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Virtual reality and persecutory delusions: Safety and feasibility

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Abstract

Objective: Virtual reality (VR) has begun to be used to research the key psychotic symptom of paranoia. The initial studies have been with non-clinical individuals and individuals at high risk of psychosis. The next step is to develop the technology for the understanding and treatment of clinical delusions. Therefore the present study investigated the acceptability and safety of using VR with individuals with current persecutory delusions. Further, it set out to determine whether patients feel immersed in a VR social environment and, consequently, experience paranoid thoughts.
Method: Twenty individuals with persecutory delusions and twenty non-clinical individuals spent 4 min in a VR underground train containing neutral characters. Levels of simulator sickness, distress, sense of presence, and persecutory ideation about the computer characters were measured. A one-week follow-up was conducted to check longer-term side effects.
Results: The VR experience did not raise levels of anxiety or symptoms of simulator sickness. No side effects were reported at the follow-up. There was a considerable degree of presence in the VR scenario for all participants. A high proportion of the persecutory delusions group (65%) had persecutory thinking about the computer characters, although this rate was not significantly higher than the non-clinical group.
Conclusions: The study indicates that brief experiences in VR are safe and acceptable to people with psychosis. Further, patients with paranoia can feel engaged in VR scenes and experience persecutory thoughts. Exposure to social situations using VR has the potential to be incorporated into cognitive behavioural interventions for paranoia.

Keywords: Persecutory delusions; Early psychosis; Schizophrenia; Virtual reality

1. Introduction

Presence in virtual reality (VR) occurs when a person has a sense of being in the place depicted by the VR system and responds realistically (Sanchez-Vives and Slater, 2005). This has been exploited in the treatment of anxiety disorders by exposing patients to virtual environments related to their fears (e.g. Difede and Hoffman, 2002; Emmelkamp, et al., 2002; Garcia-Palacios et al., 2002; Rothbaum et al., 2000).Intriguingly, people have been found to respond to computer-generated characters (avatars) as if they were social agents (Garau et al., 2005; Pertaub et al., 2001), even in extreme social situations

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(Slater et al., 2006). Subsequently, individuals' reactions to avatars have been used to investigate paranoid thinking, a key symptom of psychosis (see review by Freeman, 2008).

Paranoia exists on a continuum in the general population, ranging from mistrust to clinical persecutory delusions (e.g. Combs and Penn, 2004; Fenigstein and Vanable, 1992; Freeman, 2007). VR has several key advantages in studying paranoia. If individuals are presented with a neutral social situation, then any paranoid thinking that occurs is known to be unfounded. Moreover, the participant's own mistrustful or unusual behaviour cannot elicit hostile responses from the avatars. Further, if patients do experience paranoid thoughts in virtual reality then this offers the possibility of the technology being incorporated into the emerging cognitive behavioural treatments (Freeman et al., 2006).

In the initial reports virtual reality has been used to study persecutory ideation in the general population (e.g. Freeman et al., 2008) and those at high risk of psychosis (Valmaggia et al., 2008). The validity of the methodology has been shown by higher levels of trait paranoia being associated with the occurrence of persecutory ideation in VR. Of theoretical interest these studies have consistently shown that persecutory ideation in VR is predicted by anxiety, worry, interpersonal sensitivity and perceptual anomalies.

The main aim of the present study was to investigate if it was feasible to use immersive VR with people with psychosis who have current persecutory delusions. We predicted that VR would be safe and acceptable to people with persecutory delusions. Safety was operationalised as the absence of an increase in level of anxiety, no triggering of significant levels of simulator sickness, and no adverse experiences in the following week. Simulator sickness refers to symptoms similar to motion sickness (e.g. nausea, dizziness) that can sometimes be caused by virtual environments because the visual system indicates movement while the balance mechanisms in the inner ear register no movement.

The secondary aims of the study were to examine whether people with persecutory delusions could be immersed in a VR social scene (i.e. experience presence) and whether they would have paranoid thoughts about neutral avatars. We also hypothesised that people with persecutory delusions would be more likely to report paranoid thoughts in VR than non-clinical volunteers.

2. Method

2.1. Participants

Twenty participants with early psychosis were recruited from two specialist early intervention in psychosis services in London. These early intervention services accepted referrals of people aged 16–35 presenting to mental health services for the first time with symptoms of non-organic psychosis (e.g. F20–29; F31; ICD-10, World Health Organization, 1992). The inclusion criteria for the study were: diagnosis of non-affective psychosis; a score of at least moderate severity (4) on the Suspiciousness item (P6) of the Positive and Negative Syndrome Scale (PANSS) (Kay et al., 1987); and a current persecutory delusion as defined by Freeman and Garety (2000). The exclusion criteria were: primary diagnosis of substance misuse or learning disability. Twenty age-matched non-clinical participants were recruited from participant panels at the Institute of Psychiatry, King's College London and University College London (UCL). The inclusion criteria were: no previous psychiatric history and a negative screen for psychotic symptoms on the Psychosis Screening Questionnaire (Bebbington and Nayani, 1995). Exclusion criteria for both clinical and non-clinical participants were: poor command of English; a history of epilepsy. The demographic and clinical characteristics of the participants are displayed in Table 1.

2.2. Design and procedure

The study had received approval from a NHS research ethics committee. The study was conducted in four stages. All participants completed the baseline assessments before entering the virtual environment. The second stage involved entering the virtual environment. The virtual reality equipment was situated in the Department of Computer Science, University College London. There was a training task to help participants to familiarise themselves with VR. The training task lasted approximately 5 min and required the participant to move through a series of numbers to practice navigation in VR. The experimental environment consisted of a virtual underground train carriage. Participants boarded the virtual train and disembarked after two stops. The train journey lasted 4 min. The instructions were "Please explore the environment, and try to form an impression of what you think about the people in the train and what they think about you." In the third stage, after the virtual train ride, participants were asked to complete a series of assessments of their experience. Lastly, participants were contacted by telephone a week later to investigate the occurrence of any adverse reactions.

2.2.1. Virtual environment

2.2.1.1. Apparatus. The virtual environment was displayed in an immersive projection system typically

Table 1
Demographic and clinical characteristics

Characteristic	Persecutory delusions group ($n=20$)	Non-clinical group ($n=20$)	Test	p
Gender				
(Males) N(%)	17 (85%)	19 (95%)	$\chi^2(1)=1.1$	.605
Age				
Mean (SD)	23.5 (3.1)	25.5 (4.4)	$t(38)=-1.7$	.088
Ethnicity				
Black	7 (35%)	5 (25%)		
Asian	9 (45%)	8 (40%)		
White	4 (20%)	7 (35%)	$\chi^2(2)=1.2$	.546
Occupation				
Unemployed	12 (60%)	1 (5%)		
Employed	6 (30%)	8 (40%)		
Student	2 (10%)	11 (55%)	$\chi^2(2)=15.8$	<.001*
Pre-morbid IQ (WTAR)				
Mean (SD)	97.9 (10.6)	108.4 (5.5)	$t(36)=-3.8$	.001*
PANSS				
Positive symptoms[a]	17.5 (3.0)	–	–	–
Negative symptoms	13.9 (4.6)	–	–	–
General psychopathology	37.2 (6.4)	–	–	–
Mean duration of contact with mental health services in months				
Mean (SD)	12.8 (9.2)	–	–	–
Previous admission to hospital?				
Yes (%)	9 (45%)	–	–	–
Diagnosis[b]				
F20 schizophrenia	10 (50%)	–		
(F20.0 Paranoid schizophrenia)	(7 (35%))	–		
F29 Unspecified non-organic psychosis	10 (50%)	–	–	–
Antipsychotic medication[c]				
Low dose	15 (75%)	–		
Medium dose	3 (15%)	–		
High dose	0	–	–	–

WTAR = Wechsler Test of Adult Reading; PANSS = Positive and Negative Syndrome Scale. *$p<.01$.

[a] Scores on Item P6 Suspiciousness were as follows: 14 people scored Moderate; 4 people scored Moderate/Severe; 2 people scored Severe. Scores on Item P1 Delusions: 15 people scored Moderate; 3 people scored Moderate/Severe; 2 people scored Severe.

[b] ICD-10, (World Health Organization, 1992).

[c] Levels of medication in Chlorpromazine equivalents. Two clinical participants were not taking antipsychotic medication.

referred as CAVE (Cruz-Neira et al., 1993) – specifically a Trimension ReaCTor – that has three back-projected vertical screens (3 m × 2.2 m) and a floor screen (from a ceiling mounted projector) (3 m × 3 m) controlled by a Silicon Graphics Onyx 2. Participants had their head position and orientation tracked with an inertial/ultrasonic system. They also carried a tracked joystick in their hand. Lightweight CrystalEyes LCD shutterglasses delivered a stereo view of the virtual world. Participants moved around the virtual space with a combination of walking and whole body turning, and also could virtually locomote by pressing a button in the joystick.

2.2.1.2. Environment. The virtual environment was a tube train ride developed by the Department of Computer Science at UCL. The environment was modelled on the interior of a London Underground train carriage and was displayed in colour (see Fig. 1). The tube ride took the participant on the London Underground Central Line from "St. Paul's", stopping at "Chancery Lane", through to "Holborn", where the participant disembarked. Background noises associated with being in the London underground were played (e.g. background rumble of the moving train, a "Mind the doors" announcement when the doors were closing). The environment was an earlier version of that used by Freeman et al. (2008).

2.2.1.3. Avatars. The environment was designed to be neutral. The carriage was populated by twenty computer-generated characters, known as "avatars". Both genders and a range of ethnicities were represented. Avatars were programmed to exhibit only neutral

Fig. 1. Virtual reality tube image.

behaviour. They could glance up and around the train carriage and occasionally they changed their facial expressions but they did not display any overtly hostile or friendly behaviour.

2.3. Measures

2.3.1. Pre-virtual reality assessment

2.3.1.1. Positive and Negative Syndrome Scale (PANSS; Kay et al., 1987). The PANSS is a 30-item, seven-point rating instrument with sub-scale scores for positive symptoms, negative symptoms and general psychopathology. The PANSS is a well established symptom rating scale in in schizophrenia research (Mortimer, 2007).

2.3.1.2. Green et al. Paranoid Thoughts Scales (G-PTS; Green et al., 2008). The G-PTS (Green et al., 2008) measures current ideas of reference (e.g. "People definitely laughed at me behind my back") and persecution (e.g. "People have intended me harm").There are two 16-item subscales: G-PTS Reference and G-PTS Persecution. Each item is rated on a 1 to 5 rating scale (1=Not at all, 5=Totally). Higher scores indicate higher levels of paranoia. The scales have been validated with clinical and non-clinical samples.

2.3.1.3. Wechsler Test of Adult Reading. (Ginsberg, 2003). The WTAR (Ginsberg, 2003) is an assessment tool for estimating premorbid intellectual functioning in individuals aged 16 to 89. The task involves reading 50 non-phonetic words.

2.3.1.4. Spielberger State—Trait Inventory (STAI; Spielberger, 1996). Only the state scale was used in the current study. This scale has 20 items that measure current level of anxiety (e.g. "I feel nervous"). Each item is rated on a 4 point scale (1=Not at all, 5=Very much so). Higher scores indicate higher levels of anxiety. Participants completed the anxiety measure questionnaire before and after entering the virtual environment to determine whether any distress was caused by the procedure (Spielberger, 1996).

2.3.1.5. Simulator Sickness Questionnaire (SSQ; Kennedy et al., 1993). The SSQ was administered before and after exposure to the virtual reality environment. The SSQ is a 16-item measure in which participants report symptoms on a scale of 0 to 3 (0=None, 3=Severe). Three types of symptoms are assessed: oculomotor dysfunctions (*O*) (eyestrain, blurred vision, difficulty in focusing), mental disorientation (*D*) (difficulty in concentrating, confusion, apathy), and nausea (*N*) (including vomiting). Unit scores (*O*,*D*, *N*) are weighted scores. The SSQ is a widely used measure of simulator sickness that has been shown to be a valid measure of this construct in VR research (Cobb et al., 1999).

2.3.2. Post virtual reality assessment

2.3.2.1. The State Social Paranoia Scale (SSPS; Freeman et al., 2007). State Social Paranoia Scale (Freeman et al., 2007) is a 20-item self-report questionnaire that is used to assess the occurrence of persecutory thoughts about virtual reality characters. There are 3 subscales. VR—persecution has 10 items assessing paranoid thinking (e.g. "Someone had it in for me", "Someone stared at me in order to upset me") that fulfil a definition of persecutory ideation (Freeman and Garety, 2000).The two remaining subscales are: VR—neutral, which has five items assessing neutral ideation about the virtual characters (e.g. "I wasn't really noticed by anybody") and VR—positive, which includes five items measuring positive ideation about the avatars (e.g. "Someone was friendly towards me"). Each of the 20 items is rated on a 5-point-scale (1=Do not agree, 5=Totally agree). Higher scores indicate higher endorsement. The SSPS has very good internal reliability (α=0.9) and clear convergent validity as assessed by both independent interviewer ratings and other self-report measures.

2.3.2.2. VR semi-structured interview(Freeman et al., 2003). This is a 5-minute semi-structured interview conducted to assess participants' experiences of the virtual tube environment. The focus is on interpersonal experiences with the computer generated characters. The interview includes questions about the content of thoughts involving intentionality and the evidence on

which these thoughts are based. The interviews were tape recorded (Freeman et al., 2003).

2.3.2.3. Sense of presence questionnaire (Slater et al., 1998). Presence is assessed by three main constructs: the sense of "being there" in the actual virtual environment, a sense of having visited a "place" rather than just having seen images, and the dominance of the virtual world over the real world where participants are located (e.g. the sense of being in the virtual tube rather than in the laboratory). This self-report questionnaire consists of 6 items, each rated on a scale of 1 to 7 with larger scores indicating a higher sense of presence (Slater et al., 1998).

A one-week *follow-up assessment* was conducted over the telephone to investigate if the VR experience had triggered any persisting adverse reactions during this period. A semi-structured interview (Valmaggia et al., 2008) was used to ask participants whether they had thought about the VR experiment and whether their behaviour and their mood had been affected in any way by their participation in the study. Participants were also asked if they had had any intrusive thoughts or images about the VR environment.

2.4. Data analysis

All analyses were conducted using SPSS for windows (version 13) (SPSS, 2005). Chi-square tests were used for group comparisons on dichotomous variables. Normality assumptions were assessed using visual assessment of the distribution of scores and the Kolmogorov–Smirnov test. Group comparisons on continuous variables were tested using *t* tests or the Mann–Whitney *U*, depending on whether parametric data assumptions were met. Spearman's correlation coefficients were used to explore hypothesised relationships between VR — persecution and potential predictor variables as the necessary assumptions for parametric tests were not met for the VR — persecution variable due to positive skew. All significance test results are quoted as two-tailed probabilities.

3. Results

3.1. Safety

In Table 2 is a summary of the data on the measures assessing the safety of VR.

Table 2
Mean values of anxiety (STA; Spielberger, 1996) and Simulator Sickness Questionnaire (SSQ: Kennedy et al., 1993) by group pre and post the VR exposure and ANOVA analyses

Descriptives	Measure [range]	Clinical group (n=20)	Non-clinical group (n=20)
STAI	Pre-VR anxiety STAI [20–100]	38.1 (8.6)	29.2 (9.1)
	Post-VR anxiety STAI [20–100]	37.9 (10.1)	27.5 (7.9)
SSQ[a]	Pre-VR nausea [0–200.3]	20.9 (33.3)	6.6 (12.0)
	Post-VR nausea [0–200.3]	17.7 (25.9)	6.2 (13.2)
	Pre-VR oculomotor [0–159.2]	22.7 (26.8)	10.2 (12.8)
	Post-VR oculomotor [0–159.2]	21.2 (22.2)	9.1 (11.7)
	Pre-VR disorientation [0–292.3]	30.6 (47.5)	11.1 (17.8)
	Post-VR disorientation [0–292.3]	21.6 (31.8)	10.4 (17.9)

ANOVA	Source	F (1,38)	p
STAI	Anxiety within subjects change (A)	2.2	.147
	Group (G)	12.1	.001**
	$A \times G$	1.4	.250
SSQ	Nausea within subjects change (Na)	1.1	.302
	G	3.3	.074
	Na × G	0.6	.437
	Oculomotor within subjects change (O)	0.3	.580
	G	4.7	.036*
	$O \times G$	0.0	.937
	Disorientation within subjects change (D)	3.8	.080
	G	2.6	.115
	$D \times G$	2.1	.131

*p<.05 **p<.01.

[a] Details on the three components of the Simulator Sickness Questionnaire: nausea (e.g. stomach awareness, nausea, sweating); oculomotor dysfunctions (e.g. difficulty focusing, headache, eyestrain, blurred vision) and disorientation (e.g. vertigo, dizziness, fullness of head).

It can be seen that independent of VR exposure the clinical group had higher levels of state anxiety and oculomotor symptoms than the non-clinical participants. It is clear that there is no evidence that VR contributed to an increase of anxiety or simulator sickness. Scores tended to decline from pre- to post-exposure. The visual inspection was confirmed by statistical analysis. Four 2×2 ANOVAs were carried out, with group as the between-subjects factor and the change in anxiety and simulator sickness following the virtual reality encounter as the within-subjects factors (see Table 2).

3.2. Follow-up

All of the clinical participants and eighteen of the non-clinical participants completed the one-week telephone follow-up. Eight (40%) of the clinical and 3 (16%) of the non-participants reported having thought about the experience (e.g. "Yes, it was very good, I thought it was like pictures, but stood out more", "I talked to a friend about it"). None of the participants reported intrusive negative thoughts, unpleasant emotions, or a change in their behaviour as a result of entering the virtual reality environment.

3.3. Sense of presence

Reported presence in the virtual environment was assessed by the Sense of Presence Questionnaire (Slater et al., 1998). Fifteen (80%) people in the clinical group and 14 (70%) of the non-clinical volunteers endorsed a high score (6 or 7) on at least one of the six questionnaire items, indicating that they felt themselves to be in the tube train. As an illustration of the results, for the item "The sense of being in the tube train was stronger than the sense of being in the laboratory", 12 (60%) of the clinical and 13 (65%) of the non-clinical participants felt that they were in a tube train during the experiment, whereas 5 (25%) of the clinical and 2 (10%) of the non-clinical participants had a sense of being in the laboratory. The remaining participants reported feeling equally in the virtual train and the laboratory. There were no significant group differences in the total sense of presence score (Clinical group mean score=24.0, range 11–33, SD=6.4; non-clinical group mean score=23.7, range 14–32, SD=5.1), t (38)=0.1, p=.876). None of the participants reported the absence of a sense of presence in the virtual environment.

3.4. Persecutory ideation in VR

There was variability in the participants' experiences of the same VR environment. Table 3 shows examples of the participants' comments.

The participants' scores for positive, neutral and persecutory appraisals of the virtual characters as assessed by the SSPS (Freeman et al., 2007) are displayed in Table 4. Persecutory thoughts about the avatars were less common than neutral and positive appraisals. Thirteen (65%) people with persecutory delusions and 12 (57%) non-clinical individuals endorsed at least one persecutory item (e.g. "Someone stared at me in order to upset me") on the SSPS (Freeman et al., 2007). The proportion of endorsement

Table 3
Examples of comments made by participants at post-VR interview

Theme	Examples
Experience of the virtual environment	"It was kind of weird… I was about to put my arm out and lean on a pole …. But then I thought: it's not there!" (Non-clinical participant)
	"It really felt like you were on an actual tube station with people interacting with you in a way… the way they looked at you… but there were times when, you could tell, you weren't really there as well… it felt surreal, it's like you are there, but you are not really there… sort of thing" (Clinical participant)
Paranoid thoughts about the avatars	"…he walked straight up to me when he came in… and he didn't flinch …so… really… that means fight…" (Non-clinical participant)
	"…then a man walked towards me, straight up to me to wind me up" (Clinical participant)
Neutral thoughts about the avatars	"It felt like they didn't notice me, really" (Non-clinical participant)
	"They mind their own business, like they were just getting on with what they were doing, waiting for their stop…" (Clinical participant)
Positive thoughts about the avatars	"… going through the aisle they kind of look towards you, and I think the first that came into my mind was "she thinks I'm cute", so… you know… then she looked away, and then I looked away…" (Non-clinical participant)
	"There was this guy and this woman, and the guy looked at me and he smiled at me, and it was like, his girlfriend or his friend, a woman next to him, and they both seemed friendly….and on the other side… there was this Black woman, and she sort of smiled at me, with friendly look on her face…" (Clinical participant)

Table 4
Persecutory, positive and neutral appraisals about virtual characters as assessed by the State Social Paranoia Scale (SSPS; 27)[a b]

	Clinical participants (n=20)	Non-clinical participants (n=20)	Test	p
VR — persecution	0.30 (0.11)	0.27 (0.09)	U=169.5	.414
VR — neutral	0.55 (0.21)	0.61 (0.27)	$t(38)$=0.9	.393
VR — positive	0.45 (0.18)	0.54 (0.13)	$t(38)$=−1.7	.097

[a] Mean number of appraisal values for each of the subscales were divided by the maximum total scale scores (VR—persecution=50; VR—positive=25 and VR—neutral=25). Each score could range from 0 to 1.

[b] Wilcoxon Signed Ranks Tests revealed that all participants reported significantly less persecutory appraisals than neutral (z=−4.7, N-Ties=39, p<.001) and positive appraisals (z=−4.9, N-Ties=38, p<.001) about the virtual characters. The mean number of positive and neutral interpretations did not differ (z=−1.6, N-Ties=38, p=.113). These findings were replicated when the analyses were conducted for each group separately.

of paranoid items about avatars by group was not significantly different, $\chi^2(1)=0.3$, $p=.748$. There was a trend for the clinical participants to rate the avatars as less friendly than the non-clinical participants.

3.5. Prediction of paranoid ideation in the clinical group

Persecutory ideation in VR by the clinical participants, as assessed by the SSPS (Freeman et al., 2007), was positively associated with having higher persecutory ideation in the real world, rho=0.62, $p=.004$, but not significantly with higher ideas of reference, rho=0.30, $p=.201$, as assessed by Scales A and B of the GPTS respectively (Green et al., 2008). PANSS Positive, rho=0.02, $p=.438$, PANSS negative, rho=0.13, $p=.620$, and PANSS general psychopathology, rho=0.12, $p=.639$, were not significant predictors of persecutory ideation in VR. Premorbid IQ also did not predict persecutory ideation about the avatars, rho=−0.05, $p=.849$.

4. Discussion

Virtual reality (VR) has previously been used to study paranoid ideation in non-clinical individuals and in individuals at high risk of psychosis. This is the first study to use the technology with people with persecutory delusions. The main aim of the study was to investigate the safety and feasibility of using VR with people with persecutory delusions. It was very clear from the data that VR did not trigger simulator sickness or an increase in anxiety. Moreover there were no intrusive thoughts or flashbacks in our participants in the week following the experiment.

Overall, the current study showed that computer generated interactive environments can be safely used with people with persecutory delusions. The generalisability of the current findings to people with persecutory delusions who have a longer chronicity of illness or who present with more severe symptomatology at the acute stage of illness will need to be investigated. Further research will also need to continue monitoring the safety of VR in people with psychosis, particularly if the time spent in VR is extended.

Individuals with persecutory delusions experienced a sense of presence in the virtual world, instead of feeling that they were in a laboratory. There was evidence that people with persecutory delusions treated the virtual social world similarly to the real world. The participants reported neutral, positive and negative appraisals of the computer characters. The virtual environment used in the current study was designed to be neutral. Accordingly, neutral positive and appraisals were the predominant response to the virtual tube experience. However there were a significant number of paranoid thoughts also reported. Sixty-five percent of people with persecutory delusions reported paranoid ideation about the computer characters, supporting the idea that virtual reality can be used to elicit state paranoia in this clinical group. Crucially this enables the possibility that virtual reality can be used as a tool in treatment approaches (Freeman et al., 2006).

It is of interest that contrary to our initial prediction the clinical group did not report significantly higher levels of persecutory ideation in VR compared with the non-clinical group. There was only a trend for the clinical participants' ratings of the friendliness and trustworthiness of the avatars to be lower than that of the non-clinical participants' ratings. There are a number of potential explanations. Our task instructions might have had encouraged paranoid interpretations among non-clinical participants who would have otherwise been less likely to focus on the actions of the computer generated characters.

Future studies could examine the key aspects of an environment that trigger paranoid thoughts and the effects of task procedures (i.e. the person's goal during the task). Sampling issues may also account for the finding. It is plausible that in the current study a clinical group willing to travel to participate were particularly enthusiastic about the research, less attuned to side effects, and less likely to

have a negative interpretation of the virtual environment. However it is the findings of safety and accessibility, and of the triggering of persecutory thoughts, that indicate great promise for the future use of the technology in the investigation and treatment of persecutory ideation.

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Contributors

Miriam Fornells–Ambrojo	Designed the study; wrote the protocol; conducted literature searches; collected data; conducted statistical analyses; wrote the various manuscript drafts.
Chris Barker	Supervised study design, protocol writing, statistical analyses, feedback on final manuscript draft.
David Swapp	Manager of virtual reality laboratory, organised attendance of participants during data collection and took part on training task for participants. Feedback on final manuscript draft.
Mel Slater	Supervised study design, supervised design of virtual environment; feedback on final manuscript draft.
Angus Antley	Involved in designing virtual environment; advice about participants behaviour in the virtual environment.
Daniel Freeman	Supervised study design, selection of measures, protocol writing, statistical analyses; main feedback and editing of manuscript drafts.

All authors have approved the final manuscript.

Conflict of interest

All authors declare that they have no conflicts of interest.

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