DOES RAISING HEART RATE PRIOR TO A BEHAVIOURAL TEST ENHANCE LEARNING IN COGNITIVE THERAPY FOR ANXIETY? AN EXPERIMENTAL TEST FOR THE TREATMENT OF FEAR OF HEIGHTS USING VIRTUAL REALITY

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BEHAVIOUR RESEACH AND THERAPY

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ABSTRACT

Background: A key clinical issue is how to maximise the belief change central to cognitive therapy. Physiological arousal is a key internal cue confirming threat beliefs in anxiety disorders. Deeper extinction of anxiety may occur if catastrophizing responses to physiological arousal are inhibited prior to joint exposure with external phobic stimuli. The aim of the study was to test whether increasing physiological arousal using exercise increases the benefits of behavioural tests.

Methods: Sixty individuals with a fear of heights had one session of VR cognitive treatment. They were randomised to have the treatment either with periods of intense physical exercise (cycling at 80% of maximum heart rate) prior to exposures or without. Linear mixed effects models were used to check the manipulation and test the primary hypothesis of a group difference in degree of conviction in the phobic threat belief.

Results: Heart rate was significantly higher in the exercise group throughout compared with the control group. Both groups showed significant reductions in threat beliefs after the VR treatment ($d=1.0$, $p<0.001$) but there was no significant group difference ($d=0.1$, $p=0.56$).

Discussion: An increase in physiological arousal achieved via exercise did not enhance cognitive change in beliefs about feared stimuli.

Keywords: cognitive therapy; anxiety; exercise; fear of heights; virtual reality (VR)

HIGHLIGHTS

- Optimising behavioural tests in cognitive therapy is a key clinical skill.
- A randomised controlled design was used to evaluate a treatment for fear of heights.
- Increasing physiological arousal was tested to deepen anxiety extinction.
- Intensive exercise significantly increased heart rate.
- Intensive exercise prior to behavioural tests did not enhance new learning.

INTRODUCTION

One of the most powerful techniques in cognitive therapy is belief change via direct experiential evaluation. For example, in therapy a patient can be helped to overcome acrophobia by repeatedly being exposed to heights in order to learn that he or she will not fall off the edge. The challenge for the clinician is to know how best to make the most of such behavioural experiments, which is often the art in evidence-based practice. Recently attempts have been made to enhance exposure procedures such as behavioural tests via the application of an inhibitory learning theoretical framework (Craske et al, 2014). Clinical insights for exposure techniques are derived from understanding that an anxious patient's negative associations with the feared stimulus are not erased but are overcome by the creation of an inhibiting non-fearful association (i.e. new learning). Deepened extinction is hypothesised to follow when learning is made about multiple cues - both internal and external - during exposure. A key internal cue in anxiety disorders is physiological arousal, typically misinterpreted as confirmation of the threat beliefs (e.g., Chambless et al., 1984). In this study we experimentally test whether increasing physiological arousal, prior to combining with external phobic stimuli, enables greater belief change. The exemplar used is the treatment of the fear of heights.

Evidence for the inhibitory learning model has grown (Jacoby & Abramowitz, 2016). Inhibitory learning refers to the development of new (inhibitory) associations with the feared stimulus that are created during exposure and that counteract the old anxiety associations. However, the old anxiety association is vulnerable to re-activation, for example due to a new context, re-traumatization, or time elapsed since exposure (Craske

et al., 2008; Craske, Treanor, Conway, Zbozinek & Vervliet, 2014; Craske, 2015). Furthermore, individuals with anxiety disorders may have difficulties making inhibitory learning (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 (deepened extinction), occasional reinforced extinction, and incorporating retrieval cues. These ideas are increasingly being tested (e.g. Shiban et al, 2013; 2015). Here we focus on deepened extinction, combining internal and external cues. 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. Therefore, we planned to use exercise to raise physiological arousal prior to behavioural tests with height stimuli.

There have been only a small number of studies with adults testing the effects of exercise on exposure outcomes. In a randomised controlled experiment, Jacquart et al. (2017) asked adults with a fear of heights to complete 20 minutes of aerobic exercise prior to virtual reality (VR) exposure, which was expected to upregulate the brain derived neurotrophic factor (BDNF) and enhance learning consolidation, but no effects of exercise on symptom outcomes was found. Notably, participants in this study returned to their resting heart rate before starting exposure. In a small randomised study, Powers and colleagues (2015) sought to enhance prolonged exposure for PTSD by aerobic exercise but, perhaps importantly, this was only five minutes before starting exposure. Exercise was found to have a large positive augmentation effect on symptom outcomes. In both of

these studies the interest was in the effects of exercise on brain plasticity rather than physiological arousal. 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) and in the treatment of panic disorder (Broocks et al., 1998).

We set out to test the effects of raising and then maintaining physiological arousal via repeated periods of exercise prior to exposure behavioural experiments. We used an automated virtual reality treatment for fear of heights. The VR treatment developed by Freeman et al (2018) incorporated many of the recommendations made by Craske et al (2014). In a randomised controlled trial with 100 individuals with a fear of heights, approximately two hours of the VR treatment produced large clinical effects (d=2.0) (Freeman et al, 2018). We expected that any bodily changes (e.g. increasing heart rate, light headedness, sweating) in the context of exercise would be appraised neutrally and that these changes , would then carry over to support the making of new learning when presented with virtual heights. We hypothesised that all participants would benefit from the virtual reality but that greater belief change would occur for those who had the repeated periods of exercise during treatment. We also explored three potential psychological predictors of belief change (use of safety-seeking behaviours, risk aversion, and sensitivity to internal phobic cues).

METHOD

Design

The study used a between-groups randomised controlled experimental design. All participants received a session of automated virtual reality treatment for fear of heights having been randomly assigned to the experimental condition (exercise) or the control condition (no-exercise). The design of the study is summarised in Figure 1. The study was 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 given by the University of Oxford Medical Sciences Interdivisional Research Ethics Committee (REF: R58997/RE001).

Figure 1 about here

Participants

Sixty participants with a fear of heights were recruited via advertisements aired on local radio in Oxfordshire over a 6-week period. The content of the radio advert was: "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." People replied to the advertisement via text and were sent a link

to an online screening questionnaire to assess eligibility. The inclusion criteria were: aged between 18 – 65 years old and scoring ≥45 on the anxiety subscale and ≥8 on the avoidance subscale of the Acrophobia Questionnaire (AQ) (Cohen, 1977; Şoflău & Matu, 2016, p. 3). Exclusion criteria were: photosensitive epilepsy; no stereoscopic vision or balance problems; unable to complete a short period of intense exercise on an indoor bike; or currently receiving treatment for fear of heights. Of the 205 people that were screened, 85 were excluded due to scoring below the cut-off on the AQ (n=83) or being above the age cut-off (n=2). 55 people could not be contacted, one person declined to participate, one person had health concerns, and three people did not attend the research appointment.

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). Higher scores indicate higher levels of anxiety about heights.

Fear of heights threat belief. 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% (I'm certain it won't happen) to 100% (I'm certain it will happen). The belief was established in a brief clinical interview and is in line with Craske et al's. (2014) recommendation for measuring expectancy violation.

Heart rate was recorded in beats per minute (bpm) from the beginning to completion of the study. 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). A resting baseline heart rate in bpm was recorded whilst participants completed the initial questionnaires.

Safety Behaviour Inventory (SBI) is a new 20-item scale that assesses the latent trait tendency to use safety behaviours (Brown, in preparation). The SBI was scored using the following subscales: physical vigilance, cleanliness, and checking. Higher scores indicate greater use of safety-seeking behaviours.

The Risk Orientation Scale (ROS) is a 15-item scale to assess risk aversion (Brown, et al., 2020). The ROS was scored using the following subscales: financial risk, social risk, and physical risk. Higher scores indicate lower risk aversion.

The 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) (Osman et al., 2010) and good validity. The subscales of physical, cognitive, and social sensitivity were used. Higher scores indicate higher anxiety sensitivity.

VR treatment

As in the clinical trial by Freeman et al (2018), the VR fear of heights treatment was delivered using an HTC Vive (a consumer VR head-mounted display) and a gaming personal computer. The software 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). Participants stand throughout the treatment and can move freely. A single half hour session of the treatment was used (the first 30 minutes of the approximately two hour full treatment).

The treatment is cognitive: it uses a series of behavioural experiments around heights that allow users to drop safety-seeking behaviours, test out their predictions, and evaluate the phobic threat beliefs (i.e. the mechanism of change is designed to be threat beliefs) (Freeman et al, 2018). All participants start in the virtual therapist's office. The virtual coach explains what drives fear of heights and how it is best treated. Participants are asked questions about their fear of heights including which of the following common fears best reflects their own fears: 'I will trip and fall', 'the structure will collapse', 'I will try to jump' or 'I'm not sure'. Participants then rate how certain they are that this would happen if they were to be exposed to a height. Participants are taken by the virtual coach to the internal atrium of a tall virtual building and asked to choose a floor between 1 and 5, where they would expect to feel moderately anxious. The coach then takes them in a lift to the chosen floor, where the tasks begin.

Participants were positioned in VR behind a waist height (virtual) barrier when they started each floor. On floors one and two, this was a solid colour whereas 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 part of treatment. Following an introduction to the floor and initial psychoeducation, the virtual therapist asked participants if they would like to lower the barrier. This was then lowered in three stages and participants were prompted to look around their environment and try tasks such as swaying from side to side. Once the barrier had been lowered all the way, a bucket with coloured balls appeared next to the participant. The virtual 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, to 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.

Progression to a higher floor in the experiment was taken as the second half of treatment. 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. In this challenging task, the platform was extended into the atrium from the balcony and brought back again to complete the task.

Exercise experimental conditions

Participants in the experimental condition completed one minute of cycling once their heart rate had been raised to the target bpm (80% of their maximal heart rate) and took up to 15 seconds to rest once this had been completed. 80% of participants' maximal heart rate was calculated by age using the 220-age equation outlined by Fox et al. (1971). Participants cycled again until their heart rate reached the target bpm and then maintained this for 2 minutes. In the control condition, participants had their heart rate monitored in the same way as the experimental condition including a resting baseline, but they cycled for 3 minutes ensuring that heart rate did not go above resting. This meant using the

lightest setting on the bicycle and cycling very slowly. In both conditions participants were returned to VR within 30-60 seconds. Once all the tasks for the initial floor in VR had been completed and participants were ready to progress higher, they were taken out of virtual reality again to repeat 3 minutes of cycling according to their allocation. After this second bout of exercise participants were quickly returned back to the VR treatment for further behavioural tests. 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 VR space to minimise the time spent moving between areas.

Statistical analysis

The primary hypothesis of a group difference in threat beliefs (favouring the exercise condition) at the end of treatment was tested using a linear mixed effects model, accounting for baseline conviction and fear of heights (AQ) scores from screening. A random intercept was included to account for the repeated measures of conviction in each participant. There were no missing data. A similar analysis was conducted for heart rate data, taking an average of each participant's heart rate during the virtual reality treatment period. To test the psychological predictors of belief change, individual regressions were completed both with and without controlling for baseline conviction. 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. Analysis was completed using R version 3.5.3 statistical package and SPSS statistics® (Version 25). The study was powered to detect a large clinical effect because the aim of the manipulation was to test an augmentation that would be clinically relevant and noticeable to most patients. A linear

mixed effects model that would have at least 80% power to detect a large effect size (d=0.8) at an $\alpha = 0.05$ required 26 participants in each group.

RESULTS

Table 1 summarises the baseline characterises of the participants and their levels of fear of heights. The severity level of the fear of heights was slightly higher than that in the clinical trial (Freeman et al, 2018).

Tables 1 & 2 about here

Table 2 displays the mean scores for pre and post-conviction and heart rate, split by group. It can be seen that there is a clear difference in heart rate between the two groups between the pre and post assessment points. The clear increase in heart rate with exercise was equally apparent during both periods in VR (period 1 average heart rate for exercise group=112.0 (SD=13.6), period 2 average=114.7 (SD=14.0) . Further, both groups threat beliefs diminish in degree of conviction, but there is no clear group difference. Model 1 tested the manipulation. The cycling manipulation successfully raised physiological arousal (as measured by heart rate) in the exercise group throughout the testing session. The heart rate of the exercise group was faster by an average of 36 beats per minute on average during VR and was significantly different from the control group (p<0.001). Model 2 tested the between groups effect in threat belief conviction ratings, accounting

for baseline conviction and fear of heights screening score. This indicated that there was no difference between the groups. The mean scores show that conviction reduced in both groups, so a 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<0.001) with a large effect size (d=1.0).

Exploratory moderator analysis

In light of the possibility that the uniform effect for change in conviction across treatments may have partially come about through a degree of difference in mechanisms, exploratory analyses of various measures of belief were evaluated as moderators of the effect. Table 3 shows the results from the linear regressions testing predictors of belief change and their interaction with condition. The physical subscales were regarded as most relevant to fear of heights and so were evaluated at p = .05, with tests of the remaining subscales treated as a family of analyses with Bonferroni correction applied (effective p=.008). None of the main effects were significant; however, there was a significant interaction for the ROS physical risk scale. As shown in Figure 2, lower scores (denoting greater risk aversion) predicted higher adjusted post-test conviction ratings in the control group but lower ratings in the exercise group. There was an apparent complementary effect for low risk aversion that was not significant between groups.

Table 3 and Figure 2 about here

DISCUSSION

In this study it was tested in a randomised controlled design whether increasing heart rate increases the benefit of behavioural tests. Could eliciting, in a non-catastrophising manner, the sorts of physiological reactions that feed into threat beliefs lead to greater cognitive change in subsequent tests with external feared stimuli? From a theoretical perspective it was viewed as a possible instance of deepening extinction. The manipulation was successful: 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. However, increasing physiological arousal had no effect on change in threat belief conviction. There was simply a large reduction in belief conviction with the VR treatment for both groups. With respect to outcome, it appears that elevating physiological arousal via exercise is not needed in virtual reality treatments for fear of heights in order to reduce threat cognitions.

It might be argued that the treatment approach using the automated VR programme is so powerful that augmentation is unnecessary. Large effect size changes were found in a single half hour session. VR is a highly therapeutic medium for treatment delivery because conscious awareness that it is a simulation allows patients to approach feared simulations with greater curiosity and flexibility (Freeman et al, 2017). It would be interesting to test the hypothesis in standard face-to-face approaches. It might also be argued that group effects may only appear at a later date, although in the clinical trial, which did not use an exercise manipulation, large clinical effects were maintained at

follow-up (Freeman et al, 2018). However, a very exploratory analysis of relevant belief scales produced one finding consistent with inhibitory learning theory, suggesting participants high on risk aversion in the exercise group had lower conviction in their post-test height related fears compared to high risk aversion participants in the control group. It might be speculated that individuals who are reluctant to take part in more physically risky behaviour (e.g. go on a roller-coaster, go rafting on a fast-moving river) may actually particularly dislike the associated physiological effects of such activities, and that an increase in heart rate achieved in the study via cycling may overcome this reluctance, which then enables new non-catastrophic learning about the internal sensations. What is less understandable however from this perspective is why low risk aversion should be associated with somewhat less of a clinical benefit for the exercise condition compared to the control condition. However, replication is needed before too much attention is given to this exploratory analysis result.

There were a number of limitations in the study. First, neither researcher or participants were blind to group allocations. Second, it might be argued that the physiological effects of exercise are not a sufficient match to those seen in anxious responses. Inducing arousal using imagery either related or unrelated to the phobic stimulus may have different effects from cycling. It would also have improved the understanding made from the study to have assessed appraisals of the physiological effects of exercise. Third, it may be argued that the effects on exposure to real heights needed testing, although our clear goal was to achieve change in cognition, with the assumption that this underpins fear of heights. Fourth, a non-clinical participant group was recruited from radio advertisements, so it would be unlikely to be a representative sample. However, the severity of the fears was

high, and acrophobia is not typically a presenting complaint to mental health services. Despite these limitations, we consider the study to provide a robust evidence-based approach to the important topic of determining how best to deliver cognitive therapy techniques.

Author contributions

The study was conceived and designed by JM, DF, & GB. JM collected the data, analysed the results, and drafted the write-up. DF & GB supervised the study. All authors contributed to the paper.

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Declaration of interest

Daniel Freeman is the founder, and is a non-executive board member, of Oxford VR, a University of Oxford spin-out company, that owns the VR treatment used in the study.

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Figure 1. Study procedure

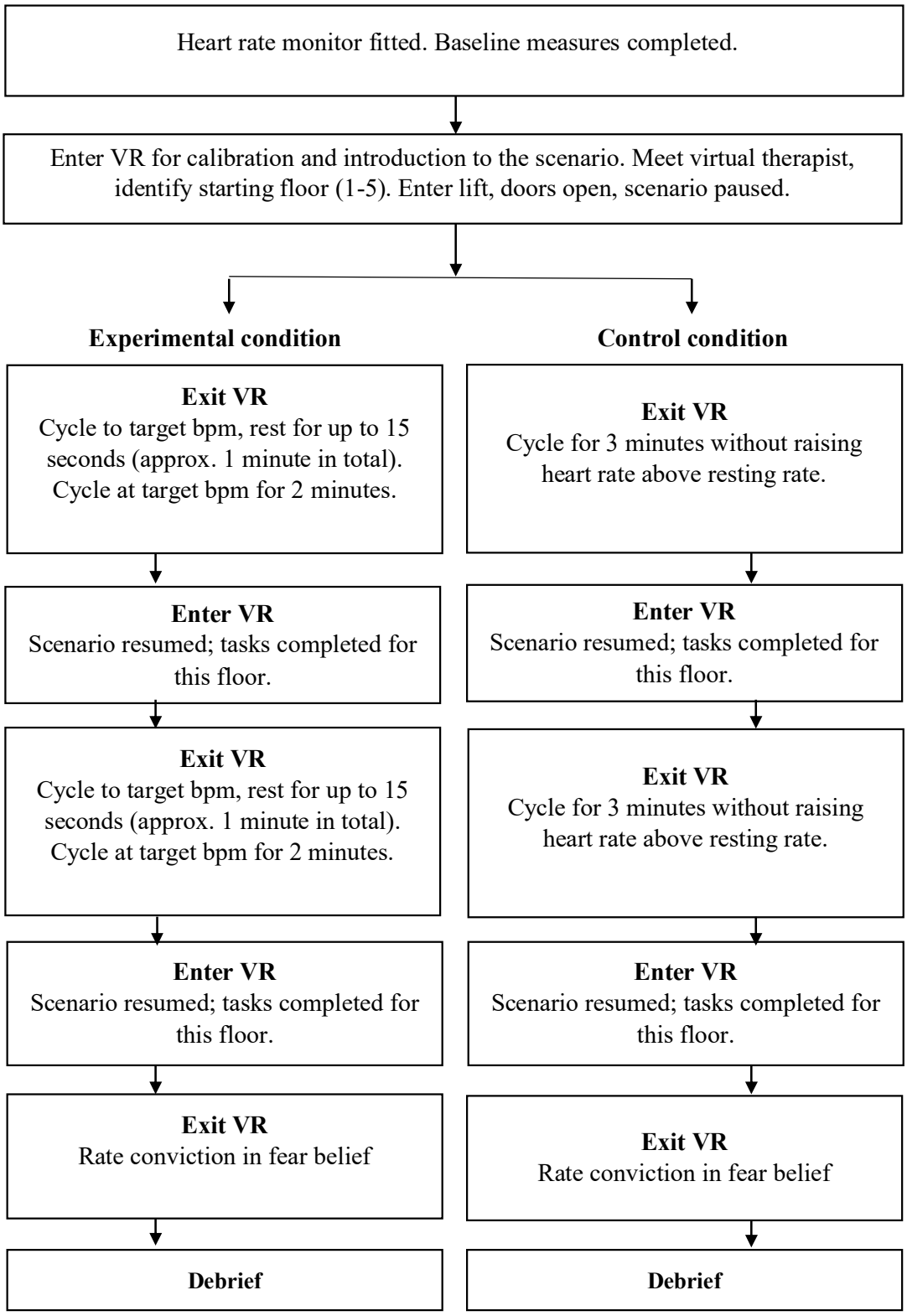

Figure 2

Change in conviction as function of physical risk aversiveness by condition

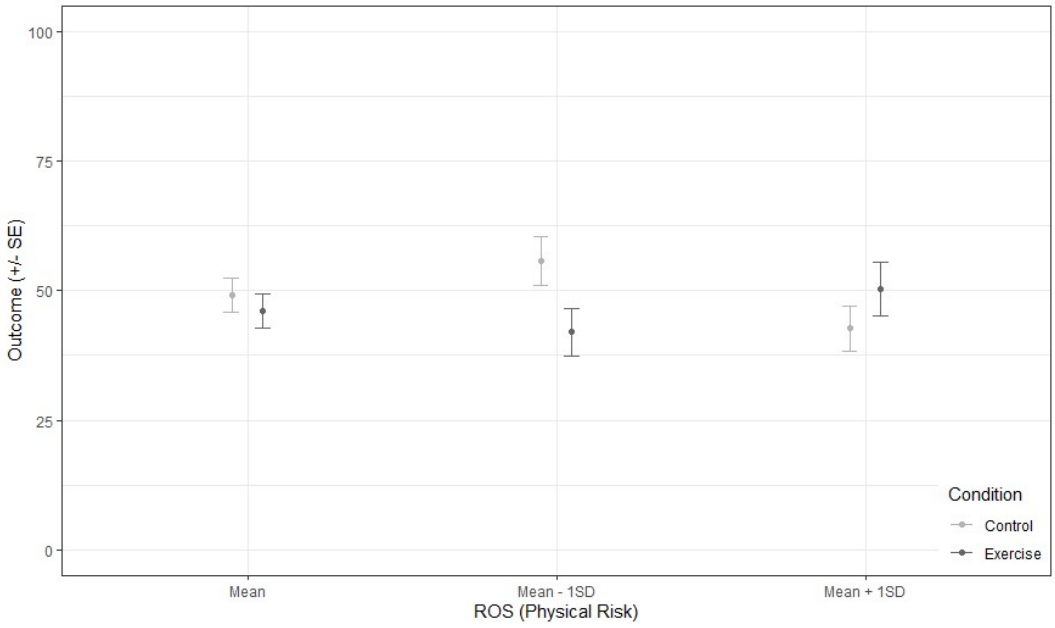

Table 1. Participant demographics and screening scores

	Exercise (n=30)	**Control (n=30)**
Age in 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)
SBI (physical vigilance)*	4.13 (2.66)	3.80 (1.67)
SBI (cleanliness)	2.73 (2.72)	2.63 (2.21)
SBI (checking)	2.70 (2.12)	2.03 (1.66)
ASI-3 (physical sensitivity)*	7.30 (4.86)	7.27 (4.50)
ASI-3 (cognitive sensitivity)	5.93 (5.16)	4.63 (3.70)
ASI-3 (social sensitivity)	12.10 (5.12)	10.87 (4.23)
ROS (financial risk)	14.27 (4.86)	16.37 (5.59)
ROS (social risk)	22.23 (5.93)	24.93 (5.62)
ROS (physical risk)	13.63 (5.45)	14.73 (6.50)

Table 2. 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)	<0.001	2.9
Average during VR	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.

Table 3. Individual linear regressions to test incremental prediction of the baseline predictors on post-conviction (main effect and interaction with condition), controlling for pre-conviction

	Main Effect			Interaction		
	F	**ΔR^2**	**p**	**F**	**ΔR^2**	**p**
SBI (physical vigilance)*	0.30	0.003	0.59	2.15	0.02	0.148
SBI (cleanliness)	0.03	0.001	0.86	0.01	0.001	0.92
SBI (checking)	0.17	0.002	0.68	6.25	0.07	0.015
ASI-3 (physical sensitivity)*	1.99	0.02	0.16	0.76	0.008	0.38
ASI-3 (cognitive sensitivity)	0.006	0.001	0.84	0.04	0.001	0.84
ASI-3 (social sensitivity)	0.03	0.001	0.87	0.002	0.001	0.96
ROS (financial risk)	0.30	.003	0.58	0.02	0.001	0.89
ROS (social risk)	2.23	0.02	0.14	2.22	0.02	0.14
ROS (physical risk) *	0.43	0.01	0.50	4.98	0.05	0.03

Note: SBI = Safety Behavior Inventory; ASI-3 = Anxiety Sensitivity Index 3; ROS = Risk Orientation Scale.

*Predictors for which a priori predictions were made. Bonferroni correction applied across the remaining set of predictors (evaluated against p = .008).

Conflicts of interest

Daniel Freeman is the founder, and is a non-executive board member, of Oxford VR, a University of Oxford spin-out company, that owns the VR treatment used in the study.