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

Running Title: Virtual reality for psychosis, a systematic review

Mar Rus-Calafell[1,2], Philippa Garety[1,2], Elinor Sason[1], Thomas J.K. Craig[1,2], Lucia R. Valmaggia[1, 2*]

1.King's College London, Institute of Psychiatry, Psychology and Neuroscience, London, England

2.South London and Maudsley NHS Trust, London, England

*Corresponding author:

Dr Lucia R. Valmaggia, King's College London, Institute of Psychiatry, Psychology and Neuroscience, Department of Psychology (PO 77), De Crespigny Park, SE5 8AF London, United Kingdom

E-mail: Lucia.Valmaggia@kcl.ac.uk

Total words abstract: 238

Total words: 4,861

Number of figures and tables: 6

Abstract

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 generalizability 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.

Keywords: psychosis; schizophrenia; paranoia; hallucinations; neuropsychology; social functioning; virtual reality; systematic review

1. 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 (Eichenberg and Wolters, 2012, Slater, 2004). 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., 2016b), 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 lab environment; to enhance the understanding of psychosis; to assess psychotic symptoms; or to treat these disorders (Freeman, 2008, Veling et al., 2014b, Valmaggia et al., 2016a).

The aim of the present study is to conduct a detailed review of the main applications of virtual reality 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.

2. Methods

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

2.1. Selection Procedure

2.1.1. Literature Search

The databases used were Web of Science, PsychInfo, Embase, Scopus, ProQuest, and PubMed. Unpublished dissertations, conference proceedings and abstracts without locatable full texts were excluded. The search was limited to studies available from selected databases up to the 1st of June 2016.

2.1.2. Inclusion and exclusion criteria

The primary criteria for inclusion were that the studies used immersive and interactive VR environments in 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.

2.1.3 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.

2.2 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.

3. Results

3.1. 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 Figure 1). While all studies assessed the safety and acceptability of the VR environment, three studies focused 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; nineteen on the assessment of psychosis symptoms; and eight on the use of VR in the treatment of psychosis.

-- Figure 1 --

3.2 Quality Assessment

Independent ratings were carried out by the first and last author, resolving disagreements by consensus. As shown in Tables 1 to 5, the majority of studies received an QATA global rating of strong. . It is however important to point out 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.

3.3 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 and 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.

- Table 1 -

3.4 Neurocognitive Evaluation

Neurocognitive evaluation can be described as a method through which data about a participant's 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, Wilkins et al., 2013a, Wilkins et al., 2013b, Weniger and Irle, 2008, Spieker et al., 2012, 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.

-- Table 2 --

Spatial working memory enables us to integrate various type 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 (Wilkins et al., 2013a, Weniger and Irle, 2008); made more errors and needed a longer time to locate targets than controls (Wilkins et al., 2013b, Spieker et al., 2012); 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 and colleagues 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., 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 and 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 (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.

3.5 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 and 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 and Leitman, 2008) and social competence (which refers to communication skills, e.g., the verbal and nonverbal 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 and colleagues (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 to 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 (Greenwood et al., 2016b, Ruse et al., 2014). The findings confirmed that individuals with schizophrenia have poorer real-time function compared to 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 (Nuechterlein et al., 2008, Ruse et al., 2014) and real-life situations (Greenwood et al., 2016a) 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., 2009a) 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., 2009a). Furthermore, both studies from Dyck and colleagues and Gutierrez-Maldonado and colleagues 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) 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., 2009b) and found that participants with schizophrenia tended to keep more physical distance and have deviation of eye gaze than non-clinical controls.

3.6 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 (for example 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.

- 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 paranoid ideation during VR was associated with anxiety, timidity and perceptual abnormalities (Freeman et al., 2005, Freeman et al., 2003). 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., 2008a, Freeman et al., 2008b, Freeman et al., 2010) and clinical populations, including individuals at ultra high risk for psychosis (Shaikh et al., 2016, Valmaggia et al., 2015a, Valmaggia et al., 2015b, Valmaggia et al., 2007) and people with psychosis (Fornells-

Ambrojo et al., 2015, Freeman et al., 2010). 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 (Freeman et al., 2014, Atherton 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 and colleagues 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 and colleagues (Veling et al., 2014a) 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 and colleagues (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 judgments. 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).

3.7 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 and 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 (Freeman et al., 2016, Gega et al., 2013, Leff, 2013). Details of these investigations are described in Table 5.

-- 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 generalization to functioning in everyday life (Wykes and Spaulding, 2011). One important challenge within cognitive remediation research has been the adaptation of VR tasks to a specific individual needs. Chan and others (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 program in the clinic. Tsang & Man (Tsang and 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 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, categorization, 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 six months 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 and colleagues (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 ten 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 and colleagues (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 four-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 and colleagues conducted a proof of concept study to test whether VR could be integrated with a 12-week cognitive behavioural treatment (CBT) program 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 weeks 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).

4. 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 and Metzinger, 2016).

The use us 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 and 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., 2015). 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 possibility of including changing levels of sensory input to increase/decrease the complexity of the task.

The studies focusing *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., 2008b). 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 focused 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., 2016a).

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 and 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 (Freeman et al., 2016, Leff, 2013) and two on-going large randomized controlled study, both currently in the final stage of recruitment may help answer some of

these questions (Pot-Kolder et al., 2016, Craig et al., 2015). 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.

4.1 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 which 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 have a higher ecological validity (Parsons et al., 2015) 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) for

example, a sense of immersion is generated by manipulating the sound of the virtual voice rather then immersing the participant in a 3D visual environment.

The reviewed studies included comparison 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 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 specialized 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.

Acknowledgments

We acknowledge the NIHR Biomedical Research Centre for Mental Health at the South London and Maudsley NHS Foundation Trust and Institute of Psychiatry King's College London for their support**.**

Conflict of interest

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

Financial Support

None

5. References

ATHERTON, S., ANTLEY, A., EVANS, N., CERNIS, E., LISTER, R., DUNN, G., SLATER, M. & FREEMAN, D. 2014. Self-Confidence and Paranoia: An Experimental Study Using an Immersive Virtual Reality Social Situation. *Behavioural and Cognitive Psychotherapy,* 11**,** 1-9.

BROOME, M. R., ZANYI, E., HAMBORG, T., SELMANOVIC, E., CZANNER, S., BIRCHWOOD, M., CHALMERS, A. & SINGH, S. P. 2013. A high-fidelity virtual environment for the study of paranoia. *Schizophrenia Research and Treatment,* 2013**,** 7.

CHAN, C. L. F., NGAI, E. K. Y., LEUNG, P. K. H. & WONG, S. 2010. Effect of the adapted virtual reality cognitive training program among Chinese older adults with chronic schizophrenia: A pilot study. *International Journal of Geriatric Psychiatry,* 25**,** 643-649.

CHAN, R. C., SHUM, D., TOULOPOULOU, T. & CHEN, E. Y. 2008. Assessment of executive functions: review of instruments and identification of critical issues. *Archives of Clinical Neuropsychology,* 23**,** 201-16.

CRAIG, T. K., RUS-CALAFELL, M., WARD, T., FORNELLS-AMBROJO, M., MCCRONE, P., EMSLEY, R. & GARETY, P. 2015. The effects of an Audio Visual Assisted Therapy Aid for Refractory auditory hallucinations (AVATAR therapy): study protocol for a randomised controlled trial. *Trials,* 16**,** 349.

DA COSTA, R. M. & DE CARVALHO, L. A. 2004. The acceptance of virtual reality devices for cognitive rehabilitation: a report of positive results with schizophrenia. *Computer Methods and Programs in Biomedicine,* 73**,** 173-82.

DICKINSON, D., BELLACK, A. S. & GOLD, J. M. 2007. Social/communication skills, cognition, and vocational functioning in schizophrenia. *Schizophr Bull,* 33**,** 1213-20.

DYCK, M., WINBECK, M., LEIBERG, S., CHEN, Y. & MATHIAK, K. 2010. Virtual faces as a tool to study emotion recognition deficits in schizophrenia. *Psychiatry Research,* 179**,** 247-252.

EICHENBERG, C. & WOLTERS, C. 2012. Virtual Realities in the Treatment of Mental Disorders: A Review of the Current State of Research. *InTech.*

FAJNEROVA, I., RODRIGUEZ, M., LEVCIK, D., KONRADOVA, L., MIKOLAS, P., BROM, C., STUCHLIK, A., VLCEK, K. & HORACEK, J. 2014. A virtual reality task based on animal research - spatial learning and memory in patients after the first episode of schizophrenia. *Frontiers in Behavioral Neuroscience,* 8.

FORNELLS-AMBROJO, M., BARKER, C., SWAPP, D., SLATER, M., ANTLEY, A. & FREEMAN, D. 2008. Virtual reality and persecutory delusions: safety and feasibility. *Schizophrenia Research,* 104**,** 228-36.

FORNELLS-AMBROJO, M., ELENBAAS, M., BARKER, C., SWAPP, D., NAVARRO, X., ROVIRA, A., SANAHUJA, J. M. & SLATER, M. 2016. Hypersensitivity to Contingent Behavior in Paranoia: A New Virtual Reality Paradigm. *The Journal of Nervous and Mental Disease,* 204**,** 148-52.

FORNELLS-AMBROJO, M., FREEMAN, D., SLATER, M., SWAPP, D., ANTLEY, A. & BARKER, C. 2015. How do people with persecutory delusions evaluate threat in a controlled social environment? A qualitative study using virtual reality. *Behavioural and Cognitive Psychotherapy,* 43**,** 89-107.

FREEMAN, D. 2008. Studying and treating schizophrenia using virtual reality: a new paradigm. *Schizophrenia Bulletin,* 34**,** 605-610.

FREEMAN, D., BRADLEY, J., ANTLEY, A., BOURKE, E., DEWEEVER, N., EVANS, N., CERNIS, E., SHEAVES, B., WAITE, F., DUNN, G., SLATER, M. & CLARK, D. M. 2016. Virtual reality in the treatment of persecutory delusions: randomised controlled experimental study testing how to reduce delusional conviction. *British Journal of Psychiatry,* 209**,** 62-7.

FREEMAN, D., DUNN, G., MURRAY, R. M., EVANS, N., LISTER, R., ANTLEY, A., SLATER, M., GODLEWSKA, B., CORNISH, R., WILLIAMS, J., DI SIMPLICIO, M., IGOUMENOU, A., BRENNEISEN, R., TUNBRIDGE, E. M., HARRISON, P. J., HARMER, C. J., COWEN, P. & MORRISON, P. D. 2015. How cannabis causes paranoia: using the intravenous administration of 9-tetrahydrocannabinol (THC) to identify key cognitive mechanisms leading to paranoia. *Schizophrenia Bulletin,* 41**,** 391-9.

FREEMAN, D., EVANS, N., LISTER, R., ANTLEY, A., DUNN, G. & SLATER, M. 2014. Height, social comparison, and paranoia: an immersive virtual reality experimental study. *Psychiatry Research,* 218**,** 348-52.

FREEMAN, D., GARETY, P. A., BEBBINGTON, P., SLATER, M., KUIPERS, E., FOWLER, D., GREEN, C., JORDAN, J., RAY, K. & DUNN, G. 2005. The psychology of persecutory ideation II: a virtual reality experimental study. *The Journal of Nervous and Mental Disease,* 193**,** 309-15.

FREEMAN, D., GITTINS, M., PUGH, K., ANTLEY, A., SLATER, M. & DUNN, G. 2008a. What makes one person paranoid and another person anxious? The differential prediction of social anxiety and persecutory ideation in an experimental situation. *Psychological Medicine,* 38**,** 1121-1132.

FREEMAN, D., PUGH, K., ANTLEY, A., SLATER, M., BEBBINGTON, P., GITTINS, M., DUNN, G., KUIPERS, E., FOWLER, D. & GARETY, P. 2008b. Virtual reality study of paranoid thinking in the general population. *British Journal of Psychiatry,* 192**,** 258-63.

FREEMAN, D., PUGH, K., VORONTSOVA, N., ANTLEY, A. & SLATER, M. 2010. Testing the continuum of delusional beliefs: an experimental study using virtual reality. *Journal of Abnormal Psychology,* 119**,** 83-92.

FREEMAN, D., SLATER, M., BEBBINGTON, P. E., GARETY, P. A., KUIPERS, E., FOWLER, D., MET, A., READ, C. M., JORDAN, J. & VINAYAGAMOORTHY, V. 2003. Can virtual reality be used to investigate persecutory ideation? *The Journal of nervous and mental disease,* 191**,** 509-14.

GEGA, L., WHITE, R., CLARKE, T., TURNER, R. & FOWLER, D. 2013. Virtual environments using video capture for social phobia with psychosis. *Cyberpsychology, Behavior, and Social Networking,* 16**,** 473-479.

GREEN, M. F., KERN, R. S., BRAFF, D. L. & MINTZ, J. 2000. Neurocognitive deficits and functional outcome in schizophrenia: are we measuring the "right stuff"? *Schizophrenia Bulletin,* 26**,** 119-36.

GREEN, M. F. & LEITMAN, D. I. 2008. Social cognition in schizophrenia. *Schizophrenia Bulletin,* 34**,** 670-2.

GREENWOOD, K. E., MORRIS, R., SMITH, V., JONES, A., PEARMAN, D. & WYKES, T. 2016a. Virtual shopping: a viable alternative to direct assessment of real life function? *Schizophrenia Research,* 172**,** 206-210.

GREENWOOD, K. E., MORRIS, R., SMITH, V., JONES, A. M., PEARMAN, D. & WYKES, T. 2016b. Virtual shopping: A viable alternative to direct assessment of real life function? *Schizophrenia Research,* 172**,** 206-10.

GUTIERREZ-MALDONADO, J., RUS-CALAFELL, M., MARQUEZ-REJON, S. & RIBAS-SABATE, J. 2012. Associations Between Facial Emotion Recognition, Cognition and Alexithymia in Patients with Schizophrenia: Comparison of Photographic and Virtual Reality Presentations. *Annual Review of Cybertherapy and Telemedicine 2012***,** 88-92.

HARVEY, P. D. & BOWIE, C. R. 2005. Late-life schizophrenia. What providers need to know. *Director,* 13**,** 90, 93-4.

JOSMAN, N., SCHENIRDERMAN, A. E., KLINGER, E. & SHEVIL, E. 2009. Using virtual reality to evaluate executive functioning among persons with schizophrenia: a validity study. *Schizophrenia Research,* 115**,** 270-277.

KESTING, M. L., BREDENPOHL, M., KLENKE, J., WESTERMANN, S. & LINCOLN, T. M. 2013. The impact of social stress on self-esteem and paranoid ideation. *Journal of Behavior Therapy and Experimental Psychiatry,* 44**,** 122-8.

KIM, K., KIM, J.-J., KIM, J., PARK, D.-E., JANG, H. J., KU, J., KIM, C.-H., KIM, I. Y. & KIM, S. I. 2007. Characteristics of social perception assessed in schizophrenia using virtual reality. *Cyberpsychology and Behavior,* 10**,** 215-219.

KIRCHER, T. T. & LEUBE, D. T. 2003. Self-consciousness, self-agency, and schizophrenia. *Consciousness and Cognition,* 12**,** 656-69.

KU, J., CHO, W., KIM, J. J., PELED, A., WIEDERHOLD, B. K., WIEDERHOLD, M. D., KIM, I. Y., LEE, J. H. & KIM, S. I. 2003. A virtual environment for investigating schizophrenic patients' characteristics: assessment of cognitive and navigation ability. *Cyberpsychology and Behavior,* 6**,** 397-404.

KU, J., JANG, H. J., KIM, K. U., PARK, S. H., KIM, J. J., KIM, C. H., NAM, S. W., KIM, I. Y. & KIM, S. I. 2006. Pilot study for assessing the behaviors of patients with schizophrenia towards a virtual avatar. *Cyberpsychology and Behavior,* 9**,** 531-9.

KURTZ, M. M., BAKER, E. K. & ASTUR, R. S. 2006. Virtual reality assessment of medication compliance in patients with schizophrenia. . *Cyberpsychology & Behavior,* 9**,** 224-229.

LANDGRAF, S., KREBS, M.-O., OLIE, J.-P., COMMITTERI, G., VAN DER MEER, E., BERTHOZ, A. & AMADO, I. 2010. Real world referencing and schizophrenia: are we experiencing the same reality? *Neuropsychologia,* 48**,** 2922-2930.

LEFF, J. 2013. Computer-assisted therapy for medication-resistant auditory hallucinations (vol 202, pg 428, 2013). *British Journal of Psychiatry,* 203**,** 313-313.

LIDDLE, P. F. 1987. Schizophrenic syndromes, cognitive performance and neurological dysfunction. *Psychological Medicine,* 17**,** 49-57.

MADARY, M. & METZINGER, T. K. 2016. Real Virtuality: A Code of Ethical Conduct. Recommendations for Good Scientific Practice and the Consumers of VR-Technology. *Frontiers in Robotics and AI,* 3.

MORITZ, S., VOIGT, M., KÖTHER, U., LEIGHTON, L., KJAHILI, B., BABUR, Z., JUNGCLAUSSEN, D., VECKENSTEDT, R. & GRZELLA, K. 2014. Can virtual reality reduce reality distortion? Impact of performance feedback on symptom change in schizophrenia patients. *Journal of Behavior Therapy and Experimental Psychiatry,* 45**,** 267-271.

NUECHTERLEIN, K. H., GREEN, M. F., KERN, R. S., BAADE, L. E., BARCH, D. M., COHEN, J. D., ESSOCK, S., FENTON, W. S., FRESE, F. J., 3RD, GOLD, J. M., GOLDBERG, T., HEATON, R. K., KEEFE, R. S., KRAEMER, H., MESHOLAM-GATELY, R., SEIDMAN, L. J., STOVER, E., WEINBERGER, D. R., YOUNG, A. S., ZALCMAN, S. & MARDER, S. R. 2008. The MATRICS Consensus Cognitive Battery, part 1: test selection, reliability, and validity. *American Journal of Psychiatry,* 165**,** 203-13.

OLIVERA, T. A., MARANGHELLO, N., SILVE, A. C. R. & PEREIRA, A. S. 2016. Virtual Laboratories Development Using 3D Environments. *Handbook of Research on 3-D Virtual Environments and Hypermedia for Ubiquitous Learning.* Hershey, PA, USA: IGI Global.

OLTON, D. S., BECKER, J. T. & G.E., H. 1979. Hippocampus. space and memory. *The Behavioral and Brain Sciences***,** 313-315. .

PARK, I. H., KIM, J. J., KU, J., JANG, H. J., PARK, S. H., KIM, C. H., KIM, I. Y. & KIM, S. I. 2009a. Characteristics of social anxiety from virtual interpersonal interactions in patients with schizophrenia. *Psychiatry,* 72**,** 79-93.

PARK, K., KU, J., CHOI, S., JANG, H., PARK, J., KIM, S. I. & KIM, J. 2011. A virtual reality application in role-plays of social skills training for schizophrenia: A randomized, controlled trial. *Psychiatry Research,* 189**,** 166-172.

PARK, S. H., KU, J., KIM, J. J., JANG, H. J., KIM, S. Y., KIM, S. H., KIM, C. H., LEE, H., KIM, I. Y. & KIM, S. I. 2009b. Increased personal space of patients with schizophrenia in a virtual social environment. *Psychiatry Research,* 169**,** 197-202.

PARSONS, T. D., CARLEW, A. R., MAGTOTO, J. & STONECIPHER, K. 2015. The potential of function-led virtual environments for ecologically valid measures of executive function in experimental and clinical neuropsychology. *Neuropsychological Rehabilitation***,** 1-31.

POT-KOLDER, R., VELING, W., GERAETS, C. & VAN DER GAAG, M. 2016. Effect of virtual reality exposure therapy on social participation in people with a psychotic disorder (VRETp): study protocol for a randomized controlled trial. *Trials,* 17.

RIZZO, A. A. & BUCKWALTER, J. G. 1997. Virtual reality and cognitive assessment and rehabilitation: the state of the art. *Studies in Health Technology and Informatics,* 44**,** 123-45.

RIZZO, A. S., BUCKWALTER, J. G., FORBELL, E., REIST, C., DIFEDE, J., ROTHBAUM, B. O., LANGE, B., KOENIG, S. & TALBOT, T. 2013. Virtual Reality Applications to Address the Wounds of War. *Psychiatric Annals,* 43**,** 123-138.

RUS-CALAFELL, M., GUTIERREZ-MALDONADO, J. & RIBAS-SABATE, J. 2014. A brief cognitive-behavioural social skills training for stabilised outpatients with schizophrenia: A preliminary study. . *Schizophrenia Research,* 143**,** 327-336.

RUSE, S. A., HARVEY, P. D., DAVIS, V. G., ATKINS, A. S., FOX, K. H. & KEEFE, R. S. 2014. Virtual Reality Functional Capacity Assessment In Schizophrenia: Preliminary

Data Regarding Feasibility and Correlations with Cognitive and Functional Capacity Performance. *Schizophrenia Research: Cognition,* 1**,** e21-e26.

SHAIKH, M., ELLETT, L., DUTT, A., DAY, F., LAING, K., KROLL, J., PTERELLA, S., MCGUIRE, P. & VALMAGGIA, L. 2016. Perceived ethnic discrimination and persecutory paranoia in individuals at ultra-high risk for psychosis. *Psychiatry Research*.

SLATER, M. 2004. Presence and emotions. *Cyberpsychology and Behavior,* 7**,** 121; author reply 123.

SMITH, M. J., FLEMING, M. F., WRIGHT, M. A., ROBERTS, A. G., HUMM, L. B., OLSEN, D. & BELL, M. D. 2015. Virtual reality job interview training and 6-month employment outcomes for individuals with schizophrenia seeking employment. *Schizophrenia Research,* 166**,** 86-91.

SORKIN, A., WEINSHALL, D., MODAI, I. & PELED, A. 2006. Improving the accuracy of the diagnosis of schizophrenia by means of virtual reality. *American Journal of Psychiatry,* 163**,** 512-20.

SORKIN, A., WEINSHALL, D. & PELED, A. 2008. The distortion of reality perception in schizophrenia patients, as measured in Virtual Reality. *Studies in Health Technology and Informatics,* 132**,** 475-480.

SPIEKER, E. A., ASTUR, R. S., WEST, J. T., GRIEGO, J. A. & ROWLAND, L. M. 2012. Spatial memory deficits in a virtual reality eight-arm radial maze in schizophrenia. *Schizophrenia Research,* 135**,** 84-9.

STINSON, K., VALMAGGIA, L. R., ANTLEY, A., SLATER, M. & FREEMAN, D. 2010. Cognitive triggers of auditory hallucinations: an experimental investigation. *Journal of Behavior Therapy and Experimental Psychiatry,* 41**,** 179-84.

SYNOFZIK, M., THIER, P., LEUBE, D. T., SCHLOTTERBECK, P. & LINDNER, A. 2010. Misattributions of agency in schizophrenia are based on imprecise predictions about the sensory consequences of one's actions. *Brain,* 133**,** 262-271.

THOMAS, B. H., CILISKA, D., DOBBINS, M. & MICUCCI, S. 2004. A process for systematically reviewing the literature: providing the research evidence for public health nursing interventions. *Worldviews on Evidence Based Nursing,* 1**,** 176-84.

TSANG, M. M. & MAN, D. W. 2013. A virtual reality-based vocational training system (VRVTS) for people with schizophrenia in vocational rehabilitation. *Schizophrenia Research,* 144**,** 51-62.

VALMAGGIA, L. R., DAY, F., GARETY, P., FREEMAN, D., ANTLEY, A., SLATER, M., SWAPP, D., MYIN-GERMEYS, I. & MCGUIRE, P. 2015a. Social defeat predicts paranoid appraisals in people at high risk for psychosis. *Schizophrenia Research,* 168**,** 16-22.

VALMAGGIA, L. R., DAY, F. & RUS-CALAFELL, M. 2016a. Using virtual reality to investigate psychological processes and mechanisms associated with the onset and maintenance of psychosis: a systematic review. *Social Psychiatry and Psychiatric Epidemiology,* 51**,** 921-36.

VALMAGGIA, L. R., DAY, F. L., KROLL, J., LAING, J., BYRNE, M., FUSAR-POLI, P. & MCGUIRE, P. 2015b. Bullying victimisation and paranoid ideation in people at ultra high risk for psychosis. *Schizophrenia Research,* 168**,** 68-73.

VALMAGGIA, L. R., FREEMAN, D., GREEN, C., GARETY, P., SWAPP, D., ANTLEY, A., PRESCOTT, C., FOWLER, D., KUIPERS, E., BEBBINGTON, P., SLATER, M.,

BROOME, M. & MCGUIRE, P. K. 2007. Virtual reality and paranoid ideations in people with an 'at-risk mental state' for psychosis. *British Journal of Psychiatry,* 191**,** s63-s68.

VALMAGGIA, L. R., LATIF, L., KEMPTON, M. J. & RUS-CALAFELL, M. 2016b. Virtual reality in the psychological treatment for mental health problems: An systematic review of recent evidence. *Psychiatry Research,* 236**,** 189-95.

VELING, W., BRINKMAN, W. P., DORRESTIJN, E. & VAN DER GAAG, M. 2014a. Virtual reality experiments linking social environment and psychosis: a pilot study. *Cyberpsychology, Behavior and Social Networking,* 17**,** 191-5.

VELING, W., MORITZ, S. & VAN DER GAAG, M. 2014b. Brave new worlds--review and update on virtual reality assessment and treatment in psychosis. *Schizophrenia Bulletin,* 40**,** 1194-7.

VELING, W., POT-KOLDER, R., COUNOTTE, J., VAN OS, J. & VAN DER GAAG, M. 2016. Environmental Social Stress, Paranoia and Psychosis Liability: A Virtual Reality Study. *Schizophrenia Bulletin*.

WENIGER, G. & IRLE, E. 2008. Allocentric memory impaired and egocentric memory intact as assessed by virtual reality in recent-onset schizophrenia. *Schizophrenia Research,* 101**,** 201-209.

WESTERMANN, S., KESTING, M.-L. & LINCOLN, T. M. 2012. Being deluded after being excluded? How emotion regulation deficits in paranoia-prone individuals affect state paranoia during experimentally induced social stress. *Behavior Therapy,* 43**,** 329-340.

WILKINS, L. K., GIRARD, T. A., KING, J., KING, M. J., HERDMAN, K. A., CHRISTENSEN, B. K. & KING, J. 2013a. Spatial-memory deficit in schizophrenia spectrum disorders under viewpoint-independent demands in the virtual courtyard task. *Journal of Clincal and Experimental Neuropsychology,* 35**,** 1082-93.

WILKINS, L. K., GIRARD, T. A., KONISHI, K., KING, M., HERDMAN, K. A., KING, J., CHRISTENSEN, B. & BOHBOT, V. D. 2013b. Selective deficit in spatial memory strategies contrast to intact response strategies in patients with schizophrenia spectrum disorders tested in a virtual navigation task. *Hippocampus,* 23**,** 1015-24.

WYKES, T. & SPAULDING, W. D. 2011. Thinking About the Future Cognitive Remediation Therapy-What Works and Could We Do Better? *Schizophrenia Bulletin,* 37**,** S80-S90.

YEH, S. C., LEE, S. H., CHAN, R. C., CHEN, S. & RIZZO, A. 2014. A virtual reality system integrated with robot-assisted haptics to simulate pinch-grip task: Motor ingredients for the assessment in chronic stroke. *NeuroRehabilitation,* 35**,** 435-49.

Figure 1: PRISMA Flow Diagram

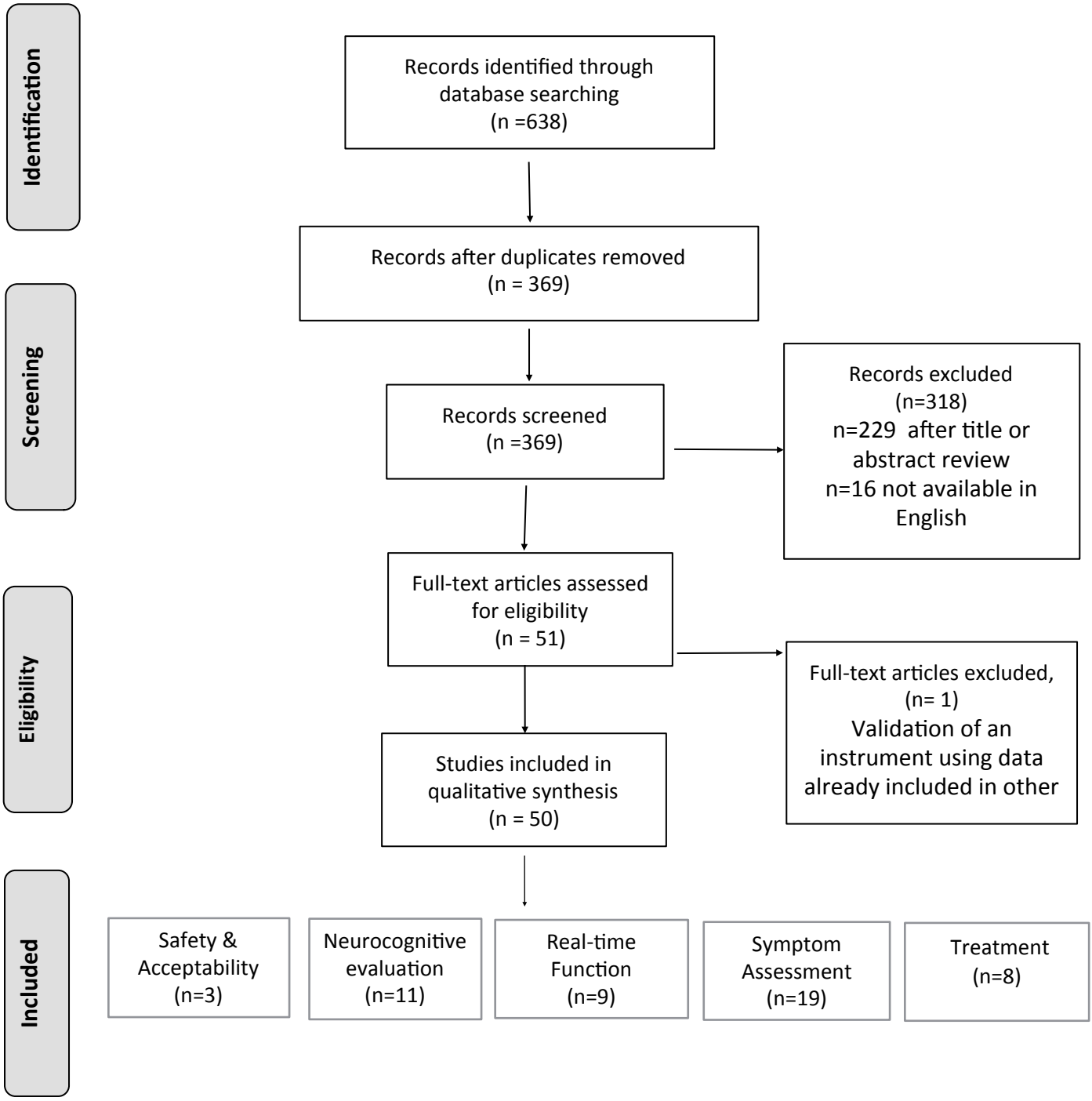

Table 1
Studies assessing safety and acceptability of virtual reality in people with psychosis

Study	Area explored	No. of Participants	VR equipment	Experimental task	Main measure	Main Findings	QATA Global Rating
Da-Costa, & De-Carvalho, 2004	Acceptability & Safety	4 participants with schizophrenia 3 males and 1 female mean age: 45 (SD 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 & Safety	20 participants with persecutory delusions 17 males and 3 females mean age: 23.5 (SD 3.1) 20 non-clinical controls 19 males and 1 female mean age: 25.5 (SD 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 one-week follow-up.	Strong
Valmaggia et al., 2007	Acceptability & Safety	21 participants with at-risk mental state 13 males and 8 females mean age: 25 (SD 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 one-week follow-up.	Strong

Note: EPHPP: Effective Public Heath Practice Project Quality Assessment Tool for Quantitative Studies; HMD: Head Mounted Display; SD: Standard Deviation; SSQ: Simulator Sickness Questionnaire; STAI: Spielberg State-Trait Inventory; VAS: Visual Analogical Scale; VR: Virtual Reality

Table 2
Virtual reality 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 8 males and 5 females mean age: 30.1 (SD 2.6) 13 non-clinical controls 6 males and 7 females mean age: 27.8 (SD 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 (SD 7.9)	HMD (no details given)	Participants' sensory integration were 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, color 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 (SD 11.9) 39 non-clinical controls 20 males and 19 females mean age 40.5 (SD 11.4)	Computer screen and joystick for navigation.	Participants were presented with ten virtual maze trials. The length of time that tool 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 to non-clinical controls. Also, longer trial completion time, distance travelled and more errors than non-clinical controls.	Strong
Weniger & Irle, 2008	Spatial memory	25 participants with schizophrenia 19 males and 6 females mean age: 30 (SD 10) 25 non-clinical controls 16 males and 9 females mean age: 32 (SD 10)	Computer screen and joystick for navigation.	Presenting participants with two virtual reality 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. 2013a	Spatial memory	20 participants with schizophrenia spectrum disorders 16 males and 4 females mean age 42 (SD 8.5) 20 non-clinical controls 7 males and 13 females mean age: 32.25 (SD 12.6)	Computer screen and navigation system (no details provided).	Participants were presented with virtual reality 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 to controls.	Strong
Wilkins et al. 2013b	Spatial memory	21 participants with schizophrenia of whom 17 were included in final analyses 13 males and 4 females mean age: 42.1 (SD 8.1) 24 non-clinical controls of whom 17 were included in final analyses 9 males and 8 females mean age: 36.2 (SD 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

Fajnerova et al. 2014	Spatial learning and memory	29 participants with psychosis 17 males and 12 females mean age: 25.8 (SD 6.2) 29 non-clinical controls 17 males and 12 females mean age: 25.7 (SD 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 female mean age: 46,7 (SD 10.6) 30 non-clinical controls 14 males and 16 female mean age: 47.7 (SD 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 (SD 3.3) 25 non-clinical controls 13 males and 12 females mean age: 24.6 (SD 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-centered 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 (SD 3.9) 20 non-clinical controls 12 males and 8 females mean age: 29.8 (SD 5.1)	While performing a pointing movement participants saw a virtual visual cursor corresponding to spatio-temporal 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

Sorkin, Weinshall, & Peled, 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 (SD 8.5)	HMD (no details provided) VR environment presented in a predetermined path	Participants navigated a VR residential neighbourhood, shopping centre and street marked. The forward movement of participants was paused when an incoherent event were 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

Note: BADS: Behavioural Assessment of the Dysexecutive Syndrome; BPRS: Brief Psychiatric Rating Scale; CGI: Clinical Global Impressions; EPHPP: Effective Public Heath Practice Project Quality Assessment Tool for Quantitative Studies; 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-SPAS: Scale for the Assessment of Negative and Positive Symptoms; SCID: Standard Clinical Interview for DSM Disorders; SD: Standard Deviation; SPM: Standard Progressive Matrices; VR: Virtual Reality; VRQ: Virtual reality Questionnaire; WAIS-R: Wechsler Adult Intelligence Scale; WASI: Wechsler Abbreviated Scale of Intelligence; WCST: Wisconsin Card Sorting Test; WMS-R: Wechsler Memory Scale Reviewed; WRAT-4: Wide Range Achievement Test-4.

Table 3
Virtual reality 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 9 females mean age 36.7 (SD 1.9) 20 non-clinical controls 11 males and 9 females mean age 36.9 (SD 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 recognize emotions in virtual faces as well as natural faces.	Strong
Greenwood et al. 2016	Ability to plan a do the shopping in a supermarket	43 participants with schizophrenia 22 male and 21 female mean age 39.5 (SD 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 recognize in VR.	Moderate

Kurtz, Baker, & Astur, 2006	Medication management	25 participants with schizophrenia 15 males, and 10 females mean age 42.1 (SD 10.5) 18 non-clinical controls 9 males, 9 females mean age 39.1 (SD 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
Ku et al., 2006	Interpersonal distance and the verbal response time	11 participants with schizophrenia 5 males and 6 females mean age 29.5 (SD 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 (SD 4.98) 30 non-clinical controls 16 males and 14 females mean age 29.50 (SD 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, Kim, et al., 2009	Emotional perception and emotional response	27 participants with schizophrenia 14 male and 13 female mean age: 28.5 (SD 5.7) 27 non-clinical controls 14 male and 13 female mean age: 26.5 (SD 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 participant a bit about themselves (where they were born, lived, what they liked or disliked, hobbies and family) they then ask the participant 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
Park, Ku, Choi, et al., 2009	Interpersonal distance and eye gaze	30 participants with schizophrenia 16 males and 14 females mean age 28.7 (SD 5.5) 30 non-clinical controls 16 males and 14 females mean age: 26.3 (SD 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 participant a bit about themselves (where they were born, lived, what they liked or disliked, hobbies and family) they then ask the participant 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 (SD 11.9) 54 non-clinical controls 19 males and 35 female mean age: 37.6 (SD 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

Note: 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; SD: Standard Deviation; SPM: Standard Progressive Matrices; 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
Virtual reality 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 (SD 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 minutes	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 male and 9 female mean age 25.9 (SD 4.2)	HMD: NVIS nVisor SX	Participants waited for a bus to arrive for about four minutes 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 a the bus stop.	GPTS, IPS, SADS, DASS, CAPS, SPSS,	Participants reported persecutory ideation whilst being in the virtual street. Mean SSPS in this study was higher than reported by Freeman and colleagues (2008)	Moderate
Fornells-Ambrojo et al., 2015	Perception of threat	10 participants with persecutory delusions all male mean age 24.2 (SD 2.3) 10 non-clinical controls 8 male 2 females mean age 23.8 (SD 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 male mean age 25.3 (SD 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
Freeman, Slater et al, 2003	Paranoid Ideation	24 healthy participants 12 male and 12 females mean age: 26 (SD 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, Garety, et al., 2005	Paranoid Ideation	30 healthy participants 15 males and 15 females mean age: 22 (SD 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-Social avoidance and distress scale; 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, Gittins et al, 2008	Correlates of Social anxiety and Paranoid Ideation	200 participants from general population 100 males and 100 females mean age 37.5 (SD 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
Freeman, Pugh et al, 2010	Paranoid Ideation	30 low non-clinical paranoia 18 males and 12 females mean age 44.2 (SD 11.2) 30 high non-clinical paranoia 18 males and 12 females mean age 36 (SD 11.7) 30 Clinical Persecutory delusions 18 males and 12 females mean age 44.2 (SD 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 Simulation sickness questionnaire	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, Evans 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 female mean age: 31.5 (SD 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 virtual reality 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 male and 40 female Mean age 29.7 (SD 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

Kesting et al., 2013	Social stress, self-esteem, Paranoid Ideation	82 participants from the general population 18 male and 64 female mean age: 24.8 (SD 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 either 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 to 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 male and 12 female mean age 40.5 (SD 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

Shaik et al., 2016	Ethnic discrimination and Paranoid Ideation	64 participants with an ultra high risk (UHR) for psychosis 38 male and 26 female mean age 22.5 (SD 4) 43 non-clinical controls 20 male and 23 female mean age 24 (SD 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, Day, Garety et al., 2015	Paranoid Ideation and social defeat	64 participants with an ultra high risk (UHR) for psychosis 38 male and 26 female mean age 22.5 (SD 4) 43 non-clinical controls 20 male and 23 female mean age 24 (SD 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, Day, Kroll et al, 2015	Paranoid ideation and childhood bullying victimisation	64 participants with an ultra high risk (UHR) for psychosis 38 male and 26 female mean age 22.5 (SD 4) 43 non-clinical controls 20 male and 23 female mean age 24 (SD 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
Veling et al 2014	Paranoid Ideation	17 participants with a first episode of psychosis 14 male and 3 female mean age 27.3 (SD 5.5) 24 healthy controls 20 male and 4 female mean age 29 (SD 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 male and 19 female mean age: 26 (SD 4.7) 20 patients at UHR 7 male and 13 female mean age: 24 (SD 4.5) 42 siblings of patients 23 male and 19 female mean age 26.4 (SD 4.8) 53 healthy controls 25 male and 28 female mean age: 24.6 (SD 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 four minutes 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, Kesting, & Lincoln, 2012	Emotion regulation and paranoid ideation	116 participants without clinically relevant levels of delusions (online study) 33 male 83 female mean age: 28.5 (SD 7.8)	Computer screen (details on interaction methods for Cyberball 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

Table 5
Virtual reality for the treatment of psychosis

Study	Therapy Outcome	No. of Participants	Allocation	VR equipment	Intervention	Primary outcome measures
Cognitive Remediation & Vocational skills						
Chan, Ngai, Leung, & Wong, 2009	Cognitive functions	27 participants who were older age (<60 Yr) inpatients with schizophrenia 12 VR group 10 male and 2 female mean age (66.4 (SD 6.2) 15 Control group 8 male and 7 female mean age: 65.9 (SD 5.4)	Random allocation: Therapy groups cf. control group	IREX: 2D VR environment presented using a large screen	Virtual reality cognitive training program (10 sessions of 15 minutes long with increasing level of difficulty). Control group attended treatment as usual in the clinic.	COGNISTAT, SSQ, VQ
Tsang & Man, 2013	Vocational skills, Cognitive functions and self-efficacy	75 Participants who were inpatients with schizophrenia 25 VR Group 7 male and 18 female mean age: 39.60 (SD 7.9) 25 Therapist group 15 male and 10 female mean age: 40.7 (SD 9.2) 25 Traditional training group 11 male and 14 female mean age 41.5 SD (9.9)	Random allocation: virtual reality 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 five weeks. The therapist administered group and the VR group had the same structure and content but different mode of training (role play vs VR). The following areas were covered during the training memory, executive functioning and cognitive functioning at work.	BNCE, DVT, RBMT, WCST, VCRS
Smith et al. 2015	Interview skills and employment	32 outpatients with schizophrenia or schizoaffective disorder 21 VR Group 11 male and 10 female mean age: 40.8 (SD 12.2) 11 Control group 6 male and 5 female man age: 39.1 SD (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 program 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)
Social Skills Training						
Park et al.,	Social skills and	64 Participants	Random	HMD: Eye Trek	Social skills training	RAS, RCS, SPSI-

Stinson et al., 2010	Auditory hallucination	30 participants who reported experiencing on a daily basis auditory hallucinations in social situations 20 male and 10 female mean age : 42.4 (SD 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 virtual reality.	Strong

Note: ASSQ: Autism Spectrum Screening Questionnaire; ATQ: Automatic Thoughts Questionnaire; BPRS: Brief Psychiatric Rating Scale; CAPE: Community Assessment of Psychic Experience; CAPS: Cardiff Anomalous Perceptions Scale; CAS: Cognitive Assessment Schedule; CGI: Clinical Global Impressions; DASS: Depression, Anxiety, Stress Scale; EPHPP: Effective Public Heath Practice Project Quality Assessment Tool for Quantitative Studies; ERQ: Emotion Regulation Questionnaire; GAF: Global Assessment of Functioning; GPTS: Green Paranoia Thoughts Scale; HADS: Hospital Anxiety and Depression Scale; HMD: Head Mounted Display; IPSM: Interpersonal Sensitivity Scale; ITQ: Immersive Tendency Questionnaire; LSAS: Liebowitz Social Anxiety Scale; LSHS: Launay-Slade Hallucinations Scale; NART: National Adult Reading Test; PANSS Positive and Negative Symptoms Scale; PEDQ-CV: Perceived Ethnic Discrimination Questionnaire community version; PQ: Presence Questionnaire; PS: Paranoia Scale; PSWQ: Penn State Worry Questionnaire; PSYRATS: Psychotic Symptoms Rating Scale; RBQ: Retrospective Bullying Questionnaire; RSES: Rosenberg Self-Esteem Scale; SAD: Social Avoidance and Distress scale; SANS-SPAS: Scale for the Assessment of Negative and Positive Symptoms; SCS: Social Comparison Scale; SD: 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; TAS-20: Toronto Alexithymia Scale; TVRS: Topography of Voices Rating Scale; VAS-VR Paranoid: Visual Analogical Scale to assess paranoia in virtual reality environment; VR: Virtual reality; VRQ: Virtual reality Questionnaire; WASI: Wechsler Abbreviated Scale of Intelligence; WDQ: Worry Domains Questionnaire; Wechsler Test of Adult Reading;

Note: BCSS: Brief Core Schema Scale; BNCE: Brief Neuropsychological Cognitive Examination; COGNISTAT: Neurobehavioural Cognitive Status Examination; DVT: Digit Vigilance Test; EPHPP: Effective Public Heath Practice Project Quality Assessment Tool for Quantitative Studies; 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; SD: 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; VCRT: Vocational Cognitive Rating Scale; VQ: Vocational Questionnaire; VR: Virtual reality; WCST: Wisconsin Card Sorting Test.