical controls	Strong

Table 2 (*cont.*)

Study	Area explored	No. of participants	VR equipment	Experimental task	Outcome measures	Main findings	QATA global rating
Weniger & Irle (2008)	Spatial memory	25 participants with schizophrenia 19 males and six females Mean age: 30 (s.d. 10) 25 non-clinical controls 16 males and nine females Mean age: 32 (s.d. 10)	Computer screen and joystick for navigation	Presenting participants with two VR tasks, which examined the navigation and learning of a virtual park and maze	Assessment of spatial memory was embedded in the VR task SCID, SAPS, SANS, GAF, CGI, WAIS-R, WMS-R	Participants with schizophrenia were significantly impaired in learning the virtual park, but no differences in performance were found in regards to learning of the virtual maze	Strong
Wilkins *et al.* (2013*a*)	Spatial memory	20 participants with schizophrenia spectrum disorders 16 males and four females Mean age 42 (s.d. 8.5) 20 non-clinical controls Seven males and 13 females Mean age: 32.25 (s.d. 12.6)	Computer screen and navigation system (no details provided)	Participants were presented with VR courtyard task in which they were asked to remember objects and recognise them from different points of view	Assessment of spatial memory was embedded in the VR task PANSS, WRAT-4, FSIQ, WAIS-III, RBANS, MRT-A	Participants with schizophrenia spectrum disorders performed worse on the VR task under 'shifted from view' condition compared with controls	Strong
Wilkins *et al.* (2013*b*)	Spatial memory	21 participants with schizophrenia of whom 17 were included in final analyses 13 males and four females Mean age: 42.1 (s.d. 8.1) 24 non-clinical controls of whom 17 were included in final analyses Nine males and eight females Mean age: 36.2 (s.d. 13.1)	Computer screen and navigation system (no details provided)	Participants were presented with virtual maze and a virtual navigation task designed to distinguish between subjects' use of spatial and response tasks	Assessment of spatial memory was embedded in the VR task FSIQ, WAIS, PANSS, RBANS	Participants with schizophrenia who navigated using a spatial technique performed worse than controls. However, participants who used response strategy (e.g. remembering the within-maze sequence of pathways) performed similarly to controls	Strong

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Fajnerova *et al.* (2014)	Spatial learning and memory	29 participants with psychosis 17 males and 12 females Mean age: 25.8 (S.D. 6.2) 29 non-clinical controls 17 males and 12 females Mean age: 25.7 (S.D. 5.4)	Blue Velvet Arena: VR displayed on a monitor and 3D circular arena	Participants were asked to find and remember four hidden goals positions. The task was divided in two parts: one two test spatial learning abilities and the other one to test ability to remember the sequence used in the previous phase of the task	Assessment of spatial learning and memory were embedded in the VR task PANSS, GAF, MATRICS battery	The VR confirmed the impairments identified with traditional measures of visual spatial functions. Participants with schizophrenia showed greater deficits spatial learning ability and spatial memory capability than the control group	Strong
Josman *et al.* (2009)	Executive functioning	30 participants with schizophrenia 14 males and 16 females Mean age: 46.7 (S.D. 10.6) 30 non-clinical controls 14 males and 16 females Mean age: 47.7 (S.D. 12.5)	Computer screen and keyboard for navigation	Assessment of executive function while performing shopping task in a virtual supermarket (Virtual Action Plan-Supermarket VAP-S)	Assessment of executive functioning was embedded in the Virtual Action Plan-Supermarket task PANSS, BADS	The Virtual Action Plan-Supermarket was found to be a valid measure of executive functioning in people with schizophrenia	Strong
Landgraf *et al.* (2010)	Ego- and allocentric spatial referencing	24 participants with schizophrenia 13 males and 11 females Mean age: 24.9 (S.D. 3.3) 25 non-clinical controls 13 males and 12 females Mean age: 24.6 (S.D. 3.2)	Computer screen (details for interaction within the environment not provided)	VR environment with 48 stimulus items, each containing a blue and a green trash can and a red ball in front of a three-winged palace seen from different angles	Assessment of ego and allocentric spatial referencing was embedded in the VR task PANSS	Adoption of an egocentric perspective was preserved in participants with schizophrenia. Adopting an allocentric point of view and switching between a landmark-centred perspective and an egocentric perspective were impaired	Strong
Synofzik *et al.* (2010)	Attribution of agency	20 participants with schizophrenia 13 males and 7 females mean age: 28.2 (S.D. 3.9) 20 non-clinical controls 12 males and 8 females Mean age: 29.8 (S.D. 5.1)	While performing a pointing movement participants saw a virtual visual cursor corresponding to spatiotemporal movement of participant's finger	Pointing task. The direction of the movement could be manipulated in real-time	Assessment of attribution of agency assessment was embedded in the VR task SAPS	When participants received visual feedback, patients performed better than they did in the condition with no visual feedback. When patients received no feedback, they were significantly less able than controls to tell whether they were responsible for the pointing action	Strong

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Table 2 (*cont*.)

Study	Area explored	No. of participants	VR equipment	Experimental task	Outcome measures	Main findings	QATA global rating
Sorkin *et al*. (2008)	Distortion in reality perception	43 participants with schizophrenia 29 matched non-clinical controls Gender distribution for the entire sample 58 males and 14 females Mean age of the entire sample was 32.6 (s.d. 8.5)	HMD (no details provided) VR environment presented in a predetermined path	Participants navigated a VR residential neighbourhood, shopping centre and street market. The forward movement of participants was paused when an incoherent event was presented which the participant had to spot and verbally identify. Incoherent events could be: sound; colour or location. Fifty incoherent events were presented	Assessment of distortion in reality perception was embedded in the VR task. PANSS	Patients with schizophrenia performed worse on the task of detecting incoherencies in the virtual experience. Most difficulties were found in the sound category. Hallucinations correlated with low detection rate of sounds	Strong

BADS, Behavioural Assessment of the Dysexecutive Syndrome; BPRS, Brief Psychiatric Rating Scale; CGI, Clinical Global Impressions; FSIQ, Full Scale Intelligence Quotient; GAF, Global Assessment of Functioning; HMD, head-mounted display; K-MMSE, Korean Mini-Mental State Examination; MATRICS, Measurement and Treatment Research to Improve Cognition in Schizophrenia; MRT-A, Mental Rotation Test-A; PANSS, Positive and Negative Symptoms Scale; RBANS, Repeatable Battery for the Assessment of Neuropsychological Status; SANS-SAPS, Scale for the Assessment of Negative and Positive Symptoms; SCID, Standard Clinical Interview for DSM Disorders; s.d., standard deviation; SPM, Standard Progressive Matrices; VR, virtual reality; WAIS-R, Wechsler Adult Intelligence Scale; WCST, Wisconsin Card Sorting Test; WMS-R, Wechsler Memory Scale Reviewed; WRAT-4, Wide Range Achievement Test-4.

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Table 3. *VR studies of functional capacity and social cognition and social competence*

Study	Area explored	No. of participants	VR equipment	Experimental task	Main outcome measures	Main findings	QATA global rating
Dyck *et al.* (2010)	Emotion recognition	20 participants with schizophrenia 11 males and nine females Mean age 36.7 (S.D. 1.9) 20 non-clinical controls 11 males and nine females Mean age 36.9 (S.D. 2.2)	Computer screen and keypad for interaction	Emotion recognition in virtual faces	Emotion recognition embedded in the VR task SCID	Participants with schizophrenia were able to recognise emotions in virtual faces as well as natural faces	Strong
Greenwood *et al.* (2016)	Ability to plan to do the shopping in a supermarket	43 participants with schizophrenia 22 males and 21 females Mean age 39.5 (S.D. 11.9)	Computer screen and joystick for navigation	Comparison between VR supermarket shopping task and in real-life supermarket shopping test	Efficiency (time and number of aisles entered) and accuracy measures embedded in the VR task, WMS-R, WWM, BADS, IIT, NART-R	VR functional capacity measurement can predict real-life performances. High positive correlations between VR measures and real-life measures for accuracy and efficiency	Strong
Gutierrez-Maldonado *et al.* (2012)	Emotion recognition	30 participants with schizophrenia no gender or age information given	3D computer screen and glasses	Emotion recognition using two different presentations: photographs and dynamic virtual faces	Emotion recognition embedded in the VR task PANSS, TAS-20	No differences between both forms of presentation of the virtual stimuli, but anger and disgust better to recognise in VR	Moderate
Kurtz *et al.* (2006)	Medication management	25 participants with schizophrenia 15 males, and 10 females mean age 42.1 (S.D. 10.5) 18 non-clinical controls Nine males, nine females Mean age 39.1 (S.D. 11.0)	Computer screen and joystick for navigation	Participants are presented with a VR apartment, that they have to navigate to take the appropriate type and dosage of medication at the appropriate time	Medication management assessment embedded in the VR task (VRAMMA) MMA PANSS CPT HVLT	Participants with schizophrenia made more errors with regard to the quantitative aspect of the task (taking more or less pill and at different time); however, they did not make more qualitative errors (taking wrong medication)	Strong

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Table 3 (*cont.*)

Study	Area explored	No. of participants	VR equipment	Experimental task	Main outcome measures	Main findings	QATA global rating
Ku *et al.* (2006)	Interpersonal distance and the verbal response time	11 participants with schizophrenia Five males and six females Mean age 29.5 (S.D. 8.95)	VR immersive environment projected on a large screen	Participants were presented with a virtual avatar in a virtual room. They had to initiate a talk and answer the avatars' questions	Assessment of interpersonal distance and verbal response time embedded in the VR task PANSS VAS	Patients stated that they perceived the avatars as real humans and interpersonal distance negatively correlated with negative symptoms	Moderate
Kim *et al.* (2007)	Perception of social emotional cues	30 participants with schizophrenia 16 males and 14 females Mean age: 19.6 (S.D. 4.98) 30 non-clinical controls 16 males and 14 females Mean age 29.50 (S.D. 5.33)	VR immersive environment projected on a large screen	Participants were presented with verbal and non-verbal social cues in a virtual context and they were asked to detect social emotions and expressions	Perception of social cues embedded in the VR task PANSS, ITQ, K-WAIS, PQ, VRQ	Participants with schizophrenia had poorer social perception ability and were less able to recognise emotions	Strong
Park *et al.* (2009*a*)	Emotional perception and emotional response	27 participants with schizophrenia 14 males and 13 females Mean age: 28.5 (S.D. 5.7) 27 non-clinical controls 14 males and 13 females Mean age: 26.5 (S.D. 4.4)	HMD (no details provided)	Participants met six different avatars. Avatars could appear happy, neutral or angry and showed verbal and non-verbal cues that matched their emotion. Each avatar introduced themselves and told the participants a bit about themselves (where they were born, lived, what they liked or disliked, hobbies and family); they then asked the participants to introduce themselves	Emotional perception embedded in the VR task PANSS PANAS Trait STAI	Participants with schizophrenia underestimated the valence and arousal of angry emotions expressed by an avatar and showed higher state anxiety in response to happy avatars. Negative symptoms were correlated with state anxiety ratings of the encounters with happy avatars	Moderate

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Park *et al.* (2009*b*)	Interpersonal distance and eye gaze	30 participants with schizophrenia 16 males and 14 females mean age 28.7 (S.D. 5.5) 30 non-clinical controls 16 males and 14 females mean age: 26.3 (S.D. 4.3)	HMD (no details provided)	Participants met six different avatars. Avatars could appear happy, neutral or angry and showed verbal and non-verbal cues that matched their emotion. Each avatar introduced themselves and told the participants a bit about themselves (where they were born, lived, what they liked or disliked, hobbies and family); they then asked the participants to introduce themselves	Interpersonal distance embedded in VR RPM PANSS	Participants with schizophrenia tended to keep more physical distance and have greater angle of head orientation than non-clinical controls	Strong
Ruse *et al.* (2014)	Transportation, finances, household management and planning	51 participants with schizophrenia 32 males 19 females Mean age: 39.7 (S.D. 11.9) 54 non-clinical controls 19 males and 35 female Mean age: 37.6 (S.D. 12.5)	Immersive VR system (no details provided)	Virtual Reality Functional Capacity Assessment Tool (VRFCAT) measures the following four functional abilities: checking an item is available to make a recipe, taking a bus, shopping in a store and paying for the items	Measures of accuracy and time were measured during the VRFCAT. UPSA-B, MATRICS	Patients with schizophrenia performed more poorly in time, errors made and failed objectives than non-clinical controls. High positive correlations between VRFCAT and MATRICS	Strong

BADS, Behavioural Assessment of the Dysexecutive Syndrome; CPT, Continuous Performance Test; HMD, head-mounted display; HVLT, Hopkins Verbal Learning Test; IIT, Intention Inference Test; ITQ, Immersive Tendency Questionnaire; MATRICS, Measurement and Treatment Research to Improve Cognition in Schizophrenia; MMA, Medication Management Assessment; NART-R, National Adult Reading Test Revised; PANAS, Positive Affect and Negative Affect Scale; PANSS, Positive and Negative Symptoms Scale; PQ, Presence Questionnaire; RPM, Raven's Progressive Matrices; SCID, Standard Clinical Interview for DSM Disorders; S.D., standard deviation; STAI, State-Trait Anxiety Inventory; TAS-20, Toronto Alexithymia Scale; UPSA-B, Performance-Based Skills Assessment; VR, virtual reality; VRAMMA, Virtual Reality Apartment Medication Management Assessment; VRQ, Virtual Reality Questionnaire; WMS-R, Wechsler Memory Scale Reviewed; WWM, Wechsler Working Memory Test.

Table 4. *VR assessment of paranoid ideation and auditory hallucinations*

Study	Area explored	Participants	VR equipment	Experimental task	Main outcome measure	Main findings	QATA global rating
Atherton *et al.* (2014)	Self-confidence and paranoid ideation	26 males from the general population reporting paranoid ideation (GPTS > 17) Mean age 43.4 (S.D. 16.3)	HMDs: NVIS SX111 or VR1280	Virtual underground train with avatars who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking) Two exposures, with an interval period of 5 min	GPTS-B; VAS social confidence; SCS; SSPS	Low self-confidence induction led to higher levels of paranoia and more negative views of the self in the VR environment	Strong
Broome *et al.* (2013)	Paranoid ideation	32 non-clinical participants 23 males and nine females Mean age 25.9 (S.D. 4.2)	HMD: NVIS nVisor SX	Participants waited for a bus to arrive for about 4 min in a virtual street based on a real busy street in a deprived area of Birmingham (UK). While they were waiting, a few avatars joined them at the bus stop	GPTS, IPS, SADS, DASS, CAPS, SPSS	Participants reported persecutory ideation while being in the virtual street Mean SSPS in this study was higher than reported by Freeman *et al.* (2008*a*)	Moderate
Fornells-Ambrojo *et al.* (2015)	Perception of threat	10 participants with persecutory delusions All males Mean age 24.2 (S.D. 2.3) 10 non-clinical controls Eight males and two females mean age 23.8 (S.D. 2.3)	CAVE Immersive projection system and Crystal Eyes shutter-glasses	Participants boarded a virtual underground train in which they met neutral characters who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking)	STAI, SPSS, qualitative interview about interpersonal experience in VR	Participant with persecutory delusions were more likely to use their own affect as evidence of persecution and less inclined to use active-hypothesis testing	Strong
Fornells-Ambrojo *et al.* (2016)	Interpersonal contingency and paranoid ideation	61 non-clinical participants All males Mean age 25.3 (S.D. 7.3)	CAVE Immersive projection system and Crystal Eyes shutter-glasses	Participants were instructed to enter into a virtual flat and interact with a virtual flatmate. The contingency behaviour of the virtual flat mate was high in one condition and low in the other	SSPS; STAI; Relationship Questionnaire; distance kept from avatar; trustworthiness of the avatar; SUS	Trusting behaviour was predicted by higher paranoia, dismissive attachment, baseline distance and avatar movement; but not by degree of contingency	Moderate

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Freeman *et al.* (2003)	Paranoid ideation	24 healthy participants 12 males and 12 females Mean age: 26 (S.D. 6)	CAVE Immersive projection system and Crystal Eyes shutter-glasses	Library with five avatars who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking)	BSI; SSPS; STAI; VR paranoia questionnaire; semi-structured interview and observer ration of persecutory ideation; SUS	Persecutory ideation was associated with interpersonal sensitivity Participants attributed mental states to avatars, including paranoid intentions	Moderate
Freeman *et al.* (2005)	Paranoid ideation	30 healthy participants 15 males and 15 females Mean age: 22 (S.D. 5)	CAVE Immersive projection system and Crystal Eyes shutter-glasses	Library with five avatars who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking)	SSPS; LSHS; structured interview for assessing perceptual abnormalities; need for closure: DASS-21; IPSM; PSCS; probabilistic reasoning task; SADS; VR paranoia questionnaire; VR-SADS; SUS	Persecutory ideation was predicted by baseline anxiety, timidity and hallucination predisposition No association was found with probabilistic reasoning or need for closure Participants attributed mental states to avatars, including paranoid intentions	Moderate
Freeman *et al.* (2008*a*)	Correlates of social anxiety and paranoid ideation	200 participants from general population 100 males and 100 females Mean age 37.5 (S.D. 13.3)	HMD: VR1280	Participants boarded a virtual underground train in which they met neutral characters who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking)	WAIS; DASS-21; PSWQ; Worry Domains Questionnaire; cathastrophising interview; BCSS; IPMS; cognitive flexibility; probabilistic reasoning; CAPS; MAP; life stressors checklist; SSQ; SELSA; SSPS; SADS	Presence of perceptual abnormalities raised the risk of paranoid reactions but decreased the risk of social anxiety	Strong

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Table 4 (*cont.*)

Study	Area explored	Participants	VR equipment	Experimental task	Main outcome measure	Main findings	QATA global rating
Freeman *et al.* (2010)	Paranoid ideation	30 low non-clinical paranoia 18 males and 12 females mean age 44.2 (S.D. 11.2) 30 high non-clinical paranoia 18 males and 12 females mean age 36 (S.D. 11.7) 30 clinical persecutory delusions 18 males and 12 females mean age 44.2 (S.D. 11.7)	HMD: VR1280	Participants boarded a virtual underground train in which they met neutral characters who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking)	GPTS; SSPS; VAS hostility; DASS-21; PSWQ; IPSM; beads task; CAPS; life stressors checklist; WAIS; SSQ	Jumping to conclusion was only present in the persecutory delusions group There was an increase in levels of interpersonal sensitivity, depression, anomalous experiences, anxiety, worry and trauma history across the three groups of paranoia	Strong
Freeman *et al.* (2014)	Perceived height in the VR was altered to assess impact on persecutory ideation and social comparison	60 from general population reporting paranoid thoughts in the last month All females Mean age: 31.5 (S.D. 13)	HMD: NVIS SX111	Participants boarded a virtual underground train in which they met neutral characters who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking) Participants were asked to undergo in a VR train ride twice: at their normal height and at reduced height	GPTS-B; SSPS; SCS	Reducing a person's height resulted in more negative views of the self in comparison with others and, therefore, the increase of paranoid thoughts was mediated by changes in social comparison	Strong
Freeman *et al.* (2015)	Effects of THC on paranoid ideation	121 participants from general population reporting paranoid thoughts in the last month 81 males and 40 females Mean age 29.7 (S.D. 8.4)	HMD: NVIS SX111	Participants boarded a virtual underground train in which they met neutral characters who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking) Participants were randomly allocated either to receive placebo, THC, or THC preceded by a cognitive awareness condition of the effects of THC on behaviour	SSPS, CAPE, CAPS, VAS-VR Paranoid	THC significantly increased paranoia, woory, anxiety, depression, negative thoughts about the self and anomalous experiences, and also reduced working memory capacity	Strong

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Kesting *et al.* (2013)	Social stress, self-esteem, paranoid ideation	82 participants from the general population 18 males and 64 females Mean age: 24.8 (S.D. 8.35)	Interactive VR environment (details not provided)	Participants played a ball tossing game over the internet with two virtual other players Participants were randomly allocated either to experimental group or control group In the experimental condition, participants were excluded during the cyber-ball game and received negative feedback after a proverb task. In the control condition, participants were included in the cyber-ball game and received neutral feedback	CAPE, VAS paranoia, VAS emotions, RSES	Participants in the experimental condition demonstrated a higher increase in paranoid thoughts compared with controls Moderation analyses suggested that social stress was associated with an increase in paranoid ideation. Self-esteem mediated the link between social stress and increase in paranoid ideation	Strong
Moritz *et al.* (2014)		33 participants with paranoia 21 males and 12 females Mean age 40.5 (S.D. 9.9)	Computer screen and keyboard for navigation	Participants were asked to walk along a VR urban street three times and to pay attention to the facial expression of other pedestrians (i.e. avatars showing neutral, angry or happy faces). Following the VR walk, participants were asked to judge the emotion of the avatar they met in the street and received feedback about whether they were correct or not	PANSS, POD, VAS paranoia checklist	Error feedback for social perception judgement was associated with a reduction of paranoia ideation Depressive and OCD symptoms did not change	Strong

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Table 4 (*cont.*)

Study	Area explored	Participants	VR equipment	Experimental task	Main outcome measure	Main findings	QATA global rating
Shaikh *et al.* (2016)	Ethnic discrimination and paranoid ideation	64 participants with an UHR for psychosis 38 males and 26 females Mean age 22.5 (S.D. 4) 43 non-clinical controls 20 males and 23 females Mean age 24 (S.D. 4)	HMD: VR1280	Participants boarded a virtual underground train in which they met neutral characters who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking)	SPSS, PQ, PEDQ-CV	Perceived ethnic discrimination was higher in participants with UHR in comparison to healthy controls. Perceived ethnic discrimination and paranoid ideation in VR were correlated across the entire sample. However, perceived ethnic discrimination was a predictor of paranoid persecutory ideation in VR for HC but not in the UHR group	Strong
Valmaggia *et al.* (2015*a*)	Paranoid Ideation and social defeat	64 participants with an UHR for psychosis 38 males and 26 females mean age 22.5 (S.D. 4) 43 non-clinical controls 20 males and 23 females mean age 24 (S.D. 4)	HMD: VR1280	Participants boarded a virtual underground train in which they met neutral characters who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking)	SDCS, DASS-21, SSPS, SCS	Participants at UHR reported significantly higher levels of social defeat than controls Paranoid ideation in VR was predicted by social defeat scores	Strong
Valmaggia *et al.* (2015*b*)	Paranoid ideation and childhood bullying victimisation	64 participants with an UHR for psychosis 38 males and 26 females Mean age 22.5 (S.D. 4) 43 non-clinical controls 20 males and 23 females Mean age 24 (S.D. 4)	HMD: VR1280	Participants boarded a virtual underground train in which they met neutral characters who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking)	RBQ, SSPS	Participants at UHR reported significantly higher levels of bully victimisation than controls Childhood bullying victimisation was associated with higher paranoid ideation in VR in the entire sample	Strong

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Veling *et al*. (2014*a*)	Paranoid ideation	17 participants with a first episode of psychosis 14 males and three females Mean age 27.3 (S.D. 5.5) 24 healthy controls 20 males and four females Mean age 29 (S.D. 9.2)	Eamgin Z800 3D visor	Participants navigated a VR café. The experimenter manipulated the ethnicity of the avatars and how crowded the café was	SSPS, Galvanic skin response	First episode participants reported more paranoid thoughts, showed more proximity to the avatars and higher galvanic skin response to avatars of a different ethnicity from their own	Strong
Veling *et al*. (2016)	Stress sensitivity, paranoid ideation	55 patients with first episode of psychosis 42 males and 19 females Mean age: 26 (S.D. 4.7) 20 patients at UHR Seven males and 13 females Mean age: 24 (S.D. 4.5) 42 siblings of patients 23 males and 19 females Mean age 26.4 (S.D. 4.8) 53 healthy controls 25 males and 28 females Mean age: 24.6 (S.D. 4.4.)	Sony HM-Z T1	Comparison of subjective distress and levels of paranoia between groups and between different social stress degrees Participants entered the VR bar five times for 4 min each time. Three parameters of social stress were manipulated: population density, ethnic density and hostility	SSPS, SUDS	People with early psychosis and individuals at UHR showed greater levels of paranoia and distress than siblings and controls. Paranoid ideation in VR and subjective distress increased with degree of social stress in all the participants	Strong
Westermann *et al*. (2012)	Emotion regulation and paranoid ideation	116 participants without clinically relevant levels of delusions (online study) 33 males 83 females Mean age: 28.5 (S.D. 7.8)	Computer screen (details on interaction methods for cyber-ball task not provided)	Participants played a ball tossing game over the internet with two virtual other players. Participants were randomly allocated either to either experimental group or control group. In the experimental condition, participants were excluded during the cyber ball. In the control condition, participants were included in the cyber-ball game	VAS paranoia, VAS emotions, ERQ, SIAS	In paranoia-prone individuals, habitual reappraisal was associated with higher paranoia ideation following social exclusion. Habitual expressive suppression did not lead to an increase of paranoid ideation following social exclusion	Strong

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Table 4 (*cont.*)

Study	Area explored	Participants	VR equipment	Experimental task	Main outcome measure	Main findings	QATA global rating
Stinson *et al.* (2010)	Auditory hallucination	30 participants who reported experiencing on a daily basis auditory hallucinations in social situations 20 males and 10 females mean age: 42.4 (S.D. 9.7)	HMD: VR1280	Participants boarded a virtual underground train in which they met neutral characters who occasionally showed potentially ambiguous behaviour (e.g. looking, smiling, talking) Participants were randomly assigned to the experimental condition (focussing on cognitions which trigger hallucinations) or control condition (focus on neutral cognitions)	PSYRATS, TVRS, HADS, LSAS, CAS, ATQ, ASSQ	Participants reported the occurrence of auditory hallucinations in the VR environment. There was no difference between the experimental group and the controls in terms of the occurrence or severity of auditory hallucinations during the VR	Strong

ASSQ: Autism Spectrum Screening Questionnaire; ATQ, Automatic Thoughts Questionnaire; CAPE, Community Assessment of Psychic Experience; CAPS, Cardiff Anomalous Perceptions Scale; CAS, Cognitive Assessment Schedule; DASS, Depression, Anxiety, Stress Scale; ERQ, Emotion Regulation Questionnaire; GPTS, Green Paranoia Thoughts Scale; HADS, Hospital Anxiety and Depression Scale; HMD, head-mounted display; IPSM, Interpersonal Sensitivity Scale; LSAS, Liebowitz Social Anxiety Scale; LSHS, Launay-Slade Hallucinations Scale; PANSS, Positive and Negative Symptoms Scale; PEDQ-CV, Perceived Ethnic Discrimination Questionnaire community version; PQ, Presence Questionnaire; PSWQ, Penn State Worry Questionnaire; PSYRATS, Psychotic Symptoms Rating Scale; RBQ, Retrospective Bullying Questionnaire; RSES, Rosenberg Self-Esteem Scale; SADS, Social Avoidance and Distress scale; SCS, Social Comparison Scale; S.D., standard deviation; SDCS, Social Defeat Composite Scale; SIAS, Social Interaction Anxiety Scale; SSPS, Social State and Paranoia Scale; SSQ, Simulator Sickness Questionnaire; STAI, State-Trait Anxiety Inventory; TVRS, Topography of Voices Rating Scale; UHR, ultra high risk; VAS-VR Paranoid, Visual Analogical Scale to assess paranoia in virtual reality environment; VR, virtual reality.

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Table 5. *VR for the treatment of psychosis*

Study	Therapy outcome	No. of participants	Allocation	VR equipment	Intervention	Primary outcome measures	Results	Follow-up	QATA Global Rating
Cognitive remediation and vocational skills									
Chan *et al.* (2010)	Cognitive functions	27 participants who were older age (<60 years) inpatients with schizophrenia 12 VR group 10 males and two females Mean age 66.4 (S.D. 6.2) 15 control group Eight males and seven females Mean age: 65.9 (S.D. 5.4)	Random allocation: Therapy groups cf. control group	IREX: 2D VR environment presented using a large screen	VR cognitive training programme (10 sessions of 15 min long with increasing level of difficulty) Control group attended treatment as usual in the clinic	COGNISTAT, SSQ, VQ	Significant improvement in cognitive function in those who received the VR intervention	No	Strong
Tsang & Man (2013)	Vocational skills, cognitive functions and self-efficacy	75 participants who were inpatients with schizophrenia 25 VR group Seven males and 18 females Mean age: 39.60 (S.D. 7.9) 25 therapist group 15 males and 10 females Mean age: 40.7 (S.D. 9.2) 25 traditional training group 11 males and 14 females Mean age 41.5 S.D. (9.9)	Random allocation: VR-based vocational training system Therapist-administrated group Traditional occupational group provided by the clinic	Computer screen, joystick and keyboard for navigation and interactions	Each group had 10 sessions over 5 weeks. The therapist-administered group and the VR group had the same structure and content but different mode of training (role play *v.* VR). The following areas were covered during the training memory, executive functioning and cognitive functioning at work	BNCE, DVT, RBMT, WCST, VCRS	The VR performed better than the others on executive functions, problem solving, categorisation, memory and attention and self-efficacy score. Both VR group and therapist-administered group showed better work performance compared with the traditional occupational group	1-month follow-up	Strong

Table 5 (*cont.*)

Study	Therapy outcome	No. of participants	Allocation	VR equipment	Intervention	Primary outcome measures	Results	Follow-up	QATA Global Rating
Smith *et al.* (2015)	Interview skills and employment	32 outpatients with schizophrenia or schizoaffective disorder 21 VR group 11 males and 10 females Mean age: 40.8 (S.D. 12.2) 11 control group Six males and five females Mean age: 39.1 S.D. (10.6)	Random allocation: VR interview job training cf control treatment as usual	Computer system that allows real-time interaction and feedback from virtual avatar	VR job interview simulation and training programme delivered over 10 hours over the course of five sessions. Control group received treatment as usual	Role-playing performance, self-confidence, gaining employment on the following 6 months (number of weeks searching for employment, job interviews done and job offers)	The VR group showed a larger improvement of job interview skills and self-confidence after the intervention. At 6-month follow-up participants in the VR groups had higher odds of receiving a job offer	6-month follow-up	Strong
Social skills training									
Park *et al.* (2011)	Social skills and motivation	64 participants who were inpatients with schizophrenia 33 VR social skills training 16 males and 17 females Mean age: 28.1 S.D. (7.7) 31 in traditional social skills training 18 males and 13 females Mean age 31.2. S.D. (7.7)	Random allocation: VR-SST cf. traditional SST	HMD: Eye Trek FMD 250 W, OLYMPUS	Social skills training and virtual environment were both administered over 10 sessions in 5 weeks	RAS, RCS, SPSI-R, blind assessors rated vocal, non-verbal and conversational skills	During the training, the VR group showed greater engagement with the training and generalisation of skills. After the training, the VR group improved more in assertiveness and conversational skills, but less in non-verbal skills	No	Strong

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Rus-Calafell *et al.* (2014)	Social cognition and social competence	12 outpatients with schizophrenia or schizoaffective disorder	N/A	3D laptop with glasses (real-time interaction and feedback provided by the system)	Participants had 16 one-to-one 1-hour sessions in which they could use the *Soskitrain*: a VR-integrated programme which consisted of seven activities based on seven target behaviours during which users practised social interactions with virtual avatars, were encouraged progressive learning of the social skills repertoire and were provided positive or negative reinforcement	PANSS, SSIT, SADS, SFS	Reduction in negative symptoms and improvement in social skills Maintained at follow-up	4-month follow-up	Moderate
VR-assisted therapy for paranoia and hallucinations									
Freeman *et al.* (2016)	Persecutory delusions and safety-seeking behaviours	30 patients with persecutory delusions 15 VR cognitive group 10 males and five females Mean age: 42.1 (S.D. 13.4) 15 VR exposure group Six males and nine females Mean age 40.6 S.D. (14.4)	Participants were randomly assigned to one of two conditions: VR cognitive or VR exposure	HMD NVIS SX111	In the VR cognitive therapy condition, participants were asked to test their threat belief and drop their safety behaviours. In the VR, exposure group with keeping of safety behaviours	VAS for conviction and distress related to paranoia	In comparison with VR exposure only, VR cognitive therapy led to large reductions in delusional conviction	No	Strong
Gega *et al.* (2013)	Social anxiety and paranoid thoughts	Six participants with schizophrenia All males No mean age given, age range: 20–36 years	Case series	The participant enters a specially designed video unit booth. They can see themselves in the projected film on the screen	Participants took part in a 12-week CBT intervention. A single VR therapy session was delivered halfway through the therapy and practise social interaction in a virtual environment	PANSS, SIAS, BCSS, GPTS	No change in anxiety or paranoia was found at 12-week immediately after treatment. However, at 24-week follow-up, both anxiety and paranoia showed a significant decrease	24-week follow-up	Strong

Table 5 (*cont.*)

Study	Therapy outcome	No. of participants	Allocation	VR equipment	Intervention	Primary outcome measures	Results	Follow-up	QATA Global Rating
Leff *et al*. (2013)	Auditory hallucinations	26 outpatients with schizophrenia 16 males and 10 females Mean age:	Participants were randomised to immediate therapy or to delayed therapy	Computerised system that enables participants with hallucination to create an avatar of the voice they hear and have a real-time dialogue with the voice	Therapy was delivered over 7 weeks Each participant creates an avatar (visual and sound) of the voice they hear using a computer programme During the therapy sessions the participant has a dialogue with the voice. The voice content is delivered by the therapist, who sits in another room. Using specialised software the sound of voice of the therapist is distorted to match the sound of the auditory hallucination as described by the participant	PSYRATS-AH BAVQ Calgary depression scale	After therapy and at 3-month follow-up, therapy was associated with a reduction of the intensity, frequency of the voices as well as the disruption the voices caused to the participants life Belief about the omnipotence and malevolence of the voices was also reduced At the end of therapy no effect was found on depression; however, there was a significant decrease of depression at follow-up	3-month follow-up	Moderate

BCSS, Brief Core Schema Scale; BNCE, Brief Neuropsychological Cognitive Examination; COGNISTAT, Neurobehavioural Cognitive Status Examination; DVT, Digit Vigilance Test; HMD, head-mounted display; PANSS, Positive and Negative Symptoms Scale; POD, Paranoid, Obsessive-Compulsive and Depression Scale; PSYRATS-AH, Psychotic Symptom Rating Scale Auditory Hallucinations Section; RAS, Rathus Assertiveness Schedule; RBMT, Rivermead Behavioural Memory Test; RCS, Relationship Change Scale; SADS, Social Avoidance and Distress Scale; S.D., standard deviation; SFS, Social Functioning Scale; SIAS, Social Interaction Anxiety Scale; SPSI-R, Social Problem Solving Inventory-Revised; SSIT, Simulated Social Interaction Test; SSQ, Speech, Spatial, and Qualities of hearing Scale; VCRS, Vocational Cognitive Rating Scale; VQ, Vocational Questionnaire; VR, virtual reality; WCST, Wisconsin Card Sorting Test.

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2010). Self-agency can be defined as the sense of ownership of one's actions and has been showed to be impaired in psychotic disorders (Kircher & Leube, 2003). By presenting the participants with complex visual VR environments, researchers were able to conclude that people with psychosis present difficulties when maintaining a non-egocentric perspective and when switching between egocentric and non-egocentric views (Landgraf *et al.* 2010), as well as some impairments in attributions of agency when non-visual feedback is provided (Synofzik *et al.* 2010).

The perception of reality is subjective, and previous studies have demonstrated that *reality distortion* is common in psychosis (Liddle, 1987). Sorkin *et al.* (2008) aimed to use VR to measure distortion in reality perception in people with schizophrenia. Participants were exposed to a VR environment in which they had to identify visual incongruities (e.g. a tree with blue leaves). Results showed that 88% of the participants with schizophrenia failed in the task, while the non-clinical participants detected incongruities successfully.

Assessing functional capacity and social cognition and social competence

Both the research and clinical community have put special emphasis on the improvement of functional disability and social functioning in people with psychosis. The term *functional capacity* encompasses areas, such as employment, residential or financial independence (Harvey & Bowie, 2005). *Social functioning* can be described as the combination of social cognition [which refers to the mental operations and capacities that underlie social interactions (Green & Leitman, 2008)] and social competence [which refers to communication skills, e.g. the verbal and non-verbal communication skills that allow successful execution of interpersonal interactions (Dickinson *et al.* 2007)].

The first attempt to use VR to measure functional capacity in people with psychosis was conducted by Kurtz *et al.* (2006) who assessed the relationship between executive function impairments and medication management skills by using a VR apartment. Results showed that people with schizophrenia made more errors, i.e. took incorrect numbers of pills and at the incorrect time compared with the non-clinical controls. More recently, researchers have focussed on the utility of VR as an ecological valid method to place individuals into everyday situations, such as supermarkets or bus and shopping centres, to study real-time deficits in functional capacity and their relationship to cognitive impairments (Ruse *et al.* 2014; Greenwood *et al.* 2016). The findings confirmed that individuals with schizophrenia have poorer real-time function compared with healthy controls. Furthermore, these two studies have also shown that VR can be as reliable and valid as well-established neurocognitive batteries [such as MATRICS (Measurement and Treatment Research to Improve Cognition in Schizophrenia) (Nuechterlein *et al.* 2008; Ruse *et al.* 2014)] and real-life situations (Greenwood *et al.* 2016) to assess functional capacity outcomes.

Five studies have explored the utility of VR technology to study different aspects of social cognition: social perception (Ku *et al.* 2006; Kim *et al.* 2007; Park *et al.* 2009*a*) and emotion recognition (Dyck *et al.* 2010; Gutierrez-Maldonado *et al.* 2012). Studies on social perception have demonstrated that virtual agents can be used to assess potential deficits in expressing emotions (Ku *et al.* 2006), deficits in the perception of incongruent social emotional cues (Kim *et al.* 2007) and high social anxiety when meeting others (Ku *et al.* 2006; Park *et al.* 2009*a*). Furthermore, both studies from Dyck and colleagues and Gutierrez-Maldonado *et al.* demonstrated that virtual faces were as valid as natural faces (photographs) to assess emotion recognition ability in people with psychosis; the dynamic component of the VR images was found to be a clear advantage over static images to display human faces (Gutierrez-Maldonado *et al.* 2012). Park *et al.* (2009*a*, *b*) studied objective parameters of physical distance in individuals with schizophrenia in comparison to healthy controls by using virtual agents in a VR social environment (Park *et al.* 2009*b*) and found that participants with schizophrenia tended to keep more physical distance and have deviation of eye gaze than non-clinical controls.

Assessment of paranoid ideation and auditory hallucinations

Eighteen studies have used VR to assess paranoid ideation and one study investigated using VR to assess auditory hallucinations. The value of VR for studying paranoid thinking rests on the assumption that programming an environment in which the degree of hostility that the virtual characters display can be manipulated (e.g. to be neutral, benign or hostile) allows a more valid assessment of paranoia than self-report methods, where it is not known whether the hostile intent reported as experienced by the patient is accurate or not (Freeman *et al.* 2005). Details of the studies reviewed are listed in Table 4.

Freeman and colleagues have been at the forefront of researching *paranoid ideation* using VR. In their first investigation, participants from the general population were asked to explore a virtual library and to form an impression of what the avatars in the library thought about them. Results showed that participants attributed mental states to the avatars and that real-time

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paranoid ideation during VR was associated with anxiety, timidity and perceptual abnormalities (Freeman *et al.* 2003, 2005). Subsequently, this research group developed a new virtual environment simulating a London Underground train, which included several avatars (e.g. people reading the newspaper, people standing up, people coming in and out of the train, etc.). The underground environment has been used by researchers to explore persecutory ideation in a number of studies in non-clinical participants (Freeman *et al.* 2008*a*, *b*, 2010) and clinical populations, including individuals at ultra high risk for psychosis (Valmaggia *et al.* 2007, 2015*a*, *b*; Shaikh *et al.* 2016) and people with psychosis (Freeman *et al.* 2010; Fornells-Ambrojo *et al.* 2015). The main conclusions drawn from these studies were that paranoid ideation can be readily elicited in VR environments, including where the avatars are programmed to behave neutrally; that the people who had paranoid reactions in the VR environment were more prone than those who did not to internal anomalous experiences (i.e. changes in levels of sensory intensity, distortion of external world) and to self-reported paranoid ideation; and that anxiety, worry and depression were also associated with both social anxiety and paranoia. Recent findings in general population samples have shown that VR can be used to explore paranoid thinking and self-confidence in relation to social comparisons (Atherton *et al.* 2014; Freeman *et al.* 2014), to investigate the effects of THC (Δ^9-tetrahydrocannabinol) on real-time paranoid ideation (Freeman *et al.* 2015) and to study the relationship between interpersonal contingency, trust and paranoia (Fornells-Ambrojo *et al.* 2016).

Exclusion from a VR cyber-ball game and negative feedback received about the performance during the game was associated with paranoid ideation (Kesting *et al.* 2013). Previously, this team had also demonstrated the use of a VR cyber-ball game to measure the relationship between emotion regulation techniques (such as suppression or reappraisal) and paranoid ideation (Westermann *et al.* 2012).

Broome *et al*. designed a walk in a virtual street and showed that levels of paranoid ideation in an urban environment where higher than those previously reported in indoor environments (Broome *et al.* 2013). Veling *et al.* (2014*a*) conducted a pilot study in which participants were asked to walk into a virtual café and report their level of paranoid thoughts while a psychophysiological measure (galvanic skin response) was recorded. The experimenters manipulated the environment by changing the ethnicity of the avatars. The results showed that patients with first-episode psychosis were more likely than healthy controls to report paranoid thoughts when walking close to avatars and that they showed a stronger galvanic response to avatars of a different ethnicity than their own. These results have been recently replicated by the same research group, including siblings of patients and manipulating also the objective distress parameters (population and ethnic density, avatars' hostility) (Veling *et al.* 2016).

Moritz *et al.* (2014) reported the results of a non-controlled pilot study in which they combined emotion recognition and error feedback for social perception judgements. The one-session feedback intervention resulted in a reduction of paranoid ideation. Although the paradigm used in this study was proposed for assessment, the authors concluded that it might function as a short intervention to reduce negative judgements in social settings.

With regard to *auditory hallucination*, the virtual London Underground was used to explore the occurrence of auditory hallucinations during VR. While participants reported hearing voices during the VR experiment, no support was found for the role of hypothesised antecedent cognition in triggering voices (Stinson *et al.* 2010).

Treatment

Eight studies were identified investigating the use of VR in the treatment of psychosis. VR has been applied as an adjunctive treatment in cognitive remediation (Chan *et al.* 2010; Tsang & Man, 2013); to improve job interview skills (Smith *et al.* 2015) and social skills (Park *et al.* 2011; Rus-Calafell *et al.* 2014); and in cognitive behaviour (Gega *et al.* 2013; Leff, 2013; Freeman *et al.* 2016). Details of these investigations are described in Table 5.

Cognitive remediation therapy for psychotic disorders can be defined as a behavioural training-based intervention that aims to improve cognitive processes (attention, memory, executive function, social cognition and metacognition) with the goal of durability and generalisation to functioning in everyday life (Wykes & Spaulding, 2011). One important challenge within cognitive remediation research has been the adaptation of VR tasks to a specific individual needs. Chan *et al.* (2010) explored the effect of adapted VR cognitive training in older individuals with a long-term diagnosis of schizophrenia.

Results showed that participants who received the 10-sessions VR intervention had a better improvement in overall cognitive function than controls, who received the usual programme in the clinic. Tsang & Man (2013) considered the effectiveness of VR as an intervention for enhancing cognitive performance among people with a diagnosis of schizophrenia with the goal of improving their vocational skills. The

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virtual intervention group engaged in tasks related to work performance in a virtual boutique. Results showed that the group who received the virtual intervention performed better on executive function, problem solving, categorisation, memory, attention and self-efficacy than the therapist-administered group (with the same task content as the VR intervention).

Smith and colleagues also investigated the use of VR to improve job-interview skills and self-confidence. Their finding suggests VR can improve the specific cognitions and behaviours needed for job interviews and employment, with positive results maintained at 6-month follow-up (Smith *et al.* 2015).

Social skills training aims to improve social and interpersonal skills in people who have difficulties in communicating in social situations. In terms of social behaviour improvement and social skills training using VR, two controlled studies were identified. Park *et al.* (2011) compared the use of a social skills intervention, i.e. traditional role-play, to a virtual environment where patients with a diagnosis of schizophrenia engage in role-play with virtual persons. All participants received 10 bi-weekly group sessions. Results showed that both groups improved in verbal skills. The virtual intervention was shown to be more engaging than the traditional intervention. Subsequently, Rus-Calafell *et al.* (2014) researched the benefits of using VR as adjunctive method for social skills training with patients with psychosis 'Soskitrain' resulted in significant improvement in negative symptoms and social avoidance together with an improvement in social skills, in comparison to baseline performance. These gains were maintained at 4-month follow-up (Rus-Calafell *et al.* 2014).

VR-assisted therapy for paranoia and hallucinations. To date, two proof-of-concept studies have investigated the use of VR-assisted therapy for paranoia and one pilot study investigated using VR to treat people with auditory hallucinations. Gega *et al*. conducted a proof-of-concept study to test whether VR could be integrated with a 12-week cognitive–behavioural treatment (CBT) programme for people with paranoia and social anxiety. One VR session was embedded in a 12-week course of CBT. In the VR session, patients were able to practice social interactions with avatars in a variety of social situations. Avatars could be hostile, neutral or friendly and asked patients innocuous or personal questions. Results showed that the VR-assisted intervention reduced social anxiety and paranoia at 24-week follow-up (Gega *et al.* 2013).

Freeman and colleagues have also conducted a proof-of-concept study in which they investigated encouraging people with long-standing persecutory delusions to test their threat beliefs and drop their safety behaviours in a VR underground and a VR lift. This one session intervention led to a significant decrease of delusional conviction in the participants (Freeman *et al.* 2016).

AVATAR therapy uses a non-immersive VR system to enable people with auditory hallucinations to challenge their beliefs about the power of the voices and gain more control over the voices they hear. Participants are asked to create an avatar of the entity that they believe is talking to them. They then engage in a dialogue with the avatar of their voice, which the therapist is able to control. A pilot study indicated that patients are able to engage in the dialogue with a virtual voice and the experimental group was found to have an overall reduction in mean scores of auditory hallucinations (Leff, 2013).

General discussion

The current systematic review examines the use of VR in the research, assessment and treatment of psychosis. According to the studies reviewed, VR is a *safe and well-tolerated* tool to explore neurocognitive deficits, to study relevant clinical symptoms, and to investigate symptom correlations and casual factors in people who suffer from psychotic disorders. Participants did not show any exacerbation of psychotic symptoms after exposure to VR environments and they did not report any distress related to the experimental situations. Extensive effort has gone into using VR according to ethical standards and it is important to design age-appropriate experiences, delivered and monitored by professionals, which a clear contextualisation and debriefing after completion of the task. Furthermore, recommendations for the ethical use of VR in scientific practice have been published (Madary & Metzinger, 2016).

The use of VR for neurocognitive assessment in psychosis is still in its infancy, and the validity and reliability of VR as a neurocognitive assessment tool remains to be established. Despite these limitations, the studies reviewed suggest that VR has the potential to be an effective additional tool in research in *neurocognitive functioning*, capturing the main impairments associated with psychotic spectrum disorder. Conventional neurocognitive testing enables the assessment of individual cognitive functions in a controlled laboratory setting but has limited generalisability to real-life situations (Rizzo & Buckwalter, 1997). VR has the potential to overcome this limitation by enabling the assessment of multiple cognitive functions in an ecologically valid environment (Parsons *et al.* 2017). Particularly, VR allows the simultaneous assessment of multimodal performance, to easily manipulate the location of objects and the subject's position within the environment, as well as the

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possibility of including changing levels of sensory input to increase/decrease the complexity of the task.

The studies focussing *on functional capacity and social functioning* have shown that VR enables the introduction of virtual agents and the manipulation of interpersonal communication cues (sounds, laughs, affect, prosody), enhancing the emotional, social and functional assessment. VR also offers innovative possibilities of modifying and controlling avatars' behaviour as well as to introducing environmental factors, such as number of people present or amount of eye contact, which may elicit paranoia and help to identify factors associated in everyday life with persecutory thoughts (Freeman *et al.* 2008*b*). This controllability and environment manipulation are very difficult to achieve in the clinical context or in a more traditional experimental setting, and leads directly to possible new intervention approaches.

The majority of *symptom assessment* studies to date have been focussed on paranoid thinking, with only one study exploring auditory hallucinations. Although these studies have used larger samples than in the neurocognitive evaluation field, the largest samples are non-clinical population studies and the generalisability of these findings to a clinical population remains to be seen. However, the use of non-clinical populations allows researchers to test theoretical hypotheses concerning the continuum of severity of paranoia in the general population and causal models (Freeman, 2008) and generated interesting and novel findings about correlates and triggers of paranoid ideation (Valmaggia *et al.* 2016*a*).

The most important added benefits of VR may, in the long run, prove to be for *treatment*. VR enables the clinician to help people to observe and modify their emotions, cognitions and behaviours directly and as they occur, and in carefully controlled environments. In three of the eight treatment studies, authors highlighted that participants reported that they enjoyed the use of new technologies in the clinical setting (Rus-Calafell *et al.* 2014), that it enhanced their motivation towards treatment (Park *et al.* 2011) and that it was more interesting and useful than conventional training (Tsang & Man, 2013). Clearly these studies are in a very early stage of development and the small total number of studies cannot yet demonstrate whether VR is more efficacious or efficient than other interventions designed for same purposes and which require less technological resources. Although the studies reviewed are mostly small pilot studies, in some cases, the effect sizes for target symptom change are promisingly large (Leff, 2013; Freeman *et al.* 2016), and two ongoing large randomised controlled studies, both currently in the final stage of recruitment, may help answer some of these questions (Craig *et al.* 2015; Pot-Kolder *et al.* 2016). It also remains unclear whether VR-based treatments improve generalisation of responses to the individual's daily life. Although some of the studies included observational measures rated by independent assessors including participant's relatives (Rus-Calafell *et al.* 2014), ecological validity of the environments is not enough to assume the transfer of learnt skills between the clinical setting and real life, and more research is needed to establish whether improvements achieved in VR do translate to changes in real-life functioning.

Limitations

Despite the clear strengths of VR, it must be noted that there are limitations to the available evidence. Since the research and application of VR in psychosis is still in its preliminary stage, and not fully implemented in the clinical context, these results should be taken cautiously. A number of limitations of the current literature should be considered: a possible limitation of the current review is the inclusion of studies that presented a 2D virtual environment using a computer screen. Different interactive computer technologies and interventions have been described as VR, including 2D computer screen tasks with an interactive component and others, which use 3D immersive head-mounted displays. While immersive 3D VR is considered to have a higher ecological validity (Parsons *et al.* 2017), earlier studies reported that the heavy head-mounted displays and cyber sickness were actually disrupting the sense of presence. Furthermore, it has been suggested that it is the degree of immersion with the artificial reality which is key in describing an environment as virtual (Olivera *et al.* 2016). Further empirical testing is needed to confirm whether 3D environments is indeed always necessary or required, in the AVATAR study (Leff, 2013), e.g. a sense of immersion is generated by manipulating the sound of the virtual voice rather than immersing the participant in a 3D visual environment.

The reviewed studies included comparison of control groups of healthy participants, but most of the samples were relatively small. Furthermore, this was a relatively unsophisticated research strategy in that comparisons with healthy controls failed to take account of any confounding factors, which may affect attention, memory and executive functioning abilities, such as the effects of the duration of illness or the use of antipsychotic medication. The processes involved in VR-assisted therapy remain relatively unexplored, and assessment studies as well as treatment studies have not generally demonstrated how the findings translate to the real-world environment. Future research would also benefit from including

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longer follow-ups leading to better understanding of the illness prognosis and maintenance of positive effects on therapy outcomes. Physiological feedback provided to VR users before and during each VR session might increase patient's self-efficacy with regards to performing a task in the real world. Therefore, future studies might benefit from including more sensitive physiological measures, such as heart rate variability, galvanic skin response and blood pressure.

It is also important to take into consideration the potential negative social implications of VR, such as those that have been linked with other technologies, including television and video games (e.g. increasing social withdrawal or addictive behaviour). However, the studies reviewed here involved the use of the technology for assessment purposes or clinical goals, always under the supervision of qualified professionals. In the past equipment, costs have also been a major limitation in this field. New VR systems can run at a fraction of the costs; however, the development of specialised software is still very costly. A final potential disadvantage of VR is that some individuals have reported simulator sickness during VR exposure. New head-mounted displays have reduced the occurrence of cyber sickness.

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Declaration of Interest

The authors work in a VR laboratory and have published some of the studies reviewed in this review.

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