Deepening extinction in a virtual reality treatment for fear of heights

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Executive summary

Chapter 1: Systematic review

Background

Clinical trials support the use of virtual reality (VR) in the treatment of mental disorders, including but not limited to anxiety disorders, post-traumatic stress disorder, depression, psychosis, eating disorders and substance misuse. It was first developed in the 1960s and has been used to treat specific phobias since the 1980s with effect sizes comparable to *in vivo* exposure. Immersive virtual reality consists of stereoscopic head mounted displays with advanced tracking systems. These allow movements of the user to mirror a computer-generated avatar within the virtual environment. VR technology has advanced in the last three years and consumer equipment is now available and easy to use. This has increased interest in using virtual reality as a treatment platform and has created real opportunities to disseminate VR technology into clinical settings.

Specific phobias are characterised by a marked fear of objects or situations that persist for several months. Phobias are relatively common within the general population with many people experiencing one or more in their lifetime. Subtypes of phobias include animal (e.g. spiders), natural environment (e.g. heights), situational (e.g. flying), blood injury (e.g. needles), and other (e.g. balloons). Exposure is the primary treatment for specific phobias and has a strong evidence base. However, current research suggests re-considering approaches that have been used for many years, namely the emotional processing model of exposure (Foa and Kozak, 1986) as within session fear reduction does not predict outcomes as theorized. Furthermore, habituation to feared stimuli was

previously considered the primary mechanism of change but evidence now indicates that it only has a partial effect. The inhibitory learning model of exposure consolidates cognitive behavioural models and experimental research on fear renewal to create a series of recommendations to maximise exposure.

Despite evidence to support virtual reality in the treatment of specific phobias in comparison to face to face therapies, the therapeutic content of these treatments has yet to be systematically reviewed.

Aims

The aim of the systematic review is to evaluate the *content* of virtual reality treatments for specific phobias in the last ten years. As VR systems are disseminated for clinical use, it is important to review current applications and to understand the treatment mechanisms specific to virtual reality. It is hoped that this will inform the design and use of future scenarios.

Method

Randomised controlled trials of virtual reality treatments of specific phobias in the last ten years were evaluated. Only studies with one (or more) arms of virtual reality treatment were included in the review. Studies with participants <18 years old or that treated disorders starting in childhood (e.g. neurodevelopmental disorders) and/or physical health conditions were excluded. Case reports, dissertations and conference papers were also excluded from the review. Embase, Medline, PsychINFO and Pubmed were searched to identify studies for the review. The search was closed on 7th February 2019. 445 studies were screened, and 16 trials were identified as meeting the inclusion criteria.

Results

The main phobias treated in the studies reviewed were fear of heights, fear of flying and small animal phobia, including fear of spiders. The samples sizes ranged from 15 to 100 and the methodological quality of studies was mixed. Most of the studies compared virtual reality to a non-virtual control such as, *in vivo* or waitlist. Medium to large effect sizes were found in on pre and post treatment scores following the virtual reality intervention in all studies. Most of the studies collected follow up data but this ranged from 1 week to 1-year post intervention and the measures were largely self-report. Behavioural avoidance tests were used in nine of the studies but there was variability in measurement and some researchers used the same virtual reality scenario that had been used in the treatment component.

Detailed reporting of treatment content was poor, yet most authors provided comprehensive descriptions of the virtual environments. The majority of studies used a hierarchical model of exposure except for one that used behavioural experiments. Seven of the studies used cognitive behavioural techniques but not all reported these in sufficient detail to evaluate or replicate the intervention. Most of the studies used psychoeducation either at the start or within the virtual scenario and four studies used therapeutic components that were external to virtual reality. The number of sessions of each intervention ranged from 1 to 16 and the overall time spent in VR from 30 minutes to 9.5 hours.

Few studies compared virtual reality treatments and only one tested individual treatment components that investigated stimulus and environmental context as a mechanism of change. One study was completely automated and involved a virtual

‘therapist’ or ‘coach’ created from a digital avatar within the system. Treatment mediators and moderators were not tested in any of the studies.

Discussion

It was not surprising that detailed reporting of treatment content was poor, as many of the studies reviewed were small and used virtual reality to replicate *in vivo* exposure rather than as a stand-alone treatment. It seemed that researchers were more concerned with the believability and immersion of the scenario than the therapeutic content. This can be partially explained by the strong emphasis on hierarchical exposure and reliance on habituation as a mechanism of change. This approach is now considered outdated as the primary method of exposure as fear often returns. However, post treatment effect sizes are medium to large, so it is likely that researchers have limited motivation to change exposure techniques. The exception was the automated treatment that used behavioural experiments to initiate cognitive change. This treatment also used many of the recommendations outlined in newer models of exposure and may provide insight into the content of future VR treatments.

Notably, only one study investigated treatment mechanisms by directly comparing virtual reality for the same phobia and manipulating a component of the scenario. This suggests that virtual reality is largely considered a tool to mirror the real world and the full potential of this technology is yet to be explored. One of the main advantages of using this virtual reality is to create scenarios that are unachievable or impractical to achieve in reality. Therefore, researchers should now focus on treatment mediators and moderators by directly comparing scenarios. This will provide a better understanding of treatment mechanisms that can be used to inform future developments and improve efficacy.

Chapter 2: Empirical project

Background

Fear of heights was one of the first phobias to be treated using virtual reality and has since developed a substantial evidence base. Post treatment effect sizes have consistently been medium to large and it is as effective as *in vivo* exposure. Virtual reality treatments are being disseminated into clinics, but many continue to use hierarchical exposure models that rely on habituation as the primary mechanism of change. Exposure does not work for everyone and fear renewal is common. The inhibitory learning model consolidates the research on fear extinction and makes a series of recommendations to maximise exposure. These include deepening extinction (combining phobic cues), violating expectancy (predicted verses actual outcomes), removal of safety signals (dropping safety behaviours), variability (varying exposure intensity) and using multiple contexts for exposure. Virtual reality provides a unique platform to investigate individual components of exposure treatments as scenarios are easily adapted and experimental conditions can be maintained. There is limited evidence examining treatment mediators and moderators of virtual reality exposure and few studies have compared treatments to investigate augmentations.

Physiological arousal is associated with fear responses to phobic stimuli. However, there is often discordance between subjective and objective measures of anxiety in both virtual reality and in the real world. Some people with a fear of heights misinterpret anxious arousal as threatening and believe it will increase the likelihood of falling. A number of studies have measured physiological responses, but few have manipulated arousal.

The evidence for predictors of treatment outcome in specific phobias is inconclusive. There is some support for an association between state and trait anxiety in spider phobics. Likewise, negative cognitive style and low mood has been found to lead to poorer outcomes. Safety seeking behaviours are key maintenance factors in anxiety disorders and are central to exposure therapies for phobias. Aversion to risk has not been investigated in this population but avoidance is a primary safety behaviour that minimises the potential for harm. Therefore, it is possible that this contributes to treatment outcome. As new treatments are developed and automated, it is important to understand predictors of outcome to ensure therapeutic content is appropriately designed.

Aims

The aim of the empirical study is to investigate whether deepening extinction by increasing physiological arousal in an automated virtual reality treatment for fear of heights enhances cognitive change.

The primary hypothesis was that deepening extinction by increasing physiological arousal in virtual reality would significantly reduce belief conviction in comparison to virtual reality alone. The secondary hypothesis was that self-efficacy and subjective units of distress would mediate the effect of increased physiological arousal on belief conviction. The final hypothesis was that tendency to use safety behaviours, risk aversion, mood, trait anxiety, sensitivity to internal phobic cues and self-reported fear of heights are predictors of overall belief reduction in virtual reality exposure therapy.

Design

A between-participants randomised mixed experimental design was used. Participants were randomly assigned to either an exercise condition (increasing physiological arousal) or a control condition. The primary outcome was conviction in beliefs about heights. This was measured at pre and post-test. Predictor measures were taken at baseline, self-efficacy and subjective units of distress were measured at multiple timepoints throughout the intervention and heart rate was measured continuously from baseline to post-test.

Method

60 participants with a fear of heights were recruited from the general public. Screening was completed via an online questionnaire (Qualtrics) and eligible participants were invited to take part. Participation took approximately 1.5-2hrs in a single visit to the VR lab. All participants completed a 30-minute session of an automated virtual reality treatment for fear of heights (for original trial see Freeman et al., 2018) Participants in the exercise condition cycled to 80% of their maximal heart rate prior to entering virtual reality. The control group maintained their resting heart rate.

Analysis and results

Linear mixed effects models were used to check the manipulation and to test the primary hypothesis. The manipulation was effective at increasing physiological arousal (p<0.0001) and had a large effect size of (d=2.9). All participants significantly improved following the virtual reality intervention (p<0.0001), (d=1.0) but increasing physiological arousal did not provide any additional benefit as there was no significant difference between the groups (p=0.56), (d=0.1). Self-efficacy improved in both groups

(p<0.0001), (d=0.8) but self-reported distress did not significantly change (p=0.98). Individual linear regressions were used to test the individual effect of predictor variables on the post-test conviction for the whole sample (groups were combined). When accounting for baseline conviction, none of the predictor measures were associated with post-test belief conviction, including the fear of heights measures.

Discussion

The main finding that physiological arousal was not associated with conviction change indicates that deepening extinction does not provided added benefit to exposure treatments and that arousal is not required to achieve cognitive change in virtual reality. One explanation for these findings is that only participants with certain fears about heights such as, losing balance or being out of control, appraised physiological arousal as threatening. It is also possible that deepening exposure was more robust to fear renewal, which this study was not designed to detect as there were no follow up measures.

The improvement in self-efficacy across all participants suggests further research is warranted to investigate feelings self-efficacy as a mechanism of change in virtual reality treatments. It is also recommended that researchers consider alternative methods of increasing arousal such as, mental imagery. Research examining the differences between subgroups of height phobics based on threat beliefs is also indicated.

Chapter 3: Integration, impact and dissemination

The objective of both the systematic review and the empirical paper was to evaluate and extend the literature on the therapeutic *content* of virtual reality treatments for specific phobias. The review identified directions for future research that were explored in the empirical paper. Main reflections on the process were the timing of the review in relation to the initial study design and ambitious recruitment targets.

The systematic review will be submitted for publication in *'Cyberpsychology, Behavior and Social Networking'* and the empirical paper will be submitted to *'Behaviour Research and Therapy'.* It is hoped that both papers will inform the development of future virtual reality treatments, including how they are designed, disseminated and tested.

Chapter 1: Systematic review

Virtual reality for specific phobias: a systematic review of treatment content

Abstract

Background

Clinical trials support the use of virtual reality (VR) in therapy as a viable treatment for specific phobias, with effect sizes comparable to *in vivo* exposure. The use of VR for mental health conditions was previously confined to specialist labs. However, over the past three years the hardware has become accessible as consumer equipment. This has seen a renewed interest in developing VR treatments to be used in clinics.

Objectives

The aim of this review is to evaluate the contemporary applications and therapeutic content of virtual reality in the treatment of specific phobias to inform the development of the next generation of VR treatments.

Methods

A systematic search was conducted of randomized controlled trials published in the last ten years with one (or more) arms using virtual reality as a treatment for specific phobias.

Results

445 papers were screened and sixteen trials meeting the inclusion criteria were identified. The precise content of the VR treatments was often poorly detailed but most used hierarchical exposure models except for one study that used behavioural experiments. Most studies used virtual reality to replicate *in vivo* exposure and none tested mediators or moderators of treatment. All studies found medium to large effect sizes on the primary outcomes from pre to post treatment.

Conclusion

The basic model of hierarchical exposure to feared stimuli in VR produces good clinical effects. However, variability in treatment effects indicates that research is needed to establish the most effective way of using VR. A research programme that includes study of moderators, mediators, and the effects of single techniques would be valuable. Future research should also focus on using the full potential of VR technology to deliver novel treatments that enhance cognitive change and reduce fear renewal.

Introduction

Evidence for the use of virtual reality (VR) to treat mental health problems is growing but it has mostly been applied to the treatment of specific phobias. This review will consider, in depth, how VR has been applied to specific phobias in order to learn precisely how the technology has been utilised and to identify potential improvements that could deliver greater treatment benefits as VR becomes increasingly used in clinics.

Specific phobias

Symptoms of specific phobias are marked by an intense fear and avoidance of specific objects or situations with symptoms persisting for several months (DSM-5, Diagnostic and Statistical Manual of Mental Disorders; American Psychiatric Association, 2013; ICD-11, International Classification of Diseases, 11th revision; World Health Organization, 2018). Phobia subtypes according to the DSM-5 are as follows: animal (spider, snake, rats, dogs), natural environment (heights, storms, water), situational (enclosed spaces, flying, lifts), blood injury (medical procedures, blood, needles) and other (choking, vomiting, loud noises, balloons). Animal phobias are the most prevalent phobia in the general population and are more common in women, usually developing in early childhood. This is closely followed by fear of heights, but most people will have more than one phobia (Curtis, 1998). Social phobia and agoraphobia are not included in the subtypes of specific phobia and are considered separate disorders (Craske & Stein, 2016; LeBeau et al., 2010).

Specific phobia is a common mental health problem with a lifetime prevalence of 18.4% and a 12-month prevalence of 12.1% (Kessler et al., 2004). Phobias often start in childhood and have an average age of onset of 8 years old with more women experiencing symptoms than men (Wardenaar et al., 2017).

Treatment of specific phobias

Treatments for specific phobias are predominantly exposure-based, such as *in vivo* exposure, virtual reality techniques, imaginal exposure, systematic de-sensitization, and Eye Movement Desensitization and Reprocessing (EMDR). Alternative approaches used either on their own or in combination with exposure include applied muscle tension, applied relaxation, progressive muscle relaxation, and cognitive therapy (Wolitzsky-Taylor, Horowitz, Powers & Telch, 2008; Grös & Antony, 2006). Exposure treatments involve facing the feared stimulus either *in vivo* (having direct contact), through imaginal techniques or within computer-generated environments. There is substantial evidence to support the use of *in vivo* exposure to treat several phobias including, but not limited to, blood injection (see review Ayala, Meuret & Ritz, 2009), dental (see review Appukuttan, 2016), spider (Öst, 1996), flying (see review Clark & Rock, 2016), heights (Baker, Cohen & Saunders, 1973), choking (see review Sahoo, Hazari & Padhy, 2016), vomiting (Veale, 2009) and water (Menzies & Clark, 1993). Exposure-based treatments are more efficacious than non-exposure controls, but the latter do have some benefit (Choy, Fyer & Lipsitz, 2007), notably cognitive therapy in the treatment of claustrophobia (Booth & Rachman, 1992). *In vivo* is often considered the most effective of the exposure treatments, however, comparable effect sizes are found in virtual reality for the treatment of phobias (Carl et al., 2019).

In vivo exposure-based therapies predominantly use habituation models. These originate in emotional processing theories of exposure (Foa & Kozak, 1986; Foa & McNally, 1996), despite the limitations in evidence to support these models (Craske, Kircanski, Zelikowsky, Mystkowski, Chowdhury & Baker, 2008). Habituation is achieved by remaining in a feared scenario until anxiety reduces but fear renewal is

common, it doesn't work for everyone, and within session fear reduction does not predict outcomes (Baker, Mystkowski, Culver, Mortazavi & Craske, 2010). This suggests habituation is not the only mechanism involved in new learning. The inhibitory learning model of exposure provides an alternative understanding that addresses these limitations. It originates in the literature on fear extinction and outlines the presence of both a primary phobic association between a feared stimulus (e.g. heights) and conditioned response (e.g. fear), and a secondary non-fearful association learned during exposure. This differs from previous models as exposure does not erase the primary association that links the stimulus with a phobic response; it is *inhibited* by the secondary association. Therefore, fear renewal and symptom reduction are dependent on the quality and strength of new learning achieved during exposure.

Craske and colleagues (2015) collate the literature on inhibitory learning and suggest additional mechanisms to maximise exposure by strengthening this secondary association. (Craske, 2015). Craske, Treanor, Conway, Zbozinek & Vervliet (2014) propose a series of therapeutic techniques that maximise outcomes based on this model of exposure. Recommendations include violating expectancy (creating a mismatch between what is expected and the outcome), varying exposure intensity (facing stages on a fear hierarchy at random), using multiple contexts (more than one setting for exposure), deepening extinction (combining phobic cues), and dropping safety seeking behaviours. The aim of this approach is to create new learning about the feared stimulus (cognitive change).

Virtual reality

Virtual reality is an immersive computer-generated environment that allows the user to explore and interact with a virtual world. It was first developed in the 1960s,

requiring large laboratories with specialist computers (Freeman et al, 2017). These have since advanced to portable head mounted displays (HMDs), CAVE automatic virtual environments created by multiple projectors within a cube shaped room (CAVE, Cruz-Neira, Sandin & DeFanti, 1993), and augmented reality headsets (Bhorkar, 2017; Zhu, Hadadgar, Masiello & Zary, 2014). Between 2013-2014, Oculus Rift released their 'Development Kit 1' to the public market and by 2016, HTC, HP, Acer, Dell, and Sony had all developed similar systems (Jerden, Grindle, Woerden & Boulos, 2018). These newer headsets, relatively low in price and easy to set up and support, have now made it possible to integrate virtual reality into clinical services, which could prove an important part of future mental health care. Furthermore, new developments in hardware are expected on the market soon, including VR headsets with advanced, self-contained tracking capabilities.

Virtual reality has been used for the treatment of phobias since the mid-1990s, with the first applications being used for fear of heights (Rothbaum, et al., 1995a; Rothbaum et al., 1995b). These environments involved a series of footbridges and balconies at different heights, and a glass elevator that scaled the side of a building. Exposure sessions lasted for 35-45 minutes and were delivered weekly for seven weeks. Since these early trials, virtual reality has been used for many different mental health problems including psychosis, substance misuse, post-traumatic stress disorder (PTSD) and eating disorders (for review, see Freeman et al., 2017). The design of these environments predominantly targets real world stimuli that can be replicated and controlled in virtual reality. In the treatment of PTSD this is trauma related stimuli whereas preliminary studies in eating disorders have experimented with changes to the body-mass index of the user's avatar (Keizer, Elburg, Helms & Dijkerman, 2016).

Likewise, Freeman and colleagues have pioneered virtual reality to assess (Freeman et al., 2003) and treat paranoia (Freeman et al., 2016). Importantly, large effect sizes in comparison to controls have been consistently reported for the use of virtual reality for specific phobias, notably, animal phobias, fear of flying and fear of heights (for a review, see Carl et al., 2019; Maples-Keller, Yasinski, Manjin & Rothbaum, 2017; Opriş, Pintea, García-Palacios, Botella, Szamosközi & David, 2012).

Existing literature and reviews

There have been several reviews and meta-analyses of the outcomes for virtual reality treatments for anxiety disorders (Benbow & Anderson, 2019; Carl et al., 2019; Fodor, Coteț, Cuijpers, Szamoskozi, David & Cristea, 2018; Lindner et al., 2017; McCann et al., 2014; Opriş et al., 2012; Meyerbröker & Emmelkamp, 2010; Powers & Emmelkamp, 2008; Gorini et al., 2008; Krijn, Emmelkamp, Olafsson & Biemond, 2004). These included some information about specific phobias but only Parsons and Rizzo (2008) evaluated the efficacy and effectiveness of virtual reality treatments in a meta-analysis of VR used for anxiety and specific phobias. More recently, Maples-Keller et al. (2017) discussed the same topic in a narrative review. There were similar findings in both reviews, despite being a decade apart; virtual reality exposure was found to reduce anxiety and phobias symptoms, but studies were often of poor quality with small sample sizes. Recommendations for further research included identifying moderators, extending follow up data, and treating other types of phobias. Most of the reviews evaluated efficacy but Garcia-Palacios, Botella, Hoffman & Fareget (2007) looked at the acceptability of virtual reality treatments for specific phobias. Lower refusal rates were found in virtual reality treatments compared to *in vivo*. Participants also preferred virtual reality due to anticipatory anxiety about facing feared stimuli in

the real world. Lindner et al. (2017) reviewed virtual reality technology in relation to specific phobias and highlighted some of the components that are relevant to modern systems such as tracking, gaze, user input and platform choice. This was an informative overview of the different components of virtual reality that were overlooked in previous reviews. However, the authors are the creators of VIMSE, a new gamified virtual reality treatment for spider phobia (Miloff, Lindner, Hamilton, Reuterskiöld, Andersson & Carlbring, 2016), and the review focused on this application to illustrate the components discussed. The content of current treatments using virtual reality for specific phobias has yet to be systematically reviewed.

Current systematic review

The current review focuses on a different aspect from the existing literature on virtual reality treatments for specific phobias. These previous reviews have predominately evaluated the efficacy of virtual reality treatments. Up to date reviews on outcomes are important in a field that relies on emerging technology as there is large potential for change (e.g. in the capabilities of the hardware and software). The purpose of this review is to evaluate and critically appraise the *content* of virtual reality treatments for specific phobias over the last ten years. Virtual reality is simply the immersive technology and the content of the treatment could vary widely and hence produce different outcome effects. Therefore, the treatment principles and VR content are scrutinised in this review. This could identify the most helpful components but also treatment ideas that could enhance efficacy. Components of the virtual reality treatments in the included studies were extracted and both the clinical implications and future directions discussed.

Method

Inclusion criteria

The inclusion criteria for studies in this review were: studies published in peer-reviewed journals; adult participant samples (18+) with a specific phobia; randomized controlled trials with at least one arm using virtual reality as a treatment modality for specific phobias; studies using immersive virtual reality (Head Mounted Display, Augmented Reality, or CAVE systems); studies published within the last 10 years of the search; and in the English language. Only randomised controlled trials (RCTs) were included as they are considered the gold standard of research to evaluate healthcare interventions (Schulz, Altman & Moher, 2010). RCTs of psychological interventions aim to test these against treatment as usual, wait lists, or alternative interventions (active controls). Virtual reality treatments tested in RCTs will be more developed than those used in case reports and, similarly, the evidence for effect sizes will be stronger.

Exclusion criteria

Dissertations, conference posters and abstracts, theory and assessment studies were excluded from the review. Participants <18 years old and child onset disorders were excluded due to potentially different treatment needs in these populations. Studies within health psychology or that used virtual reality for physical rehabilitation (e.g. fear of falling), were also excluded. Where multiple papers were published from the same trial, the study with the main outcome data on the virtual reality intervention was reviewed.

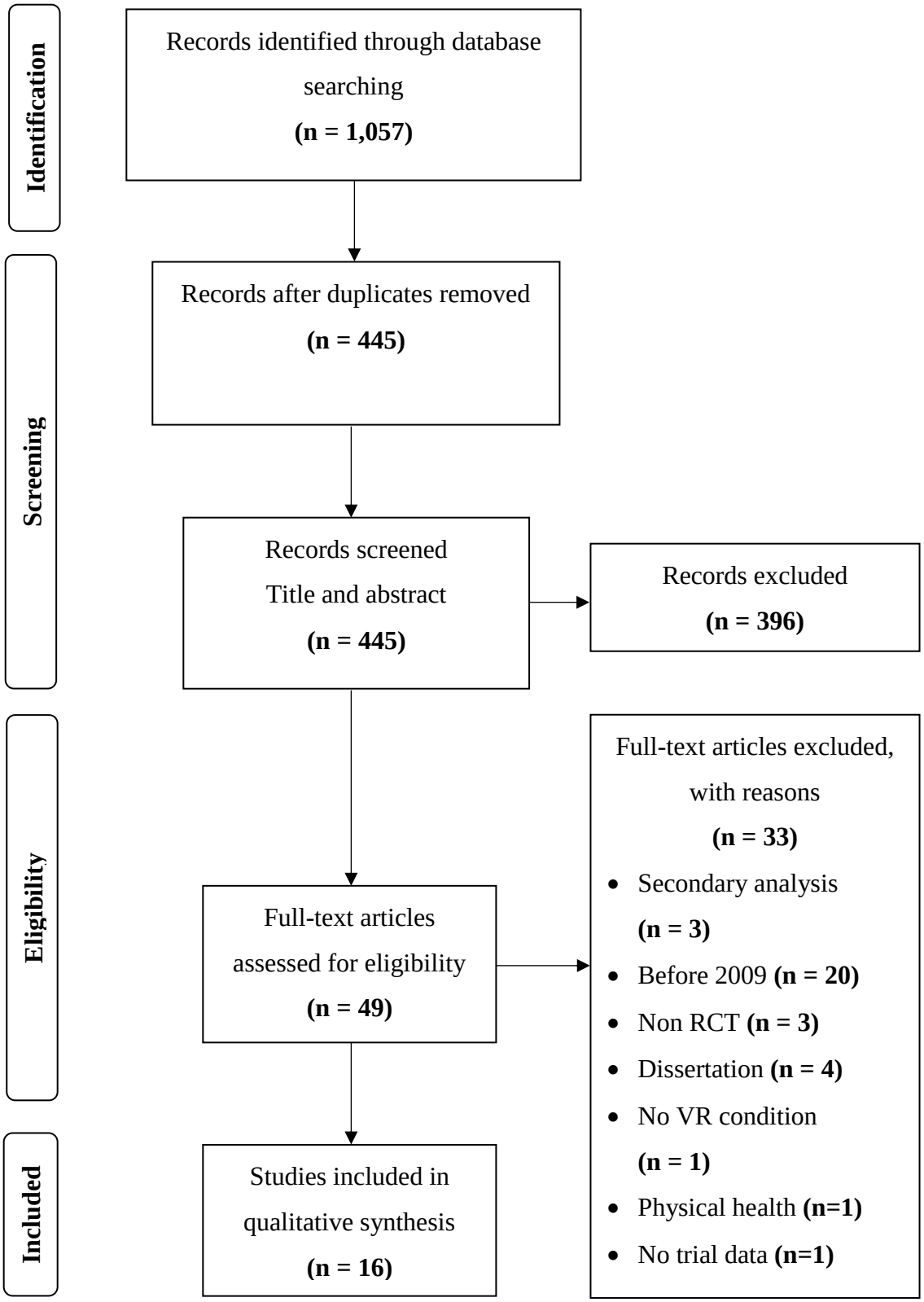
Search strategy

Four electronic social science databases were searched to identify studies relevant to this review. Ovid search engine was used for Embase, Medline and

PsycINFO. An additional search was carried out on Pubmed. The search was closed on 7th February 2019. The general search terms used for each concept were as follows: "virtual reality" AND treatment OR therapy OR intervention OR exposure AND *phobia OR *phobic OR phobia* OR "fear of".

An additional restriction of papers published in English (language) was applied. The search was limited to Titles and Abstracts in all four databases. 'Anxiety' was not used as a search term to identify studies looking at specific phobias despite falling under anxiety disorders, as the content of these results was too broad. Search results were exported to Mendeley reference management software. Duplicates were removed and the title and abstract of 445 studies were screened for eligibility. This initial screening excluded 396 studies and identified 49 that potentially met the inclusion criteria. Full text versions of these studies were all accessed online and screened for eligibility. A total of 16 studies met the inclusion criteria and were included in this review. Figure 1 shows the PRISMA flow diagram for the process of identifying, screening and selecting papers for the review.

Figure 1. PRISMA flow diagram of systematic literature review



Screening co-rating

Two independent researchers (Research Clinical Psychologists) discussed and confirmed inclusion and exclusion criteria for the review.

Quality assessment

The quality of studies included in this review were assessed using an appraisal tool adapted by the researcher to evaluate the risk of bias in selection, allocation, detection, attrition and reporting (see Table 1). The tool was informed by the Critical Appraisal Skills Programme (CASP, 2014), the Cochrane Handbook for Systematic Reviews of Interventions (Higgins & Green, 2011), and the Jadad scale (Jadad et al., 1996). The Jadad is a three-point scale ranging from 0-5 that is commonly reported to assess the quality of RCTs. However, Higgins and Green explicitly discourage the use the scored rating scales, including the Jadad, due to a disproportionate emphasis on the reporting of trials rather than the conduct. As such, the Jadad score for each study is included for reference only and is intended to be used in combination with the other factors outlined in the tool. The following websites were checked for trial registration: https://clinicaltrials.gov and http://www.isrctn.com. If a trial was registered elsewhere but the details were reported by the authors, it was classified as registered. Only trials that did not report these details and could not be found on the stated websites were described as unregistered. As registration to the ISRCTN requires a fee, clinicaltrials.gov was also used as this is a free service.

Table 1. Quality appraisal

Study	Jadad Score	N	Allocation Concealment	Primary outcome stated	Power analysis stated	Recruitment methods reported	Sample represented the clinical population	Trial registered
Minns et al. (2019)	2	77	None reported	×	×	✓	×	✓
Gujjar et al. (2019)	4	30	✓	✓	✓	×	✓	✓
Freeman et al. (2018)	5	100	✓	✓	✓	✓	✓	✓
Lima et al. (2018)	1	36	×	×	×	×	Cannot tell	×
Meyerbröker et al. (2018)	5	56	✓	✓	✓	✓	Cannot tell	✓
Jaquart et al. (2017)	3	59	×	✓	✓	✓	✓	✓
Botella et al. (2016)	5	63	✓	✓	✓	✓	✓	✓
Triscari et al. (2015)	3	65	×	×	×	✓	✓	✓

Table 1 (continued).

Shiban et al. (2015)	3	58	None reported	×	×	✓	✓	×
Moldovan & David (2014)	3	32	✓	×	×	×	Cannot tell	×
Tart et al. (2013)	5	29	✓	✓	✓	×	Cannot tell	✓
Rus-Calafell et al. (2013)	1	15	×	×	×	×	Cannot tell	×
Meyerbröker et al. (2012)	3	67	✓	✓	×	✓	✓	✓
Tortella-Feliu et al. (2011)	1	60	×	✓	×	✓	✓	×
Quervain et al. (2011)	5	40	✓	×	×	✓	×	×
Michalszyn et al. (2010)	0	32	×	×	×	✓	×	×

Results

Treatment effects

Treatment effects for each study were reported to evidence the efficacy of the virtual reality treatments included in this review. As virtual reality is still relatively new, variation between studies is expected so it is important to evidence the efficacy of each virtual intervention before evaluating individual treatment components.

To evaluate treatment effects, Cohen's d was reported for pre and post-test scores on the primary outcome. Effect sizes according to Cohen (1988) are as follows: small (d=0.20), medium (d=0.50) and large (d=0.80). In studies that compared virtual reality to a non-virtual reality control, between group effect sizes were reported. In the studies that compared two or more virtual reality conditions or with active controls (*in vivo* or imaginal exposure), within group effect sizes were reported. In studies that compared pharmacological augmentations to virtual reality, the placebo condition was used to calculate the within groups effect size. If effect sizes were not reported by the authors they were calculated by dividing the difference in means with the shared standard deviation. In within group effect sizes, the difference in means was divided by the pre-test standard deviation. The exception to this was Shiban et al. (2015) as there was no obvious control condition so within group effect sizes for all four conditions were reported.

Eleven studies used self-report measures for their primary outcome (Minns et al., 2019; Gujjar et al., 2019; Freeman et al., 2018; Lima at el., 2018; Meyerbröker et al., 2018, 2012; Jaquart et al., 2017; Triscari et al., 2015; Shiban et al., 2015; Rus-Calafell et al., 2013; Tart et al., 2011; Quervain et al., 2011). Three studies used

behavioural avoidance tests (Tart et al., 2013; Botella et al., 2016; Michalszyn et al., 2010) and one study failed to report their data (Moldovan & David, 2014).

Of the fifteen studies with primary outcome data, the majority reported large effect sizes ranging from d=0.85 to d=2.09. The three studies comparing virtual reality to *in vivo* or imaginal exposure reported small or medium between group effect sizes but larger within group effect sizes for their virtual reality conditions. Botella et al. (2016) and Michalszyn et al. (2010) found large effect sizes between d=1.0 and d=1.96. Rus-Calafell et al. (2013) was the only study to find a medium effect size for the virtual condition (d=0.61).

Table 2. Treatment effects

Study	Primary outcome	Control condition	Pre-post between group effect size *(Cohen's d)* with 95% confidence intervals [CI]	Pre-post within group effect size *(Cohen's d)* with 95% confidence intervals [CI] for the virtual reality condition
Minns et al. (2019)	Fear of spiders questionnaire (FSQ; Szymanski & O'Donoghue, 1995)	Participants watched a neutral video on a computer monitor and received psychoeducation only	0.85* CI [0.384 to 1.32]	-
Gujjar et al. (2019)	Visual analogue scale in the assessment of dental phobis (VAS-A; Luyk, Beck & Weaver, 1988)	Informational pamphlet	1.52* CI[a]	-
Freeman et al. (2018)	Height interpretations questionnaire (HIQ; Steinman & Teachman, 2011)	Usual care	2.0*** CI [1.84 to 2.51]	-
Lima et al. (2018)	Storm fear questionnaire (SFQ; Nelson, Vorstenbosch & Antony, 2014)	Progressive muscle relaxation and psychoeducation	0.72* CI[a]	-

Note: a = statistic not reported and data not available; p<0.05*; p<0.01**; p<0.001***

Table 2 (continued).

Triscari et al. (2015)	Flight anxiety sensitivity questionnaire and flight modality questionnaire (FAS, FAM; Van Gerwen, Spinhoven, Van Dyck & Diekstra, 1999)	Active controls (CBT EMDR and CBT systematic de-sensitization). Within group effect size reported for VR only condition.		
	FAS total		-	2.0*** CI[a]
	FAM total		-	2.22*** CI[a]
Shiban et al. (2015)	Fear of spiders questionnaire – German version (FAS; Rinch, Bundschuh, Engler, Muller, Wissmann & Ellwort, 2002)	No non-VR control. Within group effect sizes calculated for each arm.		
		VR (single stimulus/single context)	-	0.75[a] CI [a]
		VR (multiple stimulus/single context)	-	1.84[a] CI [a]
		VR (multiple stimulus/multiple context)	-	2.36[a] CI[a]
		VR (single stimulus/multiple context)	-	0.85[a] CI [a]

Note: a = statistic not reported and data not available; p<0.05*; p<0.01**; p<0.001***

Table 2 (continued).

Moldovan & David (2014)	Data not reported	Wait list	Data not reported	Data not reported
Tart et al. (2013)	Behavioural avoidance test (BAT)	No non-VR condition. Within group effect size calculated for VR with placebo.	-	1.79** CI[a]
Rus-Calafell et al. (2013)	Fear of flying scale (FFS; Haug, Brenne, Johnsen, Berntzen, Götestam & Hugdahl, 1987)	Active control (imaginal exposure). Within group effect size reported for VR only condition.	-	0.61* CI[a]
Meyerbröker et al. (2012)	Flight anxiety modality questionnaire (FAQ; Ven Gerwen et al., 1999)	No non-VR condition. Within group effect size calculated for VR with placebo.	-	1.55[a] CI[a]

Note: a = statistic not reported and data not available; p<0.05*; p<0.01**; p<0.001*

Table 2 (continued).

Tortella-Feliu et al. (2011)	Fear of flying questionnaire (FFQ; Bornas, Tortella-Feliu, Garcia de la Banda, Fullana & Ilabrés, 1999)	Active controls (computer assisted exposure with therapist and self-administered computer assisted therapy). Within group effect size reported for VR only condition.	-	1.68[a] CI[a]
Quervain et al. (2011)	Acrophobia questionnaire (AQ; Cohen, 1977)	No non-VR condition. Within group effect size calculated for VR with placebo.	-	0.94[a] CI[a]
Michalszyn et al. (2010)	Behavioural avoidance test (BAT)	Active control. Within group effect size reported for VR only condition.	-	1.96[a] CI[a]

Note: a = statistic not reported and data not available; p<0.05*; p<0.01**; p<0.001***

Recruitment and sample formation

Recruitment methods differed across studies which increased the likelihood of selection bias. Seven studies recruited from the general population using local radio, newspapers adverts, flyers or word of mouth (Freeman et al., 2018; Jaquart et al., 2017; Botella, Perez-Ara, Bretón-López, Quero, García-Palacios & Baños, 2016; Shiban, Schelhorn, Pauli & Mühlberger 2015; Meyerbröker et al., 2012; Tortella-Feliu et al., 2011). Three studies recruited from University populations, of which one offered undergraduate course credits in return for participation (Minns et al., 2019) and the other two studies recruited using flyers and adverts (Quervain et al., 2011; Michalszyn et al., 2010). Two studies recruited from outpatient clinics (Gujjar, van Wijk, Kumar & de Jongh, 2019; Triscari, Faraci, Catalisano, D'Angelo & Urso, 2015), one used participants on waiting lists for previous research trials (Meyerbröker, Morina & Emmelkamp 2018) and three did not report their recruitment methodology (Lima, McCabe-Bennett & Antony, 2018; Moldovan & David, 2014; Tart et al., 2013).
Only six of the studies justified their sample sizes and reported power calculations (Gujjar et al., 2019; Freeman et al., 2018; Meyerbröker et al., 2018; Jaquart et al., 2017; Botella et al., 2016; Tart et al., 2015). Studies with small sample sizes may be underpowered to detect both statistical and clinical change. Without power calculations the results are difficult to interpret. Exceptions to this standard are pilot studies which are usually underpowered. The recommendation for these trials is to report confidence intervals (Lee, Whitehead, Jacques & Julious, 2014).

Participant characteristics

Eight hundred and nineteen participants from sixteen studies were included in this review. The sample size ranged from 15 (Rus-Calafell, Gutiérrez-Maldonado,

Botella & Baños 2013) to 100 (Freeman et al., 2018) with a mean of 51 participants across all studies. There were proportionately more female participants (63.7%) than male (36.3%) but four studies did not report these data, excluding 182 participants from this calculation (Meyerbröker et al., 2018; Tart et al., 2013; Meyerbröker et al., 2012; Michaliszyn et al., 2010). All studies used adult samples (18+ years) and the mean age of participants was 32.3 years old, ranging from 19.3 to 45.5 years old. Two studies did not report the mean age of their participants and referred only to the inclusion criteria (Moldovan & David, 2014; Meyerbröker et al., 2012). Ten studies were conducted in European countries, five from North America and one from Asia. Only four studies reported data on the ethnicity of their participants (Gujjar et al., 2019; Freeman et al., 2018; Lima et al., 2018; Jaquart et al., 2017). These studies recruited participants from Malaysia, the United Kingdom, Canada and the United States of America and were 62.6% Caucasian, 24.7% Asian, 5.3% Other/not reported, 3.1% Black Afro-Caribbean, 2.6% Black American, 1.1% Middle Eastern and 0.5% Hispanic.

Phobia

All studies tested virtual reality treatments for specific phobias. Two studies included two or more phobias in the trial, using different virtual reality scenarios for each phobia (Meyerbröker et al., 2018; Moldovan & David, 2014). This resulted in smaller samples for each group and differences in treatment, particularly in Moldovan & David's (2014) study, which included participants with fear of flying, fear of heights and social phobia. Four studies included participants with spider or small animal phobia (Minns et al., 2019; Botella et al., 2016; Shiban et al., 2015; Michaliszyn et al., 2010). Four studies included participants with a fear of flying only (Triscari et al., 2015; Rus-Calafell et al., 2013; Meyerbröker et al., 2012 & Tortella-Feliu et al., 2011). Four

studies included participants with a fear of heights only (Freeman et al., 2018; Jaquart et al., 2011; Tart et al., 2013 & Quervain et al., 2011). One study included participants with a dental phobia (Gujjar et al., 2019) and one included participants with storm phobia (Lima et al., 2018).

Most of the studies (n=12) used The Diagnostic and Statistical Manual of Mental Disorders 4th Edition (DSM-4, American Psychiatric Association, 1994) or 5th Edition (DSM-5; American Psychiatric Association, 2013) to assess presence of specific phobias and eligibility for participation. Six studies used self-report measures either on their own or in combination with the DSM-4/5, and/or a behavioural avoidance test (BAT) (Minns et al., 2019; Gujjar et al 2019; Freeman et al., 2018; Lima et al., 2018; Meyerbröker et al., 2018; Jaquart et al., 2017; Michalszyn et al., 2010). Only four studies included a BAT to assess eligibility, two of these were *in vivo* tests involving a live tarantula that was rated on proximity to the vivarium, subjective units of distress ratings (SUDS) and level of interaction with the spider (Minns et al., 2019; Michalszyn et al., 2010). The other two studies using BATs used the virtual reality fear of heights scenarios used in the treatment phase and the ratings were based on progression through the scenarios and SUDS (Jaquart et al., 2017; Tart et al., 2013).

Conditions

Nine of the studies compared virtual reality to a non-virtual reality control. These included *in vivo* (Botella et al., 2016 & Michalszyn et al., 2010), waitlist (Minns et al., 2019; Freeman et al., 2018; Moldovan & David et al., 2014), muscle relaxation (Lima et al., 2018), information pamphlet (Gujjar et al., 2019) and imaginal exposure (Rus-Calafell et al., 2013). The other seven were manipulation studies comparing two or more virtual reality treatments. Augmentations of components external to virtual reality

included drug augmentations (Meyerbröker et al., 2018; 2012; Tart et al., 2013; Quervain et al., 2011) and exercise (Jaquart et al., 2017). Manipulations directly to the virtual reality treatment included changes to the environment (Shiban et al., 2015) and whether it was self-administered (Tortella-Feliu et al., 2015) or automated (Freeman et al., 2018).

Outcome measures

All sixteen studies used a combination of disorder specific self-report measures at pre and post treatment. Fourteen studies collected follow up data that ranged from 2 weeks to 1-year post treatment. Minns et al, (2019) did not collect follow up data but the post treatment timepoint was 1 week after the intervention. Likewise, Meyerbröker et al, (2012) also didn't use follow ups but collected data at each intervention session in addition to pre and post.

Nine studies used BATs. Five used *in vivo* tests, involving a live spider or cockroach contained within a vivarium (Minns et al., 2019; Botella et al., 2016; Shiban et al., 2015; Michalszyn et al., 2010), dental procedures (Gujjar et al., 2018) or a flight of stairs in a tall building (Quervain et al., 2011). The *in vivo* BATs were used at screening, pre, post and follow up timepoints. Three studies used BATs in virtual reality. These tasks were based on scenarios used during the intervention phase, for example, a glass elevator or a storm. Lima et al. (2018) and Tart et al. (2013) used the virtual BATs to measure change at pre and post treatment but Jaquart et al. (2017) used it only to assess eligibility.

Treatment content

The data extracted on the content of treatment are separated into two parts: the virtual environment and therapeutic components.

Virtual reality environments

Table 4 summarises the components of the virtual environments, the specific technology used in each study, and a brief overview of the scenarios.

Technology

Most of the studies used head mounted displays (HMDs) except for Moldovan & David (2014) who also used a CAVE automatic virtual environments (CAVE), cubed shaped rooms with multiple projectors. HMDs are wired headsets that display an image in each eye, providing a stereoscopic scene similar binocular vision. Only one study in the review used a monoscopic HMD (Michalszyn et al., 2010). Typically, HMDs use tracking to mirror the movements of the user in the virtual environment (i.e. to enable interactive experiences). In newer models, such as the Oculus Rift and HTC Vive, the tracking is greatly improved, reducing the effect of cybersickness and improving presence. Six of the studies described which systems they used (Minns et al., 2019; Freeman et al., 2018; Shiban et al., 2015; Rus-Calafell et al., 2013; Meyerbröker et al., 2012; Tortella-Feliu et al., 2011), four described only the type of technology (Lima et al., 2018; Moldovan & David, 2014; Quervain et al., 2011; Michalszyn et al., 2010), and four did not report these details (Meyerbröker et al., 2018; Jaquart et al., 2017; Triscari et al., 2015; Tart et al., 2013). One study used an augmented reality headset overlaying the real world with virtual environments (Botella et al., 2016).

Sensory feedback

It was assumed that all sixteen studies used visual displays as this is a fundamental aspect of virtual reality systems. Three studies did not report sufficient detail on the technology or exposure techniques used to establish whether additional sensory information was included (Jaquart et al., 2017; Trsicari et al., 2015; Tart et al.,

2013). Nine studies used visual and auditory feedback. The 'virtual coach' used by Freeman et al (2018) provided psychoeducation, explained the concept of safety behaviours and asked how safe the participant was feeling. This treatment used voice recognition to respond to participant answers, which was not reported in any of the other studies. Rus-Calafell et al. (2013) and Tortella-Feliu et al. (2011) both used the Virtual Flight® program designed by the Botella and Baños research team (Botella, Osma, Garcia-Palacios, Quero & Baños, 2004). This environment simulated sounds that are routinely heard at an airport and during take-off. Participants were passive observers and did not interact with avatars in the environment, the content of the audio was designed to increase anticipatory anxiety.

In addition to visual and auditory content, five studies used tactile feedback. Meyebröker and colleagues used a vibrating airline chair to simulate flying in both their 2018 and 2012 studies, and Lima et al. (2018) augmented a virtual reality treatment for storm phobias by using a wooden platform that vibrated with woofers playing sounds of thunder and lightning. Quervain et al. (2011) used a raised wooden platform that didn't provide active feedback but if the participant walked near the edge they would have experienced the feeling of a ledge. Similarly, Gujjar et al. (2019) asked participants to sit in a dentist's chair during the virtual reality session to replicate the feeling of being in a clinic room. Gujjar and colleagues were also the only research team to include olfactory feedback in the form of clove oil on the chair to simulate clinical smells associated with being at the dentist.

The scenarios were reported as either seated or standing with variation as to whether participants were passive or could move freely through the virtual environment. Eight of the treatments were seated and were designed for small animal phobia

(including spiders), fear of flying, dental phobia and storm phobia (Gujjar et al., 2018; Meyerbröker et al., 2018 & 2012; Botella et al., 2016; Shiban et al., 2015; Rus-Calafell et al., 2013; Tortella-Feliu et al., 2011 & Lima et al., 2018). The seated position matched the avatar in the dental phobia treatment as the scenario took place in a dentist's chair. It also matched the final element of the flying treatments that involved sitting on an aircraft waiting for take-off. However, it was not clear from the remaining studies whether there was discordance between the avatar's position in the virtual environment and the participant's position in the room. This has the potential of negatively affecting presence in the virtual environment and reducing anxious responses to feared stimuli.

Five studies required participants to stand in virtual reality for the treatment of fear of heights scenarios (Freeman et al., 2018; Meyerbröker et al., 2018; Jaquart et al., 2017; Tart et al., 2013; Quervain et al., 2011). In all five of these studies the participants were also able to move freely through the virtual environment. Two seated treatments for small animal and spider phobia allowed participants to control their movement in the virtual scenarios. Shiban et al. (2015) allowed participants to change the perspective of their avatar by using a computer joystick whereas Botella and colleagues (2016) used an augmented reality system allowing participants to use their own hands to interact with virtual cockroaches and spiders. Four studies in this review did not report on the position of their participants during the treatment (Minns et al., 2019; Triscari et al., 2015; Moldovan & David, 2014; Michalszyn et al., 2010).

Type of exposure

Thirteen of the studies in this review used hierarchical exposure for the model of treatment in virtual reality, which involved exposing participants to scenarios of

increasing difficulty. Participants were either asked to stay in the environment until their anxiety reduced as measured by subjective units of distress scales (Jaquart et al., 2017; Tart et al., 2013; Rus-Calafell et al., 2013; Tortella-Feliu et al., 2011; Quervain et al., 2011) or for 'as long as possible' within a specified time limit (Minns et al., 2019; Gujjar et al., 2019; Meyerbröker et al., 2018, 2012; Botella et al., 2016; Shiban et al., 2015). The only study to report a different exposure model was Freeman et al. (2018) who used a series of behavioural experiments and based progression on belief ratings and task completion. Two studies did not report the content of the exposure used in virtual reality (Triscari et al., 2015; Michalszyn et al., 2010).

Table 3. Scenario summaries and components of virtual reality environments

Study	Senses	Standing or sitting	Move freely through scenario	VR system	Scenario summary
Minns et al. (2019)	Visual	NR	×	HMD: Oculus Rift	A Grammostola rosea spider (tarantula) in different scenarios, gradually getting closer to the participant.
Gujjar et al. (2019)	Visual Auditory Olfactory	Sitting	×	HMD: Oculus development kit 2	The dentist's clinic room with scenarios increasing in difficulties (teeth examined to the dentist holding a drill).
Freeman et al. (2018)	Visual Auditory	Standing	✓	HMD: HTC Vive, headphones, microphone	Participant is supported by a 'virtual coach' to complete tasks overlooking a large atrium. Tasks include throwing balls over the edge and rescuing a cat from a tree. **Oxford VR software.**
Lima et al. (2018)	Visual Auditory Tactile	Seated	✓	HMD: brand not reported, speakers in chair. Vibrating platform.	Participants started inside a house and ventured outside into different extremes of weather. **Virtually Better software.**

Abbreviations: NR, not reported; HMD, head-mounted display; CAVE, cave automatic virtual environment

Table 3 (continued).

Meyerbröker et al. (2018)	Visual Auditory Tactile	Sitting (flying) Standing (heights)	✓ (heights only)	Not reported	The flying scenario involved taking off, in flight turbulence and landing. The heights scenario was a series of floors in a shopping mall that participants could walk to by stairs or via a lift. They could look over the edge and change the floor to glass.
Jaquart et al. (2017)	NR	Standing	✓ Remote control	Not reported	Participants went up a 35-story building in a glass elevator. They could look over the edge of the railings and move around the space. **Virtually Better software.**
Botella et al. (2016)	Visual	Sitting	✓	HMD: Augmented reality (Vuzix)	Spiders and cockroaches projected near to and onto the hands of the participants and therapists by augmented reality.

Abbreviations: NR, not reported; HMD, head-mounted display; CAVE, cave automatic virtual environment

Table 3 (continued).

Triscari et al. (2015)	NR	NR	NR	Not reported	Treatment detail not reported.
Shiban et al. (2015)	Visual	Seated	✓ (joystick)	HMD: Z800 3D Visor	Participants were exposed to different dark basements (contexts) and different spiders (stimuli). They were then asked to look around the basement, housing one of the spiders using a joystick to steer gaze.
Moldovan & David (2014)	Visual Auditory	NR	NR	HMD: brand not reported. CAVE: system using multiple projection screens.	Treatment detail not reported.
Tart et al. (2013)	NR	Standing	✓	Not reported	Participants went up a hotel glass elevator and explored a series of balconies and walkways.

Abbreviations: NR, not reported; HMD, head-mounted display; CAVE, cave automatic virtual environment

Table 3 (continued).

Rus-Calafell et al. (2013)	Visual Auditory	Sitting	×	HMD: 5DT HMD	Participants progressed through three levels: packing at home, arriving at the airport and waiting for take-off. **Virtual Flight® software.**
Meyerbröker et al. (2012)	Visual Auditory Tactile	Sitting	×	Stereoscopic glasses: Cybermind Visette Pro stereoscopic glasses. Vibrating aircraft seats.	A series of 25-minute flights in different weather conditions and increasing technical issues with the aircraft.
Tortella-Feliu et al. (2011)	Visual Auditory	Sitting	×	HMD: 5DT HMD 800	See Rus-Calafell et al. (2013) **Virtual Flight® software.**
Quervain et al. (2011)	Visual Auditory Tactile	Standing	✓	HMD: brand not reported	Participants progressed through an environment with a series of bridges and elevators, connecting platforms of variable height.
Michalszyn et al. (2010)	Visual	NR	✓ (mouse)	Monoscopic I-glasses brand not reported	Participants confronted a large black widow spider.

Abbreviations: NR, not reported; HMD, head-mounted display; CAVE, cave automatic virtual environment

Therapeutic components

Table 4 summaries the therapeutic components of virtual reality treatments in each study.

Length of treatment

Most interventions were delivered in 20-30 minute sessions. This dictated session doses in most of the studies, requiring short breaks to alleviate potential fatigue, eyestrain, or nausea. The exception was Botella and colleagues (2016) who used augmented reality for 3 hours as users are less likely to experience sickness with these headsets. Cybersickness is a motion related issue that may stem from tracking delays between the headset and the virtual environment or in scenarios where the virtual environment does not match the user's movements, causing symptoms similar to motion sickness (Rebenitsch & Owen, 2016). As augmented reality systems combine real and virtual worlds, tracking delays are less problematic.

Eight studies used virtual reality for a single intensive session ranging from 30 minutes to 3 hours in duration. The remaining interventions were delivered in multiple sessions over a period of days and weeks. The most amount of time participants spent in virtual reality were reported by Triscari et al. (2015), Rus-Calafell et al. (2013) and Michalszyn et al. (2010) at 6 hours, 6-7.5 hours and 9.5 hours respectively. However, large effect sizes were found across studies regardless of time. The number of sessions largely reflected the amount of time in virtual reality, except for Triscari and colleagues who reported 16 sessions and only 6 hours *in virtuo*. Their pre and post effect size was one of the largest in the review (d=2.0) but most of their intervention involved *in vivo* tasks such as visiting air traffic control, speaking to a pilot, and participating in a simulated take off. In addition, the content of the virtual reality component of the

intervention was not reported by the authors. There was no trend in the number or length of sessions according to the phobia being treated.

Therapist involvement

Six studies used therapists during the virtual reality treatment. Rus-Calafell et al. (2013), Tortella-Feliu et al. (2011) and Quervain et al. (2011) reported minimal details on therapist involvement but described them as 'guiding' participants through the environment. Quervain and colleagues asked participants to move their heads around and to refrain from using cognitive avoidance behaviours. Tart et al. (2013) reported a more active role for their therapist who taught participants to approach feared stimuli and to challenge dysfunctional beliefs. The most involved therapists during the virtual reality scenarios were in Freeman and colleagues' (2018) automated treatment (in which the therapist was a virtual character) and Botella and colleagues' (2016) augmented reality treatment. The automated treatment was the only study to use a virtual therapist or 'coach' to guide participants through the scenario. Participants were encouraged to drop their safety behaviours and challenge beliefs about heights by completing a series of behavioural experiments. The virtual therapist interacted with participants and responded to their progress, using phrases such as "that's great, you're doing really well" and "do you feel safer than you did when you first arrived on this floor?".

The Botella et al. (2016) study was the only study to use augmented reality and a therapist that was visible to participants during virtual reality. This was made possible by the type of headset and influenced the capacity of therapist involvement. Therapists in this study used a single session exposure using modelling techniques. Botella and colleagues used the real therapist to model interaction with the feared stimuli whereas Minns et al. (2019) used the pre-recorded video for the same purpose.

Additional treatment components

Most of the studies in the review used virtual reality on its own as a treatment with variations in dose, time spent in virtual reality, the scenario design and therapist involvement. However, four out of sixteen reported additional components as well as psychoeducation. Triscari and colleagues (2015) went far beyond the virtual reality treatment, including cognitive behavioural therapy, a visit to air traffic control and a demo flight that simulated aircraft departure. These elements were the same across all their conditions and were reported in detail in the paper, yet the virtual reality component was not specified. Moldovan and David (2013) also provided additional cognitive behavioural sessions outside of their virtual reality treatment and failed to detail any of their treatment components. Relaxation and diaphragmatic breathing were provided by Rus-Calafell et al. (2013) in the form of homework and as a filler to reduce anxiety between experimental conditions by Shiban et al. (2015).

Psychoeducation

Twelve of the studies used psychoeducation at the start of therapy. This largely involved providing the rationale for exposure, the value of approaching feared stimulus, and the purpose of using virtual reality as a treatment modality. Psychoeducation was mostly delivered by the researchers apart from Freeman and colleague's (2018) who used a 'virtual coach' to guide participants through an automated treatment. In this study, psychoeducation about fear of heights and cognitive behavioural therapy was provided both at the beginning and throughout the intervention. In two studies, psychoeducation was delivered without the presence of a researcher. Minn et al. (2019) showed participants a brief video on a computer screen and Tortella-Feliu et al. (2011) provided participants with an informational leaflet. Triscari and colleagues (2015) were

the only researchers to deliver psychoeducation in a group format at the beginning and end of therapy. This was the longest intervention in the review and three sessions were dedicated to psychoeducation alone.

Cognitive behavioural techniques

Seven of the studies used cognitive behavioural techniques during virtual reality. Most of these involved challenging beliefs about the feared stimulus but no information was provided on how this was achieved (Jaquart et al., 2017; Triscari et al., 2015; Moldovan & David et al., 2014; Tart et al., 2013 & Rus-Calafell et al., 2013). Only two studies reported cognitive behavioural techniques in detail (Freeman et al., 2018; Botella et al., 2016). Freeman and colleagues' (2018) automated therapy set up a series of behavioural experiments facilitating cognitive change. Beliefs about heights were identified and rated at the beginning of the treatment and again at the end to track progress and change.

Botella and colleagues' (2016) augmented reality treatment for small animal differed from the other studies in the technology used and therapist involvement as outlined previously. The treatment was based on a single session, intensive treatment of spider phobia and involved 'reinforced practice' and 'cognitive challenging' (Öst, Salkovskis and Hellström's, 1991; Öst, 1989) However, the authors did not expand upon how cognitions were identified and challenged.

Homework

Only three of the studies in the review set homework tasks for participants. Rus-Calafell and colleagues (2013) taught participants to use diaphragmatic breathing and instructed them to practice between sessions. At the beginning of therapy, participants were also asked to purchase a plane ticket to use 15 days after the end of treatment, a

homework task also set by Tortella-Feliu et al. (2011). The purpose of this was to improve motivation and encourage completion of the intervention. Botella and colleagues (2016) also set homework following the intervention, encouraging participants to continue exposing themselves to feared stimuli. No further instructions were provided on how or when this should be done.

Maximising exposure

The therapeutic techniques recommended by Craske et al. (2014) to maximise outcomes based on the inhibitory learning model of exposure were reported in a number of the studies. The most frequently used was encouragement to drop safety seeking behaviours, such as avoidance or looking away. Eight of the studies asked participants to refrain from using these behaviours (Minns et al., 2019; Gujjar et al., 2019; Freeman et al., 2018; Lima et al., 2018; Meyerbröker et al., 2018; Jaquart et al., 2017; Shiban et al., 2015; Tart et al., 2013 & Quervain et al., 2011). Most of the authors provided minimal information on how participants were encouraged to drop safety behaviours, so it was assumed that psychoeducation was the primary tool to facilitate insight. Quervain et al. (2011) and Freeman et al. (2018) were the only researchers to mention cognitive safety behaviours, for example, participants telling themselves the scenario isn't real. This type of safety behaviour threatens presence in virtual reality and is difficult to monitor. Freeman and colleagues (2018) provided the most detail on how they addressed safety behaviours as the treatment was automated and therefore the same for all participants, for example, "Many people try to deal with their fear by using defences…closing your eyes when you're up high and not looking down, repeating a comforting phrase to yourself, taking off your shoes…". They also used a series of tasks such as lowering a barrier and playing a xylophone over the edge of a balcony to place

their participants in situations that forced them to abandon behaviours they would normally rely upon.

Freeman's automated therapy also utilised two other techniques recommended by Craske and colleagues: expectancy violation and variability. To violate expectancy, a mismatch between what is expected, and the actual outcome needs to be large so that new learning can take place. In the automated treatment, participants were asked to complete tasks that were more challenging than could be achieved *in vivo,* such as rescuing a cat from the tree. Feelings of safety were rated rather than distress, which is supported by the evidence that within-session fear reduction does not predict outcomes (Baker et al., 2010). New learning about the feared stimulus was anticipated in the remaining thirteen studies that detailed the virtual reality treatment and used hierarchy exposure models, but this was not counted as expectancy violation. This is because progression was based on SUDS ratings or time elapsing and the target was fear reduction, not what needed to be learnt about the stimulus. Freeman et al. (2018) was also the only study to use variability, by introducing tasks of varying difficulty at random. The other studies used scenarios of increasing difficulty, except for Michalszyn et al. (2010) who presented a single level of difficulty.

Shiban et al. (2015) explicitly investigated the effect of multiple contexts on a virtual reality treatment for spider phobia. This involved changing the context of the exposure to improve generalisability. Shiban and colleagues conducted a four-arm trial, changing the appearance of the stimulus (virtual spider) and the context of exposure (virtual basement). The colour of the spiders was changed to alter their appearance and the wallpaper, flooring and lighting were altered in the basement. Whilst Shiban et al. (2015) were the only authors to state multiple contexts as a construct, most of the other

studies in this review used similar methods. Five studies used the same environment but changed the stimulus. Gujjar et al. (2019) kept participants sat in a dentist's chair throughout but changed auditory content and the dentist's behaviour. Lima et al. (2018) increased the intensity of the weather, moving from a still day to thunder and lightning, similar to Meyerbröker et al. (2011) who changed weather conditions to affect turbulence on an aircraft. The other two studies changed the proximity and movements of virtual spiders and cockroaches to increase anxiety (Minns et al., 2019; Botella et al., 2016). Seven studies used multiple environments within the scenario. Five of these studies used fear heights treatments that progressed participants through a series of floors, lifts, bridges and balconies (Freeman et al., 2018; Meyerbröker et al., 2018; Jaquart et al., 2017; Tart et al., 2013 & Quervain et al., 2011). The fear of flying scenarios used by Rus-Calafell et al. (2013) and Tortella-Feliu et al. (2011) used three different contexts: a bedroom, a terminal and an aircraft.

Table 4. Therapeutic components of virtual reality treatments

Study	No. of sessions	Time in VR *Total or Mean (M)*	Psycho-education	CBT techniques	Maximising exposure	Therapist active during VR	Homework
Minns et al. (2019)	1	30 mins	✓	×	DSB	×	×
Gujjar et al. (2019)	1	40.6 mins (M)	×	×	DSB	×	×
Freeman et al. (2018)	6	124.4 mins (M)	✓	✓	DSB, MC, Var, EV	✓ (virtual)	×
Lima et al. (2018)	1	1 hour	×	×	DSB	×	×
Meyerbröker et al. (2018)	3	2.5 hours	✓	×	DSB	×	×
Jaquart et al. (2017)	1	30 mins	✓	✓	DSB	×	×
Botella et al. (2016)	1	3 hours	NR	✓	×	✓	Y
Triscari et al. (2015)	16	6 hours	✓	✓	×	NR	NR
Shiban et al. (2015)	1	20 mins	NR	×	DSB, MC	×	×
Moldovan & David (2014)	1	1.5 hours	✓	✓	×	×	×

Abbreviations: NR, not reported; DSB, dropping safety behaviours; MC, multiple contexts; Var, variability; EV, expectancy violation

Table 4 (continued).

Tart et al. (2013)	2	1 hour	✓	✓	DSB	✓	N
Rus-Calafell et al. (2013)	6	6 – 7.5 hours	✓	✓	×	✓	Y
Meyerbröker et al. (2012)	4	4 hours	✓	×	×	×	×
Tortella-Feliu et al. (2011)	1	NR	✓	✓	×	✓	Y
Quervain et al. (2011)	3	1 hour	✓	×	DSB	✓	×
Michalszyn et al. (2010)	8	9.5 hours	✓	✓	×	NR	×

Abbreviations: NR, not reported; DSB, dropping safety behaviours; MC, multiple contexts; Var, variability; EV, expectancy violation

Key findings

Virtual reality treatments were effective at reducing scores on the primary outcomes in all the studies. The biggest effects were found when virtual reality was compared to non-active controls such as waiting lists and informational pamphlets (Minns et al., 2019; Gujjar et al., 2019; Freeman et al., 2018; Lima et al., 2018; Triscari et al., 2015). These results were also reflected in the within group effect sizes of studies that used multiple virtual reality conditions or active controls. There was no statistically significant difference between virtual reality, *in vivo,* and imaginal exposure. It was therefore deemed an effective and viable treatment alternative (Botella et al., 2016; Rus-Calafell et al., 2013; Michalszyn et al., 2010).

External augmentations to virtual reality could only be evaluated for drug treatments and physical exercise. The other studies used virtual reality as the experimental condition which meant augmentations such as cognitive behavioural therapy and relaxation were used in all groups. Propanalol was more effective at reducing anxiety scores in virtual reality than placebo (Meyerbröker et al., 2018) as were Glucocorticoids (Quervain et al., 2011). Neither Yohimbine Hydrochloride nor D-Cycloserine provided any additional benefit to virtual reality exposure treatments (Tart et al., 2013; Meyerbröker et al., 2012). Physical exercise completed for 20 minutes prior to virtual reality for fear of heights did not provide any additional benefit at post-test scores one week later (Jaquart et al., 2017). However, the timing of the exercise augmentation was highlighted by the authors as a possible reason for null findings. Whether virtual reality was therapist or self-administered was not found to have an effect (Tortella-Feliu et al., 2011). However, minimal information was provided on therapist involvement during virtual reality and all groups received therapist input at the

start and finish of the intervention. The use of multiple contexts had a positive effect on self-reported spider phobia scores in the short term, but this reduced over time. Using multiple stimuli during exposure was also beneficial in the short term and was maintained at follow up (Shiban et al., 2015). There was substantial variation in the content of treatments including the number of sessions and the use of additional components external to VR. Therefore, the treatments in this review could not be directly compared so the most effective components of treatment are yet to be established.

Discussion

The purpose of this review was to evaluate the content of current virtual reality treatments for specific phobias. Randomised controlled trials, published in the last ten years that used virtual reality as a component of treatment, were reviewed. The primary treatment targets of the trials were to reduce self-reported fear and avoidance of phobic stimuli.

Approximately half of the studies discussed investigated the efficacy of virtual reality in comparison to non-virtual control conditions. The remaining studies used augmentations external to or within the virtual environment. It is widely acknowledged that immersive virtual reality is as effective as *in vivo* for the treatment of phobias (Carl et al., 2019). However, this review highlighted a paucity of research in the development and advancement of virtual reality as a stand-alone treatment and a lack of detailed reporting on treatment content. It seems that researchers have focused more on the believability and immersion of virtual environments over and above therapeutic content, directing future research to investigate new technology as opposed to treatment techniques. This is also reflected in the poor methodological quality and relatively small

sample sizes of many of the studies reviewed. Pilot trials of new VR systems have dominated the research and larger clinical trials (phase II+) are yet to be conducted. Arguably, translational research is the next step for virtual reality treatments for phobias. Researchers should now investigate the full potential of virtual reality, how it can be used to enhance treatments and how it can target unmet clinical needs.

Notably, only a few studies utilised the technology available to create novel environments. Most authors used it to replicate the real world or as controlled conditions to test the effect of medication. This is despite significant advancement in virtual reality technology, so it is important to consider why this is the case. Importantly, only in recent years have systems become affordable and commercially available. As a result, research teams no longer require a large footprint or specialist computers to run clinical trials. The headsets are now portable and some companies, such as HTC, have released wireless systems but the construction and design of virtual environments continues to be expensive. They take time to build and require specific skills in computer science, which is economically limiting. This undoubtedly affects the motivation to test components of virtual reality treatments when pre and post effect sizes are already large and equivalent to *in vivo* exposure. It also encourages research teams to re-use existing scenarios and may explain why so many studies have targeted augmentations external to virtual reality. Indeed, two studies used the same Virtually Better® software for fear of storms and fear of heights (Lima et al., 2018; Jaquart et al., 2017), and two used the same Virtual Flight® scenario (Rus-Calafell et al., 2013; Tortella-Feliu et al., 2011).

Importantly, using virtual reality simply as an alternative to *in vivo* overlooks one of its main potential future advantages, to create scenarios that are unachievable in

the real world. For example, Freeman and colleagues (2018) are the first to use a fully automated treatment that used avatars to create a virtual therapist or 'coach'. Only a few studies in the review used a therapist during the virtual reality component and not all were clinically trained so there is an evident need to integrate and standardise how treatment is delivered. Creating avatars that respond to the user and are pre-programmed to provide evidence-based therapies is a unique and exciting application of this technology. Many people with phobias don't seek treatment (Wolitsky-Taylor, Horowitz, Powers & Telch, 2008) and those that do often wait for years after the phobia developed (Le Beau et al., 2010). Therefore, automation could improve help-seeking for phobias by normalising treatments and increasing accessibility. Indeed, participants who were given the choice between virtual reality and *in vivo* exposure reported a preference for the former, suggesting virtual treatments may be effective for clinical populations that are less likely to seek help (Curtis, 1998). The use of virtual reality in the treatment of psychosis supports this notion as this is a difficult to reach population yet VR is considered acceptable and safe to use (for a review see Rus-Calafell, Garety, Sason, Craig & Valmaggia, 2018).

The potential limitation of virtual environments that do not mirror the real world is that immersion and generalizability may be affected. It is also possible that cognitive safety behaviours, for example, telling themselves it isn't real, are more prevalent. Cognitive avoidance is particularly difficult to control in virtual reality as it requires self-monitoring and disclosure. In addition, verbal communication during the scenario has the unwanted effect of breaking presence that could increase avoidance. However, careful or 'judicious' use of safety behaviours early in therapy can increase engagement and facilitate progress if used correctly (Rachman, Radomsky & Shafran, 2008).

Therefore, if the exposure is sufficiently challenging, some cognitive safety behaviours may be beneficial and could explain the lower rates of drop out reported in virtual reality treatments in comparison to *in vivo* (Garcia-Palacios et al., 2007).

Few studies compared virtual reality treatments, tested individual treatment components or created novel environments. Trials of medication augmentations were the only studies to compare the same treatments, but virtual reality was used to create experimental conditions, so the treatments were purely exposure based. Shiban and colleagues (2015) were the only researchers to compare treatment components and to investigate mechanisms of change but none of the studies tested treatment mediators or moderators. This study used virtual reality to manipulate the targeted mechanism by changing the appearance and context of virtual spiders. The trial investigated whether different combinations of single or multiple context exposure was superior or if there was no additional benefit. The results indicated that using multiple contexts for exposure reduces fear renewal in the short term but using multiple stimuli is beneficial across time points. This finding is informative as most studies used multiple contexts within their scenarios but didn't identify or test these as potential mediators.

Only one study made adaptations to the virtual environment that could not be safely or easily achieved *in vivo*, such as rescuing a cat from a tree (Freeman et al., 2018). In this study, participants were presented with novel, challenging scenarios that required them to drop safety behaviours and approach the feared stimulus, increasing opportunity for new learning. The effect sizes achieved were larger and greater than expected for face to face therapy. Most of the studies did encourage participants to drop safety behaviours but this was often in the context of habituation and involved approaching feared stimuli or limiting avoidance. Given the evidence that fear renewal

is common in the treatment of phobias, it is surprising that alterative models of exposure are not being applied. Virtual reality provides the opportunity to test out augmentations and is an obvious platform to apply the recommendations made by Craske et al. (2014) based on the inhibitory learning model of exposure. However, it is likely that the focus on fear reduction and lack of follow up data with measures capturing cognitive change, have led to minimal interest in developing treatments in this way.

Exposure models

In line with the finding that most studies used virtual reality to replicate *in vivo,* nearly all studies used a hierarchical model of exposure. The exception was Freeman et al., (2018) who set up a series of behavioural experiments. Virtual environments based on hierarchical exposure increase the intensity of the stimuli in stages and habituate participants until their anxiety reduces or a specified amount of time has elapsed. These environments were designed to be completed in stages (single or multiple sessions) and become progressively more challenging. The model is based on the principle that exposure to feared scenarios reduces anxiety as the predicted danger associated with the stimulus does not occur. Given that fear renewal is common in phobias and habituation is considered one of many mechanisms involved in extinction, it is surprising that hierarchical exposure continues to be the primary approach in virtual reality treatments.

Despite most studies using similar models of exposure, there was variation in the length of treatment, therapist involvement, and the method of progression. The overall time spent in virtual reality ranged from 20 minutes to 7.5 hours, yet this was not reflected in the effect sizes which were all medium to large. In fact, large effect sizes were found in both one session and multiple session treatments on self-report phobia measures. Notably, none of the studies tested the effect of number of sessions and

several of the longer treatments used additional components making this difficult to analyse. It is unclear why there is so much variation in the number of sessions provided as many trials of virtual reality as a treatment for phobias were published before the studies in this review. It seems that virtual reality is presented as a tool to be used as part of therapy rather than as a self-contained treatment. Freeman and colleagues' (2018) automated intervention is unique in this regard but it also threatens the role of real therapists, which other researchers may find challenging. There is also variation in how involved the scenario is and whether participants were active or passive within the environment. This partly relates to the age of the technology and the design of the system, but it is an important aspect of the exposure and will have different effects on learning.

As expected, similar virtual reality technology was used in most of the studies, with the exception of Michalszyn et al. (2010) which was the oldest study in the review. This supported the limit applied to publication date in the inclusion criteria and highlights the importance of reviewing the research as the technology develops. Head mounted displays are now being used by most research teams, with only the occasional use of CAVE automatic virtual environments. Only one study used augmented reality for small animal phobia, which is not surprising. These systems use a combination of *in vivo* and virtual feedback, combining the two environments. Hence, they are only suitable for certain phobias and may be less cost effective in the long term as it still requires components of *in vivo* exposure. In contrast, immersive head mounted displays create a self-contained world that rely solely on the technology.

Limitations of the review

There are several limitations to this review. Firstly, only randomised controlled trials were included. This meant case reports and protocols were not discussed, which may have added greater variety in treatment techniques (though less evidence of efficacy).

A second limitation is the focus on specific phobias. As one of the earliest uses for virtual reality in mental health care, the area has been reasonably well researched. This could have led to more experimental uses of the technology, but it seems that there has been less impetus to develop new applications as the treatments are well established. Expanding the search criteria to other presentations may provide a different picture of treatment techniques applied in VR.

Thirdly, most of the studies reviewed had small sample sizes and did not directly compare treatments of the same phobia. Some researchers even compared treatments for multiple different phobias within the same study, further reducing power and diluting findings. This makes it difficult to directly link treatment differences to outcomes. The variation in methodological quality was also an issue as there was large variation in recruitment strategies, study design and the reporting of findings. Until larger, high quality trials are conducted, and virtual reality is prepared for clinical use, treatments for specific subtypes of phobia are unlikely to be compared. Without direct comparisons, treatment mediators and moderators cannot be tested, limiting future progress and the development of new treatments.

Finally, the review was limited to studies published within the last ten years. This was decided upon to restrict large variation in the technology being used but relevant studies may have been excluded. As the predominate model of exposure in

virtual reality appears unchanged since early studies in the area, the review does not cover information about how these were developed. The use of existing software within trials also presents a limitation as the primary papers testing these environments may not have been included.

Future directions

One of the key findings of this review is that few researchers are investigating the content of virtual reality treatments for phobias or seeking to utilise the technology to its full capacity. Studies like Shiban et al. (2015) that compare multiple virtual reality treatments for the same phobia should be one important format for research moving forward. Virtual reality is an established treatment, the effect sizes are large, and it is equivalent to *in vivo* exposure. These treatments are now being integrated into clinical services so focus should turn to augmentations and treatment moderators and mediators to understand the mechanism of effects and to use that knowledge to increase efficacy (Dunn et al., 2015). Many of the studies in this review used additional components that were external to virtual reality, but these were not compared to adequate controls. These components need to be properly tested to understand whether they provide any additional benefit. Likewise, the number of sessions, time spent in virtual reality, and the model of exposure needs to be evaluated more thoroughly. One explanation for the large variation in content is the lack of standardised reporting of virtual reality studies. This makes it difficult for researchers to thoroughly consult the literature before testing new interventions. One solution would be the development of a checklist to guide researchers in the reporting of clinical trials using virtual reality. This would both add clarity to the evidence base and help direct researchers on study design and the development of future interventions.

Virtual reality technology has advanced, and it is now an accessible and affordable platform for health care. Consequently, the content and the methods of evaluation need to modernise if we are to maximise the potential of virtual reality in health care.

Conclusion

In summary, this review found that most virtual reality treatments for specific phobias use hierarchy exposure models. This is the same approach that was used in the early VR treatment studies despite significant advancement in virtual reality software and hardware. Only a few studies utilised virtual reality to create scenarios that can't be replicated in the real world, but the majority used it as a digital version of *in vivo* exposure. Differences in the components of virtual reality were found across studies but, notably, only one study investigated treatment mechanisms. The potential of virtual reality as a platform to deliver treatments that target new learning and fear extinction is yet to be fully explored. However, despite variation in the number of sessions and the use of additional therapeutic components external to virtual reality, the effect sizes for pre to post treatment were medium to large and comparable to *in vivo* exposure. This supports the current literature on virtual reality as a treatment for specific phobias. Future research should seek to use virtual reality beyond it's obvious use as a replica of reality and design scenarios that make further use of its capabilities. It is recommended that individual treatment components are tested, and the comparison of multiple virtual reality treatments is prioritized.

Chapter 2: Empirical study

Deepening extinction in a virtual reality treatment for fear of heights

Abstract

Background: Clinical trials indicate that virtual reality (VR) treatments for specific phobias are efficacious but how can new learning be maximised? The interest of the current study is physiological arousal as it is associated with fear responses but there is discordance between objective and subjective measures both *in vivo* and in virtual reality.

Aim: The aim of the study was to investigate whether increasing physiological arousal using exercise increases the efficacy of an automated virtual reality treatment for fear of heights. Secondary aims were to test potential predictors of cognitive change and mediation of manipulation effects.

Method: A randomised controlled clinical-experimental test was conducted. 60 individuals with a fear of heights were randomised to either the VR treatment alone or with increased physiological arousal. Participants with a fear of heights were recruited via radio and public advertisements in Oxfordshire, UK, were aged between 18-65 years old, and scored $\geq$45 on the anxiety subscale and $\geq$8 on the avoidance subscale of the Acrophobia Questionnaire. The primary outcome was degree of conviction in the phobic threat belief, which was measured before and directly after treatment. The manipulation group completed 2-3 minutes of cycling at 80% of their maximum heart rate. To test predictors of cognitive change anxiety, mood, safety behaviours and risk aversion, were assessed. To test mediation of the manipulation, self-efficacy and subjective distress were assessed. Neither participant nor researcher was blind to group allocation.

Results: There were no missing data for the primary outcome in the study. Participants spent an average of 30 minutes receiving the VR treatment. Physiological

arousal was significantly higher in the manipulation group compared to the control group, (p<0.0001), (d=2.9). There was no significant difference between the two groups in degree of conviction in the fear of heights threat belief, (p=0.56), (d=0.1). Both groups showed significant reductions in fear of heights threat beliefs after the VR treatment (p<0.0001), (d=1.0). Self-reported distress, anxiety sensitivity, risk aversion, use of safety behaviours, and mood did not predict cognitive change.

Conclusion: An increase in physiological arousal achieved via exercise does not enhance cognitive change in beliefs about the feared stimuli in virtual reality treatment. Regardless of the augmentation, participants reported a significant reduction in belief conviction after a single 30-minute session, but predictors of change were not identified. Limitations include the short-term nature of the test, the absence of blinding, and lack of follow up data.

Introduction

Virtual reality (VR) treatments for specific phobias are effective and produce similar results as face to face therapies. However, VR has yet to be used to its full potential despite substantial developments in the technology. One approach is to update the methods of exposure from outdated habituation models to inhibitory learning approaches and to investigate augmentations that may enhance treatment. Virtual reality provides both the experimental conditions to examine if and how treatments for specific phobias can be improved, and a means of developing standalone interventions that can be used in a range of clinical settings. If automated, these treatments have the potential to be widely disseminated and to address unmet clinical need without requiring specialist expertise. Therefore, it is important to consider how these treatments work and if they can be enhanced if the capabilities of VR are to be maximised.

Virtual reality

Psychological therapy delivered via virtual reality is becoming part of healthcare provision. Headsets are now affordable, and technology is no longer limited to specialist laboratories, making it possible to integrate into clinical settings (Jerden, Grindle, Woerden & Boulos, 2018; Freeman et al., 2017). Current virtual reality systems consist of head mounted displays with stereoscopic vision and advanced tracking technology to enable the simulations to rapidly update on the basis of a user's movements. The technology has developed substantially in the last few years, but virtual reality has been used in the treatment of fear of heights since the 1990s (Rothbaum, et al., 1995a; Rothbaum et al., 1995b) and has since developed an evidence base (Coelho et al., 2009; Emmelkamp et al., 2001; Meyerbroker & Emmelkamp, 2010). Research also supports

its use in the treatment of conditions such as post-traumatic stress disorder, substance misuse, eating disorders, and paranoia (for review see Freeman at al., 2017).

One reason that VR has been used for the treatment of phobias for so many years is because feared stimuli can be easily generated in the virtual world and introduced to the user without the risk of actual harm. It is also possible to design scenarios that are somewhat impractical to use *in vivo* or unachievable in the real world. However, it is the feeling of immersion in VR that makes it particularly powerful, a phenomenon known as 'presence'. Slater (2009) describes presence as a combination of place illusion and plausibility illusion. Place illusion refers to the virtual environment simulating what you would expect to experience in reality, for example, when you look around, the environment moves with you and replicates the sensory feedback of the real world. This is achieved by accurate motion trackers that minimise tracking latency and create fully immersive systems. Plausibility illusion reflects how well the virtual environment responds to the user, for example, if they step towards an avatar and the avatar steps back, the environment is reactive to user initiated movements. In exposure-based environments, presence allows users to respond as if faced with a feared scenario in the real world. As previously mentioned, Rothbaum and colleagues first did this in the 1990s by creating virtual scenarios of high places such as, buildings and stairwells that allowed people with a fear of heights to be exposed to phobic stimuli via graded hierarchies. Many studies have since followed yet little has changed as to how these treatments are delivered. The primary focus for researchers continues to be how believable and immersive the environment is to the user rather than how the treatment content can be improved. However, in a recent study by Freeman et al. (2018) an automated treatment of fear of heights was successfully trialled against a control group

with good effect. Unlike previous studies, this treatment used a 'virtual coach' to guide users through a series of tasks in the format of behavioural experiments, which differs from the habituation models featured in previous studies. This was a VR cognitive therapy for fear of heights that if disseminated into clinical settings, has the potential to improve access to psychological therapies for people with specific phobias as it is fully automated.

Fear of heights

Specific phobias are a common disorder and have a lifetime prevalence of 12.5% and a 12-month prevalence of 9.1% (The US National Comorbidity Survey Replication, NCS-R, 2004). Acrophobia or 'fear of heights' is the second most commonly reported phobia (Curtis, 1998) and has a cross-national prevalence of 2.8-5.3% (Wardenaar et al., 2017; Le Beau et al., 2010). Fear of heights is characterised by a marked fear and avoidance of high places, and a presence of phobic beliefs about falling and how this is likely to occur. These include the structure collapsing, losing balance and jumping over the edge. Beliefs about feared stimuli are a feature of specific phobias more generally (Thorpe & Salkovskis, 1995) and most people have more than one fear (Curtis, 1998). It is therefore common for people with a fear of heights to report multiple situations that could lead them to fall. They are also more likely to report internal cues of anxiety and to interpret ambiguous bodily sensations threatening (Coelho & Wallis, 2010; Davey, Menzies & Gallardo, 1997). Consequently, many people avoid high places and few seek treatment despite an established evidence base that supports the use of psychological therapies in the treatment of fear of heights.

Exposure techniques are the primary component of most treatments for specific phobias. They work by exposing the phobic person to the feared stimulus to provide

new information and, therefore, new learning that contradicts phobic beliefs and reduces fear. Often, this is achieved via habituation which requires the person to face the feared situation or object until their self-reported anxiety decreases. This continues to be used by many clinicians and to date, has been the primary approach in virtual reality treatments for phobias. Habituation is the hallmark of the emotional processing theory of exposure (Foa & Kozak, 1986; Foa & McNally, 1996) and is frequently achieved by completing graded hierarchies whereby the person progresses through scenarios of increasing difficulty. Progression is either based on anxiety reduction or waiting for a period of time to elapse. However, the emphasis on habituation has been challenged as within and between session fear reduction does not predict outcomes as suggested (Baker et al., 2010; Craske et al., 2008). Furthermore, fear renewal is common, and treatment does not work for everyone. Craske and colleagues' 'Inhibitory Learning Model' of exposure consolidates the literature on fear extinction and recommends strategies to optimize exposure and improve outcomes (Craske, Kircanski, Zelikowsky, Mystkowski, Chowdhury & Baker, 2008). These recommendations suggest that habituation is only a partial treatment mechanism and that multiple different mechanisms are required to achieve lasting therapeutic change.

Inhibitory learning

Evidence for the inhibitory learning model has accumulated (for a review see Jacoby & Abramowitz, 2016). The theory outlines possible mechanisms of exposure and the role of inhibitory learning, which is central to fear extinction. Inhibitory learning refers to new (inhibitory) associations with the feared stimulus that are created during exposure. This means that the phobic person's original association with the stimulus is not extinguished but remains intact and a new, secondary non-fearful

association is created that inhibits the original. However, the latter is vulnerable to re-activation which can occur for a number of reasons; a new context (e.g. patient exposed to spider in a laboratory encounters one at home), re-traumatization (e.g. patient with a phobia of dogs is bitten) or time elapsed since exposure (e.g. patient exposed to heights does not re-expose themselves to high places and the fear returns), (Craske et al., 2008; Craske, Treanor, Conway, Zbozinek & Vervliet, 2014; Craske, 2015). Furthermore, people with anxiety disorders have deficits in inhibitory learning, which means they find it more difficult to inhibit the original phobic association, increasing the likelihood of fear renewal (Lissek et al., 2005; Liao & Craske, 2013).

Clinical recommendations made by Craske and colleagues to maximise exposure outcomes include violating expectancy, increasing variability of the exposure (in contrast to graded hierarchies), using multiple contexts, removing safety behaviours, combining phobic cues (deepening extinction), occasional reinforced extinction, and incorporating retrieval cues. The application of these strategies to exposure treatments requires research (Craske, 2015) but the evidence base is growing. Mixed results have been found for multiple context exposure but there are large variations in study design. In a series of conditioning studies, Neumann (2006) found 3-context exposure reduced fear renewal compared to a single context session, but this wasn't replicated in a later study (Neumann, Lipp & Cory, 2007). However, varying context by light level was effective, in particular when similar to the acquisition context (Balooch & Neumann, 2011). These results were from non-clinical populations, but similar results were found with spider phobic participants during *in vivo* exposure (Bandarian-Balooch, Neumann & Barosch, 2015). Likewise, Shiban, Schelhorn, Pauli and Mühlberger (2015) used

virtual reality to manipulate treatment context and found that changing the stimulus was more effective than changing the environment.

Virtual reality provides an ideal platform to investigate these strategies as environments and stimuli can be manipulated in experimental conditions, and augmentations can be compared. Multiple context exposure has been used effectively using computer-generated spiders on a flat screen (Vansteenwagen et al., 2007) and in immersive virtual reality (Shiban, Pauli & Mühlberger, 2013). However, most studies have used virtual reality to mirror *in vivo* exposure. The full potential of this technology has not been explored, and there is a paucity of research comparing different virtual reality treatments. As habituation is only a partial mechanism of exposure (Rowe & Craske, 2008), it is surprising that treatments have not been further developed. Notably, the therapeutic content of virtual reality treatments for fear of heights has barely changed since the 1990s, with the exception of Freeman et al's. (2018) automated treatment. This intervention incorporated many of the recommendations made by Craske et al. (2008; 2015) and reported large effect sizes at pre and post treatment (d=2.0) that were maintained at follow up. However, similar to many treatment studies using virtual reality, the automated treatment was compared to a non-treatment control so it is unclear whether particular elements of the intervention were more beneficial than others. This was not aim of Freeman's study, which set out to test whether automating therapy was effective but it does raise important questions about how these treatments work and what should be included in future scenarios. As the automated therapy was efficacious, further investigation into individual treatment components and possible augmentations is warranted to maximise outcomes and refine treatment content.

Augmentations to exposure

The study of augmentations to exposure therapies is not limited to the recommendations outlined by Craske and colleagues. Indeed, researchers have investigated a range of augmentations to improve learning consolidation during and after psychological treatment for exposure therapies. For example, pharmacological augmentations such as, D-cycloserine (Tart et al., 2013), Yohimbine Hydrocholride (Meyerbröker et al., 2018 & 2012), Propanalol (Meyerbröker et al., 2018) and Glucocorticoids (Quervain et al., 2011) have been investigated by a number of researchers for their effect on learning and fear extinction. However, these produced mixed results; propanalol and glucorticoids were both found to reduce anxiety in virtual reality but D-cyloserine and Hydrocholride did not provide any additional benefit.

There is also evidence that physical exercise improves learning consolidation following exposure (Roquet & Monfils., 2018) but many of these studies focused on rodent samples with only a few using human participants. In a recent study by Jaquart et al. (2017) participants were asked to complete 20 minutes of aerobic exercise prior to exposure, which was predicted to upregulate the brain derived neurotrophic factor (BDNF) and enhance learning consolidation. BDNF is thought to be lower in anxious populations and is believed to reduce subjective fear and fear renewal, but the authors found no difference between conditions. Notably, participants in this study returned to their resting heart rate before starting exposure, which differed from a study of similar design by Powers et al. (2015). Powers and colleagues sought to enhance prolonged exposure for PTSD by also increasing BDNF but importantly, there was only 5 minutes before starting exposure compared to 20 minutes in Jaquart's study. Unlike Jaquart and colleagues, acute exercise was found to have a positive augmentation effect. One

explanation for these findings is that physiological arousal during exposure was higher in the Powers et al. (2015) study. As a result, the exposure may have been more intense and aversive than the Jaquart et al. (2017) study, providing additional opportunities for new learning about the feared stimulus.

Physiological arousal is a characteristic of fear and anxiety. In specific phobias, the relationship between arousal and subjective anxiety has been examined, but these are not always synchronous, and one does not necessarily predict the other (Emmelkamp & Felten, 1985; Taylor, 1977). Similar findings have been reported in virtual reality as skin conductance was associated with self-reported anxiety, but there was no change in heart rate (Wilhelm, Pflatz, Gross, Mauss, Kim, Wiederhold, 2005). However, the link between internal and external cues of anxiety is more relevant in specific phobias than the literature would suggest (Craske, 1991). Notably, Coelho and Wallis (2010), and Davey, Menzies and Gallardo (1997) found that people with a fear of heights often misinterpret internal cues of anxiety and appraise physiological arousal as threatening. This indicates that increased arousal heightens the perceived risk of falling and increases fear. Most of the research on physiological arousal is observational and uses virtual reality to investigate fear responses between controls and phobics (Wiederhold, Jang, Kim, Wiederhold, 2002). Few studies have directly manipulated arousal, and none have tested effects on self-reported distress or phobic beliefs.

Aerobic exercise is one method of inducing physiological arousal that was used by Jaquart et al. (2017) and Powers et al. (2015) but in these studies, physiological arousal was a by-product of the manipulation and not the primary interest. In other areas of research, acute exercise has been used successfully to reduce anxiety sensitivity i.e. fear of the internal sensations of anxiety (Sabourin, Stewart, Watt & Krigolson, 2015;

Broman-Fulks & Storey, 2008; Smits, Berry, Rosenfield, Powers, Behar & Otto, 2008; Broman-Fulks, Berman & Webster, 2004), and for the treatment of panic disorder (Broocks et al., 1998). Anxiety sensitivity is a risk factor for anxiety disorders (Taylor, 1999) and predicts fearfulness (Reiss, Peterson, Gursky & McNally, 1986). Furthermore, Taylor, Koch and McNally (1992) found anxiety sensitivity to be higher in most anxiety disorders compared to controls, except for simple phobia. However, this study did not include people with a fear of heights who are known to find anxious arousal aversive.

There are mixed results for the effect of exercise on exposure therapy, specifically anxiety disorders (for a review see Jayakody, Gunadasa & Hosker, 2012) but some positive effects have been reported. Herring, Hallgren & Campbell (2017) found that completing 30 minutes of aerobic exercise improved worry and state anxiety whereas Zeng, Pope, Lee & Gao (2018) found a reduction in depression and anxiety scores following VR based exercise. One explanation for these findings is that the effect of exercise is moderated by negative appraisals of physiological arousal and that exercising prior to or during treatment exposes the person to interoceptive cues of anxiety. This may be particularly salient for panic disorder. Alternatively, other mediating factors may explain these results such as increased self-efficacy. Evidence shows that exercise increases feelings of self-efficacy and improves positive affect (Reed & Ones, 2006; McAuley, Blissmer, Katula & Duncan, 1998; Rudolph & Butki, 1998). If self-efficacy does improve following a short period of exercise, phobics may feel more able to engage in challenging situations during exposure, increasing the opportunity for new learning and cognitive change.

Identifying augmentations is one method of improving treatment outcomes for specific phobias that can be investigated using to virtual reality technology. However, it is also important to consider who is likely to benefit from these treatments and whether specific components are more beneficial to particular groups of people. This is particularly relevant as automated treatments will need to address individual differences and overcome the absence of person centred content found in face to face therapy.

Predictors of treatment outcomes

Surprisingly, the literature on predictors of treatment outcome in specific phobias is inconclusive (Eskildsen, Hougaard & Rosenberg, 2010; Hellström & Ost, 1996). There is some evidence that limited coping skills and a negative cognitive style lead to poorer outcomes (Trumpft, Margraf, Vriends, Meyer & Becker, 2010), and that positive mental health predicts symptom remission (Tesimann, Brailovska, Totzeck, Wannemüller & Margraf, 2018) but these are relatively broad constructs. Muris, Meyer & Merckelback (1998) found a strong association between state and trait anxiety with treatment outcomes in spider phobics, with high trait anxiety negatively affecting outcomes following behavioural therapy. In a 5 year follow up study, spider phobics with lower levels of depression were found to do better. Risk aversion has been identified as a potential treatment predictor in social phobia and generalised anxiety disorder, and to affect help seeking behaviours in these populations (Lorian & Grisham, 2012). Aversion to risk has not been tested in specific phobias but similar results may be expected in this population as avoidance of threat is central to the disorder. Likewise, safety seeking behaviours that maintain phobic threat beliefs are targeted in most exposure therapies. However, we do not know if people who use more or fewer safety behaviours prior to treatment are more or less likely to benefit from the intervention.

Understanding predictors of treatment outcome in specific phobias requires clarity. This is particularly important in the development of new VR treatments scenarios can be modified according to the needs of the client group. Furthermore, there may be differences between those who benefit from VR based therapies and those that benefit from face to face therapies. Therefore, it is important to consider predictors of change when developing new VR interventions, particularly as treatment content moves away from simply replicating *in vivo* therapies.

Summary

To date, exposure treatments in virtual reality have largely used habituation to feared stimuli to create cognitive change. This is no longer considered the most effective approach. Physiological arousal and self-reported ratings of fear and anxiety are discordant in specific phobias both *in vivo* and in virtual reality. However, people with a fear of heights appraise these physical sensations as threatening. It is not clear who will benefit most from treatment for specific phobias, but this is needed to inform future therapies. To enhance cognitive change and maximise outcomes, components of virtual reality, augmentations to treatment and predictors of therapeutic change need to be investigated.

Current study

The aim of the study was to test the effects of increased physical arousal in an automated virtual reality treatment for fear of heights. In the current study, aerobic exercise was used to manipulate physiological arousal by increasing heart rate. A target heart rate was achieved by a short period of vigorous cycling to induce arousal. Additional physical effects of exercise included breathlessness, perspiration and physical tiredness. Increased feelings of self-efficacy were anticipated in the exercise

group that would allow participants to face more challenging stimuli. It was expected that increasing arousal would affect subjective fear and there would be a greater mismatch between anticipated and actual outcomes of facing feared stimuli. This mismatch was anticipated to lead to new learning about the phobic stimulus and to promote new learning.

Primary hypothesis: Increasing physiological arousal in virtual reality will significantly reduce degree of conviction in threat beliefs, in comparison to virtual reality alone.

Hypothesis 2: Self-efficacy and subjective units of distress will mediate the effect of increased physiological arousal on change in belief conviction.

Hypothesis 3: Tendency to use safety behaviours, risk aversion, mood, trait anxiety, sensitivity to internal phobic cues and self-reported fear of heights are predictors of belief reduction in virtual reality.

Method

Design

The study used a between-groups, randomised controlled experimental design. All participants received a brief automated immersive virtual reality treatment for fear of heights and were randomly assigned to the experimental 'exercise' condition or the control 'no-exercise' condition. The experimental manipulation was carried out prior to each VR session (see Figure 3 for study procedure). The primary outcome variable was a belief rating of what they most feared happening when encountering heights. Additional predictor variables were completed by all participants at baseline and there were also repeated assessments for mediation analysis.

Ethical consideration

The study was reviewed and approved by the Royal Holloway Research Ethics Committee (REC project ID: 862; see Appendix A). As the study was conducted in the Department of Psychiatry at the University of Oxford, ethical approval was also granted by the University of Oxford Medical Sciences Interdivisional Research Ethics Committee (REF: R58997/RE001; see Appendix B). Participants were required to complete questionnaires about anxiety, mood, risk aversion, safety behaviours, and fear of heights. The potential for these questionnaires to prompt difficult feelings was discussed with all participants in person and they were provided with a debrief information sheet that included signposting to external services (see Appendix C). Participants were also required to complete a short period of physical exercise. They were screened for health conditions prior to taking part and they were provided with water during participation. Virtual reality is not suitable for people with significant balance problems, some ocular and visual conditions, and people with photosensitive epilepsy. Participants were screened for suitability and any physical limitations were discussed prior to taking part. In some people, immersive virtual reality can cause cybersickness (motion related nausea and dizziness). If needed, participants could leave virtual reality at any point by removing the headset.

Participants and recruitment

60 participants were recruited via advertisements aired on local radio (Oxfordshire, UK) over a 6-week period and posters in the local area (see Appendix D). People replied to the advertisement via text and were sent a link to an online screening questionnaire to assess eligibility. Participants aged between 18 – 65 years old, scoring $\geq$45 on the anxiety subscale and $\geq$8 on the avoidance subscale of the Acrophobia

Questionnaire (AQ) were included in the study. The mean scores of people with a fear of heights on the AQ are 48 to 60 on the anxiety subscale and 4 to 14 on the avoidance subscale (Cohen, 1977; Baker, Cohen & Sanders, 1973). Cut offs for this study were based on previous studies and the range expected to detect fear of heights (Șoflău & Matu, 2016). Individuals with photosensitive epilepsy, no stereoscopic vision or balance problems were unable to complete a short period of intense exercise on an indoor bike, or people who were currently receiving treatment for fear of heights were excluded. See Figure 2 for consort diagram. Eligible participants were required to attend a 90-minute testing session at a virtual reality laboratory at the University of Oxford.

Piloting and service user involvement

Piloting took place prior to recruitment to assess acceptability of the study design and efficacy of the manipulation. Four participants took part in piloting. Two of the pilot participants did not have a fear of heights and were used to assess the procedure and manipulation; how quickly the target heart rate could be reached and how long it was maintained following two minutes of exercise. The two participants with a fear of heights completed the screening questionnaire and met the eligibility criteria to take part. They were asked to give feedback on the study and the suitability of the procedure for people with a fear of heights. This included the order of the questionnaires, introduction to the lab and explanation of the study, management of anxiety during testing and the final debrief.

Power analysis

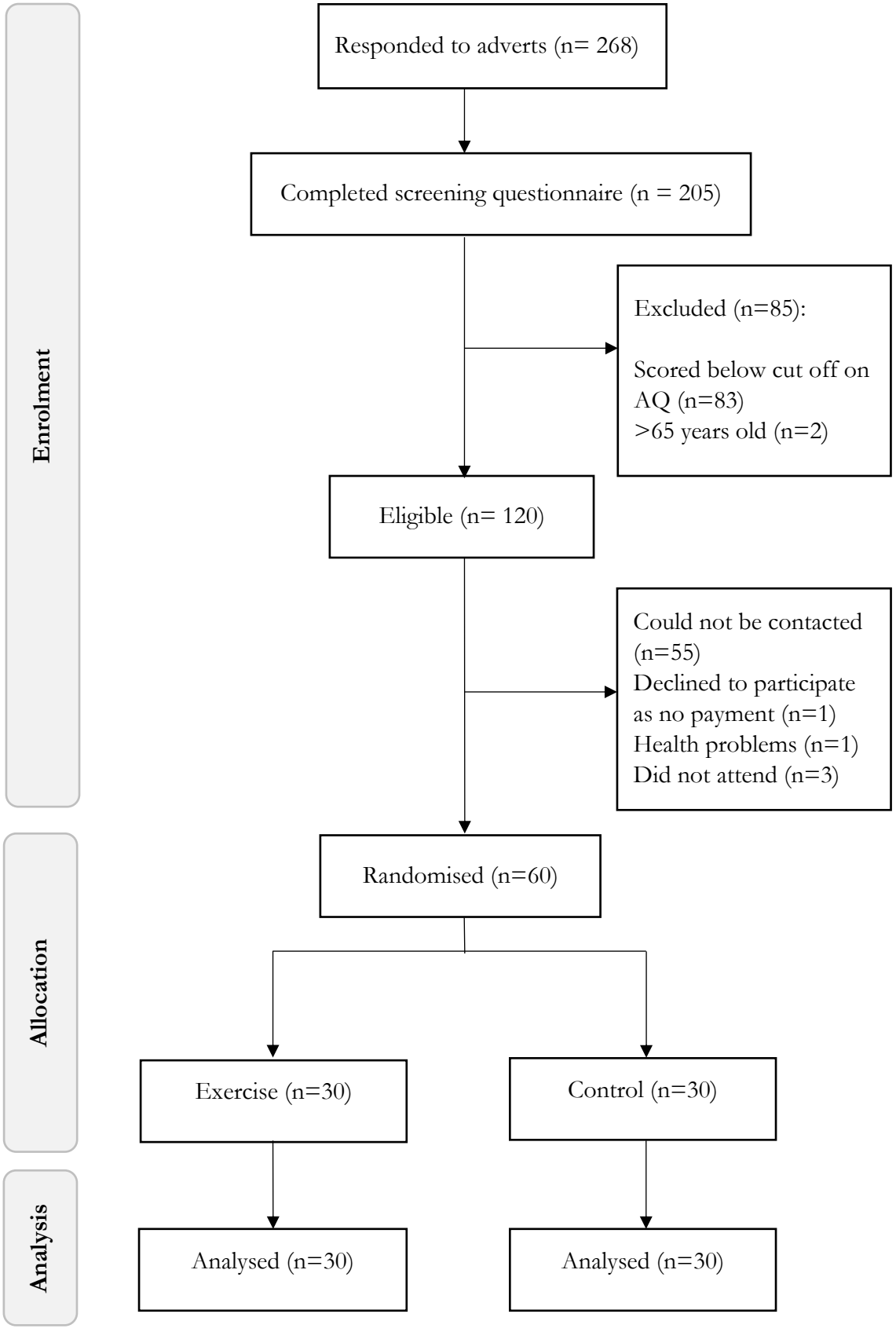
Power analysis was conducted using GPower to determine appropriate sample sizes to test the primary hypothesis. Effect sizes were categorised according to Cohen's (1988) categorisation of small (d=0.2), medium (d=0.5), and large (d=0.8) effect sizes.

To calculate sample size for a linear mixed effects model that would detect a large effect size equivalent to Cohen's d (*d*=0.8), statistical power (1 - β) was set at 0.80 and the alpha level was set at $\alpha = 0.05$. The recommended sample size for each group was 26. The reason for powering the study to detect a large effect was because the aim of the manipulation was to test an augmentation that would be clinically relevant and noticeable to most patients.

Randomisation

Allocation to group was set up by an independent researcher. Envelopes were labelled 1-60 and contained the randomisation 'exercise' or 'control'. These were then used by the researcher (JM). The envelope was opened for each person when they arrived at laboratory for testing. Participants were told they would either be completing 'fast cycling' or 'slow cycling' but no further explanation was given until the debrief.

Figure 2. Consort diagram



Measures

Participants completed measures at screening, pre-test, during and post-test (see Appendix E). Participation took place during a single 90- minute session so pre and post-test measures were directly before and after the intervention.

Screening measures

The Acrophobia Questionnaire (AQ) is a 20-item self-report questionnaire assessing anxiety and avoidance of height-related situations and is divided into two subscales (Cohen, 1977). The measure has good validity and test re-test reliability (r=0.82) for anxiety and for avoidance (r=0.86), (Baker, Cohen, & Saunders, 1973). As the AQ is a clinical measure of acrophobia, it was only be used to assess eligibility. The AQ is scored by totalling the scores with a range of 0-180 for total score, 0-120 for the anxiety subscale and 0-60 for the avoidance subscale.

Participants were also asked about their current exercise habits and were screened for health conditions that would prevent participation in virtual reality or during the exercise phase. Mental health histories were discussed verbally to ensure eligibility. Participants were also asked whether they were currently receiving any treatment for their fear of heights. See Appendix E1.

Primary outcome

***Fear of heights belief and conviction*.** Participants were asked what they most feared happening when they were in high places and asked to rate how certain they were that this would happen, on a scale from 0-100%. The belief was established in a brief clinical interview and is in line with Craske et al's. (2014) recommendation for measuring expectancy violation. See Appendix E2.

Predictor measures

Predictor measures were completed at baseline on arrival at the virtual reality lab on the day of testing. These included the Safety Behaviour Inventory (SBI), The Risk Orientation Scale (ROS), The Attitudes Toward Heights Questionnaire (ATHQ), and The Beck Depression Inventory (BDI). Three anxiety measures were also included at baseline: The Anxiety Attitude and Belief Scale (AABS-R 33), Anxiety Sensitivity Index-3 (ASI-3) and The Beck Anxiety Inventory (BAI). Multiple measures of anxiety were used at baseline as they measured different features of anxiety, which were expected to be predictive of treatment response. These included attitudes and beliefs towards anxiety, sensitivity to physiological sensations of anxiety and self-reported anxiety over the past week. Perceived self-efficacy and subjective units of distress were measured at multiple time points throughout the study. These were as follows: after completing the baseline questionnaires on the day of testing (baseline), after the first period of cycling prior to the first scenario (time 2), after finishing the first scenario in VR and taking the headset off (time 3), after the second period of cycling (time 4), and at the end of the second scenario prior to the debrief (time 5).

Safety Behaviour Inventory (SBI) is a new 20-item scale that assesses the latent trait tendency to use safety behaviours. The scale is currently unpublished (Brown, see Appendix E3). Acceptable psychometric properties have been demonstrated in previous major research projects conducted at Royal Holloway, University of London. The SBI was scored using the following subscales: physical vigilance (sum of items 19, 3, 14, 10, 7, 15, 4), cleanliness (sum of items 8, 6, 1, 12, 11) and checking (sum of items 16, 2, 5).

The Risk Orientation Scale (ROS) is a 15-item scale to assess risk aversion. The scale is currently unpublished (Brown, see Appendix E4). Acceptable psychometric properties have been demonstrated in previous major research projects conducted at Royal Holloway, University of London. The ROS was scored using the following subscales: financial risk (sum of items 13, 11, 3, 5, 2), social risk (sum of items 10, 15, 8, 7, 4) and physical risk (sum of items 1, 6, 12, 14, 9).

The Attitudes Toward Heights Questionnaire (ATHQ) is a 6-item self-report semantic scale that assesses attitudes towards height-related situations (Abselson & Curtis, 1989). Total scores range from 0-60, with higher scores indicating greater negative attitudes. Items are summed for a total score. See Appendix E5.

The Anxiety Attitude and Belief Scale (AABS-R 33) is a 33-item self-report measure to assess ongoing beliefs and expectancies related to anxiety (Brown, Hawkes, Cooper, Jonsdottir & Tata, 2015). Initial construct validity has been established and model-based reliability was good at 0.97. Items on the AABS-R-33 are recoded from 0-100 to 1-7 and summed for a total score. See Appendix E6.

Anxiety Sensitivity Index-3 (ASI-3) is an 18-item self-report measure assessing fear of anxiety related symptoms (Taylor et al., 2007). The measure has adequate reliability (α =0.89) for the total measure (Osman et al., 2010) and good validity. Items are summed for a total score. See Appendix E7.

The Beck Depression Inventory (BDI) is a 21-item self-report questionnaire that measures symptoms of depression over the past 14 days (Beck, 1967). Ratings are made on a scale of four statements ranging in intensity from 0-3. Total scores range from 0-63, with higher scores indicating severe depression. The measure has established construct validity, high internal consistency ranging from (α =0.72-0.83) and test re-test

reliability over one week ranging from (r=0.86-0.81) in clinical and non-clinical samples (Beck, Steer & Garbin, 1988). Items are summed for a total score. See Appendix E8.

The Beck Anxiety Inventory (BAI) is a 21-item self-report questionnaire that that rates anxiety over the past week. Ratings are made on a scale of 0 (not at all) to 3 (severely). Total scores range from 0-63, with the higher scores indicating severe anxiety. The measure has high internal consistency (α=.92) and good test re-test reliability over one week of (r=0.75), (Beck, Epstein, Brown, & Steer, 1988). Items are summed for a total score. See Appendix E9.

Perceived self-efficacy was measured by two questions, level of confidence in their ability to complete the scenario and to face height related stimuli *in vivo*. This was measured on a scale from 0-100, similar to previous studies (Williams & Watson, 1985). Participants were asked "how able to cope do you feel, 0 is not at all, 100 is totally able to cope" before and after each exercise phase, and at the end of the scenario. See Appendix E10.

Subjective units of distress Participants were asked "how distressed do you feel, 0 is not at all, 100 is very distressed". Ratings were taken at baseline, before and after each exercise phase, and at the end of the scenario. See Appendix E10.

Physiological measures

Heart rate was recorded in beats per minute (bpm) from baseline to completion. A resting baseline heart rate in bpm was recorded whilst they completed the initial questionnaires. In the experimental condition, heart rate was elevated to approximately 80% of their maximal, calculated by age using the 220-age equation outlined by Fox et al. (1971). Without using specialist equipment to calculate maximal heart rate, it is

difficult to validate or establish reliability with the 220-age equation, or similar (Sarzynsky et al., 2013). However, it is a widely used equation and it's use in this study was to ensure the manipulation was effective at inducing physiological arousal in the experimental group. To check the manipulation was effective, an average of each participant's heart rate during the virtual reality scenario was compared by group. Participants wore the heart rate monitor from arrival until the end of testing so any variation in timings did not impact on the collection of heart rate data.

Equipment

Virtual reality technology

The virtual reality technology used for the study was the same as that outlined in the main trial of the automated fear of heights treatment (Freeman et al., 2018). The following description is quoted from the trial paper: *"The application is a CE-marked class I active medical device (device code Z301 [standalone software]), in conformity with the essential requirements and provisions of EC directive 93/42/EEC (medical devices). The software was developed using Unity3D (version 5.6.0f3 [64-bit]; Unity Technologies, San Francisco, CA, USA) and delivered using a gaming personal computer (Chillblast Fusion Strix Gaming PC, Intel Core i7-7700K processor, 16 GB DDR4 3000 MHz memory, ASUS GeForce GTX 1080 8GB graphics card, 500 GB M.2 solid state drive/3 TB hard disc drive; Chillblast, Poole, UK) and the HTC Vive (HTC Corporation, New Taipei City, Taiwan)—a consumer VR head-mounted display that has associated hand controllers and headset tracking"*

Indoor static bike

The static bike used in the study was a JLL IC260 Indoor cycling 2018 with a 15kg flywheel and adjustable resistance. It was positioned next to the allocated virtual reality space to minimise the time spent moving between areas.

Heart rate monitor

A Polar H10 heart rate monitor was used to record beats per minute. Polar heart monitors have been validated to accurately measure heart rate variability in children (Gamelin, Baquet, Berthoin & Bosquet, 2008) and adults (Hernando, Garatachea, Almeida, Casajús & Balión, 2018).

Features of the virtual environment

Participants were standing throughout the scenario, so their body position matched that of their avatar. Tracking was established at the beginning so that participant movement was mirrored by the avatar. The scenario was not designed to be openly explored but participants could move freely, crouch, turn, look around and pick up items in close proximity. This allowed the scenario to be run in a small room. Voice recognition was used in the original trial of the fear of heights treatment but for the purposes of this study, a virtual watch worn by the participant's avatar was used to interact with the therapist (see Appendix F1). This was a feature in the original study and was chosen as the main method of feedback in the scenario due to difficulties with the voice recognition software during piloting. The watch created a screen of buttons that were used to answer pre-scripted questions.

Treatment

The automated virtual reality treatment was designed by Oxford VR and was trialled in six 30-minute sessions to test efficacy with good effect (d=2.0) (for more

detail see Freeman et al., 2018). The treatments can be used as a self-contained intervention as it has an in-built virtual therapist, and also with an external therapist in clinical settings. The treatment is a cognitive therapy rather than an exposure therapy as users do not wait for their anxiety to reduce when facing feared stimuli. Instead, it uses a series of behavioural experiments that allow users to drop safety seeking behaviours, test out their predictions and challenge phobic threat beliefs.

Virtual reality scenario

Therapist's office: All participants started the therapist's office. They were asked questions about their fear of heights including which of the following common fears reflected their own worries: 'I will trip and fall', 'the structure will collapse', 'I will try to jump' or 'I'm not sure'. Participants then rated how certain they were that this would happen if they were exposed to heights.

The atrium: Participants were taken to the atrium (see Appendix F2) and asked to choose a floor between 1 and 5 that where they would feel moderately anxious. The coach then took them in a lift to the chosen floor and started the next scenario.

Scenario 1: Participants were positioned behind a waist height barrier when they started each floor. On floors one and two, this was a solid colour and on floors three upwards, the barrier was transparent to imitate glass. Regardless of the floor chosen, all participants completed the same tasks in the first scenario. Following an introduction to the floor and initial psychoeducation, the therapist asked participants if they would like to lower the barrier. This was lowered in three stages and participants were prompted to look around their environment and try things like swaying from side to side. Once the barrier had been lowered all the way, a bucket with coloured balls appeared next to the participant (see Appendix F3). The therapist asked them to crouch down, pick up the

balls and throw them over the edge of the balcony. Participants were asked to watch the balls landing in the atrium, try and stand near the edge and to stand on one leg. Once all tasks had been completed participants could choose to progress to the next floor. If they did not feel any safer in comparison to when they started, they could choose to repeat the same floor.

Scenario 2: If participants started between floors one and four, the second environment was similar. However, if they started on floor five and progressed to six, the balcony had the appearance of a building site and the barrier was cracked. Regardless of the appearance of the floor, the barrier lowering task was repeated. The next tasks consisted of a xylophone that was played over the edge of the balcony or a painting that was completed in the same position. Whichever floor participants were on at the time, the second scenario always involved the platform task. This was a metal looking platform that participants controlled with a lever (see Appendix F4). The platform was extended into the atrium from the balcony and brought back again to complete the task.

End: At the end of the scenario, participants were taken down to the atrium.

Psychoeducation

Psychoeducation about fear of heights was delivered by the virtual therapist throughout the scenario. She stood next to the participants' avatars and talked through each task. The psychoeducation was grounded in cognitive behavioural therapy. The therapist explained why we used safety behaviours and gave examples such as, "closing your eyes when you are up high or not looking down". Avoidance was also discouraged, for example, "see what happens when you stay where you are". The therapist also prompted participants to adopt more confident and relaxed body postures,

using phrases such as, “try to imagine you are someone who isn’t afraid of heights, like Superman or Wonder Woman”. When a new task was presented, the therapist prompted participants to appraise negative thoughts and mental images differently than before, for example, “all sorts of things must be going through your head right now, but it is important to remember that they are just thoughts”. The psychoeducation component was the same for all participants with small variations depending on the task being completed and whether they felt safer than before.

Procedure

Eligible participants were contacted by telephone. The study was described and the requirements for participation were outlined. Exclusion criteria were also discussed and, if eligible, they were invited to attend for testing. The participant information sheet (see Appendix G) and directions were sent via email. Participation took place in a single visit to the virtual reality laboratory in the University of Oxford’s Department of Psychiatry at the Warneford Hospital, Oxford. The study was verbally described for a second time at arrival, to ensure they understood the requirements and were able to provide informed consent. They were also offered another copy of the participant information sheet to read. Two consent forms were read and signed before starting, one kept by the researcher, one by the participant (see Appendix H).

Participants were fitted with a Polar H10 heart rate monitor before completing the baseline questionnaires. This provided a resting heart rate as the questionnaires took approximately 20 minutes to complete. Next, a verbal discussion about their fear of heights identified the primary fear belief (What do you most fear happening when you encounter heights?) and their conviction rating (0% – I’m certain it *won’t* happen, 100% - I’m certain it *will* happen). They were also asked to rate how distressed they felt (0 –

Not at all, 100 – Very distressed) and how able to cope their felt (0 – Not at all, 100 – Totally able to cope). These ratings were rated verbally at multiple timepoints throughout testing.

Participants entered virtual reality and remained in the scenario until reaching their chosen floor. The scenario was paused to allow them to come out of virtual reality and complete the first stage of the exercise manipulation. Pausing the scenario prevented progression through the tasks but movement in the virtual environment was unaffected.

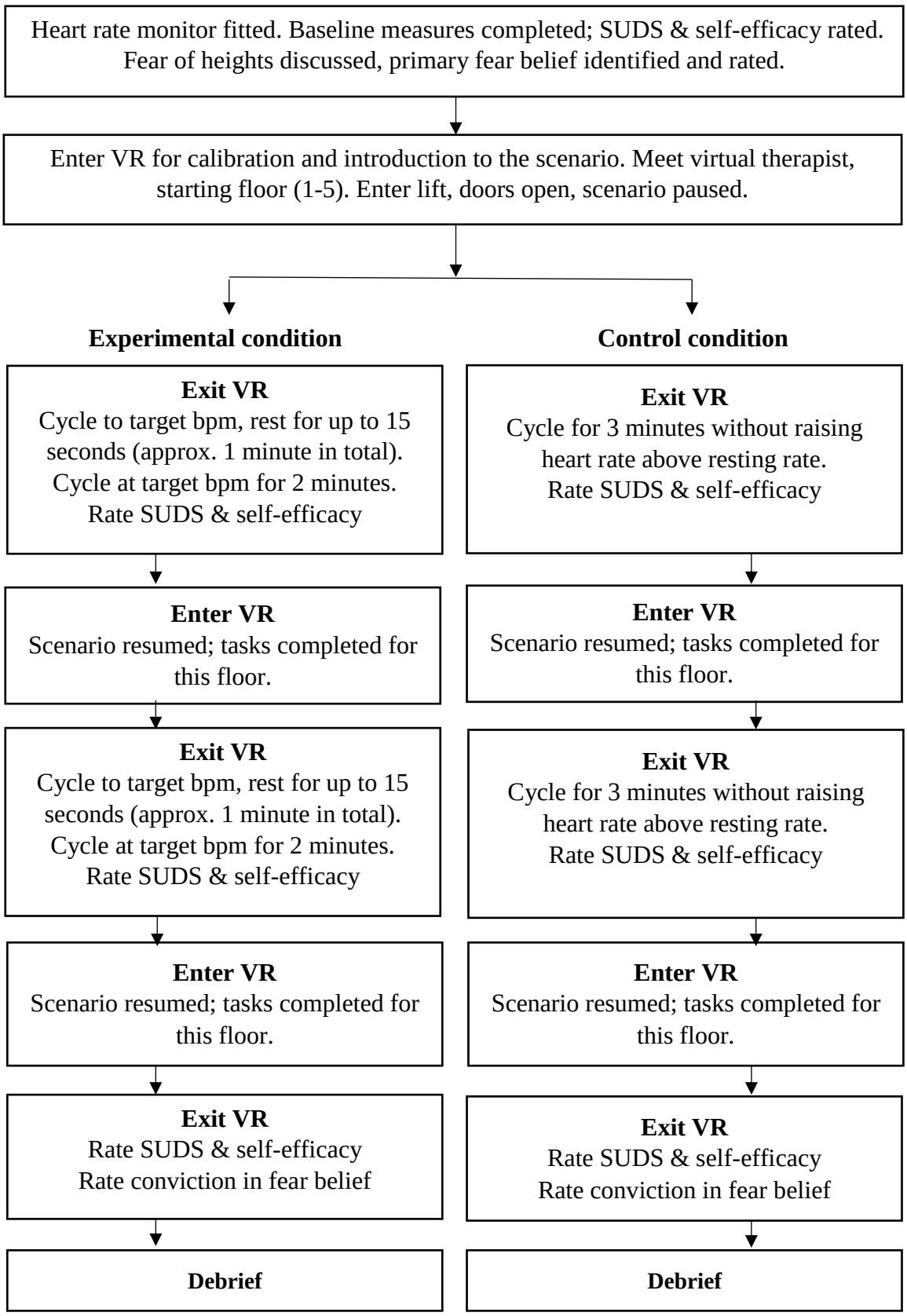
Next, participants in the experimental condition completed 1 minute of cycling to raise their heart rate to the target bpm (80% of their maximal heart rate) and take up to 15 seconds to rest once this had been reached. Participants cycled again until it reached the target bpm and maintained this for 2 minutes. This technique was used as piloting found it to be the most effective way of maintaining an increased heart rate. As heart rate was recorded for all participants, it ensured there was a difference in arousal between the groups and that the manipulation was effective. In the control condition, participants were asked to monitor their heart rate in the same way as the experimental condition, but they cycled for 3 minutes ensuring that it did not go above resting. This meant using the lightest setting and cycling very slowly.

Once complete, participants were asked to verbally rate how distressed and how able to cope they felt. They were returned to VR within 30-60 seconds and the scenario was resumed. Once all the tasks for the current floor had been completed, the participant was given the option to repeat the same floor or continue to the next, depending on whether they felt safer and ready to progress. They were taken out of virtual reality again and asked to verbally rate their distress and ability to cope. Participants repeated

the 3 minutes of cycling according to their allocation and returned to VR for the final scenario.

At the end of the second scenario participants were asked to re-rate the fear belief that was identified at the start. They were given a debrief information sheet and signposted to NHS services if they wanted to pursue additional treatment for their fear of heights. Figure 2 outlines the testing procedure.

Figure 3. Study procedure



Analytic plan

Primary analysis

The primary hypothesis that increased physiological arousal reduces conviction in beliefs about heights relative to control was tested using a linear mixed effects model, accounting for baseline conviction and fear of heights (AQ) scores from screening. This approach was used as it accounts for repeated measures of conviction and is suitable for mediation analysis (hypothesis two). Residuals were visually checked for normality using histograms to assess distribution and Q-Q plots to assess homoscedasticity. Linear mixed effects models are robust to deviations from normality and missing data, so the latter was accounted for within the model. A random intercept was included to account for the repeated measures of conviction in each participant. Analysis was completed using RStudio version 1.2.1335 statistical package and SPSS statistics® (Version 25).

The first model tested the manipulation to see whether increased physiological arousal (as measured by heart rate) was maintained throughout the virtual reality scenario. The second model tested the effect of condition on conviction in belief about heights. Significance was set to a value of p=<0.05. Cohen's *d* effect sizes were calculated by dividing the mean difference by the pooled standard deviation at baseline. Effect sizes were categorised as small (0.2), medium (0.5) and large (0.8) according to Cohen (1988).

Secondary analysis

Linear mixed effects models were used to test hypothesis two; self-efficacy and subjective units of distress mediate the effect between increased physiological arousal and belief conviction. This approach is outlined by Whittle, Mansell, Jellema & van der Windt (2017) and overcomes some of the issues such as unmeasured confounders in the

Baron and Kenny method (1986). If no effect was found between physiological arousal and change in belief conviction (primary hypothesis), the effect of condition on each potential mediator would be tested individually to test whether the manipulation had changed them.

Hypothesis three was tested using individual linear regressions. The aim was to test the individual effect of the predictor variables on conviction in beliefs about heights post intervention. Individual regressions were completed both with and without accounting for baseline conviction.

Results

Table 5 shows the baseline characterises of the participants and means of total and subscale scores on the Acrophobia Questionnaire (AQ) used to assess fear of heights at screening. There were slightly more females than men. The mean age was 41 years old, and the participants in the control group were slightly older than in the exercise group. The exercise group reported a slightly greater fear of heights than the control group at screening. There were only 3 individual items of missing data on the BAI. These items were prorated prior to analysis. There was no missing data on the primary outcome. Participants completed two floors in virtual reality that each took approximately 15 minutes to complete. This varied as some people completed the tasks quicker than others, but approximate time spent in VR was 30 minutes as estimated from piloting the procedure.

The most common threat belief reported was losing balance and falling (n=23). Fears about the internal experience of anxiety was the next most reported threat belief (n=11) with participants associating increased arousal with falling (e.g. “I’ll feel

nauseous and dizzy and fall over the edge"). The remaining threat beliefs reported were something unknown that was out of their control making them fall (n=9), the structure collapsing (n=7), jumping over the edge (n=7) and falling without an explanation as to how this would happen (n=3).

Table 5. Participant demographics and screening scores

	Exercise (n=30)	**Control (n=30)**
Age years, range, (SD)	38.67 (M), 24-52 (range), 9.58 (SD)	43.57 (M), 27-58 (range), 8.85 (SD)
Gender female (F), male (M)	15 F/15 M	17F/13M
AQ total Mean, (SD)	83.50 (16.97)	76.63 (13.85)
AQ anxiety Mean, (SD)	68.1 (12.67)	60.53 (10.32)
AQ avoidance Mean, (SD)	15.93 (4.65)	13.87 (4.03)

Hypothesis 1: Effect of increased physiological arousal on fear of heights belief conviction.

Table 6 shows the mean scores for pre and post-conviction and heart rate, split by group. Model 1 tested the manipulation. The cycling manipulation successfully raised physiological arousal (as measured by heart rate) in the exercise group throughout the virtual reality intervention. The heart rate of the exercise group was faster by an average of 36 beats per minute and was significantly different from the control group ($p<0.0001$). Model 2 tested the between groups effect in threat belief conviction ratings, accounting for baseline conviction and fear of heights screening

score. This showed there was no difference between the groups despite the manipulation. The mean scores show that conviction reduced in both groups, so post-hoc exploratory analysis was conducted to assess statistical significance. Assumptions of normality were not met so a non-parametric Wilcoxon Signed Ranks Test was used to compare pre and post-conviction scores for all participants, which found the virtual reality intervention significantly reduced fear of heights belief conviction (Z= -6.08, p<0.0001) with a large effect size (d=1.0).

Table 6. Linear mixed effects models testing manipulation efficacy and between group differences on belief conviction, accounting for baseline AQ score

	Exercise group: mean (SD)	**Control group: mean (SD)**	**Adjusted mean difference (95% CI)**	**p-value**	**Effect size (Cohen's *d*)**
Model 1: (manipulation check)					
Heart rate (bpm)					
Pre	77.47 (12.09)	77.37 (11.17)	35.60 (35.14; 39.05)	<0.0001	2.9
Post	113.3 (13.54)	77.37 (13.54)			
Model 2:					
Belief conviction					
Pre	69.42 (22.79)	70.33 (21.77)	-3.08 (-12.89; 6.74)	0.56	0.1
Post	45.50 (23.09)	48.83 (22.43)			

Notes: Measures included in each linear mixed effects model were as follows: model 1 = heart rate and condition; model 2 = belief conviction, baseline AQ and condition.
Abbreviations: SD, standard deviation; CI, confidence intervals; AQ, acrophobia questionnaire; bpm, beats per minute.

Hypothesis 2: Mediation analysis

There is no main manipulation effect from the study and therefore no manipulation effect for a mediation analysis to explain. However, it is of interest to know whether the manipulation did change the hypothesised mediators. Table 7 shows the mean scores for the effect of physiological arousal on self-efficacy and subjective units of distress. There was no effect of condition on either of these measures. However, the mean scores show that self-efficacy increased over time for both groups so post-hoc exploratory analysis was completed to test change in self-efficacy across the whole sample. Assumptions of normality were not met so a non-parametric Wilcoxon Signed Ranks Test was used to compare self-efficacy scores at baseline and T5, which indicated that self-efficacy significantly improved over time for all participants (Z= -4.04, p<0.0001) with a large effect size of (d=0.8). Similar analysis was conducted to assess change in scores from baseline to T5 on distress as assumptions of normality were also not met. There was no significant change in distress over time across the whole sample (Z= -0.03, p=0.98), which supports existing research that within group fear reduction does not predict outcomes (Baker et al., 2010).

Table 7. Linear mixed effects models testing the effect of physiological arousal on self-efficacy and subjective units of distress, accounting for baseline scores

	Exercise group: mean (SD)	**Control group: mean (SD)**	**Adjusted mean difference (95% CI)**	**p-value**	**Effect size (Cohen's d)**
Model 3: (self-efficacy)					
Baseline	54.17 (28.71)	61.17 (21.68)			
Time 2	73.42 (28.39)	74.33 (26.06)	-0.04 (-13.30; 13.21)	0.99	0.03
Time 3	74.00 (23.76)	73.67 (28.83)	1.21 (-12.05; 14.46)	0.86	0.01
Time 4	81.50 (23.82)	77.83 (23.12)	4.54 (-8.71; 17.80)	0.50	0.16
Time 5	82.50 (26.77)	76.00 (27.02)	7.38 (-8.71; 17.80)	0.28	0.24
Model 2: (suds)					
Baseline	16.67 (20.31)	20.77 (18.35)			
Time 2	14.83 (20.15)	11.97 (16.13)	4.24 (-7.17; 15.66)	0.47	0.16
Time 3	26.00 (26.27)	34.83 (25.58)	-7.46 (-18.87; 3.96)	0.20	0.34
Time 4	15.23 (22.39)	23.17 (23.36)	-6.56 (-17.97; 4.86)	0.26	0.35
Time 5	19.00 (25.20)	23.07 (25.59)	-2.69 (-14.12; 8.73)	0.64	0.16

Hypothesis 3: predictors of belief change

Total scores on the BAI and ASI were within normal ranges indicating both groups were in the 'low anxiety' range. Likewise, scores in the BDI indicated 'minimal' depressive symptoms. See Appendix I for mean scores on the predictor measures.

Table 8 shows the results from linear regressions on individual predictor variables. The social risk subscale of the risk orientation scale was significantly associated with conviction (p=0.05) but after accounting for baseline conviction it was no longer significant. The cognitive subscale of the ATHQ and the BDI were both approaching significance (p=0.07) but this was also not maintained when accounting for baseline conviction. None of the predictor variables significantly predicted conviction change.

Table 8. Individual linear regressions to test incremental prediction of the baseline predictors on post-conviction, controlling for pre-conviction

				Controlling for baseline conviction		
	F-statistic	**Ad R^2**	**p-value**	**F-statistic**	**Ad R^2**	**p-value**
ATHQ (cognitive subscale)	3.35	0.04	0.07	0.34	0.34	0.52
ATHQ (danger subscale)	<0.01	-0.02	0.95	16.09	0.34	0.97
BAI	2.91	0.03	0.11	17.43	0.36	0.87
SBI (physical vigilance)	0.05	-0.02	0.82	16.29	0.34	0.59
SBI (cleanliness)	1.49	0.01	0.23	16.07	0.34	0.86
SBI (checking)	0.57	-0.01	0.45	16.18	0.34	0.68
ASI-3 (physical sensitivity)	3.20	0.04	0.08	17.61	0.36	0.16
ASI-3 (cognitive sensitivity)	0.33	-0.01	0.57	16.06	0.34	0.94
ASI-3 (social sensitivity)	1.82	0.01	0.18	16.07	0.34	0.87
AABS2-R-33	0.71	-0.01	0.41	16.18	0.34	0.69
ROS (financial risk)	0.17	-0.01	0.68	16.29	0.34	0.58
ROS (social risk)	4.08	0.05	0.05	17.79	0.36	0.14
ROS (physical risk)	2.16	0.02	0.15	16.41	0.34	0.50
BDI	3.36	0.04	0.07	16.59	0.35	0.41

Discussion

This study tested whether increasing heart rate increased cognitive change in a fear of heights treatment, in order to test the broader theoretical view that deepening extinction is clinically valuable. The aim was to investigate whether combining physiological arousal with phobic cues in virtual reality increases new learning about feared stimuli and reduces belief conviction. Potential predictors of conviction change were also tested.

It is important to highlight that the manipulation worked: heart rate was significantly elevated and sustained in the vigorous exercise group (while it did not change in the control group). Therefore, the study was able to test the main hypothesis. The results of the analysis testing the primary hypothesis showed that increasing physiological arousal did not have an effect on the change in threat belief conviction. There was not even an indication of a group difference. There was, however, a large reduction in belief conviction for all participants, regardless of group allocation, after completing the intervention. As improvement was seen regardless of condition, the main conclusion is that elevating physiological arousal is not required in virtual reality treatments for fear of heights to achieve cognitive change. It is possible that all participants experienced anticipatory anxiety before their session, elevating physiological arousal prior to arrival. However, excessive levels of arousal are clearly not required to achieve positive effects. Alternatively, it may be that conviction change in both groups was achieved via different routes and that deepening extinction (i.e. the manipulation group) was more robust to fear renewal. As follow up data were not collected, the study was not capable of testing whether fear was more or less likely to

return. Future research should include real world behavioural avoidance tests and multiple follow up time points to test the longevity of positive treatment outcomes.

Cognitive change is achieved in habituation models by exposing the phobic person to feared stimuli to demonstrate that what they fear will happen, does not happen. This challenges their beliefs about the stimuli and therefore violates expectancy (anticipated versus actual outcome). However, as physiological arousal and distress did not predict the decrease in belief conviction, it can be assumed that conviction change occurred as a result of other treatment components. These may include the removal of safety signals, varying intensity of the stimuli, or violating expectancy by completing tasks that are unachievable in the real world. All of these treatment components sought to create new learning by testing out dysfunctional beliefs in a series of behavioural experiments. Habituation was not required for cognitive change as self-reported distress did not decrease, but self-efficacy did improve across the whole sample, suggesting participants felt more able to cope with heights regardless of their level of arousal and fear. This interpretation of the data should be considered cautiously as these treatment components were not tested individually and mediation analysis was not completed. Further research is therefore recommended to make conclusions about the role of each component on cognitive change.

Deepening extinction was hypothesised to enhance exposure as suggested by Craske and colleagues (2014) but this was not supported in the current study. One reason for this finding is that physiological arousal is not appraised as threatening by all participants. Participants in this study reported a range of phobic beliefs including, fear of losing balance, the structure collapsing, something outside of their control causing them to fall and fear of feeling anxious. Participants who feared the latter, found the

feeling of anxiety aversive and believed it would increase their risk of falling. Therefore, it is possible that raising physiological arousal is an effective augmentation but only in subgroups of people who associate falling with anxious arousal. This study was not powered to detect these effects but future research into treatment differences based on subtypes of phobic belief is warranted.

As discussed in the systematic review, most virtual reality treatments for phobias use hierarchical exposure models and seek to create environments that mirror the real world and maximise fear responses. The results from this study suggest treatment components targeting cognitive change should be prioritised in the development of new therapeutic content. Findings from Freeman et al (2018) trial of the automated virtual reality treatment used in this study is supported by the within group conviction change for all participants. Large effect sizes were found in both studies (although larger in the original trial) despite pausing the scenario on three occasions to complete the manipulation in the current study. The treatment is therefore robust to breaks in presence as belief conviction significantly reduced after completing only two levels in virtual reality (approximately 30 minutes). One interpretation is that coming out of the scenario was beneficial as it allows participants to push themselves on tasks they find challenging, but this was not compared to a scenario where they completed it without a break, so is a tentative conclusion. Alternatively, it is possible that stopping the scenario increased the use of cognitive safety behaviours that participants may have used to complete the scenario.

The mediation analysis was not completed as the manipulation had no effect on conviction. Interestingly, the manipulation also had no effect on either self-efficacy or distress. Post-hoc exploratory analysis on self-efficacy found an increase in both groups,

suggesting participants felt more able to cope with heights as they progressed through the intervention. In comparison, self-reported distress levels did not change significantly over time. It is possible that participants felt more able to manage their distress as the tasks were designed as a series of behavioural experiments. This meant they were encouraged to challenge beliefs about their safety rather than waiting for fear responses to reduce. As a result, participants progressed through the scenario regardless of how fearful they were feeling. This included completing tasks that are not possible in the real world such as the platform task. These were designed to challenge threat beliefs and may have increased feelings of self-efficacy more than tasks that could easily be achieved *in vivo*. To understand the added benefit of each type of task delivered in virtual reality scenarios, further research is needed comparing different treatment components and types of task.

The non-significant results from the predictor measures for change in the threat beliefs were unexpected, particularly for state anxiety, anxiety sensitivity, use of safety behaviours, and fear of heights. One explanation is that both groups scored within the low anxiety and minimal depression range. Whether similar results would be found in phobics with high anxiety or low mood is unknown. It is also possible that an association would have been seen at follow-up if data had been collected. High anxiety, low mood and reliance on safety behaviours may have made participants less likely to re-expose themselves to feared stimuli post intervention, limiting opportunities for learning consolidation. It is also important to note that participation in the study required a certain amount of motivation, including travelling over an hour to the laboratory for a number of participants. Therefore, the sample may have been biased towards participants with lower anxiety, stable mood, and higher levels of motivation.

The non-significant result between safety behaviour use and conviction change may also be explained by low anxiety across the sample. Safety behaviours are an importance maintenance factor in anxiety disorders so these results may be different in a highly anxious population (Thwaits & Freeston, 2005). Safety behaviours were directly targeted in the intervention to achieve cognitive change and they are a common feature in fear of heights. Therefore, it is likely that participants in this study used them in the context of their phobia but did not use them excessively in other areas of their life. As the scores on this measure were analysed as a predictor of change, it is likely that only the safety behaviours targeted by the intervention, for example, standing away from the edge or looking away, would be significantly associated with conviction change.

Notably, both the AQ and ATHQ fear of heights measures were not significantly related to conviction when accounting for baseline. This is a surprising finding that indicates these measures do not capture beliefs about heights and are less sensitive to cognitive change, particularly as there was a strong correlation between pre and post-conviction scores. It also raises questions about how adequate these measures are at capturing cognitive change in other studies and whether this changes the interpretation of results of previous trials using the AQ and ATHQ as primary outcomes. However, as these measures were only completed at baseline, it is possible they would have captured change in addition to belief conviction. Given that these measures evidently differ, future researchers should carefully consider if they capture the targeted mechanism of change and whether beliefs about heights should be measured separately.

Strengths

One of the main strengths of the study was the randomized design. Recruitment targets were met, groups were equal, and the randomization was successful. In addition,

participants were recruited from the general public, so the sample was more likely to be representative of the relevant population. Another particular strength of the study was the use of an automated virtual reality treatment as this reduced variation between sessions, minimised confounds, and meant participants received similar interventions. Whilst the procedure had multiple components, this was achieved seamlessly in the virtual reality laboratory as the scenario could be paused and minimal time was required to move between the bike and the headset. Another strength is that the manipulation clearly worked as intended: heart rate increased in the vigorous exercise group and continued to be elevated during the virtual reality intervention. This meant the main study hypothesis could be tested and the null result is not due to a failure of experimental procedure.

Limitations

There were a number of limitations in the study. Firstly, there were no follow up data or behavioural avoidance tests used in this study. The target mechanism in exposure was violating expectancy so beliefs about heights were rated pre and post-treatment but it is possible that changes between groups would have been evident over time or in a real-life simulation. Given that large treatment effect sizes are often found post treatment, it is perhaps more important to collect follow up data in future research as fear renewal is common. It would also have been interesting to see whether there were any differences between groups during behavioural avoidance tests as heart rate variability is more evident *in vivo* than in virtual reality. It is possible that this could have increased tolerance to physical sensations of anxiety and improved performance in a behavioural test.

Another limitation of the study was that in order to manipulate physiological arousal via cycling, participants had to leave virtual reality for 3-5 minutes. Ideally, this could have been achieved in the virtual world but to do so would have required redesigning the scenario so that the avatar and environment matched the participants' movements. To overcome this issue, participants left virtual reality twice to use the bike. Leaving the environment will have broken presence and reminded participants that they are safe and cannot fall as anticipated. It also allows them to move their attention to the cycling task and take a break from the virtual phobic cues. The timing of the cycling differed from previous studies as they were immediately returned to virtual reality after cycling but as explained, it does not control for the use of cognitive safety behaviours or distraction.

When measures were completed presented another limitation, particularly subjective units of distress that were measured as the participant left virtual reality. Although these weren't used for the analysis as mediation could not be completed, the timing of these measures requires discussion. The decision to rate distress when they were not in virtual reality was to minimise disruption to immersion, yet this was already occurring by entering and exiting to complete the manipulation. This could have been rectified by adding a series of questions to the scenario, but it suffers from similar limitations as the cycling.

Whilst the manipulation was effective, there were no self-report measures to rate subjective experiences of physiological arousal. It was anticipated that raising heart rate increased arousal similar to anxiety, but this may have been different for each participant. It is also possible that arousal is important, but this may differ according to how it is achieved. For example, inducing arousal using imagery related or unrelated to

the phobic stimulus may have different effects from cycling. A self-report measure of arousal may have identified differences between participants on the content of their beliefs and in how they appraise bodily sensations.

Finally, participants were recruited after responding to a radio advert in Oxfordshire, which may not be representative of the wider population of people with a fear of heights. Participation also required a high level of motivation due to the location of the testing site and the time taken to complete the study. Furthermore, neither participant nor researcher were blind to allocation. All these factors combined could have biased results and should be considered when interpreting the findings.

Conclusion

This study aimed to investigate whether increasing physiological arousal in a virtual reality treatment for fear of heights reduced threat belief conviction. Physiological arousal was successfully increased but it did not have an effect on conviction change. Deepening extinction by combining interoceptive cues of anxiety with external phobic cues did not enhance exposure as hypothesised but this may be explained by participant differences in phobic beliefs and threat appraisals of physiological arousal. Different methods of increasing arousal may be more beneficial than exercise in people with a fear of heights or with lower levels of anxiety sensitivity. The results do not support habituation models of exposure as self-reported distress remained high despite changes in belief conviction. This supports previous evidence that within session fear reduction does not predict outcomes (Baker et al., 2010) which contradicts Foa and Kozak's (1986) emotional processing model of exposure. Feelings of self-efficacy were not affected by the manipulation but there was a significant change in both groups from pre to post intervention. The results from this study inform the

development of future virtual reality treatments, specifically the therapeutic content. Increased physiological arousal, at least by the means generated in the current study, is not required for treatments to be effective, so researchers should be encouraged to develop components targeting new learning and cognitive change rather than increased fear responses. It is also recommended that treatment components are tested independently to maximise treatment efficacy.

Chapter 3: Integration, impact and dissemination

Integration

The aim of this thesis was to bring together, and contribute to, the literature on virtual reality as a treatment for specific phobias. The systematic review and empirical paper focused on the content of virtual reality treatments to increase understanding of current use, treatment mechanisms, and future directions. Virtual reality technology has developed substantially in the last decade and we are now on the cusp of clinical dissemination, yet relatively little is known about how it differs from traditional treatments and therefore, how it can be maximised.

Challenges of the systematic review

The systematic review highlighted that most virtual reality treatments for phobias are designed to replicate *in vivo* approaches. There is also substantial variation in the use of external components and the overall reporting of therapeutic tools. These findings suggested that further examination of treatment mechanisms in virtual reality needs to be explored and that more studies should compare treatments instead of non-virtual controls. It also found that most studies restricted their scenarios to what could be achieved in the real-world and that environments that pushed these boundaries have yet to be explored.

Variation in how virtual reality is developed, reported and applied presented another challenge for the review. Initially, the plan was to look at the content of all anxiety disorders but there were too many papers and therapeutic approaches to make sense of current treatment content. A large proportion of these papers were on post-traumatic stress disorder (PTSD) and many were case reports from military contexts. This presented a dilemma as although PTSD was not the topic of empirical project, the technology is already integrated into military units so the real-world application could

have been examined in depth. Whether to include the literature from other anxiety disorders, particularly case reports, was also debated as the cost of developing new virtual environments is prohibitive and excluding smaller projects may have limited the overall findings. As the empirical study was conducted within a clinical research team, I utilised the expertise of other researchers to discuss the topic and narrow down the review. As a thorough review of virtual reality treatment content is needed in other areas, it was agreed that this larger topic would be completed jointly with other clinical researchers, following completion of the doctorate. This allowed me to focus on a narrower subject area for this systematic review that would fit into a larger body of work post qualification.

Integration with the empirical project

The review set up the empirical paper and placed it within the evidence base. This was planned from the initial discussions with my research supervisors about future directions for virtual reality and current theories of exposure. Integration of the two papers developed as the review topic was narrowed down following exploratory searches on the initial larger topic, as discussed. Whilst a smaller review of the literature was completed prior to the major research proposal, the systematic review was completed in conjunction with the empirical paper. The initial review provided a background on the development of virtual reality treatments for phobias, gaps in the literature and recommendations for future interventions. However, whilst initially reviewing the literature identified the value of both papers, it would have been beneficial to complete the systematic review prior to developing a research design and submitting the proposal.

A number of different areas for future research were raised by the systematic review that had not been accounted for in the design of the empirical paper. One important finding was the lack of follow up data and standardized behavioural avoidance tests to measure post treatment fear renewal. Including these measures would have substantially increased testing time and may have affected recruitment rates, but if planned effectively it could have been achieved. The re-use of existing virtual reality scenarios in multiple studies was also raised as an issue in the literature. The automated treatment used for the empirical paper had previously been tested and was included in the review (Freeman et al., 2018). This allowed me to test a manipulation within an evidence-based treatment, but directly highlighted an issue raised in the review; economic and time constraints limit the development of new environments for experimental investigations. It is unlikely that this could have been changed given the time and financial limitations of the project as designing even a simple environment would have required a computer scientist capable of building virtual scenarios. However, it is possible that small augmentations to the scenario could have been achieved in a shorter time frame. This would have allowed existing components of the automated treatment to be compared. These challenges are not unique to doctoral research and are often encountered in clinical research, particularly with virtual reality. I was fortunate to be integrated into a team with expertise in the area, including computer scientists specialising in virtual reality. If this project was completed in an external site with less support, it is likely that there would have been many additional challenges that would have affected the overall running of the study. On reflection, this is similar to the boundaries of clinical research, the influence of grants on academic curiosity, and the need for support in the completion of larger projects.

One of the challenges of developing a cohesive thesis was to avoid tackling large concepts or multiple problems and to design a study that would be targeted and informative. As highlighted in the review, virtual reality is not a new idea, but it is continuously evolving and can be used to create environments that are not possible in the real world. The untapped potential of virtual reality also means there are many research avenues to follow but environments can quickly become outdated. This is one of the main reasons for looking at mechanisms and treatment components as it has the potential to inform future therapeutic content.

Similar to the systematic review, the empirical project was narrowed down following discussions with my supervisors and consulting the evidence base. My primary research interest was how virtual reality as a treatment modality could be enhanced. It was suspected that most studies used hierarchical exposure models and were not updating these approaches according to current research. This was supported by the systematic review. Therefore, the purpose of the empirical project was to use newer approaches to exposure to inform augmentations that would be compared to a control condition. This would expand the research on the mechanisms of exposure and explore methods of enhancing virtual reality. The automated treatment used for this study differed from most of the research as it used a series of behavioural experiments on each level and incorporated many of the recommendations used by Craske and colleagues (2014) that formed the theoretical basis of the augmentation. It also used a virtual therapist, which provided a controlled environment to test the manipulation. This treatment had also been tested in a randomised controlled trial prior to the empirical study so there was existing data that supported it as an effective treatment for fear of heights.

Challenges of the empirical project

The recruitment targets set out for the empirical study were met within an appropriate timeframe and testing was completed to schedule. The manipulation was also effective, and the study ran largely as planned. However, there were a number of challenges that were overcome that will be discussed.

One of the main challenges with the empirical project was the size of the sample and the time that was required to screen and test participants. An approximate time to complete the study was anticipated as I had previous experience with virtual reality research and had worked on a non-clinical study prior to training. I also piloted the study before opening recruitment to establish a clear testing time frame. This meant I had existing knowledge of recruitment schedules, how long it would take to test, how many I could see in a day, and how to use the technology in a trial scenario. I was also familiar with the Department of Psychiatry at the University of Oxford, where the study was run, and had existing relationships with the clinical research team. This was invaluable as participants often had to be tested in the evenings and at weekends, which meant a member of the department was required to be in the building to conform with lone working policies. Integrating myself into the research team for the duration of the project also allowed me to access computer support and to overcome any issues with the technology.

The main challenges when working with virtual reality are unavoidable incompatibilities between scenarios that are developed externally, and hardware. The technology has noticeably advanced and it is relatively easy to use but glitches do occur, and the solutions aren't always obvious. The most common glitches during the study were losing tracking (participant is no longer mirrored by the avatar), the scenario

freezing, and losing connection with the handsets. These were most problematic at the start of the study as it took time to learn how to fix common errors before starting the scenario. I also swapped the headset after the first ten participants from a wireless to wired set up. This removed the tracking errors and prevented participants from losing presence mid scenario. It was important to find a solution to this error as losing presence also increased the likelihood that participants would use cognitive safety behaviours such as, "it isn't real" or "I'm in VR, I'm safe", to assist them with the tasks. Some reliance on safety behaviours during the intervention was expected but where possible, participants should be encouraged to engage with their environment as they would in the real world to maximise new learning. The within group reduction in conviction across the whole sample actually suggests losing presence is less important than predicted as participants were removed from virtual reality twice to complete the manipulation. This created a larger break in presence than losing tracking, but the latter was unexpected when it occurred, which may have been more problematic.

As expected, there were challenges with recruitment due to the time restraints of the doctorate. This was largely related to poor planning at the start as I received a large number of responses in the first few weeks that I didn't have the capacity to follow up and test during my allocated research days. This invariably led to a loss of some participants who did not receive a timely response. It also meant that the second wave of recruitment received less response as it targeted the same population and was run a few weeks before Christmas. On reflection, I should have created a written recruitment plan that would have accounted for time required to follow up participants, testing time, data management and unexpected issues with the equipment.

Impact and dissemination

Clinical impact

It is hoped that the systematic review and the empirical study will be informative for researchers and clinicians in the development and use of virtual reality as a treatment for mental health disorders. The finding that most virtual reality treatments for phobias use hierarchical exposure models highlights the issue that therapeutic content is not being updated. This is informative for researchers seeking to develop new environments and to consider how virtual reality should be used. It also suggests re-considering using scenarios that are unachievable in the real world and adopting models of exposure that are in line with current research. As the technology is now more available and easier to use, these treatments are already being developed for clinical use. Therefore, the review findings have the potential to help shape the next generation of virtual reality treatments for phobias. This will be particularly relevant as virtual reality moves towards being a stand-alone treatment such as the automated treatment trialled by Freeman et al (2018) that was also used in the empirical study. The review highlighted that many therapeutic components reported in trials of virtual reality are delivered externally to the virtual environment. Therefore, if automation is a real possibility, as Freeman et al. (2018) suggest, virtual environments have to be re-designed to incorporate these components. To some extent this may require re-designing old scenarios but there is potential for modification in the interim such as, progression based on belief change rather than self-reported fear or distress.

Findings from the systematic review suggest large post-test effect sizes are deceptive as follow up data is not always reported, and most scenarios rely on habituation which is vulnerable to fear renewal. It also raises questions about the

methods of measuring change, when and how this is achieved, and which mechanisms are being targeted in the intervention. In the empirical paper, two commonly used fear of heights measures (AQ and ATHQ) were not correlated with beliefs about heights yet pre and post belief conviction scores were strongly correlated. Researchers should therefore consider the possibility that the measures they use do not capture cognitive change and that a combination of measures or behavioural avoidance tests may be required to overcome these issues.

When considering the clinical impact of the review and the empirical study, it is important to recognise that although virtual reality is expected to be integrated into clinical teams in the coming years, it is still in the developmental phase. In the long term, the potential is that psychological interventions can be delivered to many more people without the need for specialist skills. In the short term, these treatments need to be prepared and tested for clinical use and researchers need to understand more about the treatment mechanisms specific to virtual reality. The finding from the empirical paper that physiological arousal is not required for cognitive change is informative for both areas of development. Clinically, it means that outcomes are not dependent on fear responses within virtual reality and that these treatments are somewhat robust to breaks in presence. In relation to future research, it suggests virtual scenarios should prioritise components that target cognitive change instead of increasing overall fear arousal. In the review, it was highlighted that researchers are often too concerned with how realistic the virtual environment is to the user in order to achieve maximum immersion and arousal. Interestingly, this approach is flawed as a method of raising fear responses regardless of whether it is effective at creating cognitive change as existing research on

presence suggests immersion in virtual reality is not dependent the quality of the graphics (Slater, 2009).

Dissemination

The systematic review and the empirical study will be edited and submitted for publication following completion of the doctorate. The systematic review will be submitted to *'Cyberpsychology, Behavior and Social Networking'*. This is a peer-reviewed journal with an impact factor of 2.689 that publishes research to further understanding of the 'psychological impact' of communication technologies. It has published articles on the application and understanding of virtual reality technology for over 20 years and would be viewed by researchers developing, testing or augmenting new environments for mental health disorders.

The empirical study will be submitted to *'Behaviour Research and Therapy'.* This is a peer-reviewed, multi-disciplinary journal with an impact factor of 4.134. The aims of the journal are to increase understanding of the treatment and prevention of emotional and behavioural disorders. The journal has a strong focus on cognitive behavioural techniques, psychophysiological methodologies, experimental designs and studies that examine treatment mechanisms, moderators and mediators, and novel treatments. The empirical study investigated a potential mechanism of change by manipulating physiological arousal in a controlled, experimental setting so it was considered appropriate for the remit of this journal.

Conclusion

The purpose of this study was to examine how virtual reality is being applied in the treatment of specific phobias and to investigate treatment mechanisms and to improve intervention outcomes. This was an ambitious project that developed my

general research skills that included: designing and co-ordinating a study, recruitment, data management, data analysis, and using virtual reality within the context of research. There were a number of challenges that were overcome to meet recruitment targets, notably, completing over 100hrs of testing whilst managing the other demands of the clinical doctorate. One of the main process reflections related to the systematic review, which was completed prior to submission of the study protocol. Conducting a systematic review gave me an in depth understanding of the subject area, which would have been informative at the design stage. Whilst this was not possible due to time constraints of the doctorate, it highlighted the importance of thoroughly consulting the literature in the planning stage of research and the added value of systematically evaluating the evidence. It is hoped that this research will be of value to academics and clinicians in the development of virtual reality treatments and will inform a larger body of work post qualification.

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Appendices

Appendix A. Royal Holloway ethical approval

Ethics Application System <ethics@rhul.ac.uk>

Mon 09/07/2018, 15:06
McInerney, Josephine (2016);
Brown, Gary;
ethics@rhul.ac.uk
Inbox

PI: Dr Gary Brown
Project title: Exercise and exposure: Deepening extinction in virtual reality for fear of heights

REC ProjectID: 862

Your application has been approved by the Research Ethics Committee.
Please report any subsequent changes that affect the ethics of the project to the University Research Ethics Committee ethics@rhul.ac.uk

Appendix B. University of Oxford ethical approval

MEDICAL SCIENCES INTERDIVISIONAL RESEARCH ETHICS COMMITTEE

Research Services, University of Oxford, Wellington Square, Oxford, OX1 2JD
Tel: +44(0)1865 616577 Fax: +44(0)1865 280467
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CONFIDENTIAL

Ref: R58997/RE001

Ms Josephine McInerney and Professor Daniel Freeman
Department of Psychiatry
University of Oxford
Warneford Hospital
Oxford

02 August 2018

To whom it may concern,

Research Ethics Review – External Researchers recruiting from the University of Oxford

Study title: Exercise and Exposure: Deepening extinction in a virtual reality treatment for fear of heights

I am writing to confirm that the documentation for this research study has been reviewed by the Secretariat of the University of Oxford Medical Sciences Interdivisional Research Ethics Committee (MS IDREC).

On the basis of the information provided to the MS IDREC, the proposed research has been judged as meeting University of Oxford ethical standards. We are happy for you to proceed with recruiting at the University of Oxford using these documents.

Please note that this letter does not constitute formal ethical approval of the study by the University of Oxford. This approval has been provided by Royal Holloway University Research Ethics Committee (project ID 862) and any queries about the study should be directed to them.

Please do not hesitate to contact me if you have any queries.

Yours Sincerely

Dr. Helen Barnby-Porritt
Research Ethics Manager, Medical Sciences

Appendix C. Participant debrief information sheet

o-cap

PARTICIPANT DEBRIEF INFORMATION
Exercise and exposure: a virtual reality study for fear of heights
Principal Investigator: Josephine McInerney

Study completed as part of a Doctorate in Clinical Psychology,
Royal Holloway University of London

Thank you for taking part in this study. The following information explains what happens next and where you can go for further support if needed.

What happens next?

You have now completed your participation in the study. We will be testing 60 people with a fear of heights to see whether physical exercise improves the virtual reality treatment for fear of heights. Once we have tested everyone, we will write up the results and submit them to Royal Holloway University as part of a Doctorate in Clinical Psychology. An additional paper will also be written for publication in an academic journal. All of your data will remain anonymous as outlined in the participant information sheet.

Where can I get more support for my fear of heights?

If you would like more help with your fear of heights, we recommend that you see your GP for further advice. If you live in Oxfordshire, they may refer you to Talking Therapies, a service that offers brief talking therapies for people with depression or anxiety, which includes phobias. You can also self-refer to this service by following the link on their website:

https://www.oxfordhealth.nhs.uk/talkingspaceplus/

Participant debrief information. V1. 09/08/2018.
Ethical permission granted by Royal Holloway University Research Ethics Committee – Project ID 862

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Appendix D. Recruitment tools

Appendix D1. Poster

Exercise and Exposure:

An augmented Virtual Reality Study for Fear of Heights

Are you able to complete a short period of physical exercise?

Do you have a fear of heights?

Are you over 18?

We are looking at the effect of exercise on a virtual reality treatment for fear of heights.

If you would like more information about the study and to find out if you are eligible to take part, contact us via email us at josephine.mcinerney.2016@live.rhul.ac.uk

VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk	VR for Fear of Heights Josephine.mcinerney.2016@ live.rhul.ac.uk

Appendix D2. Radio advert

Do you have a fear of heights? Would you be interested in taking part in psychological research in virtual reality? At the University of Oxford, we're looking for volunteers to take part in a study investigating the effects of physical exercise on a virtual reality treatment for fear of heights. If you're interested then please text the word STUDY to [insert number] for more information. That's STUDY to [insert number

Appendix E. Measures

Appendix E1. Screening measure, Acrophobia Questionnaire (AQ)

Acrophobia Questionnaire (AQ) from Cohen, 1977.

INSTRUCTIONS: Below is a list containing situations involving height. Some people become anxious (tense or uncomfortable) and avoid these situations because of their fear. Please indicate how you would feel in each situation by circling one of the numbers on each scale.

1. Diving off the low board at a swimming pool.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

2. Stepping over rocks crossing a stream.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

3. Looking down a circular stairway from several flights up.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

4. Standing on a ladder leaning against a house, second story.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

Appendix E1 (continued).

5. Sitting in the front row of a balcony at a theater.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

6. Riding a ferris wheel.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

7. Walking up a steep incline during a country hike.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

8. Airplane trip across the country.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

9. Standing next to an open window on the third floor.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

Appendix E1 (continued).

10. Walking on a footbridge over a motorway.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

11. Driving over a large bridge (e.g., Severn Bridge, Clifton Suspension Bridge).

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

12. Being near a closed window in an office on the 15th floor of a building.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

13. Seeing window cleaners 10 flights up on a scaffold.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

14. Walking over a drain grate.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

Appendix E1 (continued).

15. Standing on the edge of an underground platform.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

16. Climbing a fire escape to the third floor.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

17. On the roof of a 10 story apartment building.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

18. Taking the lift to the 50th floor.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

19. Standing on a chair to get something off a shelf.

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

Appendix E1 (continued).

20. Walking up the gangplank of a cruise ship (A gangplank is used to board and leave a ship at the docks).

0----------1----------2----------3----------4----------5----------6

Not anxious Slightly anxious Moderately anxious Extremely anxious

0----------1----------2

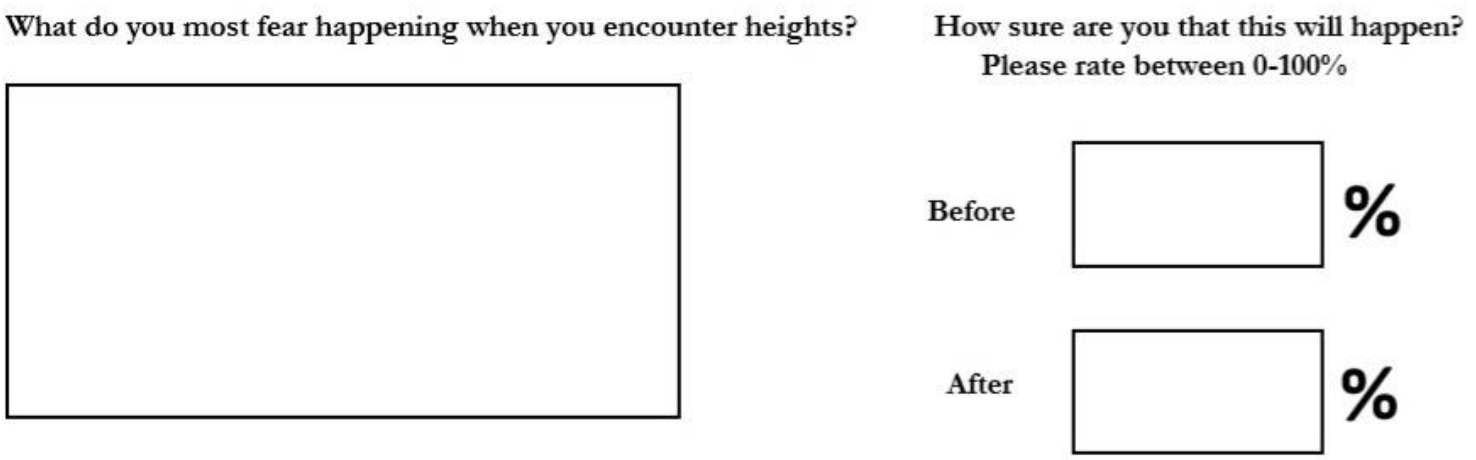
wouldn't avoid situation would try to avoid doing it would not do it under any circumstance

Avoidance Score: /60

Anxiety Score: /120

Total Score: /180

Appendix E2. Belief of heights conviction and self-efficacy



Appendix E3. Brief Safety Behaviour Inventory (SBI)

Please indicate how often you engage in the following behaviors.

	Never or almost never	Sometimes	Often	Always
1. Take a long time washing food before preparing a meal.				
2. Check that the gas is turned off more than once before leaving home.				
3. Take deep breaths before going into a social situation.				
4. Get up slowly and carefully so as not to fall over.				
5. Double-check water taps to make sure they are turned off.				
6. Avoid touching things you know have been touched by other people.				
7. Make sure you know where the nearest restroom is.				
8. Wash your hands when you have just done so not long before.				
9. Avoid emotionally arousing films, books, or television shows				
10. Make sure to have someone with you when you are out in public				
11. Eat very slowly and carefully				
12. Be very careful about what you eat				
13. Drink alcohol before going into social situations.				

Appendix E3 (continued).

14. Monitor your blood pressure				
15. Turn to others for reassurance about how you have conducted yourself.				
16. Check more than once that the door is locked before leaving.				
17. Keep things instead of deciding what should be thrown away.				
18. Check in on loved ones to make sure they are safe and sound				
19. Closely monitor your pulse or heartbeat.				
20. Budget money very carefully.				

Appendix E4. Risk orientation scale (ROS)

Risk Orientation Scale

The following items describe behaviors that might be considered risky in some respect. Please rate the *percent likelihood* that you would engage in the behaviors described if given the opportunity.

	NOT AT ALL LIKELY						EXTREMELY LIKELY
1. Go on a roller-coaster or similar amusement park ride.	0	20	40	50	60	80	100
2. Move somewhere far from your friends and family.	0	20	40	50	60	80	100
3. Completely change careers	0	20	40	50	60	80	100
4. Tell a friend you disagree with them about something important.	0	20	40	50	60	80	100
5. Walk through an unsafe part of a city.	0	20	40	50	60	80	100
6. Go rafting down a fast-moving river.	0	20	40	50	60	80	100
7. Ask someone to stop causing a disturbance.	0	20	40	50	60	80	100
8. Openly take the unpopular side of an issue in a group of people.	0	20	40	50	60	80	100
9. Take a turn at piloting a small plane.	0	20	40	50	60	80	100
10. Disagree with an authority figure about something important.	0	20	40	50	60	80	100
11. Put a portion of your savings into a risky investment.	0	20	40	50	60	80	100
12. Dive off a high board.	0	20	40	50	60	80	100
13. Make a substantial wager on a sporting event	0	20	40	50	60	80	100
14. Go scuba diving.	0	20	40	50	60	80	100
15. Speak up in defense of someone who is being bullied.	0	20	40	50	60	80	100

Appendix E5. Attitudes towards heights questionnaire (ATHQ)

Attitudes Towards Heights Questionnaire (ATHQ)

Below are some common feelings that people have towards high places. In the scales below, please rate how you feel about high places by circling one of the numbers on each of the scales.

0	1	2	3	4	5	6	7	8	9	10

Good **Bad**

0	1	2	3	4	5	6	7	8	9	10

Attractive **Terrible**

0	1	2	3	4	5	6	7	8	9	10

Pleasant **Unpleasant**

0	1	2	3	4	5	6	7	8	9	10

Safe **Dangerous**

0	1	2	3	4	5	6	7	8	9	10

Non-threatening **Threatening**

0	1	2	3	4	5	6	7	8	9	10

Harmless **Harmful**

Appendix E6. The Anxiety Attitude and Belief Scale (AABS-R 33)

INSTRUCTIONS: This inventory lists different beliefs that people sometimes hold. Please read each statement carefully, decide how much you believe what is stated, and circle the number corresponding to how much you agree. Please try not to think too much about each item--people are different, so there is no right or wrong answer. To decide how much you agree with a statement, simply keep in mind what you are like **most of the time**.

EXAMPLE	I DON'T BELIEVE THIS AT ALL						I BELIEVE THIS COMPLETELY
You should not put off until tomorrow what you can do today.	0	20	40	50	60	(80)	100

In the example, the number "80" has been circled, indicating strong, but not complete, agreement with the statement.

Please now make a rating for each of the following items.

	I DON'T BELIEVE THIS AT ALL						I BELIEVE THIS COMPLETELY
1. The way to avoid problems is not to take any risks.	0	20	40	50	60	80	100
2. Even with small problems, one thing can lead to another and quickly turn into something huge.	0	20	40	50	60	80	100
3. If you imagine something bad happening, it can help make that thing come true.	0	20	40	50	60	80	100
4. You should be constantly looking out for things happening within your body so that you can detect things going wrong.	0	20	40	50	60	80	100
5. It is better not to rock the boat than to make changes.	0	20	40	50	60	80	100
6. People don't experience anxiety unless there is actually something they should be concerned about	0	20	40	50	60	80	100
7. People will make negative judgments if they think something is wrong with you.	0	20	40	50	60	80	100

Appendix E6 (continued).

	I DON'T BELIEVE THIS AT ALL						I BELIEVE THIS COMPLETELY
8. Anticipating the worst outcome prepares you for the worst.	0	20	40	50	60	80	100
9. It is essential to avoid being disapproved of by other people.	0	20	40	50	60	80	100
10. You should avoid being seen acting awkwardly.	0	20	40	50	60	80	100
11. To avoid disasters, you need to be prepared for anything.	0	20	40	50	60	80	100
12. Thinking about bad things that have happened to other people could cause the same thing to happen to you.	0	20	40	50	60	80	100
13. Planning every detail in advance is the only way to avoid unpleasant surprises.	0	20	40	50	60	80	100
14. It is important to be on the lookout for the first, small signs of an illness.	0	20	40	50	60	80	100
15. Anxiety is generally a sign that something is wrong.	0	20	40	50	60	80	100
16. Picturing something happening might cause it to really happen.	0	20	40	50	60	80	100
17. It is best not to let on if you are in public and feel that something is wrong with you.	0	20	40	50	60	80	100
18. Minor difficulties can easily get out of control and grow into major ones.	0	20	40	50	60	80	100
19. Insanity can develop without warning.	0	20	40	50	60	80	100
20. There is no such thing as being too careful when it comes to your health.	0	20	40	50	60	80	100
21. An unusual physical sensation in your body is likely to be a sign that something is seriously wrong with you.	0	20	40	50	60	80	100
22. When making a decision, it is better to play it safe rather than risk making the wrong choice.	0	20	40	50	60	80	100

Appendix E6 (continued).

	I DON'T BELIEVE THIS AT ALL						I BELIEVE THIS COMPLETELY
23. In general, it is better to keep things the way they are than to take the risk of making things worse.	0	20	40	50	60	80	100
24. It is important to always appear fully at ease.	0	20	40	50	60	80	100
25. It is unwise to proceed with something unless you have all of the possible information you might need.	0	20	40	50	60	80	100
26. You should not allow yourself to be seen losing control of yourself in any way	0	20	40	50	60	80	100
27. It is crucial to anticipate potential difficulties so that you have a better chance of avoiding them.	0	20	40	50	60	80	100
28. If someone is feeling anxious, there must be something for them to be concerned about.	0	20	40	50	60	80	100
29. Imagining things that might happen can help bring those things about.	0	20	40	50	60	80	100
30. It is necessary to continually be aware of signs that a health problem is developing.	0	20	40	50	60	80	100
31. One should always be on the lookout for trouble that might be developing.	0	20	40	50	60	80	100
32. Anxiety does not happen without there being a reason for it.	0	20	40	50	60	80	100
33. It would be difficult to ever live down the embarrassment of losing control of yourself or acting strangely in public.	0	20	40	50	60	80	100

Appendix E7. Anxiety sensitivity index – 3 (ASI-3)

4. (ASI-3)

Please circle the number that best corresponds to how much you agree with each item. If any items concern something that you have never experienced (e.g., fainting in public), then answer on the basis of how you think you might feel *if you had* such an experience. Otherwise, answer all items on the basis of your own experience. Be careful to circle only one number for each item and please answer all items.

	Very little	A little	Some	Much	Very much
1. It is important for me not to appear nervous.	0	1	2	3	4
2. When I cannot keep my mind on a task, I worry that I might be going crazy.	0	1	2	3	4
3. It scares me when my heart beats rapidly.	0	1	2	3	4
4. When my stomach is upset, I worry that I might be seriously ill.	0	1	2	3	4
5. It scares me when I am unable to keep my mind on a task.	0	1	2	3	4
6. When I tremble in the presence of others, I fear what people might think of me.	0	1	2	3	4
7. When my chest feels tight, I get scared that I won't be able to breathe properly.	0	1	2	3	4
8. When I feel pain in my chest, I worry that I'm going to have a heart attack.	0	1	2	3	4
9. I worry that other people will notice my anxiety.	0	1	2	3	4
10. When I feel "spacey" or spaced out I worry that I may be mentally ill.	0	1	2	3	4
11. It scares me when I blush in front of people.	0	1	2	3	4
12. When I notice my heart skipping a beat, I worry that there is something seriously wrong with me.	0	1	2	3	4
13. When I begin to sweat in a social situation, I fear people will think negatively of me.	0	1	2	3	4
14. When my thoughts seem to speed up, I worry that I might be going crazy.	0	1	2	3	4
15. When my throat feels tight, I worry that I could choke to death.	0	1	2	3	4
16. When I have trouble thinking clearly, I worry that there is something wrong with me.	0	1	2	3	4
17. I think it would be horrible for me to faint in public.	0	1	2	3	4
18. When my mind goes blank, I worry there is something terribly wrong with me.	0	1	2	3	4

Scoring: Physical concerns = sum of items 3, 4, 7, 8, 12, 15. Cognitive concerns = sum of items 2, 5, 10, 14, 16, 18. Social concerns = sum of items 1, 6, 9, 11, 13, 17.

Appendix E8. Beck depression inventory (BDI)

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Appendix E9. Beck anxiety inventory (BAI)

This page is not included due to copyright restrictions

Appendix E10. Subjective units of distress and self-efficacy record sheet

Subjective Units of Distress (SUDS)

Record sheet

During exposure

Time point	Verbal SUDS rating 0-100	Self-efficacy rating 0-100
After questionnaires		
After cycling, pre VR		
Pre cycling x2		
Post cycling x2		
End of VR		

Floor chosen in VR:

Fear of heights in VR:

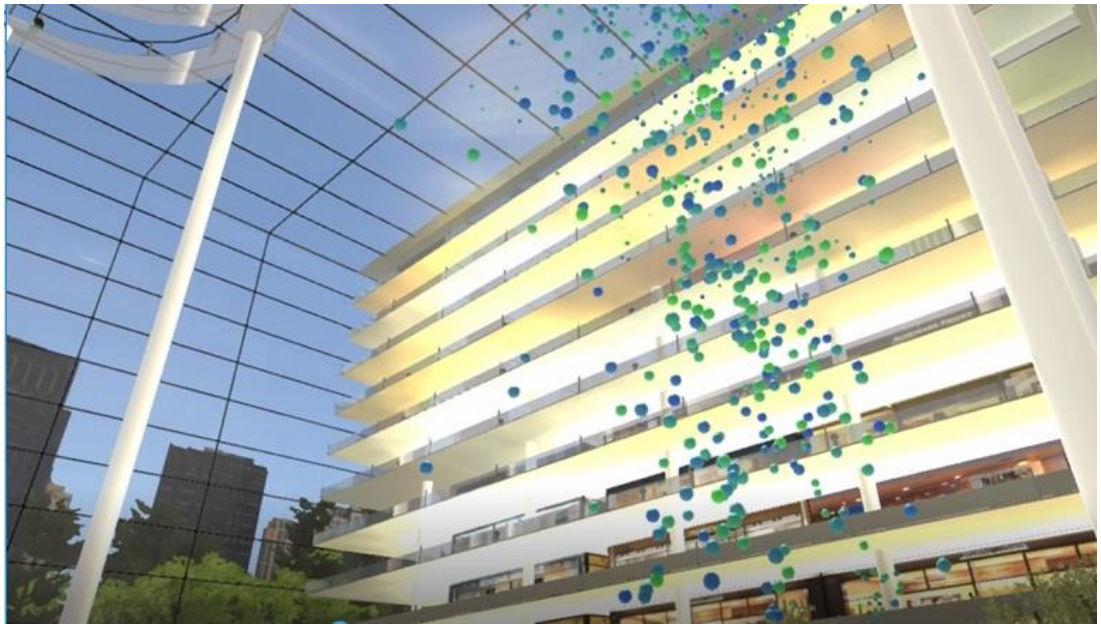
Conviction (pre exposure) in VR:

Conviction (post exposure) in VR:

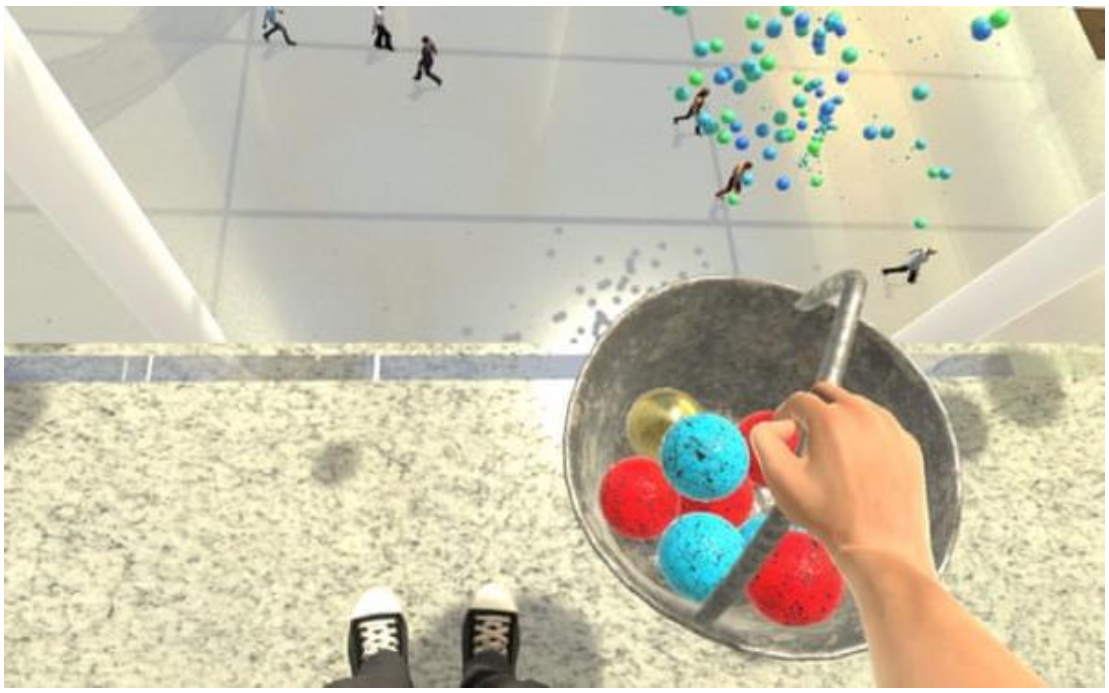
Appendix F: Images of the virtual scenario

Appendix F1: Virtual therapist

Appendix F2: Atrium



Appendix F3: Throwing balls over the edge



Appendix F3: Throwing balls over the edge

Appendix G. Participant information sheet

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PARTICIPANT INFORMATION SHEET

Exercise and exposure: a virtual reality study for fear of heights

Principal Investigator: Josephine McInerney

Study completed as part of a Doctorate in Clinical Psychology,
Royal Holloway University of London

We would like to invite you to take part in a research study. Before you agree to take part, we would like you to have all the information that you need to fully understand what the study involves. If you do not understand the information in this sheet or you have any additional questions, please inform the researcher (Josephine McInerney) and these will be explained.

Key facts:

- This study is for people with a fear of heights.
- The purpose of the study is to see whether exercise enhances a virtual reality treatment for fear of heights.
- All participants will receive a virtual reality treatment for fear of heights.
- All participants will be asked to complete a short period of exercise in conjunction with the virtual reality treatment.
- All participants will be asked to fill in some questionnaires about how they are feeling and have their heart rate monitored during the study.
- All participants need to state whether they are physically able to engage in an acute period of exercise (static cycling) and virtual reality using a head mounted display.
- Participation in this study is voluntary and you are free to withdraw at any time, without giving a reason.

Participant information sheet. V2. 14/06/2018.
Ethical permission granted by Royal Holloway University Research Ethics Committee – Project ID 862

What is the purpose of the study?

The purpose of the study is to investigate ways to improve treatments for fear of heights. We know that virtual reality treatments for phobias can work well for some people but we want to see if we can make it better to increase the chance of more people overcoming their fear in the long term. Using virtual reality to treat phobias means that more people will have access to these types of therapies than is currently available.

Why have I been asked to participate?

You have been asked to take part because you are aged 18+ and you have a fear of heights. You have also stated that you are physically able to complete a short period of vigorous exercise and to use the head mounted display for the virtual reality scenario.

Do I have to take part?

No, you don't have to take part if you don't want to. Your participation is voluntary and if you decide not to take part, you don't have to give a reason. If you do agree to participate, you may withdraw yourself from the study at any time, without giving a reason, by advising the researchers of this decision.

What will the study involve if I participate?

If you would like to take part, you will be asked to attend a single visit at the virtual reality lab in the Warneford Hospital, Oxford. You will be asked to sign a consent form to participate and given a number of questionnaires to fill in that will ask you about your fear of heights, your mood and your anxiety. You will also be fitted with a heart rate monitor that you will wear for the duration of the study. In conjunction with the virtual reality scenario, you will be required to complete a period of exercise on a static bike in the lab so you may prefer to wear comfortable clothing when you take part. A head mounted display is used to enter virtual reality, which is similar to a pair of goggles and can be worn over glasses. At the end of the scenario, you will be asked to complete a few more questionnaires and you will be debriefed about the study. The study should take approximately 2 hours to complete.

What are the potential advantages or disadvantages of taking part?

The virtual reality exposure treatment that we are using is designed to reduce a fear of heights but this is a new programme and has only recently been tested in a full trial. However, we know that similar treatments are effective so you may be less frightened of high places following your participation. The treatment involves exposing you to high places in virtual reality so it is likely that you will feel frightened and may find the scenarios difficult to tolerate. This is a key element of exposure treatment so we may encourage you to stay in

the situation that makes you feel anxious. However, you can exit virtual reality at any point, which will be explained to you when you take part. You will be given information about getting further help for your fear of heights after your participation if you feel you need additional support.

Will my personal and research data be kept confidential?

Your questionnaire answers will be made anonymous and kept separate from any identifying information that has your name at the top according to data protection laws. All paper data will be kept in a locked cabinet and digital data will be kept anonymously in a password protected file. This study will be written up to partially fulfil the criteria for a Doctorate in Clinical Psychology as well as publication in a public journal. Your data will not be identifiable when the study is written up and can be removed up until the point of publication. All research data is destroyed 10 years after the research has taken place.

Some of your personal data will be collected for the duration of the study to support your participation. This includes your contact details and your signed consent form. Your consent form provides evidence that you willingly took part in the study so this will be kept for the same length of time as the research data. Any additional personal information will be destroyed after the study has been completed and is no longer required.

Your research data will be accessed by the researcher, staff members examining or supervising this study as part of a Doctorate in Clinical Psychology, and by designated members of the University of Oxford and/or Royal Holloway University for the purposes of monitoring and/or auditing of the study.

Your personal data will be accessed by the researcher and by designated members of the University of Oxford and/or Royal Holloway University for the purposes of monitoring and/or auditing of the study.

What if I have a complaint?

If you have a complaint about any aspect of the study, you can discuss your concerns with the principal researcher, Josephine McInerney. If you would prefer to speak to another person, you can contact Dr Gary Brown (contact details below) at Royal Holloway University.

Who has reviewed this study?

This study has been reviewed by the Royal Holloway University research ethics committee and the University of Oxford Central University Research Ethics Committee (CUREC).

Data Protection

The Royal Holloway University and the University of Oxford are the data controllers with respect to your personal data, and as such will determine how your personal data is used in the study.
The Universities will process your personal data for the purpose of the research outlined above. Research is a task that we perform in the public interest.

Further information about your rights with respect to your personal data is available from http://www.admin.ox.ac.uk/councilsec/compliance/gdpr/individualrights/.

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Appendix H. Consent form

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CONSENT FORM

Exercise and exposure: a virtual reality study for fear of heights
Principal Investigator: Josephine McInerney

Study completed as part of a Doctorate in Clinical Psychology,
Royal Holloway University of London

Please initial boxes

1. I confirm that I have read and understood the participant information sheet and have had the opportunity to ask questions, which have been answered. ☐
2. I understand that my participation in the study is voluntary and I can withdraw at any time without giving a reason ☐
3. I understand that both personal and research data will be kept confidential but it may be accessed by responsible members of the Royal Holloway University to fulfil requirements for the Doctorate in Clinical Psychology, or by designated individuals from either University for the purposes of monitoring and/or audit of the study. ☐
4. I understand that the study data will be included in a student thesis, and may be published in a scientific journal. All data will be fully anonymous in any publication. ☐
5. I consent to participate in the study ☐

Name of person taking consent	Signature	Date
Name of participant	Signature	Date

Consent form. V1. 19/03/2018.
Ethical permission granted by Royal Holloway University Research Ethics Committee – Project ID 862

Appendix I. Baseline mean scores on predictor variables

	Exercise: mean (SD)	**Control: mean (SD)**	**Overall mean (SD)**
BAI	9.55 (9.02)	8.40 (7.21)	8.88 (8.12)
SBI (physical vigilance)	4.13 (2.66)	3.80 (1.67)	3.97 (2.21)
SBI (cleanliness)	2.73 (2.72)	2.63 (2.21)	2.68 (2.45)
SBI (checking)	2.70 (2.12)	2.03 (1.65)	2.37 (1.91)
ASI-3 (physical sensitivity)	7.30 (4.86)	7.27 (4.50)	7.28 (4.64)
ASI-3 (cognitive sensitivity)	5.93 (5.16)	4.63 (3.70)	5.28 (4.50)
ASI-3 (social sensitivity)	12.10 (5.12)	10.87 (4.27)	11.48 (4.71)
ASI-3 total score	25.33 (11.45)	22.77 (9.57)	24.05 (10.54)
AABS2-R-33	117.53 (28.35)	116.4 (30.32)	116.98 (29.10)
BDI	10.62 (10.42)	9.38 (6.76)	10.00 (8.74)
ATHQ (cognitive subscale)	22.60 (5.16)	21.43 (6.35)	22.02 (5.77)
ATHQ (danger subscale)	24.07 (4.19)	23.60 (4.66)	23.83 (4.40)

Abbreviations: BAI, Beck Anxiety Inventory; SBI, Safety Behaviours Inventory; ASI-3, Anxiety Sensitivity Index 3; AABS2-33, The Anxiety Attitude and Belief Scale (33 item); ROS, Risk Orientation Scale

Appendix I (continued).

ROS (financial risk)	159.33 (80.68)	190.67 (88.12)	175.00 (85.24)
ROS (social risk)	285.00 (90.81)	326.33 (88.42)	305.67 (91.27)
ROS (physical risk)	146.67 (88.72)	162.67 (103.82)	154.67 (96.08)
Self-efficacy heights	36.22 (26.01)	35.17 (26.11)	35.69 (25.89)
Self-efficacy heights in VR	58.5 (26.04)	60.50 (21.39)	59.50 (23.65)
Conviction (pre)	69.42 (22.78)	70.33 (21.77)	69.88 (22.11)

Abbreviations: BAI, Beck Anxiety Inventory; SBI, Safety Behaviours Inventory; ASI-3, Anxiety Sensitivity Index 3; AABS2-33, The Anxiety Attitude and Belief Scale (33 item); ROS, Risk Orientation Scale