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Exposure therapy in a virtual environment: Validation in obsessive compulsive disorder

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ABSTRACT

Exposure and response prevention (ERP) is the current first-line psychological treatment for Obsessive-compulsive disorder (OCD). However, substantial inter-individual variability exists in treatment outcomes, including inadequate symptom improvements, and notable refusal and attrition rates. These are driven, in part, by impracticalities in simulating intrusive thoughts within clinical settings. Virtual reality (VR) offers the potential of overcoming these limitations in a manner that allows for finely controlled anxiety-provoking scenarios to be created within supportive clinical settings. To validate the potential of VR for treating contamination-based OCD, 22 patients undertook a VR ERP session and a matched session of the current gold-standard of *in vivo* ERP. In VR, patients were immersed within a contamination environment that permitted flexible delivery of customisable, graded exposure tasks. The VR environment utilised HTC Vive hardware, to allow for patients to both interact with, and physically move through the environment. Subjective and objective measures of distress were recorded, including heart and respiration rates. These measures indicate virtual and *in vivo* ERP sessions provoke consistent anxiety profiles across an exposure hierarchy. Virtual exposure was advantageous for engagement and adherence to tasks, and the therapeutic alliance was upheld. VR is a promising mechanism for ERP in contamination OCD.

1. Introduction

Obsessive-compulsive disorder (OCD) is characterised by persistent intrusive and upsetting thoughts, images or urges (obsessions), and/or repetitive behaviours or mental acts (compulsions), that are performed to reduce discomfort (American Psychiatric Association, 2013a). Cognitive behaviour therapy including exposure and response prevention (ERP) is the recommended first line non-pharmacological treatment for OCD (American Psychiatric Association, 2007, 2013b; National Institute for Health and Care Excellence, 2005; The Australian Psychological Society, 2018). Typically, ERP sessions utilise exposure hierarchies to assist clients to sequentially face anxiety provoking scenarios in a graded manner while simultaneously withholding compulsions to assist in learning new associations to feared stimuli (Abramowitz & Larsen, 2006; Powers et al., 2006). Despite a strong evidence-base, 15–25 % of clients refuse ERP, a further 14–25 % drop out prematurely (Abramowitz, 2006; Jenike, 2004; Ong et al., 2016; Öst et al., 2015; Schruers et al., 2005), and up to 41 % of clients demonstrate inadequate treatment response (Simpson et al., 2006, 2008). These figures may partly stem from the impracticalities of simulating triggering situations and associated intrusive thoughts within clinical settings, which can feel removed from client's daily experiences, as well as low compliance with ERP between sessions (Lind et al., 2013). Given these substantial engagement and symptom-provocation shortfalls in standard ERP approaches, new avenues to provide evidence-based treatment are needed. Innovative technologies such as virtual reality (VR) offer a unique opportunity to create novel ERP tools that translate traditional strengths of ERP while addressing current limitations.

VR uses computer simulations to create immersive, carefully controlled three-dimensional environments. Audio-visual features mimic and extend reality, providing the opportunity of seemingly endless experiences that can be customised. Current technologies enable

Abbreviations: ERP, exposure and response prevention; OCD, obsessive-compulsive disorder; SUDs, subjective units of distress; VR, virtual reality.

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users to ambulate within virtual environments and choose their actions freely, which heightens presence and distinguishes VR from more passive experiences like watching a movie. Virtual environments offer the opportunity to capture comprehensive, carefully controlled research data in these ecologically valid settings. These capabilities may also be leveraged to address barriers in traditional treatment delivery, potentially improving service uptake, targeted symptom provocation, and facilitating in-home therapeutic engagement. In doing so VR could overcome the challenge of replicating client's day-to-day experiences in a clinician's office. VR exposure sessions in post-traumatic stress disorder and specific phobias have been shown to significantly reduce disorder symptoms, and are not inferior to real-world *in vivo* exposure with respect to therapeutic outcomes (Gonçalves et al., 2012; Parsons & Rizzo, 2008; Rizzo et al., 2014). Given the similarities in underlying mechanisms of anxiety and stress disorders have led to commonalities in exposure-based treatment approaches, VR exposure-based therapy holds promise as a potential treatment tool for other similar disorders, such as OCD.

In ERP, the combination of both *in vivo* and imaginal exposures currently generate the greatest improvements in anxiety and OCD symptoms at post-treatment (Abramowitz, 1996; Gillihan et al., 2012). VR-based ERP for OCD could enhance upon these treatment modalities by simulating situations of the real-world in a more realistic manner. Additionally, exposures that may otherwise be perceived as dangerous or impractical *in vivo* could feel more 'safe' or feasible in VR. In order to validate virtual exposure tasks, it is crucial to demonstrate that provocation of disorder-specific emotions can occur in response to relevant virtual stimuli, to a comparable level to real-world exposure. Specific emotional experiences can be targeted in ERP depending on clients' symptom profiles. Fear and disgust dimensions are particularly relevant in several anxiety-related disorders, such as contamination-based OCD (Cisler et al., 2009). Evidence is building that subjective and objective measures of OCD-related anxiety can be heightened in VR, including the provocation of fear and disgust (Belloch et al., 2014; Inozu et al., 2020; Kim, Cha et al., 2008; Kim, Kim et al., 2008, 2009; Laforest et al., 2016). VR-based ERP for OCD may also offer advantages beyond existing treatments, such as greater standardisation of exposures *via* precise control over graded tasks (Cloos, 2005).

Better designed studies are urgently needed in order to translate VR-based ERP into clinical practices. A systematic review concluded that there was an insufficient number of studies that compared VR to either *in vivo* or imaginal exposure (Diemer et al., 2014). This type of analysis remains vital to understanding the relative strengths and weaknesses of VR-based ERP as a treatment tool by using existing treatment modalities as a benchmark. Establishing this evidence will require studies to use clinical samples that meet diagnostic criteria and make comparisons to 'treatment as usual' groups. These are notable gaps in the literature to date, which in contamination-OCD has lacked control comparisons (Belloch et al., 2014) primarily focused upon sub-clinical samples (Inozu et al., 2020), non-immersive technology (Kim, Cha et al., 2008; Kim, Kim et al., 2008), and provided no comparison condition to existing best practices of *in vivo* treatment (Laforest et al., 2016).

Studies that concurrently measure clinically relevant objective and subjective responses to VR-based ERP and directly contrast with *in vivo* ERP are needed to ascertain the therapeutic utility of VR-based ERP. For instance, subjective units of distress (SUDs), is the most commonly used self-report assessment of client experience. SUDs are used in developing treatment hierarchies and monitoring treatment engagement and process (Wolpe, 1973). In anxiety populations, including those who display contamination concerns, fear and disgust responses may also correspond with distinct heart and respiratory changes (Kreibig, 2010), providing an opportunity for parallel psychophysiological measurements to further quantify emotional experiences (Diemer et al., 2014; Freire et al., 2010; Meyerbröker & Emmelkamp, 2010). These advancements will provide important evidence for the utility of VR in eliciting relevant emotional engagement.

Beyond evidence of anxiety provocation, the clinical acceptability of new VR treatment tools must be addressed to facilitate translation into clinical practice. Clinicians' perception of 'usefulness' is a predictor of VR implementation (Bertrand & Bouchard, 2008) and limited understanding of benefits and insufficient training are reported as key barriers to VR uptake (Schwartzman et al., 2012). Research will need to measure and report clinical factors in order to improve clinicians' familiarity and likelihood of acceptance. In particular, any impact of VR on the therapeutic relationship and client engagement factors are important to ascertain as these are known predictors of treatment response (Abramowitz et al., 2002; Martin et al., 2000). It is also imperative that research examines the unique impact of technology on therapeutic alliance factors; either enhancing client's empowerment over their own treatment, or creating a barrier to communication (*e.g.* face-to-face engagement) (Meyerbröker & Emmelkamp, 2008; Riva, 2005).

In light of the above, this study aims to robustly validate a novel VR exposure system (development described elsewhere; Cullen et al., 2021). In a contamination-based OCD sample, we aimed to investigate the comparability of a session each of VR and *in vivo* ERP, across subjective and objective responses as measured by self-reported anxiety, therapeutic alliance and exposure engagement, and psychophysiological heart rate and respiration indicators of emotional response. These findings will help determine whether VR is a valid method for exposure therapy in OCD, using a clinically diagnosed sample to examine anxiety provocation and clinical indicators of engagement.

2. Method

2.1. Participants

Twenty-two consenting adult participants were recruited from OCD treatment clinics and the general public, *via* clinician referral, flyers (waiting rooms, support groups) and research databases. To be included in the study, participants needed to be 18 years and above, meet primary diagnostic criteria for OCD according to the Diagnostic and Statistical Manual of Mental Disorders 5th Edition (American Psychiatric Association, 2013a) using the Mini International Neuropsychiatric Inventory, endorse primary contamination concerns on the Yale-Brown Obsessive Compulsive Scale II (YBOCS-II; Goodman et al., 1989), and report stable psychoactive medication type and dosages in at least the prior three months, if prescribed. These criteria were assessed by a psychologist (AJC) in a semi-structured clinical interview. Individuals were excluded for any co-morbid diagnostic history that may have posed a safety risk (given limited published safety protocols specialised for VR in psychological populations). Ethics approval was obtained from The Melbourne Clinic Research Ethics Committee and Monash University Human Research Ethics Committee. Additional methodological information is available elsewhere (Cullen, 2020; Cullen et al., 2021).

2.2. Apparatus

2.2.1. VR hardware and software

A HTC Vive system with wireless adaptor for the head-mounted display was used, as this permits free movement within a defined walkable space. The visual display adapts according to participant actions, for example turning in a different direction and walking over to look at a new area in the environment. Two handheld wireless controllers enable the user to manipulate objects in the virtual environment. Custom virtual environments were built in Unity software (see Fig. 1). Software design was collaborative and iterative, incorporating feedback from OCD patients and clinicians (detailed information; Cullen, 2020; Cullen et al., 2021).

2.2.2. Psychophysiology hardware and signal acquisition

Physiological signals were acquired using the Equivital LifeMonitor wireless monitoring system (Liu et al., 2013). Signals were live streamed

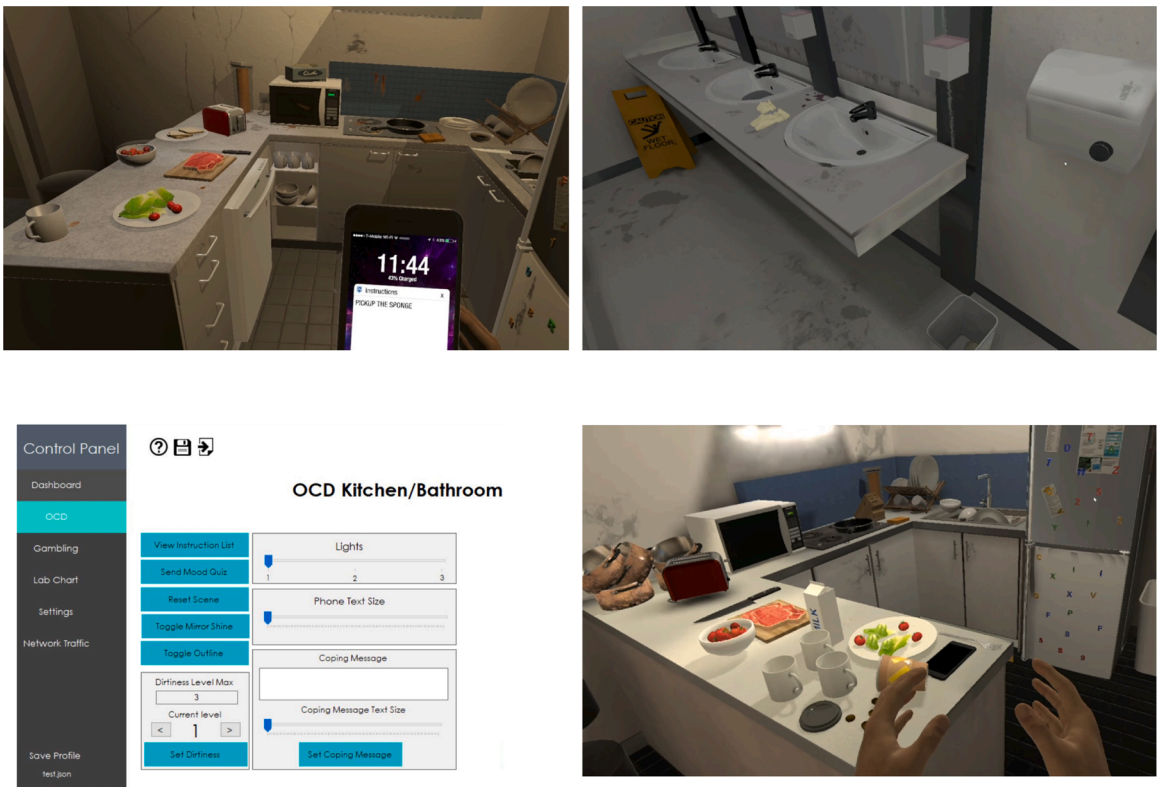

Fig. 1. Sample of Virtual Environments and Control Panel Interface.

via Bluetooth to the AD Instruments LabChart Pro analysis software v.8.1.6 and recorded. Custom built software integrated the physiology and VR programs. This permitted real-time virtual environment modifications, such as making new stimuli available to commence an exposure task, with synchronised event-markers sent to the physiology software. Electrocardiogram (ECG) and respiration were measured *via* the Equivital Sensor Belt, which contains ECG electrodes and an expansion based respiratory belt transducer. Device sampling rates are predetermined at 256/s. A bandpass filter of 1–30 Hz was applied to the ECG signal (Andreassi, 1995; Bailey et al., 1990; Buendía-Fuentes et al., 2012).

2.3. Procedure

All recruited participants attended the sessions. This is notable given the typical rates of treatment refusal in OCD (Jenike, 2004; Öst et al., 2015; Schruers et al., 2005). The study design was repeated measures and counterbalanced with random allocation. For each participant, following informed consent, a clinical interview was conducted to characterise OCD symptoms and provide psychoeducation to ensure familiarity with SUDs and ERP session structure. SUDs were discussed in detail to ensure understanding and reliability in reporting, including what different ratings out of 100 represented. Participants were advised that they would be asked to report their SUDs at two key timepoints, being *Instruction* for the anticipatory distress, and *Contact* when experiencing contamination distress. This was connected to the explanation of these two key phases, as outlined further below. Additionally, that they could advise researchers of their SUDs at any time a pertinent change occurred, at the participant's discretion. Participants and researchers developed exposure hierarchies according to SUDs ratings, in keeping with standard ERP procedures (Abramowitz, 1996). Generic hierarchies were collaboratively designed for kitchen and bathroom settings. Using this understanding of each participant's symptoms, researchers translated this into a tailored hierarchy that would be expected to sequentially heighten anxiety for each participant. This was necessary to ensure that a distinct novel fear response could be exhibited when each task instruction was provided. This approach balanced research validity and comparability (pre-determined tasks able to be generated using the VR software) with the clinical need to address each participant's unique symptoms and elicit emotional responses. Participants selected to use either a kitchen or bathroom environment, and hierarchies were matched across virtual and *in vivo*.

Pre-session measures were collected using an online questionnaire platform (Qualtrics, 2005), except for two participants who felt their OCD symptoms would impede completing a questionnaire, with data being collected *via* interview in these instances. Psychophysiology was recorded coincident will all VR and *in vivo* exposure activities. There were no refusals from participants due to the equipment (*i.e.*, insurmountable fears of being contaminated), nor instances of simulator-sickness. Participants started either the virtual or *in vivo* session according to their randomised order. Within-session ERP data (SUDs, psychophysiology; see Materials within-session below) was recorded at two key points for each exposure task; *Instruction* and *Contact. Instruction* is when participants were informed of the task, whereas *Contact* refers to when they made contact with the anxiety-provoking stimuli. Consistent with standard therapy, session pace and the number of tasks were participant-driven, with support from the researchers (see Data Analysis for further exposure task level information). Communication between researcher and participant was possible throughout sessions to enable engagement and ongoing monitoring. Post-exposure questionnaires were administered at the conclusion of each session.

A rest break between sessions was provided, of a duration that was guided by patient needs and symptom provocation levels, typically 20−30 min. The second exposure session followed the same procedure as above, on the same day. Participants were debriefed and provided a 60 dollar gift-card in appreciation of their time.

2.4. Materials

The State-Trait Anxiety Inventory (State subscale; STAI-S, Y-form) is a 20-item questionnaire that was used to measure current anxiety symptoms pre- and post-session. Higher summed Likert ratings represent greater severity. Psychometric properties indicate sound reliability and validity, with adequate discrimination between low and high stress situations (Barnes et al., 2002; Metzger, 1976; Spielberger et al., 1983). Internal consistency for pre-session and post-session were $\alpha = .96$ and $\alpha = .95$ respectively.

The Session Rating Scale Version 3 (SRS), is considered a reliable, valid, and feasible tool to measure therapeutic alliance (Duncan et al., 2003), and is appropriate for session-by-session use. The Patient Adherence Scale for Exposure and Response Prevention Therapy (PEAS) was used to measure client engagement in exposure processes (quantity, quality, ritual prevention), as compliance is a known predictor of outcome (Abramowitz et al., 2002). The scale has excellent inter-rater reliability and good face and content validity (Maher et al., 2012; Simpson et al., 2010). The SRS and PEAS were administered at the conclusion of each exposure session. Internal consistency values for the current study were $\alpha = .79$ and $\alpha = .70$ respectively.

2.4.1. Within-session

SUDs were measured on a 0–100 scale at defined points (including *Instruction* and *Contact* phases). Self-reported anxiety provocation is commonly operationalised using such fear ratings in clinical and research contexts (Carl et al., 2019; Meyerbröker & Emmelkamp, 2010; Morina et al., 2015).

ECG and respiration signals were acquired continuously with semi-automated real-time event marking of key times. For example, triggers were programmed to be sent to LabChart software automatically when participants pressed a button on the VR controller, indicating contact with objects. Recordings were post-processed using these markers into the *Instruction* and *Contact* windows, with the aim of examining fear and disgust responses respectively (Cisler et al., 2009; Diemer et al., 2014). By dividing these signals into meaningful epochs, we intended to capture detailed fluctuations in psychophysiological activity which relate to conceptually meaningful anxiety experiences.

2.5. Data analysis

2.5.1. Psychophysiology data extraction

For heart rate, beats were classified according to standard human QRS classifications, averaged across 4 beats, and manually reviewed for detection accuracy. Respiration was classified using cyclic human chest expansion parameters (analysed as breaths per minute). Exposure hierarchy task levels 1–6 were extracted for analysis. Each task included *Instruction* and *Contact* event-markers. Post-processing defined consistent post-trigger epochs (5 and 10 s respectively) to allow inter-individual comparison. These time durations were driven by theoretical conceptualisations of rapid anticipatory fear and a relatively longer disgust reaction, and to exclude any longer habituation experience from being falsely calculated in the averaged value. Separating signals into these theoretically meaningful windows has a drawback of limiting identification of the acceleration and deceleration of signal responses between tasks that have been theorised to be distinct for anxiety, fear, and disgust (Kreibig, 2010). Therefore, a secondary analysis was conducted that incorporated both *Instruction* and *Contact*, with the intent of capturing potential fluctuations in signals from one emotional state to the next.

2.5.2. Cleaning

Data for all measurements was transferred to SPSS Statistics v.25 software for analysis (IBM, 2017). One case was excluded from all within-session analyses due to missing data for one ERP session (subsequent n = 21). Regarding specific signals, three cases were excluded from heart rate analyses due to anomalous signal features stemming from conflicting environmental signals and imperfect fitting of psychophysiology hardware belt to the participant (heart rate analysis n = 18). Where participants reached their upper threshold for subjective anxiety before hierarchy level six (*in vivo* sessions; 2 at *Instruction*, 4 at *Contact*, VR sessions; 1 at *Contact*), missing data was imputed using Expectation Maximisation (Tabachnick & Fidell, 2007). Out of range values and univariate outliers were winsorized. No multivariate outliers were identified. Normality was met, aside from a few instances whereby analysis proceeded due to more cases than dependent variables and equal group sizes. Assumptions were met for all analyses (Hills, 2011; Tabachnick & Fidell, 2007).

2.5.3. Statistical analysis and equivalence testing

Dependent t-tests were used to analyse pre- to post-session data and clinical factors. Within-session data was analysed using two-way Group x Level repeated-measures ANOVAs, with conservative Greenhouse-Geisser corrections under Sphericity violations (Tabachnick & Fidell, 2007). Groups were defined by method of exposure delivery: virtual or *in vivo*. The Level variable was the exposure hierarchy task levels from one to six. For each measured signal, ANOVAs were conducted on *Instruction* and *Contact* separately, as well as both phases incorporated into the same analysis (see Psychophysiology data extraction).

Heart rate and respiration analyses that identified no significant differences between groups were followed up with equivalence testing. These statistical tests were used to determine whether the non-significant differences in responses could be considered unimportant in scope, within the context of the research and signals (Mara & Cribbie, 2012). Two one-sided *t*-tests were used, in keeping with the paired nature of samples (Cribbie & Arpin-Cribbie, 2009). Traditional *in vivo* ERP is considered the current gold-standard, so equivalency tests examined whether VR was comparable to that benchmark. Critical mean differences were the standard deviation of average *in vivo* heart and respiration rates. These measures were chosen given that the signals lend themselves to robust, objective levels of equivalence, unlike the subjective data, which meant ranges could be pre-defined according to Cribbie and Arpin-Cribbie (2009) recommendations of definitive, probable, or potential equivalence.

3. Results

The sample was aged 18–65 with *M(SD)* = 32.91(9.84), predominantly female (64 %), unemployed (50 %), living with family (64 %), and single (50 %), which is representative of typical OCD samples (Karno et al., 1988). Highest education was Year 12 or bachelor's degree (32 % of each). Total YBOCS-II score was *M(SD)* = 29.41(6.51), ranging from 18 to 45. Psychiatric medication dosages were stable in the months preceding participation with 64 % of the sample taking at least one psychoactive medication. Most common co-morbid diagnoses were depression and panic disorder (past and current). See Table 1 for further characterisation.

3.1. Within-Session SUDs

SUDs significantly increased across the hierarchy levels, with large effect sizes. There were no statistically significant differences attributable to group, nor interaction between group and level in determining SUDs, as shown in Fig. 2 (*Instruction:* Group, $F(1, 40) = 1.38$, $p = .25$, Level, $F(3.51, 140.29) = 14.57$, $p < .001$, partial $\eta^2 = .27$, Group x Level, $F(3.51, 140.29) = 1.93$, $p = .12$. *Contact:* Group, $F(1,40) = 1.30$, $p = .26$, Level, $F(3.40, 136.06) = 17.87$, $p < .001$, partial $\eta^2 = .31$, Group x Level $F(3.40, 136.06) = .92$, $p = .44$).

3.2. Pre- and post-session anxiety

Compared with the VR session, pre-session anxiety was higher before

Table 1
OCD Symptom Severity, Psychoactive Medications, and Comorbidities for the Sample.

Demographic information	Number of Participants	Proportion of Sample
YBOCS-II Total Score Categorisation		
Mild	1	4.5 %
Moderate	10	45.5 %
Severe	10	45.5 %
Very Severe	1	4.5 %
Psychoactive Medication Classes (current)*		
Selective Serotonin Reuptake Inhibitors	9	40.9 %
Tricyclic Antidepressants	3	13.6 %
Benzodiazepines	2	9.1 %
Atypical Antipsychotics	1	4.5 %
Anticonvulsants	1	4.5 %
Co-morbid Psychiatric Diagnoses (past and current)		
Major Depressive Disorder	14	63.6 %
Panic Disorder	6	27.3 %
Generalised Anxiety Disorder	4	18.2 %
Post-Traumatic Stress Disorder	1	4.5 %

* *Note:* Two participants were prescribed multiple psychoactive medications, as such the percentages in this table to do not sum to the above mention of 64 % - as this referred to the proportion of the sample taking *some form* of psychoactive medication.

in vivo exposure, $t(20) = 2.74$, $p = .013$, Cohen's $d = 0.45$ (medium), with a mean difference of 6.03, 95 % CI [1.49, 10.98] (see Table 2). No significant differences in anxiety remained between the two exposure modalities post-sessions, $t(20) = 1.53$, $p = 0.14$.

3.3. Clinical factors

Engagement and adherence to exposure tasks in the Virtual session was higher, $t(20) = 2.17$, $p = .042$, Cohen's $d = 0.41$ (medium), with a mean difference of 1.14 between the two conditions, 95 % CI of difference [0.04, 2.24]. Therapeutic alliance did not differ across exposure methods, $t(20) = 1.70$, $p = .11$.

3.4. Psychophysiological response

Across the exposure hierarchy levels, there were no significant increases in heart rate (*Instruction:* $F(2.98, 101.37) = 1.25$, $p = .30$, *Contact:* $F(2.96, 100.50) = .99$, $p = .40$) nor respiration rate (*Instruction:* $F(4.15, 165.95) = 2.22$, $p = .067$, *Contact:* $F(1, 40) = .10$, $p = .75$).

Heart rate at both phases, and respiration at *Contact*, also did not differ significantly between exposure methods, and no interaction effect was evident. Heart Rate *Instruction:* Group, $F(1, 34) = .54$, $p = .47$, Group x Level, $F(2.98, 101.37) = 1.04$, $p = .38$; *Contact:* Group, $F(1, 34) = .38$, $p = .54$, Group x Level, $F(2.96, 100.50) = .66$, $p = .58$. Respiration *Contact:* Group, $F(1, 40) = .10$, $p = .75$, Level, $F(4.37, 174.62) = 1.51$, $p = .19$, Group x Level, $F(4.37, 174.62) = .48$, $p = .77$. Equivalence testing for heart and respiration rate at each level met criteria for probable to definitive equivalence of the VR to *in vivo* standard.

A significant interaction effect and group differences were evident for respiration rate at the *Instruction* phases, *Instruction:* Group, $F(1, 40) = 6.01$, $p = .019$, partial $\eta^2 = .13$ (medium), Group x Level, $F(4.15, 165.95) = 2.64$, $p = .034$, partial $\eta^2 = .06$ (small to medium). Profiles displayed in Fig. 3 exemplify the nature of this difference, whereby *in vivo* exposures have variable trends (upward trend in respiration rate to level 4, then downward to 6) whereas VR tends to fluctuate around a stable trend line.

For each of the psychophysiological signals, a combined analysis of both *Instruction* and *Contact* was utilised to capture the change from one event to another. This was to explore potential accelerations and decelerations of signals across fear and disgust (for further information see earlier section: Statistical analysis and equivalence testing**)**. For respiration, there was an interaction between group and level (Group, $F(1, 40) = 2.86$, $p = .099$, Level, $F(11, 40) = 1.71$, $p = .069$, Group x Level, $F(11, 40) = 2.00$, $p = .027$, partial $\eta^2 = .048$ (small to medium)) but this was not evident for heart rate (Group, $F(1, 34) = 0.47$, $p = .50$, Level, $F(5.48, 186.43) = 1.47$, $p = .20$, Group x Level, $F(5.48, 186.43) = 0.74$, $p = .61$), see Fig. 3.

4. Discussion

For individuals with moderate-severe OCD, virtual and *in vivo* exposure sessions resulted in comparable symptom provocation and clinical indicators. Self-reported anxiety increased across the exposure hierarchy for both exposure methods. Psycho-physiological signals were also comparable; however, in neither method of exposure did they increase across levels. While pre-session state anxiety was higher before *in vivo* ERP, this did not remain at post-session. Virtual exposure was

Table 2
Mean Values for Clinical Variables of both Exposure Methods.

Measure	Virtual *M(SD)*	*in vivo M(SD)*
Pre-Session Anxiety (STAI-S)	42.29(13.47)	48.52(12.82)
Post-Session Anxiety (STAI-S)	43.19(13.15)	47.71(14.36)
Therapeutic Alliance (SRS)	38.05(2.72)	36.86(2.99)
Engagement and Adherence (PEAS)	16.00(2.61)	14.86(2.94)

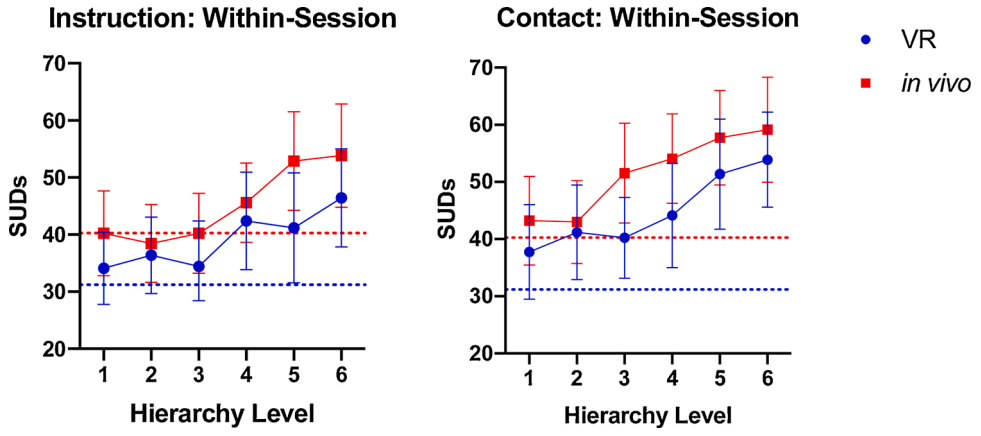

Fig. 2. Profiles for SUDs at Instruction and Contact Stages. Plot of Means with 95 % Confidence Interval Bars. Trend Lines at Y-axis Represent Reported SUDs Once Within Environment, Before Task Onset.

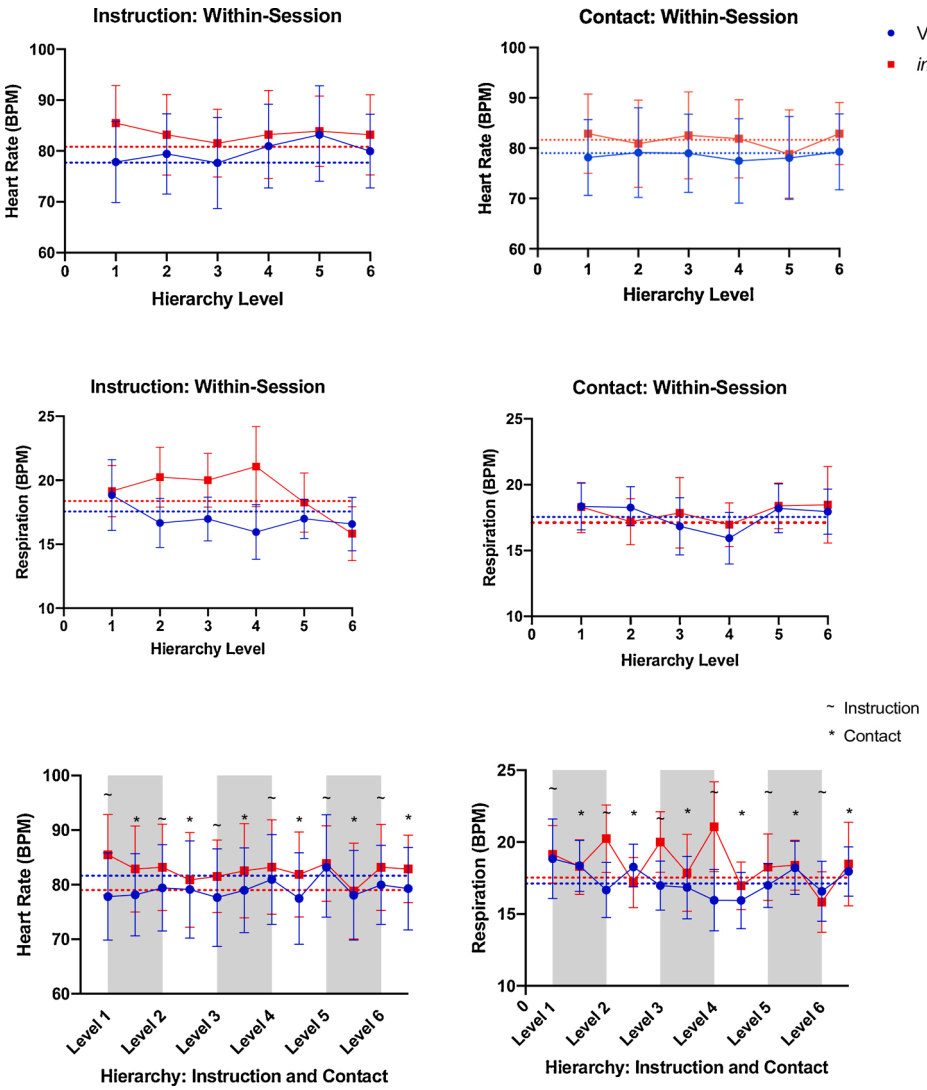

Fig. 3. Heart (Beats Per Minute) and Respiration Rates (Breaths Per Minute) Responses During Instruction and Contact Phases across the Six Levels of the Hierarchy. 95 % Confidence Intervals Presented as Bars. The Y-axis Dashed Plot Line Indicates the Average Baseline Level of Physiological Arousal that was Obtained when Participants First Entered the Environment Before ERP Commenced.

advantageous for participant engagement and adherence to exposure tasks, and the therapeutic alliance was not adversely affected in VR. These findings provide evidence in support of VR as an exposure modality that can enhance participant engagement and elicit relevant anxiety symptoms while maintaining the therapeutic relationship.

For both exposure methods, the increase of SUDs across hierarchy levels indicates that the subjective experiences of distress from anxiety-related fear and disgust were comparable. The higher pre-session anxiety for *in vivo* suggests that participants may have expected *in vivo* to be more anxiety-provoking than virtual. On the basis of this finding, VR may offer a more acceptable ERP method for patients who would find *in vivo* unacceptably anxiety provoking pre-session, thereby overcoming refusal and drop-out rates. Interestingly, this state anxiety disparity did not endure to a significant level at post-session. Given that subjective distress heightened for both within-sessions, it may be that the subjective experiences of VR and *in vivo* were more alike than expected, explaining this absence of a difference at post-session. Taken together, our findings suggest that subjective distress can be heightened in these VR exposures to a comparable degree to *in vivo*, consistent with the central tenets of ERP (Foa & Kozak, 1986). These results are consistent with previous findings that VR-based ERP can elicit relevant symptoms, suggesting utility for anxiety assessment and treatment purposes (Inozu et al., 2020; Kim, Cha et al., 2008; Kim, Kim et al., 2008, 2012; Laforest et al., 2016; Van Bennekom et al., 2017). Contaminated VR environments have elicited anxiety, evidenced by measures such as increased STAI scores and heart rate, in people who have heightened fears of contamination but do not meet diagnostic criteria (Inozu et al., 2020) and people with OCD, to a greater degree than individuals without such concerns (Laforest et al., 2016). Our study shows not only that VR can elicit anxiety, but that the degree of anxiety elicited is consistent with the best-practice standard *in vivo* therapy, providing considerable supportive evidence for VR implementation.

Therapeutic alliance showing no difference across groups is a clinically meaningful finding, consistent with previous speculation that VR technology could maintain rather than inhibit the therapeutic relationship by acting as a common ground between client and clinician (Coyle et al., 2007; Riva, 2005; Riva et al., 2002; Wrzesien et al., 2015). Although empirical studies that have compared VR exposure-based therapy to the traditional therapeutic alliance remain relatively limited, findings to date suggest there are no differences in contexts with and without technology for phobia treatment (Wrzesien et al., 2013) and that alliance can continue to be positively related to VR exposure-based therapy outcome in some disorders (Meyerbröker & Emmelkamp, 2008).

Adherence and engagement in exposure tasks was higher in the virtual session than *in vivo*. This is particularly notable finding in OCD where there can be low levels of engagement and high no-show rates. The PEAS outcome measure represents the percentage of tasks attempted, the degree of engagement, and percentage of urges to ritualise successfully resisted. Additionally, when considering engagement from a technology design perspective, there were no instances of refusal due to the equipment (*e.g.*, fear of contamination from VR handheld controllers). No simulator-sickness occurred, which may in part be accounted for by the ambulant technologies used that minimised the experience of sensorimotor discrepancy. Informal feedback from the participants in this study suggested that the novelty and nature (*i.e.* safety) of VR heightened their likelihood of engagement in therapeutic processes. Further qualitative research may assist to explain these experiences and perspectives.

The psychophysiology data provides another valuable insight into participants' experiences within sessions and are consistent with the self-report data showing an absence of significant differences between exposure methods. The only exception was a significant interaction (and group) effect at the fear-related stage of *Instruction* that emerged for respiration. This was reflected in the *Instruction* profile graph as higher breathing rate at the anticipation of the middle level exposure tasks for *in vivo* exposures, which was not evident in *Contact*. Aside from this, heart rate and respiration (*Contact* only) were comparable across groups. The absence of change in heart rate across an exposure hierarchy co-occurring with subjective anxiety and respiration changes is consistent with previous VR exposure-based therapy studies (Freire et al., 2010; Moore et al., 2002; Notzon et al., 2015; Wiederhold et al., 2002; Wilhelm et al., 2005). It is possible that heart rate differences may only emerge in the highest anxiety-provocation levels of virtual environments (Mühlberger et al., 2007). When considered more broadly, the increase in self-reported anxiety across a hierarchy without associated psychophysiology changes is an established clinical phenomenon, despite clients commonly reporting symptoms in physiological terms, such as racing heart or sweaty palms (Grossman et al., 2001; Mauss et al., 2005; Wilhelm et al., 2001). This incoherence has practical implications, such as casting doubt upon the ability of biofeedback systems to modify psychophysiological arousal in these patient groups (Henriques et al., 2011). For the purposes of our research questions, the key finding remains that the pattern of both the subjective and objective data obtained followed the same patterns in both VR and *in vivo* exposures.

4.1. Strengths, limitations, and future directions

This is the first study to directly compare subjective, objective, and therapeutic responses to VR, in a sample of people diagnosed with OCD, to the existing benchmark of *in vivo* ERP. These findings advance the existing literature by utilising a clinical sample, theoretically meaningful heart and respiration rate responses, measurement of clinical factors, and by making comparisons to the current gold-standard in psychological treatment techniques. Acquiring high quality psychophysiology signals in a dynamic ambulatory environment is a considerable challenge. The current paradigm has successfully navigated this task, with mean heart rate and respiration data consistent with those previously reported in people with high anxiety (Dishman et al., 2000; Donahue et al., 2009; Freire et al., 2010; Laforest et al., 2016). Advancing upon these findings will require future studies to expand the measures utilised, to monitor changes in cognitive and behavioural domains, such as pre-post behavioural assessment and risk appraisals, across multiple sessions.

Future studies should investigate VR *versus in vivo* ERP across multiple sessions in increasingly diverse samples to better understand longer-term client therapeutic outcomes, alliance, and clinician perspectives. Theoretically, therapeutic success depends upon the establishment of disconfirming beliefs, and tolerance of distress (Abramowitz, 1996; Craske et al., 2014). This relies upon elicitation of emotional arousal, as explored in the present study, and subsequently the establishment of new associative learnings that anticipated outcomes remain unlikely to occur over time, which will require future multiple session studies. As the SUDs profiles in our study changed in a comparable manner across the session, while pre- and post-session state anxiety differed, future studies should directly investigate expectancy violation across conditions and multiple sessions. This will enable clarity regarding the comparability across modalities. Specifically, regarding any discrepancy between expectancy and experience, and subsequently the achievement of inhibitory learning (Craske et al., 2014).

Although SUDs did not significantly differ between the exposure mechanisms, *in vivo* scores were consistently relatively higher than VR, and future research should examine the clinical relevance of this potential trend. Similarly, the trend of STAI scores pre- to post- session within each exposure modality warrants further review to consider the extent of subjective anxiety change that would be required for clinically meaningful anxiety provocation and learning. A consistent trend was observed whereby responses to *Contact* tasks were consistently higher than to *Instruction*, within each exposure modality. Although not reaching statistical significance in the current study, it warrants further investigation to determine whether the experience of contact is more anxiety provoking than anticipation. Should this occur to a comparable degree in virtual to *in vivo* this would provide additional evidence in support of validity.

From a technology perspective, advances in VR will offer new opportunities to be tested, such as realistic virtual clinicians embedded in environments. Furthermore, the breadth of empirical measurements should expanded, including psychophysiology as objective evidence for anxiety arousal and extinction processes (Diemer et al., 2014), particularly as research-grade technologies become integrated with VR systems. Future work should be undertaken that expands beyond contamination-based concerns, to examine the comparable utility of VR across other OCD domains. Challenges for VR-based ERP in OCD will include managing cognitive and behavioural processes (*e.g.* neutralising, safety, "It's just a game/simulation") which may counteract presence and immersion.

4.2. Conclusion

By demonstrating responses that were consistent with the existing first line in therapeutic treatment for OCD, we provide validation evidence for this novel VR system. The *in vivo* and virtual sessions elicited comparable increasing levels of anxiety across an exposure hierarchy, thereby preliminarily meeting this core foundational requirement for ERP processes. Heightened patient engagement and lower pre-session anxiety support the notion that virtual exposures could offer a more acceptable modality for ERP, potentially overcoming the current challenges of refusal rates in traditional therapy. Evidencing that the therapeutic alliance can be maintained in VR is a unique and clinically meaningful contribution to the literature, suggesting technology may not pose a barrier when engagement is factored into design. Collectively, this multifaceted evidence highlights the exciting opportunities for VR technology in OCD research and treatment applications, to advance the current best-practices in a novel and engaging manner.

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Declaration of Competing Interest

The authors report no declarations of interest.

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