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Scoping review of the hardware and software features of virtual reality exposure therapy for social anxiety disorder, agoraphobia, and specific phobia

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Introduction: The use of virtual reality technology to deliver exposure therapy in the treatment of phobic anxiety (i.e., social anxiety disorder, agoraphobia, and specific phobia) has been proposed to be advantageous compared with *in-vivo* exposure therapy. These supposed advantages depend on the features of the virtual reality technology and how it is used therapeutically. Therefore, the aim of this study was to provide a comprehensive overview of the features of the hardware and software used in studies examining virtual reality exposure therapy studies for phobic anxiety disorders.

Methods: 70 studies using virtual reality exposure therapy to treat social anxiety disorder, agoraphobia and/or specific phobia, were systematically reviewed for 46 data points relating to these features.

Results: We found that studies generally did not utilize contemporary virtual reality technology and that hardware and software features were inconsistently delineated.

Discussion: The implications of these findings are that the use of modern virtual reality technology represents a relevant frontier in anxiety treatment and that a framework for reporting technical features of virtual reality exposure interventions would benefit the field.

KEYWORDS

virtual reality exposure therapy, social anxiety disorder, agoraphobia, specific phobia, virtual reality technology, scoping review

Introduction

Social anxiety disorder (SAD), agoraphobia and specific phobia are characterized by pronounced fear and often extensive avoidance of specific situations and/or stimuli (American Psychiatric Association, 2013). Patients with SAD fear situations where they perceive a risk of negative evaluation from other people. Patients with agoraphobia fear situations in which escape is difficult or where help might not be available in the event of a panic attack, panic-like symptoms, or incapacitating symptoms such as loss of bladder and/or bowel control. Patients with specific phobia have extreme fear reactions to either specific animal types (e.g., dogs, spiders), natural environments (e.g., thunder, heights), injury (e.g., dentists, injections, blood) or situations (e.g., enclosed spaces, flying). Phobic disorders are associated with marked reduction in normal functioning capabilities, have an early onset, long duration and are highly prevalent, with estimates ranging from 4%–12% depending on the country (Kessler et al., 2005, 2012; Wang et al., 2005; Stein et al., 2017).

Cognitive Behavioral Therapy (CBT) has proven an effective intervention for SAD and agoraphobia and is the recommended first-line treatment in several clinical guidelines (National Institute for Health and Care Excellence, 2011a; National Institute for Health and Care Excellence, 2011b; National Institute for Health and Care Excellence, 2013; Sundhedsstyrelsen, 2016). An important element of CBT for phobic disorders is exposure therapy. In exposure therapy, the patient is systematically confronted with feared stimuli and the patient's expectations of the likelihood and consequences of a feared outcome are challenged (Abramowitz et al., 2019). However, the application of exposure therapy is generally dependent on the disorder and the underlying theory that the clinician aligns with.

Thus, exposure therapy for specific phobia often involves probability estimations before/after exposures, long exposure exercises allowing the patient to gradually approach the feared object and minimal therapeutic work before and after exposure exercises (Öst, 2012).

Exposure therapy for agoraphobia often involves exposure to a combination of physiological sensations (e.g., dizziness, being out of breath, the urge to urinate/defecate/vomit) and the specific situations triggering these sensations, which is generally situations where escape or help is perceived to be unavailable (e.g., public transportation, elevators, driving alone, bridges) (Craske, 2002).

For SAD, exposure therapy is often combined with social skills training and attention training (i.e., shifting from an inward to an outward focus) and involves both public speaking exercises and one-on-one social interactions (Turk et al., 2008).

Beyond the disorder specific variations in exposure therapy, multiple explanations for the psychological mechanisms underlying exposure therapy have been proposed. Of these, two theories in particular have informed practice in recent decades: Emotional Processing Theory and Inhibitory Learning Theory.

In Emotional Processing Theory, between-session habituation (i.e., the lessening of an initial fear response during an exposure, between two exposure exercises) is thought to reflect progress in emotional processing and is therefore an important treatment goal and benchmark of progress (Foa and McLean, 2016).

In contrast, for Inhibitory Learning Theory, the primary goal of exposure exercises is to maximize the discrepancy between what the patient fears will happen and what actually happens during exposure. One strategy to maximize this discrepancy is to purposefully design exercises to be more challenging than how those actions are commonly performed (e.g., asking strangers for directions to nonsensical locations). Another strategy is to minimize or remove safety signals (i.e., a companion) and safety behaviors (i.e., rehearsing social interactions) (Craske, 2022).

Therefore, depending on the disorder and theoretical underpinnings, the execution of exposure therapy can vary and may thus also vary in logistical demands and aversiveness (Butler, 1985; Olatunji et al., 2009; Neudeck and Einsle, 2012; Pittig et al., 2019).

In virtual reality exposure therapy (VRET), the patient is exposed to feared stimuli via immersive Virtual Reality (VR) technology. The proposed benefits of VRET compared with *in-vivo* exposure therapy is flexibility, acceptability and decreased logistical demand because it allows patients to confront virtual, yet credible, feared situations from the therapist's office or from home (Botella et al., 2017; Bouchard et al., 2017; Freeman et al., 2017). Immersive VR technology encompasses all technology that induces an illusion of actually being in a virtual environment, an experience termed presence (Lombard and Ditton, 1997).

VRET is commonly delivered via head-mounted displays (HMD). HMDs typically place one or two display optics in front of the user's eyes, combined with a head tracking system and an input device for interacting with the virtual environment (e.g., a controller) (Cieślik et al., 2020). Meta-analysis has shown that the treatment effect of VRET for phobic anxiety, either as a stand-alone treatment or integrated into CBT, is not significantly different from active control conditions (Carl, 2018; Chesham et al., 2018). However, for SAD specifically, VRET has been found to result in significantly lower effect sizes compared to control groups that received equal amounts of *in-vivo* exposure (Wechsler et al., 2019). Considering the proposed benefits of VRET, what might explain these findings?

An important aspect of VRET, is that potential benefits are contingent on the characteristics of its hardware (e.g., quality of optical device, tracking capabilities) and software (e.g., interaction options, range of environments). For example, if a VRET 'setup' (i.e., it's software and hardware) does not allow patients to converse, it might be inadequate for many patients with SAD (Emmelkamp et al., 2020). In addition, the cognitive and behavioral strategies available in VRET will depend on the VRET setup (Bouchard, 2012).

The patients experience of the virtual environments is also contingent on the quality of the hardware and software in a VRET setup. Sense of presence, has been found to be greater in high-immersion VR setups as compared to low-immersion VR setups (Cummings and Bailenson, 2016). Anxiety and presence seem to correlate (Ling et al., 2014; Diemer, 2015), which points to its importance, because exposure therapy is thought to rely on the patient experiencing a certain level of anxiety (Foa and McLean, 2016; Craske, 2022). Yet, findings relating to presence and treatment efficacy are inconclusive, especially for SAD (Price et al., 2011; Ling et al., 2014).

However, it stands to reason that the VRET setup must influence the quality of therapy, since it determines:

- Applicability (e.g., the range of virtual environments that are available)
- Acceptability (e.g., ease-of-use for patient and therapist)
- Accessibility (e.g., options for self-led VR-based therapy)
- The visual and auditory quality of the virtual environments
- The cognitive and behavioral strategies that are possible (e.g., the degree to which interaction is possible in the virtual environments)

One step towards a better understanding of the impact of a VRET setup on treatment efficacy is a systematic mapping of the hardware and software features in existing research. This should put researchers in a better position to interpret results and make informed decisions when developing new VRET interventions.

Such a review could also serve as a framework that can assist researchers to systematically describe VRET interventions in future research.

Objectives

In this scoping review, we systematically describe and categorize the hardware and software features used in VRET research for phobic anxiety disorders. We were guided by the following research questions:

- What are the technical features of the hardware and software used in extant VRET research for phobic anxiety disorders?
- What are the salient features of the hardware and software used in VRET for phobic anxiety disorders and to what extent are they reported?

Methods

Eligibility criteria

To be included in the review, publications needed to:

- Use VRET in the treatment of SAD and/or agoraphobia and/or specific phobia
- Use HMDs as their method for delivering the visual stimuli in their VR setups
- Examine clinical populations, assessed with validated diagnostic instruments
- Have been published in 2005 or after, due to the fast pace of development in virtual reality technology in recent years
- Be peer-reviewed
- Be in English, Danish, Swedish or Norwegian

Information sources

To identify relevant studies the following bibliographic databases were searched on 31.03.2021 and on 13.04.2022: PubMED, PsycINFO and Web of Science. Additionally, appropriate reviews and meta-analysis were searched for relevant studies, which our search strategy might have missed (See Supplementary Material S1, for a list of the reviews and meta-analysis searched). Lastly, one author (BTA) asked peers for knowledge of newer studies our search strategy might have missed.

Search strategy

A three-step search strategy was employed. First, an initial search was conducted on the above-mentioned databases to identify the index terms, words in titles and abstracts, and keywords in the resulting studies. Second, the identified keywords and index terms were used to construct a search string used in all the databases. In addition, the following criteria were added to the search: Only peer-reviewed studies, only studies from 2005 or newer (See Supplementary Material S1, for the exact search string and criteria applied). The results of these searches were downloaded as.ris files and uploaded to Covidence, a web-based program specializing in streamlining the systematic review process (Veritas Health Innovation, 2022). Third, duplicates were removed by the built-in function on the website.

Selection of sources of evidence

Two authors selected the sources of evidence: BTA and JS. First, studies were screened by one author (BTA or JS) for eligibility by reading title and abstracts. If there was any doubt about eligibility, another author would be involved in the screening.

Second, studies that survived the first level of scrutiny were fully read by both authors to confirm eligibility. Disagreements on study selection and data extraction were resolved by discussion with a third author. See Figure 1 for a flowchart of the selection process.

Data charting process

A data-charting form was developed to determine relevant variables of interest. The development process was iterative as reviewers continuously discussed the variables and updated the form throughout the review. In choosing the variables of interest, it was decided to be as exhaustive as possible, since no consensus exists on what the salient features of a VR setup for exposure therapy are. Exhaustiveness was sought by including every variable in the data-charting form that was reported by any of the included studies, unless it was decided through discussion that a reported variable could have no salience for the conductance of the intervention (e.g., the model no. of a computer running the VR environments).

All publications were scrutinized for all data items in the final data-charting form. Data was gathered manually from the included publications, from webpages and from technical documents. When websites were not available or no longer provided relevant information, an earlier snapshot of the site would be found using the 'Wayback Machine' (the Internet Archive, 2022), based on the year of the relevant studies' publication. See Supplementary Material S2, for the final data charting form.

Results

In the following section, data charted from the 70 included studies will be presented. Every data point will not be addressed in this section. However, Supplementary Material S2, contains all data points for all included studies. See Table 1 for an overview of included studies.

Software features

Social anxiety disorder

21 studies examining SAD were included. The virtual environments used were built around various performance

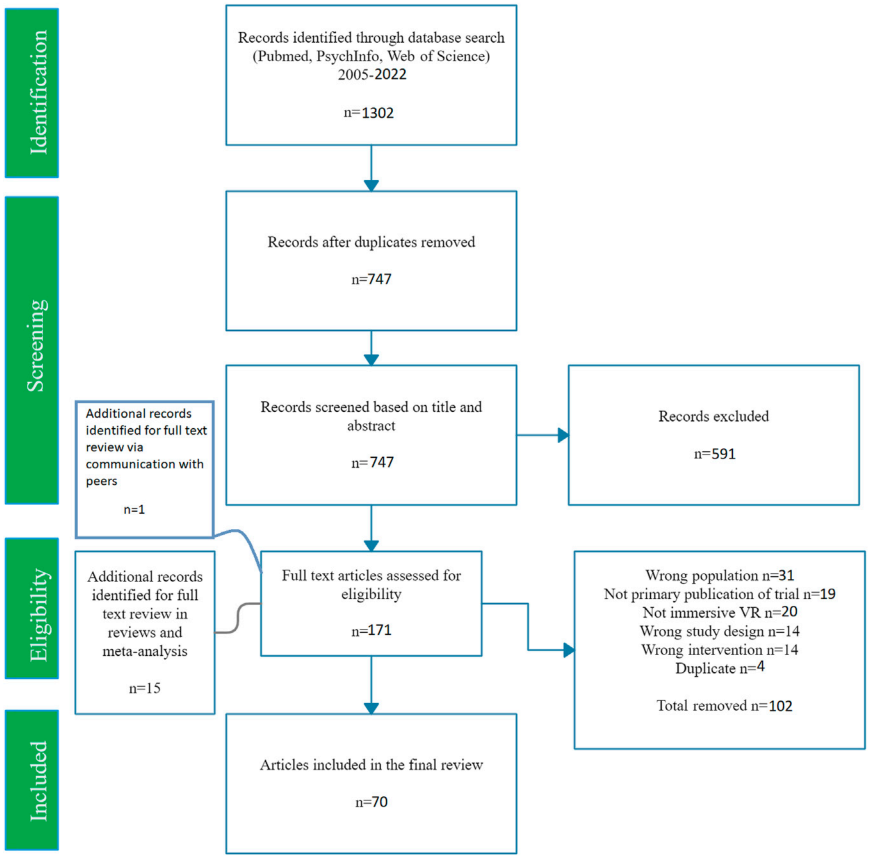

FIGURE 1
Flowchart of the study selection process.

TABLE 1 Overview of included studies.

Diagnosis group	Number of studies
SAD	Generalized SAD = 15[a]
	Performance-only subtype = 10
Agoraphobia	10[a]
Specific phobia	Aviophobia = 14[a]
	Arachnophobia = 11
	Acrophobia = 8[a]
	Dental phobia = 3
	Hemophobia = 2
	Cynophobia = 1
	Squalophobia = 1
	Nyctophobia = 1

[a]Three studies are counted twice because they treat SAD and agoraphobia (Arnfred et al., 2022), SAD and aviophobia (Moldovan and David, 2014), and acrophobia and aviophobia (Meyerbröker et al., 2018).

situations (e.g., interviews, presentations), formal social interactions in public (e.g., shopping) and informal social interactions (e.g., eating with coworkers). Of the 21 studies included, three used 360-degree videos (Clemmensen et al., 2020; Zainal, 2021; Arnfred et al., 2022) and one used video-recorded actors superimposed onto a static 360-degree background (Lindner et al., 2019). The remaining studies used rendered environments or did not specify the type they used.

In four out of 21 studies examining SAD, conversation was simulated through the use of pre-recorded sentences and gestures (Herbelin, 2006; Hartanto, 2016; Kampmann et al., 2016; Bouchard et al., 2017). The remaining 17 studies focused on variations of public speaking tasks and situations requiring no conversation (e.g., riding a bus). Audiences in rendered public speaking environments could be made to look bored, interested, or neutral (e.g., Wallach et al., 2011; Anderson et al., 2013; Nazligul, 2017; Jeong et al., 2021). Beyond this, most VR setups had the option of adjusting difficulty by changing the number of avatars, their gender, and their attitude (e.g., Geraets et al., 2019; Kim et al., 2020; krijin and Emmelkamp, 2007). Lastly, for SAD, five studies used VRET at least partially as a self-led therapy tool (Hartanto, 2016; Lindner et al., 2019; Kim et al., 2020; Trahan et al., 2021; Zainal, 2021).

Agoraphobia

Ten studies examining agoraphobia were included. The virtual environments were based on confined spaces where it might be difficult to escape/get help (e.g., elevators, subway, cars, planes) and open spaces where it might be difficult to escape/get help (e.g., empty country, malls, town squares). One study also had an environment designed to induce sensations for interoceptive exposure (Pelissolo, 2012). Of the ten studies, three used 360-degree videos (Lundin, 2021; Shin et al., 2021; Arnfred et al., 2022), while the remaining seven used rendered environments.

The difficulty of the environments could be adjusted by manipulating the number of anxiogenic cues (e.g., the number of avatars), triggering feared outcomes (e.g., turbulence) and manipulating the length of the exercise (e.g., the amount of time needed to stand in line). Additionally, some VR setups allowed the therapist to overlay the environments with cues for feared bodily symptoms (e.g., palpitations and blurred vision) (Botella, 2007; Pérez-Ara et al., 2010; Malbos et al., 2013).

In some VR setups, patients could move and interact with the environment, by using a separate input device (Choi et al., 2005; Botella, 2007; Pérez-Ara et al., 2010; Malbos et al., 2013; Meyerbroeker et al., 2013). Interaction options beyond movement were opening doors, driving, pushing buttons, picking up objects and paying for goods while shopping. Lastly, for agoraphobia, one study used VRET as a therapist independent self-led treatment tool (Shin et al., 2021).

Specific phobia

41 studies examining variations of specific phobia were included. For the 14 studies examining aviophobia, environments were all rendered and consisted of bedrooms (i.e., getting ready to depart), airports, boarding and airplane rides, including lift-offs and landings. Difficulty was in some studies manipulated prior to immersions by changing the weather, amount of turbulence and whether a seatbelt was required (Tortella-Feliu et al., 2011; Meyerbroeker et al., 2012; Rus-Calafell et al., 2013; Botella, 2014). In three studies, patients could pack suitcases, obtain boarding passes, and read magazines before flying (Tortella-Feliu et al., 2011; Rus-Calafell et al., 2013; Botella, 2014). In four studies, patients used VRET while sitting in real airplane chairs with seatbelts and a powerful bass system installed that could vibrate to simulate lift-off and turbulence (Rothbaum et al., 2006; Meyerbroeker et al., 2012; Breuer, 2017; Meyerbröker et al., 2018).

For the 11 studies examining arachnophobia, environments were all rendered and consisted of indoor (e.g., living room) or outdoor (e.g., garden) localities with spiders. Difficulty was graduated by changing the size, amount, behavior, proximity, and realism of the spiders. In two studies, the patient could kill spiders by stepping on them (Bouchard et al., 2006) or swatting them with a magazine (Cote and Bouchard, 2005). Two studies used a gamification principles, in that the patient was required to interact in various ways with spiders to progress in the treatment (Miloff, 2019; Lindner et al., 2020). In one study, treatment was also self-led (Lindner et al., 2020). Lastly, one study draped the HMD wearing patient with a black cloth to block ambient light (Michaliszyn et al., 2010).

For the eight studies examining acrophobia, environments were all rendered and consisted of terraces, balconies, open elevators, and bridges. In three studies, six-degrees of freedom tracking allowed patients to move within a small area and hold on to a physical railing which was also represented virtually (Krijn et al., 2004; Whitney, 2005; Meyerbröker et al., 2018). In some studies, difficulty could be manipulated by increasing the height and/or perceived safety of the situation (Coelho et al., 2006; Graske and Barlow, 2008; de Quervain et al., 2011).

For the three dental phobia studies, the environments were 360-degree videos and consisted of a dental operatory with a dentist (Gujjar et al., 2017; Gujjar et al., 2018, 2019). In challenging difficulties, the dentist would carry various dental tools towards the patient. The patient received the therapy while seated in an actual dental chair and a body representing the patient's body was visible in the virtual dentist's chair. Lastly, dental operatory odor was simulated by placing cottons soaked in clove oil near the patient.

For the two hemophobia studies, environments were 360-degree videos and consisted of a blood draw performed in a doctor's office (Meindl et al., 2019) and various procedures performed by health professionals in hospital and dental settings (Jiang et al., 2020). In one study, the virtual needle prick was timed with a physical prick from a pencil to simulate needle insertion and the therapy room was also made to look almost identical to the virtual doctor's room (Meindl et al., 2019). In the other study both rendered, and 360-degree video environments were used. In the rendered environments, the patient could experience the procedure either as an observer or as the patient (Jiang et al., 2020).

For the one study examining cynophobia, the environment was 360-degree videos of dogs of different breeds presented in the same office room where therapy took place (Farrell et al., 2021). Difficulty was graduated by changing the breed of the dog, the proximity of the dog, the presence of an owner and the whether the dog was leashed or not.

For the one study examining squalophobia, environments were rendered and consisted of swimming in a pool, a lake and a sea-cove (Malbos et al., 2020). The patient could move using a handheld controller, including swimming and diving. The body of the patient was represented, and arms could be seen doing breaststrokes while swimming. Animals in the environments would react to the presence of the patient by swimming away and the patient could pick up objects, examine them and throw them. The therapist controlled the appearance and movement of a great white shark and used this to challenge the patient.

TABLE 2 Overview of the software feature present in the included studies.

Diagnosis group	Movement	Visible body	Interaction elements	Pre-immersion customizability	Live-controllable elements	Live view
SAD (N = 21)	Yes: 3	Yes: 3	Yes: 2	Yes: 16 No: N/A	Yes: 9	Yes: 2
	No: 3	No: 1	No: 3	Not reported: 5	No: 1	No: 1
	Not reported[a]: 15	Not reported: 17	Not reported: 16		Not reported: 11	Not reported: 18
Agoraphobia (N = 10)	Yes: 4	Yes: 0	Yes: 5	Yes: 8	Yes: 4	Yes: 4
	No: 3	No: 0	No: 3	No: 0	No: 2	No: 2
	Not reported: 3	Not reported: 10	Not reported: 2	Not reported: 2	Not reported: 4	Not reported: 4
Specific phobia (N = 41)	Yes: 18	Yes: 6	Yes: 8	Yes: 13	Yes: 11	Yes: 9
	No: 5	No: 0	No: 2	No: 0	No: 0	No: 0
	Not reported: 17	Not reported: 35	Not reported: 29	Not reported: 28	Not reported: 30	Not reported: 32
All studies (N = 70)	Yes: 25	Yes: 9	Yes: 15	Yes: 37	Yes: 24	Yes: 15
	No: 11	No: 1	No: 8	No: 0	No: 3	No: 3
	Not reported: 34	Not reported: 60	Not reported: 47	Not reported: 33	Not reported: 43	Not reported: 52

[a]Not reported = Information could not be found in main manuscript, supplementary files, referenced studies published in English or through online searches.

For the one study nyctophobia, the environment was a rendered house with five distinct rooms (Servera et al., 2020). The therapy was gamified so that the patient was rewarded with tokens for exploring the rooms and remaining in darkness. During VRET, the patient interacts with a virtual helper, while the therapist can control light levels, rain intensity, insert helpful phrases and teleport the patient to the various rooms.

In general, software characteristics were inconsistently reported. More than half of all included studies did not delineate:

- Interaction options within virtual environments.
- What the therapist could see during VRET (e.g., casting or mirrored rendering).
- If the therapist could manipulate the virtual environments during VRET (e.g., changing the facial expressions of avatars during a presentation).
- If the participant had a representation of themselves within the environments and/or whether their body was tracked.
  See Table 2 for an overview of the software feature present in the included studies.

Hardware features

The HMD models used in the included studies were varied, with 25 different models being used across 57 studies (the remaining 13 studies did not disclose HMD model). The most commonly used HMD was a Samsung Gear with a smartphone, being used in seven studies. For standalone HMDs, the most common model was the eMagin z800. HMDs with high resolution displays (>800 × 600 pr. eye) and high field of view (>90° diagonally) were used in 23 studies, which includes seven studies using smartphone-based HMDs. See Table 3 for an overview of the HMDs used in included studies.

It was often unclear what kind of tracking a study used, either because it was not reported or because it was unclear if the software and therapeutic procedures took advantage of any tracking capabilities. Three studies explicitly used six degrees of freedom tracking (Krijn et al., 2004; Whitney, 2005; Meyerbröker et al., 2018). The remaining 67 studies either did not report their tracking or used three degrees of freedom tracking.

Audio delivery system was widely undescribed, though several studies implied that they used the built-in audio system of the HMDs. Directional sound (i.e., sound that discernably matches the location from which it is heard in the virtual environments) was reported in one study (Meyerbröker et al., 2018), and noise cancellation (i.e., headsets that block or mitigate sound from the external environment) was reported in one study (Arnfred et al., 2022).

As has been mentioned, hardware features were generally inconsistently reported. More than half of all included studies did not delineate:

- Tracking capabilities (e.g., degrees of freedom)
- The Interaction method (e.g., controller)
- Audio delivery system, including features related to it (e.g., noise cancellation)

Discussion

In this scoping review, 70 studies were included that use HMD-based VRET to treat SAD, agoraphobia and/or specific phobia. All included studies were reviewed for 46 data points relating to the

TABLE 3 Overview of the HMDs used in included studies.

HMD model	Number of studies	Field of view in degrees (diagonally, otherwise specified)	Resolution (pr. eye)	Tracking capabilities
Not reported*	14	N/A	N/A	N/A
Smartphone + smartphone-based HMD	7	96 (3)	1,280 × 720 (5)	3-DoF built-in
		101 (1)	375 × 667 (1)	
			1,480 × 720 (1)	
eMagin z800	5	40	800 × 600	3-DoF
Oculus Rift DK2	5	100	960 × 1,080	6-DoF
V6	4	60	640 × 480	Requires external sensors
nVisor SX	3	60	1,280 × 1,024	3-DoF with InertiaCube IMU
VFX3D	3	35	263 × 240	3-DoF
Visette Pro	3	70.5	640 × 480	6-DoF
Oculus Rift CV1	3	110	1,080 × 1,200	6-DoF
HTC Vive Pro	3	110	1,440 × 1,600	6-DoF
Oculus Go	2	90 horizontal	1,280 × 1,440	3-DoF built-in
HMZ-T1	2	45	1,280 × 720	Requires external sensors
V8	2	60	640 × 480	Requires external sensors
I-glasses, PC/SVGA	2	26	800 × 600	Requires external sensors
I-Glasses, i-O systems	2	N/S	640 × 480	Requires external sensors
5DT	2	26 (LCOS version)	800 × 600	Requires external sensors
		40 (OLED version)		

The following models were used in a single study: HTC Vive, Pico Goblin, Kaiser Pro View 60, Virtual Realities HMD 42 Pro, Sony Glasstron PLM-A55, PICO G2, PlayStation VR, HMZ-T2, Virtual Research Flight.

features of the hardware and software used in VRET. A strength of scoping reviews is that they can identify gaps in existing literature and propose avenues for future research (Arksey and O'Malley, 2005; Pham et al., 2014). As such, the discussion will address the state of extant VR setups vs. contemporary VR technology, as well as the inconsistent reporting of VR features in the included studies.

Gaps between examined VR setups and contemporary VR technology

How large is the gap between existing VR setups and contemporary VR technology? And to what extend might this gap affect relevant clinical variables, such as symptom reduction, acceptability, and attrition?

First, the HMDs used generally had poor specifications compared with widely available and affordable current-generation HMDs (i.e., the Oculus Quest 2). This is especially true for SAD and agoraphobia, where no studies reported their tracking to be six degrees of freedom. Several studies did use HMDs that were capable of six degrees of freedom tracking, but it was never stated that the software utilized took advantage of these capabilities.

Second, the movement and interaction within virtual environments were generally limited. Only four studies utilized the actual physical movement of the patient in therapy (Krijn et al., 2004; Whitney, 2005; Meyerbröker et al., 2018; Reitmaier et al., 2022) and the method for interacting was also generally outdated, with no studies utilizing body tracking. Similarly, there were only two studies utilizing haptic feedback (Meindl et al., 2019; Jiang et al., 2020) and three studies utilizing olfactory feedback (Gujjar et al., 2017; Gujjar et al., 2018, 2019). Notably, all the above-referenced studies examined specific phobia.

Third, no studies reported using any multi-user functions (i.e., two or more users using a shared virtual environment) within virtual environments. Though one study used a program where it was possible (Geraets et al., 2019).

Lastly, though seven studies examined self-led VR-based therapy (Hartanto, 2016; Lindner et al., 2019, 2020; Kim et al., 2020; Shin et al., 2021; Trahan et al., 2021; Zainal, 2021), no studies utilized online multi-user VR-based therapy (i.e., multiple users meeting online in the same virtual environment). One trial, not included in the present review, is currently in progress examining online multi-user VR-based group therapy for depression (Dilgul et al., 2021).

It seems fair to summarize that VR setups for phobic anxiety, and especially SAD and agoraphobia, has yet to take full advantage of contemporary VR technology. However, it is unclear how important this gap is for clinical outcomes. On the one hand, studies have found display factors (i.e., resolution, field of view, refresh rate), audio factors (e.g., directional sound), tracking, and framerate (i.e., the number of pictures displayed pr. second) to be related to a higher degree of presence (Youngblut, 2003; Cummings and Bailenson, 2016; Felton and Jackson, 2022), engagement (Sylaiou, 2010; Brade, 2017) and embodiment (i.e., the experience of owning a body within VR) (Slater, 2018) as well as a lower degree of cybersickness (i.e., motion sickness-like symptoms caused by prolonged HMD use) (Chang, 2020; Saredakis et al., 2020).

On the other hand, several studies have failed to find significant associations between presence and treatment efficacy (Krijn et al., 2004; Price and Anderson, 2007; Meyerbröker et al., 2011). Though contradictory evidence does exist (Price et al., 2011). Similarly, it remains unclear if presence is necessary to generalize learning achieved in virtual environments to real-life, with studies producing contradicting results (Makransky et al., 2019; Grassini et al., 2020).

The concept of presence has generally been difficult to study due to a plethora of competing definitions and measurement methods (Lombard, 2015; Grassini and Laumann, 2020). Even so, presence has been consistently found to be correlated to anxiety in virtual environments (Bouchard et al., 2008; Gorini et al., 2011; Ling et al., 2014; Peperkorn et al., 2015; Peperkorn et al., 2016) and is thus still considered an important aspect of VRET (Diemer et al., 2014; Morina, 2015).

Nevertheless, software and hardware features directly affect the range, customizability and interactability of virtual environments and thus influence therapists' ability to manipulate the presentation of conditional stimuli (central in all exposure therapy), and therefore also the ability to manipulate exposure exercises for graduation of difficulty, habituation, and expectancy violation.

For example, using 360-degree video environments (e.g., Zainal, 2021) which at best allow limited interaction, may not be optimal for exposing patients to social interactions and/or training social skills. On the other hand, using virtual environments to access extremely challenging or otherwise unethical exposure exercises (e.g., Cote and Bouchard, 2005; Arnfred et al., 2022) may be a useful way to maximize expectancy violation, especially when testing expectancies regarding internal states (e.g., "I'll clam up if I ever get into a conflict with my boss").

Further, utilizing multi-user virtual environments could provide a method for engaging patients in a wide variety of social interaction, which may otherwise be difficult to simulate (Emmelkamp et al., 2020). Roleplaying with a therapist in multi-user virtual environments has been used successfully in the treatment of social anxiety in patients with psychosis (Pot-Kolder et al., 2018), but was not utilized in any of the studies included in this review.

For treating certain types of specific phobia, the use of six degrees of freedom tracking allowing patients to physically approach feared objects (e.g., Reitmaier et al., 2022) may be an important feature. Further, any measures to increase comfort and reduce cybersickness would allow patients to stay in the environments for extended periods, mimicking the gold standard treatments (Öst, 2012). As such, these features may be especially important when treating specific phobia using VRET.

For agoraphobia, three studies incorporated cues in an attempt induce fear of bodily sensations (Botella, 2007; Pérez-Ara et al., 2010; Malbos et al., 2013). This could be combined with classic interoceptive exposure exercises, such as spinning to induce dizziness, hyperventilating to induce tingling/dissociation, or drinking water to induce a need to urinate. However, no included studies stated they did so. As with the other phobic disorders, VR also allows access to useful but otherwise unethical situations, such as having your car break down on a heavily trafficked bridge (Arnfred et al., 2022).

Meta-analysis has already shown promising results for VRET in the treatment of phobic anxiety (Carl, 2018; Wechsler et al., 2019; Morina, 2021), but superiority to active control conditions has not yet been established. As such, the development of contemporary VR setups that fully capitalize on the advantages of the technology according to the specific disorder and an underlying empirically based theory, may be an important avenue for future clinical research.

Inconsistent reporting

In general, the data of interest for the present review was rarely reported consistently. The data charting form in this review was exhaustive and thus it was expected that some study designs and publication types (e.g., brief reports) would not provide information on every datapoint. Nevertheless, certain salient datapoints were expected in every publication or its referenced material because they directly impact the therapeutic procedure. These were:

- A description of how VR was used in therapy (e.g., presence of a therapist) and how much VRET was administered.
- A description of the hardware used, including: visual output device, auditory output device, interaction device, and tracking.
- A description of the software used, including: The virtual environments (or screenshots/video links), interaction elements, customizability (during and/or before immersion), movement and any auxiliary software that the therapist used during exposure (e.g., casting a live view of the patient's point of view to a monitor).
- A description of further measures taken to improve or alter the experience of the VRET, including the use of: Olfactory feedback, haptic feedback, and/or miscellaneous measures (e.g., placing cloth over a participant's head to block light).

Only three studies reported all of the above information, either in-text or through references (Malbos et al., 2013; Kampmann et al., 2016; Zainal, 2021). For an additional eight studies, the above information was found in-text, through referenced studies and through online searches (Whitney, 2005; Botella, 2007; Miloff, 2019; Lindner et al., 2020; Servera et al., 2020; Lundin, 2021; Shin et al., 2021; Arnfred et al., 2022). For the remaining 59 studies, all the information could not be found in English. This presents the reader of these 59 studies with two problems: First, is the problem of interpreting the results of a study in which you do not have an adequate understanding of the intervention. Second, is the problem of re-creating or adapting a treatment that is not thoroughly described (Boutron, 2009; Guidi et al., 2018). The latter is perhaps especially true in the quickly developing field of VR-based treatment for mental health disorders.

A framework for reporting VR setups

A reporting framework may be a useful way to increase transparency of VR-based interventions. Two challenges to clear dissemination were repeatedly observed:

1. Referring to websites which were no longer active, or which no longer contained any relevant information pertaining to the study in question.
2. Reporting unimportant features, such as the components of the computer rendering the virtual environments (e.g., graphics processing unit, central processing unit), while omitting to describe salient features (e.g., tracking, HMD model).

Because it is unfeasible to report all technical features of a VR setup, the information that is the most pertinent to the hypothesis of the study should be prioritized. In studies investigating VRET-based treatment, the salient features are those that impact the therapeutic procedure. For example, information about the processing power of the computer rendering the virtual environments is less important compared to the effect it has on the experience of the virtual environments, that is, preferably producing a high and stable framerate.

Case in point, low framerate has been associated with increased risk of cybersickness (Jones et al., 2004), while high framerate has been associated with a greater sense of presence (Meehan et al., 2002; Meehan, 2003). Yet, of the included studies, only one mentioned the framerate of their virtual environments (Meyerbroeker et al., 2012), while 37 studies reported at least one component of the computers running their virtual environments. A framework for reporting VR setups in VRET studies may be a useful way to counteract these challenges in future studies. Such a framework should contain information that gives the reader a clear idea of the participants experiences of the virtual environments and the therapeutic procedures possible within them. Lastly, such a framework should be accompanied by media (e.g., videos or photos) of the virtual environments, since media can give the viewer an immediate idea of the quality and content (e.g., the number of conditioned stimuli available) of the environments.

Examining which exact features should be included in such a framework and how the ultimate quality of a therapeutic VR setup should be evaluated is beyond the scope of the current study but would be useful areas of future research. A preliminary framework based on the data charting form used in this review, can be found in Supplementary Material S3.

Limitations

There were two primary limitations in conducting the present study. First, when extracting the data of the included studies, we considered it appropriate to derive some data indirectly. This was often the case with the audio hardware used, which was rarely directly stated to be the built-in headset/speakers of the HMD but was often indirectly stated. In such cases, it was discussed between the authors if it was appropriate to include it in the study. Data was only included when it was deemed by all involved authors to be accurate. Individual data-points which were not directly reported, has been marked as such in the data chart (See Supplementary Material S2).

Second, there was a general challenge in interpreting the interplay between the software and the hardware used in the VR setups of the included studies. Using a powerful HMD with contemporary visual specifications and tracking is inconsequential if the software run on it does not take advantage of the hardware. Conversely, the quality of high-fidelity virtual environments can be severely negatively impacted by being presented on older or low-end HMDs. This interaction was not accounted for in this study and may thus represent a source of bias in the interpretation of the findings.

Conclusion

Research has yet to examine VRET for phobic anxiety delivered with top-of-the-line hardware and software. Thus, to the extent that technical features affect important variables such as accessibility (e.g., access for homebound patients), acceptability (e.g., ease-of-use, minimal cybersickness), applicability (e.g., a range of environments for a general clinical population) and treatment effect (e.g., presence induced, availability of therapeutic procedures), the development of contemporary VR setups may represent an important Frontier in the field.

Despite the seeming importance of the hardware and software used for VRET, existing publications inconsistently report the technical aspects of their intervention. Thus, pertinent questions in the field are difficult to approach and extant research is difficult to build upon. A framework for delineating the salient technical features of a VR setup for VRET may increase transparency in future studies. A preliminary framework is proposed.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

BA initiated the review. Wrote the protocol, determined the search strategy and drafted the initial data charting form. BA performed approximately 50% of the work assosciated with evidence selection and data charting process. BA wrote the initial draft for the manuscript and all further revisions. JS performed approximately 50% of the work assosciated with evidence selection and data charting process. JS also calculated and edited tables. CH criticially examined the review methodology. AA critically examined the technical terminology, the phrasing of the data charting form and provided general technical expertise. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2023.952741/full#supplementary-material

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