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A systematic review and narrative synthesis of the use and effectiveness of extended reality technology in the assessment, treatment and study of obsessive compulsive disorder

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ABSTRACT

Extended reality (XR) technologies including virtual and augmented reality are seeing increasing research interest in the field of mental health. Obsessive compulsive disorder (OCD) is a condition that remains difficult to assess and treat despite the availability of effective therapies. This systematic review synthesises the current knowledge regarding the use and effectiveness of XR in the assessment, treatment, and study of OCD. The protocol for this review was registered on PROSPERO (ID: CRD42021248021). Searches of six databases were conducted. The xReality framework was used to define which technologies would be included as XR. Studies that recruited analogue samples as well as clinical OCD populations were included. A narrative synthesis of the findings was planned. There was consistent evidence for the use of virtual reality as a tool for symptom provocation in people with contamination-related OCD, as part of exposure and response prevention. Significant heterogeneity exists between study designs found in both symptom provocation and treatment outcome studies. This review has important implications about the narrow focus of research in this area thus far, highlighting the need for further study of different uses of XR in providing positive treatment outcomes across a broader range of OCD symptoms.

1. Introduction

Obsessive-compulsive disorder (OCD) is a mental health condition which can be chronic and debilitating, with an estimated 1–2% global lifetime prevalence (Fawcett et al., 2020; Ruscio et al., 2010). OCD is characterised by obsessions, which are recurrent intrusive thoughts, images, and/or impulses that cause significant distress to the individual (American Psychological American Psychiatric Association, 2013). The content of obsessions can range from immoral or blasphemous thoughts to concern over physical contamination, or pathological doubt (Bloch et al., 2008; Purdon, 2021). Obsessional content has been grouped in a taxonomy of overarching symptom dimensions such as contamination/cleaning and harm/checking (Fullana et al., 2010; Ruscio et al., 2010). In response to such obsessions, individuals feel compelled to carry out compulsions, which refer to intentional, repetitive behavioural or mental actions (APA, 2013). Compulsions aim to prevent or avert a perceived disastrous outcome and can take a wide range of forms. For example, mental rituals intended to neutralise intrusive thoughts (Sibrava et al., 2011) and more overt behaviours such as repeated and thorough washing or checking could be considered compulsions. OCD is associated with significant impact on social and occupational functioning. Furthermore, approximately 14–26% of people with OCD report attempting suicide at least once in their lifetime (Albert et al., 2019; Torres et al., 2006), compared to 18.8% and 4.8% in bipolar disorder and major depressive disorder respectively (Baldessarini et al., 2019).

Given the highly heterogenous nature of symptoms, OCD is a complex disorder to assess and treat. Traditional assessments of OCD, such as

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clinical interviews or self-report scales, rely on accurate recall of details from daily life while in a clinical setting. This recall is often difficult (Grabill et al., 2008) and limits the amount of detailed information patients can provide on the frequency and nature of their symptoms (Kim et al., 2009). Symptoms might be more pronounced in private/-personally relevant areas of their lives than in unfamiliar areas such as the clinician's office, and thus might be forgotten during recall (van Bennekom, de Koning, & Denys, 2017). These difficulties with assessment contribute to delays between symptom onset and the initiation of effective treatment (Hezel et al., 2022; Hollander et al., 1997). Real-time assessments would allow clinicians to observe the full diversity, frequency, and nature of symptoms without relying on a patient's recall ability outside their usual environments. However, this entails practical difficulties for clinicians such as recreating difficult or impossible-to-access environments and situations.

Effective first line treatments for OCD include pharmacotherapy with selective serotonin reuptake inhibitors (SSRIs) (Del Casale et al., 2019; Pittenger & Bloch, 2014) and cognitive-behavioural interventions, such as cognitive behavioural therapy (CBT) with exposure and response prevention (ERP) (McKay et al., 2015; Öst et al., 2022). In this psychotherapeutic treatment, patients encounter the situations/stimuli that trigger their obsessions and anxiety and practise refraining from performing compulsions. Numerous trials and meta-analyses suggest that CBT, and particularly its ERP elements, yield large effect sizes in the reduction of OCD symptoms (Skapinakis et al., 2016; Öst et al., 2015, 2022). However, despite the efficacy of ERP, there is also evidence that people treated for OCD very often do not receive exposure-based treatment, with studies suggesting a rate of ERP application as low as approximately 16–50% (Böhm et al., 2008; Külz et al., 2009; Stobie et al., 2007). Furthermore, evidence suggests if ERP is used it is often not correctly applied according to guidelines. For example, imaginal exposure (where anxiogenic stimuli and situations are imagined by the patient) may be used when in vivo exposure (where patients confront anxiogenic stimuli in real life) is required (Gillihan et al., 2012). While imaginal exposure offers a more approachable way for patients to engage in exposure, it might not be realistic enough to provoke sufficient anxiety for ERP to be effective, and is susceptible to cognitive avoidance strategies (Bush, 2008). When in vivo exposure is used it can often rarely be performed outside of clinicians' offices despite the fact that obsessions might be more likely to be triggered in a patient's personal environment than in an unfamiliar space (Rowa et al., 2007).

There are several suggested reasons as to why ERP may be underutilised in the psychological treatment of OCD. One is the practical restrictions regarding time and resources for clinicians to provide idiosyncratic, contextually specific exposure environments/stimuli to patients with OCD and to maintain engagement with ERP between sessions (Jacobson et al., 2016; Lind et al., 2013). Another is what has been called "phobie à deux" (Moritz et al., 2019) which refers to a situation where therapists believe their patients may be fearful or resentful about having to do exposure (Kim et al., 2009), while therapists are simultaneously concerned about in vivo exposure inducing severe side effects an negative psychological reactions which would be difficult to manage safely (Meyer et al., 2014).

Moritz et al. (2019) suggest that therapists need to adhere more strictly to guidelines of ERP in treatment, but that there could be ways to bridge the gap to approach these concerns and restrictions therapists may feel. One suggested method is to use extended reality (XR) technologies like virtual reality (VR). While in vivo exposure is often the most preferable method, creating real-life exposure scenarios can be unsafe, impractical or in some cases impossible, but as will be explored later, this issue can be addressed with XR (Gega, 2017). Furthermore, evidence from studies in other disorders treated with exposure such as specific phobias has found XR to be an effective yet more approachable method of exposure. For example, one study showed 76% of patients preferred VR to in vivo exposure, and a treatment refusal rate of 3% for VR and 27% for in vivo (Garcia-Palacios et al., 2007). As such, there is suggestion that the above-mentioned problems with OCD assessment and treatment may be addressed using this rapidly developing set of technologies, known as XR.

1.1. Extended reality (XR)

XR refers to a new generation of technologies that gives the user the experience of being immersed in a digital environment, or the experience of viewing and interacting with digital objects mapped onto the real world. These range from 360° video to virtual and augmented reality. However there remains significant disagreement within the literature as to what each term precisely defines, leading to confusion and overlap between terminologies.

This review uses the xReality model proposed by Rauschnabel et al. (2022), which is based on critical review of previous models and in-depth focus groups and interviews with industry professionals experienced in the use and study of these technologies. It focuses on the user's experience, rather than technological specifications, to better define different technologies. In this model the "X" in "XR" does not represent "extended" but rather functions as an algebraic indicator that technologies included under the term generate some form of new reality, either partially or totally. When using the term "XR" the model still refers to the technologies described previously, as such, going forward, this review uses the term "XR" to refer to this concept of xReality.

This xReality model divides XR technologies into two main categories: virtual reality (VR) and augmented reality (AR) – the key difference between these being that in VR the real environment a user is situated in plays no part in the experience; they are totally (at least visually) occluded from their surroundings. This means that only technologies which completely immerse the user, such as head-mounted displays (HMDs) or 6-sided Cave Automatic Virtual Environment (CAVE) systems are defined as VR. In AR, the real environment still plays some role in the experience and is still visible to the user, thus includes a wider range of technologies, from smartphones to immersive AR headsets like the Microsoft HoloLens.

Within these categories technologies are placed along spectrums depending on the level of presence they can produce in users. Presence is commonly defined as an illusion where people feel themselves "being there" in a virtual environment (Felton & Jackson, 2022; Slater, 2009; Slater & Sanchez-Vives, 2016), and this single construct approach is commonly adopted in studies of XR usage. However, the xReality model distinguishes between VR and AR with two different types of presence: telepresence in VR and local presence in AR. The definition of telepresence is identical to the aforementioned and commonly accepted definition of presence, which is the feeling of the user "being there" in the virtual environment rather than the real environment (Felton & Jackson, 2022; Slater, 2009; Steuer, 1992). VR technologies prioritise telepresence differently, and for some applications it is secondary to accomplishing a particular more important goal such as modelling a physical space or training a particular motion. For others, it is vital to ensure users experience the virtual environment as being as real as possible, for example when needing to evoke a particular feeling or emotion is important, as in VR exposure therapies. According to emotional processing theory (Foa & Kozak, 1986), the stimulus being presented must evoke a sufficient emotional response as a basic requirement of effective exposure treatment. Research on VR exposure consistently demonstrates that increased levels of telepresence results in increased emotional response (Diemer et al., 2015; Ling et al., 2014). In situations such as these, as is the case in the treatment of OCD, telepresence is a much greater priority.

Local presence in AR is defined as the feeling of virtual elements "being here" in the user's real environment (Rauschnabel et al., 2022; Verhagen et al., 2014) and AR technologies are placed along this spectrum depending on the quality and integration of virtual elements into the real environment. At one end of the spectrum the application may display text-based factual information to users depending on what objects they see in their environment as part of a sightseeing tour (Han et al., 2013). At the other end an application may integrate 3D virtual elements into an environment that are tracked and positionally locked in 3D space so that they appear seamlessly as part of the user's view of a real environment (Ventura et al., 2018).

1.2. XR in OCD

Immersive technologies, and their ability to make users feel either present in a virtual environment or feel like virtual elements are present in their real environments, allow researchers and clinicians to access and have complete control over myriad environments/stimuli. This provides significant opportunities for both the assessment and treatment of OCD. For example, using XR as an assessment tool, patients can be exposed to computer-generated anxiety provoking stimuli in a controlled manner, allowing real-time observation of symptoms rather than relying on retrospective recall. Furthermore, the use of XR makes it possible to automatically record behavioural metrics (e.g. movement through the environment, eye gaze, interactions with objects) as part of the software, as well as simultaneously record physiological data during exposure. This enables the collection of objective data on internal processes such as attention to stimuli (Lutz et al., 2017) which may be useful in diagnostic and assessment processes.

Similarly, in terms of treatment, XR could be an effective tool for the conduct of exposure therapy. The environment a patient faces can be specifically tailored to their particular anxieties (Rizzo & Koenig, 2017), evoking a similar anxiogenic response as exhibited in the real world, enabling them to then undergo the process of inhibitory learning and attenuate to the anxiety (Abramowitz & Arch, 2014; Craske et al., 2008; Wechsler et al., 2019). Clinical trials comparing VR and in vivo exposure have demonstrated this effect in specific phobia disorders and social anxiety disorder, where VR exposure therapy has been shown to be as, if not more, effective as in vivo at producing significant treatment outcomes which generalise to patients' daily lives (Bouchard et al., 2017; Morina et al., 2015).

1.3. Study aims and research questions

While reviews have been conducted which cover the topics of XR and OCD, they lack such a clear classification for XR as the xReality model provides. In some cases this has led to the inclusion of studies which use technologies that would not normally be considered amongst XR technologies (such as the rubber hand illusion), or inconsistency between reviews (Dehghan et al., 2022; Hu et al., 2022). Another reason for the current review is that previous reviews which cover this area have either focused narrowly on only one type of XR or one aspect of OCD, or have focused broadly on many different disorders (Riva & Serino, 2020; van Loenen et al., 2022). Given the complexity of OCD and ambiguity about the definition of various technologies under the umbrella of "XR", this review uses an up-to-date framework to clearly delineate how XR technologies have been applied in the field of OCD, and synthesise the knowledge gained through their use thus far.

This review's aim is contained within two research questions, the first being: how have XR technologies been applied to the field of OCD? This is intended to provide a detailed synthesis which addresses the elements of both XR and OCD as the key terms such as: the purpose of the technology's use; how it was designed; the specific symptom dimensions to which it has been applied; and how research has been designed to investigate this. The second research question is: how effective are XR technologies as assessment and treatment tools in OCD?

2. Methods

2.1. Protocol and registration

The review protocol was preregistered with PROSPERO (CRD42021248021). The reporting of this review follows PRISMA 2020 guidelines (Page et al., 2021) for reporting of systematic reviews.

2.2. Information sources and search strategy

Six electronic databases were searched (PsycINFO (APA PsycNet); PubMed; Scopus; Web of Science; ACM Digital Library; and IEEE Xplore), for publications between 1960 and April 2022 (when the original search was conducted). The starting year of 1960 was chosen as this is the decade in which the initial development of VR technologies was first documented (Slater & Sanchez-Vives, 2016) (i.e., the first immersive virtual environment system, Heilig's Sensorama in 1962) and first system recognised as VR (the Sword of Damocles) (Sutherland, 1968). The reference lists of book chapters and reviews included at full text review were also searched by hand. The search was updated in December 2023.

Search terms included: OCD, obsessi*, compulsi*, obsessive compulsive disorder, virtual reality, VR, virtual environment, virtual environments, VE, augmented reality, AR, mixed reality, MR, extended reality, cross reality, XR. For a detailed explanation of the search strategy (adapted for each database) see Appendix A.

2.3. Eligibility criteria

To be eligible for inclusion, studies were required to meet the following criteria: focus on OCD as the primary topic/target of study, assessment or intervention; report the results of primary research; be written in English or have an English translation available; be published either in peer-reviewed journals, conference proceedings or book chapters; use an XR technology as defined by the xReality framework. In line with the xReality framework, studies were excluded if; the technology labelled as VR did not fully visually occlude the real environment from the user (e.g., 2D desktop monitors displaying 3D virtual environments or wrapround/3-sided CAVE systems). Furthermore, technologies which used an appropriate display method (head-mounted display (HMD), 6-sided CAVE system) but not a virtual environment which would meet the minimum graphical content requirements to be considered VR, such as displaying photograph images inside an HMD, were excluded. Eligible environments included interactive, computer-generated environments or 360° videos.

For studies focusing on assessment and treatment the following inclusion criteria needed to be met: in analogue samples participants were included if they completed a baseline measure of OCD symptoms or an anxiety scale related to topics relevant to OCD e.g., contamination anxiety; in clinical samples participants were included if they had received a clinical diagnosis of OCD. No restrictions were made regarding study type, study duration, study outcomes or comparators.

2.4. Selection process and data extraction

All search results were compiled in EndNote and then uploaded to Covidence (Veritas Health Innovation, 2019). See Appendix B for further information on the data extraction form used by reviewers on Covidence. When the original searches were conducted, two reviewers independently screened all records at the title and abstract stage as well as at the full text review stage. If further information was required to determine if the record met eligibility criteria it was put forward to full text review. Any items of data extraction or quality assessment where there was not 100% agreement were discussed between the reviewers and, when required, a third reviewer was consulted. Only one reviewer screened the new records found in the search update.

The following information was extracted: source - study authors, publication year; methods - study design, setting, duration etc.; participants - number (enrolled, completed), demographics, diagnostic criteria and diagnosis method (if clinical sample), comorbidity, treatment history; intervention - data for interventions were extracted according to the TIDieR (Template for Intervention Description and Replication) checklist (Hoffman et al., 2014); materials (technological specifications, design features), procedures, provision, tailoring etc.; outcomes - definitions, measures; results - summary data, p values, key author conclusions etc. 30% of the included studies' data was extracted independently by two reviewers, with the remaining 70% extracted by one reviewer. See Appendix B for full details of the Data Extraction form used.

2.5. Quality assessment of included studies

The quality of included studies was assessed independently by two reviewers and any discrepancies were discussed to reach consensus. The Mixed Methods Appraisal Tool (MMAT) (Hong et al., 2018) was chosen for its ability to assess all study designs within the one measure. The MMAT groups study designs into five overarching categories and each category contains five criteria upon which reviewers assess each study. The MMAT questions whether every criterion is successfully met, with reviewers answering "Yes", "No" or "Can't tell" for each. The outcome of the MMAT assessment of included studies is reported as part of the narrative synthesis to inform the analysis of evidence. In addition, a score out of five for each study is provided in Table 1 (See Appendix C).

2.6. Data synthesis

A narrative synthesis was planned due to the expected heterogeneity of study designs. The synthesis is organised into sections based on the focus of included studies, for example, phenomenology, assessment and treatment. Each section synthesises findings from studies focusing on that topic to answer the two research questions. A meta-analysis was not applicable due to the lack of consistency of outcome measurements and designs between studies.

3. Results

From all sources 982 records were retrieved. After removal of duplicates, 767 records were screened at the Titles and Abstracts stage, with 62 going forward to full-text review. From these a total of 16 studies were included (see Fig. 1 for PRISMA diagram).

An overview of the characteristics of included studies is provided in Table 1 (See Appendix C). Studies focused on phenomenology ($N = 1$) are presented first, followed by those focused on assessment ($N = 2$), concluding with studies focused on treatment ($N = 13$). Treatment studies were categorised as either focused on symptom provocation or treatment outcomes. Symptom provocation refers to studies where the focus is solely on induction of OCD symptoms and anxiety through the use of XR. Treatment outcomes studies include the measurement of symptom induction and the reduction of OCD symptoms and anxiety over time, and other areas such as acceptability of interventions.

Publication years ranged from 2008 to 2023, with studies being conducted across a range of locations, with the most in Europe ($N = 6$), followed by North America ($N = 5$), then Asia ($N = 4$) and Australasia ($N = 1$).

3.1. Participants

There were a total 663 participants, of these 283 had a clinical diagnosis of OCD and 315 formed non-clinical control groups. Clinical diagnosis was verified in several ways in the included studies: the Mini International Neuropsychiatric Inventory Interview, the Structured Clinical Interview for Axis 1 Mental Disorders, or an otherwise unspecified clinical interview/assessment carried out by a clinical professional. One study did not specify the diagnosis method (Benzina et al., 2020). The majority of studies that focused on assessment and treatment ($n = 13$) utilised participant samples with a clinical diagnosis of OCD (age (based on the nine studies that reported age) $M = 31.18$, $SD = 10.15$). The Yale-Brown Obsessive Compulsive Scale (Y-BOCS) (Goodman et al., 1989) was the most widely used measure of OCD severity (11/15). Only one study (Kim et al., 2008) did not specify method of OCD symptom measurement. Wong et al. (2020) compared two groups ($N = 130$ participants total) without elevated OCD symptoms in a study focusing on phenomenology of OCD. Analogue samples were used in two studies (age $M = 20.65$, $SD = 3.65$), with participants categorised as either high or low in contamination fear as measured by the Padua Inventory-Washington State University Revision (PI-WSUR) (Sanavio, 1988).

In terms of OCD symptom dimensions examined, contamination/washing OCD was the most commonly studied, appearing in 13 studies. Five studies examined doubt/checking OCD symptoms. In addition to the examination of contamination and doubt, Wong et al. (2020) included repugnant obsessions, and Fajnerová et al. (2023) included the dimensions of symmetry and hoarding as these were relevant symptom dimensions according to the ICD-10 nomenclature used in their design.

3.2. Study design

All studies employed a quantitative design, with three also collecting qualitative data in the form of subjective evaluation of immersion in VR (Miegel et al., 2022, 2023) and change in anxiety during exposure and anecdotal evidence about quality of life changes (Benzina et al., 2020). The most common study designs were quasi-experiments ($N = 8$), followed by case series and case studies ($N = 3$). There were three randomised controlled trials ($n = 2$ with a clinical population), one repeated measures study and one lab experiment. Seven studies used an experimental setting, seven used an outpatient setting, one used an inpatient setting and one used a university lab clinic setting.

3.3. Interventions

14 studies used VR and only two studies used AR, both of which used a 3D AR headset. 12 studies used HMDs, with two of these using 360° videos, and 10 using computer-generated 3D virtual environments. Two studies used a 6-sided CAVE system.

In terms of assessment, both of the two included studies investigated VR as a tool for diagnosis. Six studies approached the use of VR in treatment purely by testing its ability to provoke symptoms in the target population, and one study used the same approach with AR technology. Six studies tested VR's ability to provide relevant treatment outcomes when used as an intervention, with one study using the same approach with AR.

3.4. Quality assessment

All included studies ($N = 16$) were assessed. The quality of studies overall was high, $N = 11$ were rated as high quality (meeting either of 5/5 or 4/5 criteria), $N = 4$ as moderate quality (3/5 or 2/5) and $N = 1$ as low quality (1/5 or 0/5). See Table 1 (See Appendix C) for the MMAT scores for each study.

3.5. Narrative synthesis

3.5.1. Assessment

Two quasi-experimental studies (Kim et al., 2010, 2012) investigated the use of VR as an assessment tool for diagnosis of doubt(harm)/-checking OCD. Both studies recruited clinical populations with doubt/checking as their primary concern, with mean Y-BOCS scores indicating moderate-severe OCD (Storch et al., 2015). The studies tested whether performance metrics recorded within the virtual environment (VE) could discriminate between people with doubt/checking OCD and controls (Kim et al., 2012 used two control groups: non-clinical controls and people with OCD without primary doubt/checking concerns). Such performance metrics included: behavioural trajectory (the physical

Table 1
Characteristics of included studies.

ID	Study	Country	Technology used	Study design	Participants: N(% female) – Mean age (SD)	OCD Diagnosis/measures	OCD Domain studied	MMAT Score
Phenomenology								
1	Wong et al. (2020)	Canada	VR – 360° video in HMD	Lab experiment	G1: 65(80) – 22.57 (3.98) G2: 65(76.9) – 23.34 (5.85)	Undergraduate students	Contamination/ washing, repugnant obsessions, doubt (harm)/checking	3/5
Assessment								
2	Kim et al. (2010)	South Korea	VR – HMD	Quasi-experiment	G1 OCD: 30(20) – 30 (9.28) G2 Healthy controls: 27(37) – 31.3(10.84)	DSM-IV OCD diagnosis with primary checking symptoms – mean Y-BOCS = 23.77	Doubt(harm)/checking	5/5
3	Kim et al. (2012)	South Korea	VR – HMD	Quasi-experiment	G1 Checking OCD: 22 (18.2) – 30.5(8.4) G2 Non-checking OCD: 17(29.4) – 28.35 (6.54) G3 Healthy controls: 31(38.7) – 31.25 (10.34)	DSM-IV OCD diagnosis (subtype assessed with Y-BOCS) – G1: mean Y-BOCS = 26.54, G2: mean Y-BOCS = 22	Doubt(harm)/checking	5/5
Treatment – symptom provocation								
4	Kim et al. (2008)	South Korea	VR – HMD	Quasi-experiment	G1 OCD: 33(n/r) – n/r G2 Healthy controls: 30(n/r) – n/r	DSM-IV OCD diagnosis	Doubt(harm)/checking	4/5
5	Laforest et al. (2016a)	Canada	VR – CAVE system	Quasi-experiment	G1 OCD: 12(66.6) – 30.08(n/r) G2 Healthy controls: 20(65) – 30.2(n/r)	DSM-IV OCD diagnosis with primary contamination symptoms – mean Y-BOCS = 25.04	Contamination/ washing	5/5
6	Inozu et al. (2021)	Turkey	VR – HMD	Quasi-experiment	G1 High contamination fear: 33(87.8) – 20.85 (3.55) G2 Low contamination fear: 33(78.8) – 22.33 (3.59)	Analogue sample separated by PI-WSUR contamination fear scores – 1.5 SDs above/ below sample mean	Contamination/ washing	4/5
7	Cullen et al. (2021)	Australia	VR – HMD	Repeated measures	22(63.6) – 32.91 (9.84)	DSM-V OCD diagnosis with primary contamination symptoms – mean Y-BOCS = 29.41	Contamination/ washing	4/5
8	García-Batista et al. (2021)	Dominican Republic	AR – low-cost HMD	Quasi-experiment	G1 OCD: 17(70.5) – 27.47(11.19) G2 Healthy controls: 11(63.6) – 26.55 (9.95)	SCID-1 OCD diagnosis – Y-BOCS score >13	Contamination/ washing	4/5
9	García-Batista et al. (2022)	Dominican Republic	VR - HMD	Quasi-experiment	G1 OCD: 20(70) – 23.39(6.69) G2 Healthy controls: 20(55) – 28.36(11.60)	SCID-1 OCD diagnosis – Y-BOCS score >13	Contamination/ washing	4/5
10	Fajnerová et al. (2023)	Czech Republic	VR – HMD	Quasi-experiment	G1 OCD: 44(40.9) – (Mdn)32(11.63) G2 Healthy controls: 31(58) – (mdn)31 (15.08)	ICD-10 OCD diagnosis – Y-BOCS Mdn score = 22.50	Contamination/ washing, control/checking, symmetry, hoarding	4/5
Treatment – treatment outcomes								
11	Laforest et al. (2016b)	Canada	VR – CAVE system	Case series	3(100) – n/r	DSM-IV-TR OCD diagnosis with primary contamination symptoms – Y-BOCS scores of 22, 31, 30	Contamination/ washing	3/5
12	Benzina et al. (2020)	France	VR – 360° video in HMD	Case study	1(100) - 50	Unspecified clinical OCD diagnosis – Y-BOCS score of 33	Contamination/ washing	1/5
13	Inozu et al. (2020)	Turkey	VR – HMD	Randomised controlled trial	G1 VR-ERP Intervention: 9(77.7) – 20.44(2.13) G2 Waitlist control: 12 (100) – 21.17(3.81)	Analogue sample with high contamination fear – 2 SDs above $N = 1059$ sample mean of PI-WSUR scores	Contamination/ washing	3/5
14	Javaherirenani et al. (2022)	Iran	VR - HMD	Randomised controlled clinical trial	G1 CBT with VR-ERP Intervention: 15(93.3) – 35.67(7.52)	DSM-V OCD diagnosis with primary contamination symptoms – mean Y-BOCS = 31.60	Contamination/ washing	5/5

(continued on next page)

Table 1 (*continued*)

ID	Study	Country	Technology used	Study design	Participants: N(% female) – Mean age (SD)	OCD Diagnosis/measures	OCD Domain studied	MMAT Score
					G2 CBT with ERP comparison intervention: 14(57.1) – 38(9.70)			
15	Miegel et al. (2022)	Germany	VR - HMD	Case series	6(100) – 40.13(11.53)	MINI Y-BOCS OCD diagnosis with primary contamination symptoms – mean Y-BOCS = 29	Contamination/washing	5/5
16	Miegel et al. (2023)	Germany	AR – HMD	Randomised controlled pilot study	G1 MERP Intervention: 9(88.9) – 27.78(9.01) G2 Care as usual: 11 (54.5) – 38.00(13.65)	MINI DSM-V OCD diagnosis – mean Y-BOCS = 25.60	Contamination/washing	3/5

Note. n/r = not reported; Mdn = median; HMD = head-mounted display, VR = virtual reality, AR = augmented reality, CAVE system = Cave automatic virtual environment system; Y-BOCS = Yale-Brown Obsessive Compulsive Scale (0–7 = sub-clinical, 8–15 = mild symptom severity, 16–23 = moderate, 24–31 = severe, 32–40 = extreme), PI-WSUR = Padua Inventory – Washington State University Revision, SCID-1 = Structured Clinical Interview for Axis 1 Mental Disorder, MINI = Mini International Neuropsychiatric Interview; G1 = Group 1, G2 = Group 2, G3 = Group 3; MMAT scores represented as a fraction out of 5, indicating the number of criteria the study definitively achieves ("Yes" answer).

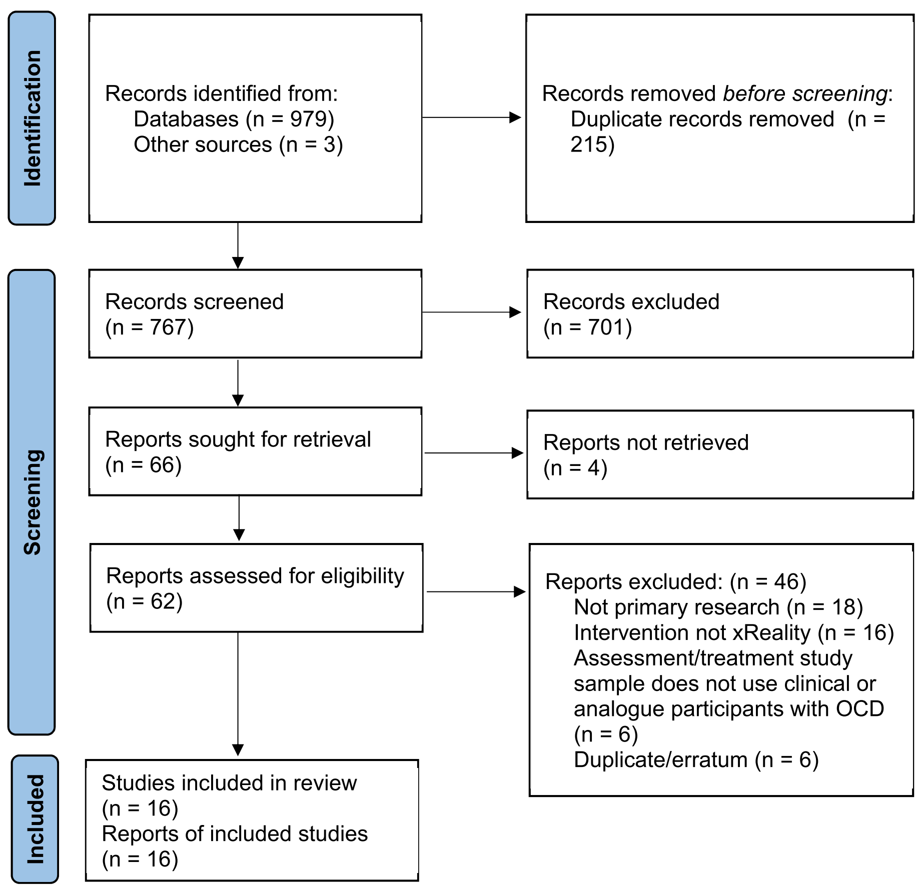

Fig. 1. PRISMA diagram of study identification, screening and inclusion (Page et al., 2021).

distance and directions travelled in VR), total time spent checking and gazing time during checking behaviour. Kim et al. (2010) also measured the correlation between VR performance metrics and traditional measures.

Both studies used the same virtual environment (VE); 3D computer-generated environment displayed on an HMD, through which the participants navigated and interacted with the environment using a joystick. Initially a home and an office environment were used, but the office environment was discontinued after findings that VR performance metrics only correlated with self-reported checking urges in the home environment (Kim et al., 2010). Both environments were designed by a team of psychiatrists, social workers and biomedical engineers. Participants were instructed to get ready to leave the environment in three stages: Training – participants received specific instructions, such as turning on lights and the stove to make subsequent checking of the environment necessary. This was followed by a distraction task, and then the main stage where participants were given an indefinite amount of time to check everything was ready for their departure, for example by turning lights off.

The assumption of these studies is that VR is a feasible assessment tool when VR-recorded performance metrics show significantly different results between people diagnosed with doubt/checking OCD and controls. Based on this assumption, these studies suggest that VR is an effective tool for the diagnosis of doubt/checking OCD. The most consistently useful VR performance metric was checking time – defined as the total duration of time spent performing checking behaviours. Checking behaviours in VR were defined as interactions participants performed with an object after the initial instructed check had been performed. Checking time showed significant differences between people with doubt/checking OCD and controls in both studies and correlated with participants' Y-BOCS scores. The second useful VR performance metric was length of trajectory, defined as the physical distance a participant travelled in VR. This measure also revealed significant differences between people with OCD and controls, but did not distinguish between people with doubt/checking OCD and people with other forms of OCD. Post-hoc analyses found that while people with doubt/checking OCD scored significantly higher than healthy controls, there were no significant differences between people with OCD without primary doubt/checking concerns and either of the other groups (Kim et al., 2012).

Finally, there was some suggestion in the studies that VR may primarily be useful as a measure of symptom severity, rather than frequency and type. While Kim et al. (2010) found correlations between VR-recorded performance metrics and Y-BOCS, no correlation was found with the Maudsley Obsessive Compulsive Inventory (MOCI) which is designed for frequency and type.

3.5.2. Treatment – symptom provocation

A total of seven studies investigated the ability of XR to provoke symptoms of OCD to see if XR would be a useful tool for exposure therapies, with six using a quasi-experimental design (Cullen, Dowling, Segrave, Carter, & Yücel, 2021; Fajnerová et al., 2023; García-Batista et al., 2021, 2022; Inozu et al., 2021; Kim et al., 2008; Laforest, Bouchard, Crétu, & Mesly, 2016) with clinical samples of people with OCD and healthy controls, with the exception of one study which used an analogue sample of people with high or low contamination fear (according to the PI-WSUR) (Inozu et al., 2020). One study used repeated measures with a clinical population, comparing VR exposure to in vivo exposure (Cullen, Dowling, Segrave, Carter, & Yücel, 2021). The majority (n = 5) focus on the contamination/washing domain of OCD, while one focuses on doubt(harm)/checking symptoms and one used stimuli relevant to multiple symptom dimensions. Only one study investigated the use of AR (García-Batista et al., 2021), the other five focusing on VR. Assessment with the MMAT found all studies in this area were rated 4/5 or above, indicating a high quality of research – a common flaw being that attempts to account for confounding variables such as comorbidity or treatment history are not often discussed in descriptions of study samples.

The main metric by which XR's ability to provoke symptoms of OCD was assessed was the extent to which the XR elicited anxiety, and the difference in this between conditions. Anxiety evocation was measured at several time points, including baseline to post-exposure, during exposure and from the point of exposure to the point after performing compulsions. Of note is the fact that for two studies (Laforest, Bouchard, Crétu, & Mesly, 2016; Garcia-Batista et al., 2022) the baseline measurement was taken in a non-anxiogenic virtual environment rather than before using VR at all. The most common method used to measure anxiety at baseline was self-report via the State Trait Anxiety Inventory (STAI) (Spielberger et al., 1983), and Subjective Units of Distress (SUDs) or Visual Analogue Scales (VASs) during exposure conditions. Two studies collected physiological indices of anxiety in the form of heart rate and respiration rate during exposure (Laforest, Bouchard, Crétu, & Mesly, 2016 & Cullen, Dowling, Segrave, Carter, & Yücel, 2021). Four studies also measured how anxiety evoked in VR exposure correlates with other measures such as symptoms of mental health conditions (including OCD), global functioning, immersive tendencies and presence (Fajnerová et al., 2023; García-Batista et al., 2021; Kim et al., 2008; Laforest, Bouchard, Crétu, & Mesly, 2016). Measures of acceptability, such as simulator sickness and therapeutic quality, were investigated in three studies (Cullen, Dowling, Segrave, Carter, & Yücel, 2021; Fajnerová et al., 2023; Laforest, Bouchard, Crétu, & Mesly, 2016).

All virtual environments (N = 6) were computer-generated 3D environments and used either home kitchens or public bathrooms, displayed predominantly on HMDs, with $N = 1$ study using a CAVE system. Participants could freely navigate and interact with these environments, while the AR used in Garcia-Batista et al. (2021) only allowed participants to view stimuli. Kim et al. (2008) used a "home" environment of a kitchen and a bedroom, with a focus on doubt(harm)/checking OCD symptoms instead of contamination/washing, while Fajnerová et al. (2023) used a "home" environment consisting of several different rooms. N = 3 VR studies used a neutral environment (an uncontaminated room) for training purposes, and in some cases also baseline measurements (Laforest, Bouchard, Crétu, & Mesly, 2016; Inozu et al., 2021 & Garcia-Batista et al., 2022).

Contamination-focused VR applications all implemented exposure hierarchies, either by adjusting the environments around the participant or by increasing the difficulty of tasks. Commonly participants are immersed in these environments and given tasks to perform via various instruction methods, either within VR (a virtual smartphone that receives text instructions) or outside VR (a therapist giving verbal instructions). Tasks vary from being asked to simply touch contaminated surfaces to performing a series of related actions designed to evoke contamination concerns, such as cutting a slice of cake with a knife that has been laid next to raw chicken. In one case, participants are simply standing in the environment while the therapist gradually increases the dirtiness around them (Garcia-Batista et al., 2022).

The rationale behind these studies' designs is that if XR provokes greater anxiety in people with OCD than controls, and that anxiety in people with OCD is significantly increased as a result of exposure, then it is an effective tool for symptom provocation. Based on this, the evidence suggests that virtual reality-ERP (VR-ERP) technologies are largely effective in provoking anxiety in people with contamination/washing OCD. One study investigated the use of AR as a tool for symptom provocation, finding much less evidence for its utility (Garcia-Batista et al., 2021), as only one of the four stimuli tested provoked greater anxiety in people with OCD than controls. In four studies comparing between groups, anxiety was significantly higher for people with contamination/washing OCD or high contamination fear and healthy controls when exposed to VR with contaminated virtual environments (Fajnerová et al., 2023; Garcia-Batista et al., 2022; Inozu et al., 2021; Laforest, Bouchard, Crétu, & Mesly, 2016). VR-ERP is also able to function as a tool with exposure hierarchies, shown by the increases in anxiety observed across increasing levels of contamination in virtual environments (Cullen, Dowling, Segrave, Carter, & Yücel, 2021; Inozu et al., 2020 & Inozu et al., 2021).

Arguably VR-ERP provokes contamination/washing symptoms at the same level as the current gold-standard in vivo ERP, based on results finding no significant differences in subjective or objective measures of anxiety (heart rate and respiration rate) between the two methods (Cullen, Dowling, Segrave, Carter, & Yücel, 2021). Furthermore VR-ERP appears to be an approachable and acceptable tool for symptom provocation, demonstrating lower anticipatory anxiety pre-exposure, greater engagement with exposure and no negative effects on therapeutic alliance. Two studies investigated VR-ERP's ability to provoke disgust (Inozu et al., 2021; Miegel et al., 2022), but both studies found that VR-ERP was able to provoke this emotion – in one case in an analogue sample and the other a clinical sample. Inozu et al., 2021 found that it provoked significantly greater disgust than anxiety and that the level of disgust provoked was also significantly higher for people with high contamination fear than low contamination fear.

Only one symptom provocation study addressed doubt(harm)/checking OCD symptoms specifically (Kim et al., 2008), thus it is difficult to synthesise within this field alone. However, when taken with the comparisons between participants with OCD and healthy controls described earlier in the field of assessment (Kim et al., 2010, 2012), we might conclude that VR is also able to provoke anxiety and checking compulsions in people with doubt(harm)/checking OCD.

In VR studies which collected presence data there appears to be an effect whereby sense of presence increased in people with contamination concerns significantly more than controls when they enter a contaminated virtual environment, regardless of their experience with VR or immersive tendencies (Inozu et al., 2021; Laforest, Bouchard, Crétu, & Mesly, 2016). Also, in people with contamination/washing OCD a positive relationship between anxiety and presence experienced in anxiogenic VR environments was found (Laforest, Bouchard, Crétu, & Mesly, 2016), with a similar relationship emerging between anxiety and local presence in AR stimuli (Garcia-Batista et al., 2021). However, no such relationship was found between presence and anxiety in doubt (harm)/checking OCD (Kim et al., 2008).

3.5.3. *Treatment outcomes*

All six studies in this area investigated exposure using XR in terms of treatment outcomes for contamination/washing OCD (Benzina et al., 2020; Inozu et al., 2020; Javaherirenani et al., 2022; Laforest, Bouchard, Bossé, & Mesly, 2016; Miegel et al., 2022, 2023). Five studies used a clinical sample of people with diagnosed OCD and one study used an analogue sample of people with high contamination fear (Inozu et al., 2020).

Three used a randomised controlled trial design, with one clinical trial (Javaherirenani et al., 2022) and two pilot trials (Inozu et al., 2020; Miegel et al., 2023). Javaherirenani et al. (2022) used a comparison intervention of regular CBT with in vivo ERP, Inozu et al. (2020) used a waitlist control and Miegel et al. (2023) used a care-*as*-usual control. These studies all used Y-BOCS to investigate changes in OCD symptom severity change from baseline to post-treatment, but otherwise do not share the same measures. Inozu et al. (2020) included within-session measures using VASs for anxiety, disgust and urge to wash hands, while Javaherirenani et al. (2022) included no within-session measures but did include three-month follow-up measures. Miegel et al. (2023) recorded within-session qualitative appraisal of the AR intervention and also included three-month follow-up measures, including a measure of intervention safety based on Y-BOCS score deterioration. MMAT scores for these studies indicate a moderate-high quality of research, with a score of 3/5 for Inozu et al. (2020) and Miegel et al. (2023) and 5/5 for Javaherirenani et al. (2022).

Three studies used a case study/series design (Laforest, Bouchard, Bossé, & Mesly, 2016; Benzina et al., 2020 & Miegel et al., 2022). All used Y-BOCS to measure change in OCD symptom severity and also all used the Simulator Sickness Questionnaire (SSQ) to measure cybersickness. All three also included some qualitative data, but to assess different facets, such as a description of treatment outcomes, acceptability of the intervention and within-session anxiety. MMAT scores for case study/series range widely from 1/5 to 5/5, indicating a great variability in quality of research.

Less information is available regarding the design and design process of XR used in studies of treatment outcomes compared to symptom provocation. Four studies used 3D computer-generated virtual environments, with three using HMDs (Inozu et al., 2020; Miegel et al., 2022 & Javaherirenani et al., 2022) and one using a CAVE system (Laforest, Bouchard, Bossé, & Mesly, 2016), while one used 360° video displayed on an HMD (Benzina et al., 2020). Only one study used a form of AR (Miegel et al., 2023). Virtual environments were more varied in design under two broad themes: public contaminated spaces, such as public bathrooms (Laforest, Bouchard, Bossé, & Mesly, 2016 & Miegel et al., 2022), going to the shops and trying on clothes (Benzina et al., 2020); and rooms in the home, such as kitchens (Inozu et al., 2020), bathrooms and toilets (Javaherirenani et al., 2022). In some cases, the environments are specifically designed to remove any possibility of neutralising contamination, with no cleaning products or running water, for example (Laforest, Bouchard, Bossé, & Mesly, 2016; Miegel et al., 2022 & Javaherirenani et al., 2022). In most computer-generated environments ($n = 3$) participants are able to navigate and interact with the environment, although interactivity is not described in one case (Miegel et al., 2022)

Four studies implemented XR as part of a broader CBT protocol, including elements such as discussion, cognitive restructuring and homework involving exposure practice and challenging obsessions and compulsions (Javaherirenani et al., 2022; Laforest, Bouchard, Bossé, & Mesly, 2016), Laforest, Bouchard, Bossé, & Mesly, 2016lthough in two cases the structure of the protocol and the XR procedure are not described in detail (Miegel et al., 2022 & Miegel et al., 2023). The length of treatment course and number of VR-ERP sessions varies widely between studies from two to fourteen sessions. Three studies use exposure hierarchies within the VR-ERP (Laforest, Bouchard, Bossé, & Mesly, 2016; Inozu et al., 2020 & Javaherirenani et al., 2022). Due to the nature of 360° video, in Benzina et al., 2020 the participant simply views the environment around her, then discusses this with her therapist and is encouraged to self-expose as homework.

Compared to symptom provocation, the evidence that VR is useful for producing significant treatment outcomes is much less conclusive – VR is associated with positive outcomes, but the effects are not consistent across studies. Synthesising across the three randomised controlled trial studies is difficult due to the differences in sample type, length and measures taken. Inozu et al. (2020) found that people with high contamination fear saw a significant decrease in anxiety, disgust and urge to wash hands within sessions over the course of treatment, and that this decrease was significantly greater than controls (anxiety $\eta p^2 = 0.38$; disgust $\eta p^2 = 0.49$; urge to wash hands $\eta p^2 = 0.47$). However, no significant difference in Y-BOCS, STAI, PI-WSUR or the Disgust Scale-Revised was observed between sessions or between interventions. This contrasts with Javaherirenani et al. (2022) who found that CBT with VR-ERP significantly reduced severity of OCD symptoms, reduced obsessional thoughts and improved severity of disability to a greater extent than CBT with in vivo ERP (symptom severity $\eta p^2 = 0.82$; obsessional thoughts $\eta p^2 = 0.56$; severity of disability $\eta p^2 = 0.53$). The authors of Inozu et al. (2020) argue that the lack of effect between sessions may be due to the measures used being unsuitable for a trial this short and with an analogue sample. The main finding of Miegel et al., 2023 was that reduction of symptoms was the same across intervention groups ($\eta p^2 = 0.005$), with no significant deterioration of symptoms in the AR group, indicating it is a safe intervention tool.

Case studies ($n = 3$) show only limited success in the application of VR to OCD treatment. Taken across all cases included in the review only 5/12 participants showed a reduction in Y-BOCS score that would be considered a clinical response (Mataix-Cols et al., 2016; Hirschtritt et al., 2017; Laforest, Bouchard, Bossé, & Mesly, 2016–3/3; Miegel et al., 2022–2/8, Benzina et al., 0/1), and in one study this response was only significant on the Y-BOCS compulsion subscale (Miegel et al., 2022). Laforest, Bouchard, Bossé, and Mesly (2016) was the only case study to include follow-up measures and found that only 1/3 participants had maintained therapeutic gains at 8 months. Miegel et al. (2022) provide the least information on the design of their VR application, so it is possible there were flaws affecting the VR's quality – participants reported several features of their environments which reduced presence, although it is not clear how exactly this might impact outcomes. It may be possible that the length of treatment course is responsible, as Inozu et al. (2020) and Miegel et al. (2022) use shorter courses than the other three studies in this area (2–4 sessions; 4 sessions respectively).

However, the evidence does suggest that VR seems to be a highly acceptable treatment tool for contamination/washing OCD. VR-ERP is reported as being more approachable for people with OCD than in vivo, feeling more able to perform exposure activities while still finding the VR realistic and sufficiently anxiogenic (Laforest, Bouchard, Bossé, &

Mesly, 2016; Miegel et al., 2022). In one case VR-ERP was found to be engaging and acceptable to a patient after being refractory to two previous group CBT protocols and in vivo exposure sessions. As with Cullen, Dowling, Segrave, Carter, and Yücel (2021) measures supported the idea of a strong therapeutic alliance within VR-ERP (Laforest, Bouchard, Bossé, & Mesly, 2016) and participants report VR-ERP having no negative effects on other interventions (Miegel et al., 2022). While there does seem to be a very low level of cybersickness reported in VR-ERP, this was only significant enough to cause issues in one case, where homework VR-ERP was not carried out due to sickness caused by the headset used. It is possible that this is due to the low cost of the headset used for homework, where insufficient hardware can cause rendering quality issues that lead to cybersickness. Furthermore, as noted by Laforest, Bouchard, Crétu, and Mesly (2016), it is difficult to isolate the effects of VR on feelings included within the symptoms of cybersickness from anticipatory anxiety or disgust reactions people may have to contaminated content in the virtual environment. While evidence from Miegel et al., 2023 suggests AR is a safe and acceptable tool, subjective evaluations of the intervention suggest there is significant room for improvement of the stimuli used for it to be more effective.

3.5.4. *Theoretical investigations*

Only one study from those included used VR in the context of phenomenological enquiry. Wong et al., 2020 used an HMD with 360° video in an experimental paradigm testing the causal relationship between the idea of a person's "feared self" and OCD symptom. Using an experimental manipulation within a VR application (called the Fear-of-Self or FOS-VR), an experimental group of participants from a non-clinical sample were encouraged to perform behaviours that would be congruous with the idea of their feared self, thus increasing their perception that they were similar or had become this feared self. The effect this induction of feared-self perceptions had on OCD symptoms was then tested. The domains of symptoms investigated included contamination/washing, repugnant obsessions and doubt (harm to self or others)/checking. Each of the three domains was investigated with four VR scenarios, designed through collaboration with OCD experts and based on examples from the Fear-of-Self Questionnaire. Scenarios began with a first-person viewing of the event – the participant was then presented with an interface where they chose how the event concluded, choosing between actions either congruent or incongruent with the feared self, which they then experienced. The experimental condition was encouraged to perform feared self-congruent actions by awarding more points for those options, while the control received more points for incongruent actions.

This study lends limited support to the theory that fear of self might cause OCD symptoms. The experimental condition showed a significantly higher frequency of and urge to suppress harm-related intrusions, but no significant difference with controls in either of the other two domains. Furthermore, although feared self-perceptions were moderately higher in the experimental group, this did not reach significance. It is unclear whether the effects of the manipulations were unique to OCD symptoms, as the groups did not differ on any measures of mental health condition symptoms.

3.5.5. *Common additional findings between studies*

Across the studies included in this review, there is a consistent finding that the content used as part of the design of XR environments and stimuli has a notable influence on results, and thus the effectiveness of XR as a tool. Garcia-Batista et al. (2022) found that a public bathroom environment generated higher anxiety in people with contamination/washing OCD than a home kitchen, and that only specific AR stimuli generated significant levels of anxiety compared to controls (Garcia-Batista et al., 2021). This echoes the findings of Kim et al. (2010), where self-reported checking urges were correlated with performance on a VR task only in the home environment and not the office. Furthermore, it appears that relevance of the environment to the patient has an important impact, as in the case of Laforest, Bouchard, Bossé, and Mesly (2016), where one patient responded significantly better to treatment as their contamination concerns most closely matched the scenario in the VR. Cullen, Dowling, Segrave, Carter, and Yücel (2021) is the only study where participants chose the environment for their exposure, and they report strong results regarding VR's efficacy as a symptom provocation tool, further demonstrating the need for personalised VR environments.

It is worth noting that there has not been a systematic investigation into the side effects and safety of technically supported ERP of any kind, including XR. Six of the included studies reported results from the SSQ as a measure of cybersickness (Benzina et al., 2020; Fajnerová et al., 2023; Laforest et al., 2016a, 2016b; Miegel et al., 2022). The majority found that participants with OCD reported low levels of cybersickness during exposure in VR, and that this was not significantly different from controls without OCD, with the exception of Laforest, Bouchard, Crétu, & Mesly, 2016 who did find that people with OCD experienced significantly higher cybersickness. Otherwise, there was no uniform measurement of other side effects associated with XR-supported ERP, for example therapeutic alliance was measured in only two studies and using two different scales (Cullen, Dowling, Segrave, Carter, & Yücel, 2021; Laforest, Bouchard, Bossé, & Mesly, 2016). More research is necessary to quantify the side effects and safety of XR-supported ERP.

4. Discussion

This review aimed to provide a detailed narrative synthesis of the outcomes of studies implementing XR in the field of OCD research, and a clear summary of the many variations and combinations of technologies, symptom domains and applications explored within these two overarching terms. From the 16 included studies VR is the most studied XR technology by far, most often being applied to the purpose of treating contamination/washing OCD, the most commonly studied symptom dimension although not the most frequently reported symptom dimension of OCD (Ruscio et al., 2010). VR shows promise as an assessment tool for doubt(harm)/checking OCD, by virtue of the ability to automatically collect VR-recorded data that can reliably discriminate people with doubt(harm)/checking OCD from controls. VR is consistently able to provoke the anxiety necessary for ERP in people with contamination/washing OCD, but when applied to a course of treatment is less reliable in producing desired outcomes.

The most common application of XR technology has been to test VR's utility as a treatment tool for contamination/washing OCD. Of 16 included studies, 14 investigate VR, and of these 12 focus on the contamination/washing OCD symptom dimension. Estimates suggest that contamination/washing symptoms only account for 25% of obsessions among people with OCD, while doubt(harm)/checking symptoms account for 79% (Ruscio et al., 2010), so it appears contamination/washing OCD is overrepresented in terms of applying XR to its treatment. Furthermore, AR technologies are extremely underrepresented in the field of OCD, which seems to be a common feature within the wider clinical literature (Vinci et al., 2020). The vast majority of clinical AR research focuses on reducing anxiety through exposure therapy for specific phobias (Chicchi Giglioli et al., 2015), and overall results suggest AR could be a tool to enhance exposure based therapy. Thus it could provide similar benefits when applied to ERP for OCD treatment, which works on a similar extinction-based premise (Jacoby & Abramowitz, 2016).

VR shows promise as an assessment tool for doubt(harm)/checking OCD, by virtue of its ability to automatically record measures from the VR that can reliably discriminate between people with doubt(harm)/checking OCD and controls. However, the evidence from this review is scarce ($n = 3$) and only one method – testing significant differences between the target population and controls - was used to judge the success of the assessment tool. Perhaps other methods used to assess assessment tools in other technologies should be applied in this field as well, such as psychometric validation (Coles et al., 2007). It is also worth noting that, while several measures were found to be able to discriminate between groups between studies, only one VR-recorded measure (time spent performing checking behaviours) consistently discriminates between groups and correlates with traditional assessment measures. Thus, while VR shows potential as a diagnostic tool, there is a need to refine XR assessment tools and the data they collect.

Findings show consistent effects in terms of anxiety provocation through VR for people with contamination/washing OCD across a range of measurement methods, but there is less evidence for usefulness as part of a treatment package. While results show consistent support for the idea that VR can provoke anxiety, it is worth highlighting the significant heterogeneity between studies in terms of quantifying anxiety, the procedures and combinations used to measure anxiety and the relevant phenomena to study; for example only two symptom provocation studies measured disgust. Arguably this is an oversight of the included studies given the mounting research interest surrounding the role of disgust in OCD (Knowles et al., 2018), with some arguing that not all people with OCD experience anxiety as much as disgust (Mataix-Cols et al., 2007). Thus, disgust is an important concept the majority of included studies neglect, and highlights the need for greater homogeneity of symptom provocation studies.

Similar heterogeneity exists for treatment outcomes studies, where VR was applied in a variety of configurations of sessions and content of VR environments. It is possible that the greater variety in treatment outcomes may be related to this greater variety of content in VR environments, but this cannot be discerned from the results of this review. For example, this heterogeneity could also be due to variation in aspects of the CBT within which VR treatment was delivered. Differing quality of psychoeducation, therapist effects, homework and duration of treatment may have made some CBT packages more optimal than others. Future research should aim to refine and homogenise this side of the treatment, to be better able to measure the differential effects of VR.

5. Limitations

The xReality model was chosen as the framework upon which the inclusion criteria of this review was based due to its clear delineation of different technologies based on user experience rather than technical specifications. The model provides a clear understanding of the terms VR and AR with little room for conflation and is based on previous models followed by up-to-date research with industry and academic experts on the topic. However, as a result of using this framework, several studies that use virtual environments (but do not meet the necessary experiential hallmarks to be classified as VR) were not included. This is not to say that non-included studies do not provide valuable findings for improving the use of XR technology in the field of OCD, and findings from these studies can direct future research. For example, there seems to be potential for VR to be used as a tool for increasing public awareness and understanding of OCD (Liaskou & Rizopoulos, 2023). This could be valuable for treatment by improving a patient's systemic support, but this area of enquiry was missed by the xReality criteria.

Another potential limitation is the broad inclusion criteria for study design. This broad approach was taken to comprehensively capture as many examples of the usage of XR as possible. While this was successful, it also lead to significant heterogeneity in the designs of symptom provocation and treatment outcome studies. In symptom provocation studies this meant there was significant disagreement about how best to measure the arousal of anxiety and other related symptoms by XR technologies, making quantitative synthesis impossible. Additionally, in treatment studies this heterogeneity made it difficult to disentangle the differing effects of VR from the differing effects of their designs, as discussed in the previous section.

6. Future research and clinical implications

In terms of assessment, there are three major avenues for further study based on the results of this review: firstly, as stated earlier, not all VR-recorded measures consistently distinguish between samples. This leaves room for diagnosis procedure to be refined and optimised as per Pedroli et al. (2019) who used a computational approach to discern the optimal combination of computer-based and traditional metrics to discriminate OCD patients from controls on a test of executive functioning. Refining XR-recorded measures could also improve the testing of the ability of virtual environments to provoke symptoms, by automatically measuring behaviours rather than relying on anxiety measurements. Secondly, thus far evidence only supports the use of VR in diagnosing doubt(harm)/checking OCD, but it might be possible to assess different symptom dimensions, or indeed multiple symptom dimensions at once. Preliminary work to this effect has been conducted in a similar manner to studies included in this review, but with non-immersive desktop virtual environments (van Bennekom et al., 2017b, 2021). Finally, XR could be used in other assessment functions besides diagnosis, as in a series of Italian studies which found consistent evidence that virtual environments can be used as an assessment of executive function in people with OCD (La Paglia et al., 2012; Cipresso et al., 2013, LaPaglia et al., 2014a; La Paglia, La Cascia, Rizzo, et al., 2014; La Paglia et al., 2016). These were not included in the review due to not meeting the criteria for XR, but demonstrate principles that may be applied with XR technology.

Given the higher frequency of treatment outcomes studies in recent years, it seems that research is already moving away from initial tests of XR's ability as an exposure tool and towards producing meaningful outcomes. For example, Lohse et al. (2023) have produced a protocol for an upcoming RCT examining the treatment of contamination-related OCD using AR. This trend is perhaps worthwhile given the varied success of such studies seen in this review, but the evidence from this review shows there are still issues to be addressed before a fully realised XR treatment can be tested clinically. For example, given the narrow focus on contamination/washing OCD in this review, there remain many unknowns in terms of how XR can be applied to other symptom dimensions. Furthermore, one of the key findings of this review is that the content of XR applications can influence outcomes significantly – further investigation into the most appropriate virtual environments to use and how far personalisation of material to the patient can be achieved is necessary. In a related vein, Cullen, Dowling, Segrave, Morrow, et al. (2021) have proposed a step-by-step design protocol for creating effective VR exposure materials for OCD, demonstrating the first steps in this direction.

Finally, it can be observed in this review that XR technologies have been used only to replace what is available in reality and make it more accessible to clinicians. This is a worthwhile application of XR, in that it could remove barriers to treatment for people with OCD who struggle to leave their home or who have co-occurring conditions like depression (Leeuwerik et al., 2023). Indeed, some people with OCD struggle to even contemplate in vivo exposure, so XR could provide a stepping stone to begin treatment. However, given the technological potential there is plenty of opportunity to wield XR's reality-creation and alteration abilities to a greater extent (Slater, 2009), and not only improve access to treatment but enhance it. This is a common flaw found with research applying technology to the treatment of psychological disorders (Cooper et al., 2022), and represents a massive growth area for XR technology in the treatment of OCD.

7. Conclusion

This review provides an in-depth synthesis of the ways XR technology has been applied to OCD and the knowledge gained from this endeavour. Within the XR framework, VR is the most-studied technology, and is used most commonly in the domain of treatment of contamination/washing OCD symptoms. The greatest success has been found in provoking the anxiety necessary for exposure therapy, while success in terms of producing treatment outcomes is more limited. While preliminary evidence exists for VR use as an assessment tool in the doubt (harm)/checking symptom dimension of OCD, both the use of XR as an assessment tool and the use of XR in this symptom dimension are underrepresented in the research compared to the treatment of contamination/washing OCD. The trend of XR-OCD research seems to be moving towards focusing on treatment outcomes, but there remain many issues from earlier stages of the treatment process to be explored. This includes investigating different types of assessment besides diagnosis, the appropriate design of environments/stimuli for use in XR treatment (and how the effectiveness of this content is assessed) and the replication of studies with different OCD symptom dimensions.

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Michael Colman: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Josie Millar:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Bhagyashree Patil:** Writing – review & editing, Supervision, Conceptualization. **Daniel Finnegan:** Writing – review & editing, Supervision, Conceptualization. **Ailsa Russell:** Writing – review & editing, Supervision. **Nina Higson-Sweeney:** Writing – review & editing, Investigation, Formal analysis. **Mariana Da Silva Aguiar:** Writing – review & editing, Investigation, Formal analysis. **Danae Stanton Fraser:** Writing – review & editing, Supervision, Conceptualization.

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Data availability

Data will be made available on request.

Appendix A. Supplementary data

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