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Low-Cost Virtual Reality to Support Imaginal Exposure Within PTSD Treatment: A Case Report Study Within a Community Mental Healthcare Setting

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Revisiting what happened during (or after) a traumatic event is an important part of the treatment process in trauma-focused cognitive therapy (TF-CT). However, clinicians may have difficulty helping patients to intentionally retrieve these memories in order to engage with their content. As such, clinical tools to support the access and delivery of imaginal exposure content within treatment may prove to be particularly useful for therapists. This case report introduces work undertaken with Mr. A, a 38-year-old male, who 2 years prior had experienced a city centre assault. Initial assessment revealed a PCL-5 score of 64 and he met DSM-5 criteria for posttraumatic stress disorder (PTSD). Mr. A received 10 sessions of TF-CT wherein the traditional imaginal exposure components were implemented via a newly developed virtual reality (VR) development workflow called "VR Photoscan." After 10 sessions, results showed PCL-5 scores decreased from 64 to 19 and Mr. A no longer met DSM-5 PTSD criteria. VR Photoscan was used during 4/10 sessions and included (1) reliving, (2) memory updating, and (3) stimulus discrimination activities. Mr. A also reported VR Photoscan as helpful regarding preparation for site visits. In conclusion, VR Photoscan technology provided a more visceral exposure experience which supported Mr. A to revisit the trauma memory. He reported high levels of satisfaction with the quality of the virtual environment and no issues using the VR technology. Produced with lower costs and shorter development times than typical computer-generated environments, VR Photoscan may be more easily implemented within routine care, although further research is required.

A defining characteristic of posttraumatic stress disorder (PTSD) is the repeated and unwanted "reexperiencing" of the trauma (Ehlers & Clark, 2000, p. 319). Yet reconstructing or revisiting "what happened [during] or after the trauma" is an important part of the treatment process (Ehlers et al., 2004, p. 413). To achieve this, imaginal exposure (IE) techniques feature heavily within the literature (Asukai et al., 2010; Bryant et al., 2003; Foa & Kozak, 1985, 1986; Foa et al., 1999a; Marks et al., 1998; Schnurr et al., 2007; Speckens et al., 2006; Taylor et al., 2003), whereby "patients are asked to recall the details of the traumatic event while focusing their attention on . . . sensory feelings, thoughts, and emotions" (Arntz et al., 2007, p. 345). Some conceptualize IE as supporting the treatment of PTSD through emotional processing (Foa et al., 1999a), whereas others use IE more specifically to identify (and elaborate) particular aspects within the trauma memory (Ehlers & Clark,

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2000; Resick et al., 2002). Within more cognitively orientated PTSD treatment models, the focus of IE techniques is to identify emotional hotspots and the relevant cognitive themes. As such, IE has been adapted and combined with other techniques over the years (Arntz et al., 2007; Grunert et al., 2007; Resick & Schnicke, 1992). This has included combining IE with cognitive restructuring, imagery rescripting and in-vivo exposure (Arntz et al., 2007; Foa et al., 1999a; Grunert et al., 2007) or to use in combination within other elaboration techniques, such as written narratives, audio-recordings, and behavioral experiments with trauma-specific stimuli (Grey, 2009).

There are potential limitations to IE, however, particularly in situations where "fear" is not the key maintaining emotion in the patient's PTSD. When nonfear emotions, such as anger, guilt, and shame, are predominant, there is little compelling evidence that these habituate during IE (Grey et al., 2001; Grunert et al., 2007; Holmes et al., 2005; Smucker et al., 2003). Indeed, research by Arntz et al. (2007, p. 364) compared IE to IE plus image rescripting (IR) and found that "the addition of IR techniques led to significantly better effects on anger control, externalized anger, hostility, guilt and perhaps shame." In addition, some studies have suggested that patients may find it difficult to visualise the trauma memory or are unwilling to engage in the process as a form of avoidance (Difede et al., 2007; Rizzo & Shilling, 2017; Shulman et al., 2019). More recently, we are beginning to see another evolution of IE—one that uses virtual reality (VR) technology to provide a more visceral imaginal experience and potentially address some of the barriers associated with traditional forms of IE (Rizzo et al., 2019).

VR can be described as the perception of being present in a virtual environment via mediated sensory information, e.g., imagery, audio, touch, and smell (Ryan et al., 2019). Virtual Reality Exposure Therapy (VRET) retains some of the core components of IE (verbally recalling details of the event, reporting thoughts/feelings, etc.), but incorporates a virtual environment containing relevant sensory stimuli (typically auditory and visual) to facilitate access to the trauma memory. The virtual environment is often experienced by the client while viewing within a VR headset. The visuals may contain computer-generated imagery or real-world photography or video projected in the 3D environment. These may include a full representation of the trauma environment or some specific relevant fear-related stimuli. So far, studies using VRET for PTSD have revealed largely positive results (Best et al., 2020; Cieślik et al., 2020; Deng et al., 2019), with recent reviews showing comparable effects to in-vivo exposure (Carl et al., 2019). However, the extent to which VR technology adds value or whether it adds an unnecessary technological and practical layer to current treatment protocols is unclear. For example, wearing a VR headset may create a visual barrier for assessing changes in emotion via facial expressions. There are also additional cost implications when purchasing suitable hardware and software—albeit several scholars have suggested that VR-based simulations decrease logistics and provide more economically viable solutions when compared to in-vivo exposure (Bouchard et al., 2017; Sherrill et al., 2020). In a qualitative study by Thorup Arnfred et al. (2021) of patients' and therapists' experiences of using VR for the treatment of social anxiety, some practical issues were highlighted regarding the setting up and storing of equipment, which did have an impact on exposure times (in VR) for some participants. Potential technological issues are highlighted by Harris et al. (2019) in regards to whether "virtual" objects can elicit the same neural and behavioural responses as "real" objects, given the general lack of haptic feedback (touch, vibration). In addition to this, they cite issues, such as the artificial perception of depth generated with virtual environments (which is often viewed as flatter). Another important factor to consider is whether the quality of memory access, recall, and elaboration is enhanced or degraded by VR-assisted IE. As Ehlers et al. (2004, p. 408) note, much of "what is retrieved from the memory about a traumatic event *depends on the retrieval route*." As such, experiencing intrusive images and flashbacks in an uncontrolled and involuntary manner rarely facilitates memory processing. Effective IE is therefore conducted in a controlled and purposive manner, quite distinct from the experience of intrusive memories or thoughts about the event. Therefore, it is important to ascertain whether aspects of VR-assisted IE may be counterproductive to successful retrieval or whether they introduce negative effects. Finally, a number of concerns remain about the infrastructure within community mental healthcare settings to fully utilize VR technology, mainly related to cost and routine implementation. As such, and despite of the growing evidence base, there is a dearth of studies that have implemented VR within local community mental health settings (Best et al., 2020).

The current case study presents work with Mr. A, a 38-year-old male who was assaulted outside a nightclub and referred for Trauma-Focused Cognitive Behavioral Therapy (TF-CBT) enhanced with a new type of low-cost VR technology called "VR Photoscan."

Trauma-Focused CBT

TF-CBT is recommended by the National Institute for Health and Care Excellence (2018) and is one of the most effective treatments for PTSD (Paintain & Cassidy, 2018; Peskin et al., 2019). For this study, Ehlers and Clark's (2000) Cognitive Model (TF-CT) of PTSD was used as a framework to develop the treatment protocol. TF-CT has shown to be effective across multiple trauma types, with higher retention figures than other CBT approaches (Duffy et al., 2007; Ehlers et al., 2005; Gillespie et al., 2002). The model draws upon an extensive evidence base in relation to the treatment of PTSD but provides "a unique synthesis" (Ehlers et al., 2005). The Ehlers and Clark model for PTSD has three main goals to reduce the sense of current threat: (1) reducing reexperiencing by elaborating the trauma memory and discrimination of related triggers; (2) modifying negative appraisals, namely, personal meaning of the trauma memories and its sequelae; (3) identifying and replacing unhelpful cognitive and behavioral strategies (Ehlers & Clark, 2000; Ehlers & Wild, 2020). The Ehlers and Clark model differs from previous, more exposure-based CBT models in a number of ways: the model has a strong emphasis on identifying and modifying negative appraisals of the trauma and the sequelae. One important distinction is that imaginal reliving is not used to promote emotional habituation to a painful memory but instead is used to identify ''hot spots'' as targets for cognitive restructuring and to elaborate the trauma narrative. The TF-CT model includes a number of fairly novel techniques, such as: stimulus discrimination to reduce involuntary triggering of reexperiencing symptoms; inputting updating information into the trauma memory during short reliving of memory hotspot segments; behavioral experiments (such as thought suppression) and imagery transformation techniques. Imaginal and in vivo exposures are used within TF-CT as techniques to treat PTSD; however, unlike prolonged exposure protocols (PE; Foa & Rothbaum, 1998), TF-CT does not involve repeated imaginal exposure to the trauma memory in the form of recurrent imaginal reliving sessions (Ehlers & Wild, 2020). When IE techniques are used with TF-CT (e.g. reliving) the purpose is to identify hotspots, key appraisals and aspects of the trauma memory that require elaboration. These hotspots and associated negative appraisals are specific points within the trauma memory that can cause the greatest distress (Grey & Holmes, 2008). Hotspots contain sensory-laden material such as images, sounds, and smells, and are commonly revealed as one relives the traumatic event via IE. IE is used to locate the hotspots and cognitive techniques are employed to identify associated maladaptive meanings (Ehlers & Clark, 2000; Ehlers & Wild, 2020). Finally, as trauma memories are idiosyncratic in nature, each reliving session is unique to that individual. Typically, only one complete reliving of the trauma session is required in the early stage of therapy to identify aspects of the trauma memory that need to be updated. Thereafter, only the hotspots are revisited by imaginal reliving for the purpose of installing new corrective information and updating the trauma memory during the reliving of these segments.

Discussed in more detail below, this presents a challenge for those seeking to develop virtual environments within routine mental healthcare (for PTSD) as it would require a new (personalized) environment for each individual client, which may impact its affordability.

VT Technology and PTSD

In PTSD, trauma memories, by definition, are distressing and are often accompanied by intense physiological and emotional sensations. In addition, recalling traumatic events can be a challenge and may include difficulties "accessing important details, confusion about the order of events [and] difficulty in accessing information that updates impressions" (Ehlers et al., 2004, pp. 412–413; Ehlers & Wild, 2020). It is therefore unsurprising that clients can be highly avoidant and emotionally distant from trauma memories. Thought suppression is commonly used by clients with chronic PTSD and clients find it challenging to engage with the exposure process, especially if therapy involves repeated reliving sessions (Rauch & Rothbaum, 2016; Rothbaum et al., 1999; Shearing et al., 2011). This has led to high dropout rates among those in receipt of some trauma-focused treatments (Eftekhari et al., 2020; Imel et al., 2013; Keefe et al., 2018; Lewis et al., 2020). In contrast, dropout rates with TF-CT have been impressively low (Ehlers et al., 2005).

There has been much excitement and debate about the potential utility of VR technology within clinical practice to sensorially augment IE or in-vivo techniques, given the features inherent within VR environments. This includes affordances and assets that exhibit the potential to recreate trauma environments and recreate situations that may be difficult to experience in the real world or to provide error-free (safe) learning (Rizzo et al., 2004). For treatment purposes, VR has been used since the early 1990s (Cromby et al., 1996; Hilty et al., 2020; Riva, 2002; Rizzo & Koenig, 2017; Rothbaum et al., 1995; Wilhelm et al., 2005), and it is becoming a well-established safe and therapeutic tool among a variety of patient populations, including psychosis (Bisso et al., 2020), eating disorders (Gadsby, 2019), and anxiety disorders (Rizzo & Koenig, 2017). There is also evidence that VR-based exposure is tolerated well by clients (McLay et al., 2011; Rothbaum & Hodges, 1999; Wood et al., 2008) and in some cases better than IE (Best et al., 2020).

For PTSD treatment specifically, VR has been used to improve the sense of presence during exposure-based therapies and provides a setting for exposure, memory updating, and emotional processing to occur (Best et al., 2020; Eshuis et al., 2020; Wiederhold & Wiederhold, 2004). To date, a large majority of evidence in relation to VR and PTSD treatment has been gathered from military samples by recreating encounters within various Middle Eastern towns and villages (Mozgai et al., 2021; Mozgai et al., 2019; Rizzo et al., 2018). There have also been single-case studies in which VR environments have been created based on road traffic–related trauma, a bus bomb attack and the attack on the World Trade Center in 2001 (Best et al., 2020). While results in each of these studies have been promising, we are yet to see this translated in the context of routine care—perhaps due to the various practical issues surrounding the cost of producing VR custom-made applications, availability of equipment and lack of guidance regarding how to use these within a clearly defined protocol.

The current study uses a newly developed production workflow, "VR Photoscan," a low-cost approach to creating VR environments. Often interactive and navigable VR experiences are created using 3D sculpting and illustration in a production process that requires a team of specialist creatives. VR Photoscan removes the typically time-intensive sculpting and illustration processes and instead involves sculpting real-world 2-dimensional (2D) images into a 3-dimensional (3D) VR environment. This process brings benefits of increased photorealism while retaining the 3D navigation affordances offered by VR. A basic example of this is given in Figure 1. Images of the original trauma location are first captured using a mobile phone camera. These images are then placed within a 3D virtual environment to construct the virtual scenery of 3D walls and objects. In addition to increased photorealism, VR Photoscan significantly decreases both the time to produce VR environments (initial tests have shown production times of 1–2 days) as well as associated labor costs. As such, custom-made VR environments may be produced quickly at a lower cost and thus create a more affordable and economically viable pathway for use in routine clinical settings.

Aims and Objectives

The aim of this case study was to incorporate innovative, low-cost VR into a standardized TF-CBT treatment protocol.

Objectives

- Examine potential benefits of TF-CT enhanced with VR Photoscan technology to treat PTSD;
- Explore client acceptability of low-cost VR Photoscan technology;
- Examine the feasibility of implementing VR technology within a local community care setting.

Method

A single-subject case study design was employed to explore the efficacy of TF-CBT enhanced using VR Photoscan technology within a local community mental healthcare setting. The research design was informed by the CARE guidelines for case report research (Gagnier et al., 2013) and ethical approval for the study was granted by the Queen's University Belfast Research Ethics committee (024_2122). Before taking part, informed consent was obtained and a project information sheet was provided. In addition to this, COVID prevention measures were in place regarding the cleaning, handling, and storage of VR headsets before and after use.

Patient Demographics and Presenting Symptoms

Mr. A was a 38-year-old, single White male. He had no children and lived with his partner in rented accommodation. Initial assessment revealed that Mr. A had been out of work for over 2 years following an assault at a nightclub in which he was attacked by three men and choked until he lost consciousness. Psychometric scores (see below) indicated the presence of PTSD and depression symptoms. He had previously been prescribed daily anti-depressant medication (Citalopram, 40 mg) but had stopped taking these approximately 8 weeks before the assessment interview.

Mr. A described having intrusive images regarding this attack—particularly when he was being choked and losing consciousness. He stated that he would "relive" the event (flashback) on a daily basis and would regularly dwell (ruminate) on what "could have happened." The main "triggers" (that cause a trauma memory reexperiencing) appeared to be loud noises and groups of people. When triggered, physical symptoms included sweating and increased heart palpations. He described his strongest emotion as "fear" (100% on subjective units of distress scale) but also had equally strong feelings of shame (100%) and anger (100%) regarding what happened. The incident led to the development of various posttrauma appraisals regarding the world ("the world is dangerous") and others ("people can't be trusted"). To manage these symptoms Mr. A engaged in numerous strategies to

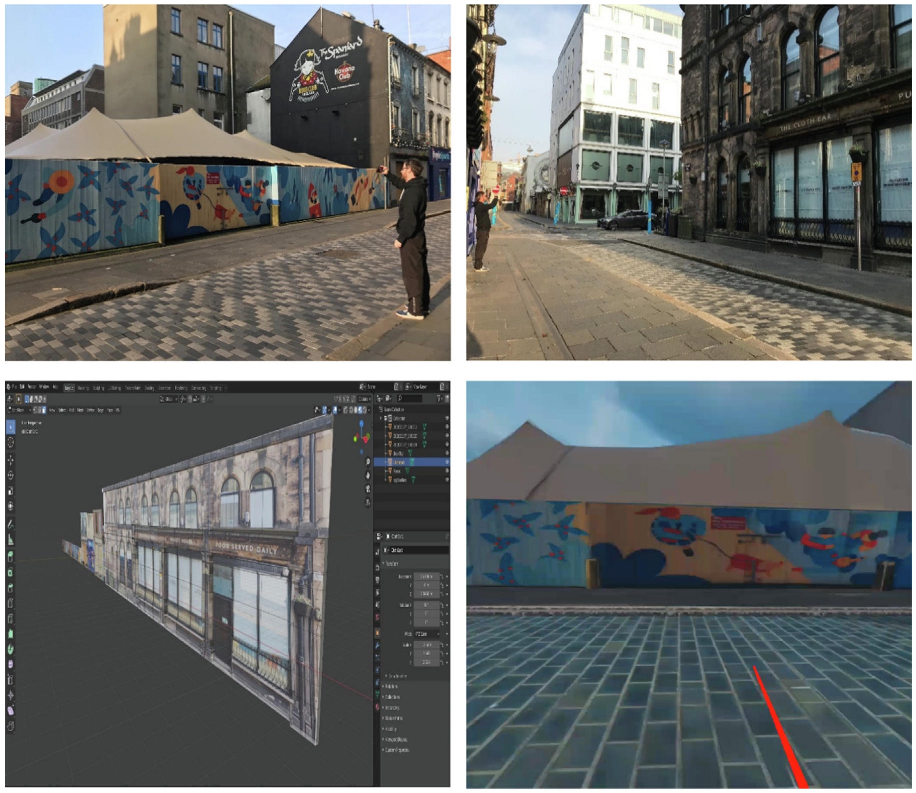

Figure 1. 2D Image (mobile phone) being converted into 3D.

control the sense of threat, such as thought suppression, used, rarely leaving the house and stopping all contact with family and friends. Mr. A's presenting problems and symptoms met criteria for PTSD with symptoms classifiable across criteria A-H of the DSM-5 (American Psychiatric Association, 2013). For over 2 years, his symptoms included intrusive images and flashbacks (being choked), persistent avoidance (rarely left the house, avoided site where trauma took place), negative alterations in cognitions ("it is my fault") and mood, marked alterations in arousal and reactivity (witnessed in-session), significant distress (witnessed in-session), all of which were not attributable to the effects of a substance. There was a high sense of "nowness" (i.e., the extent to which it seemed to be happening now instead of being something from the past) during flashbacks coupled with intense affect, which is indicative of an inadequately processed trauma memory (Handley et al., 2009; Michael et al., 2005). Mr. A had no previous or current history of self-harm or suicidal ideation and was considered low risk.

At the time of assessment, Mr. A was attending a weekly support group for depression within a local community mental health service and charity. This service provides mental health support and training across a number of conditions, including those with depression, bipolar disorder, anxiety, and PTSD. Mr. A was referred by his group facilitator for one-to-one TF-CT following disclosures within his support group. One-to-one services are provided free of charge, whereby clients can access weekly CBT treatment for a maximum of 20 sessions. Sessions last approximately 60–90 minutes, depending on the condition being treated. On receipt of the referral, the case was allocated to a CBT therapist for initial assessment. The assessment took place approximately 2 weeks after the referral was made. Assessments are conducted using an agency-based tool that include questions on social history, risk, problem list (frequency, duration and severity), and goals. There is also an additional (disorder specific) subsection that includes PTSD DSM-5 criteria items, such as reexperincing symptoms, avoidance, negative alternations in cognitions and mood, and negative alterations in arousal and activity. This is supplemented with various psychometric measures, including for PTSD and depression symptoms (see below for more detail).

Formulation

Treatment was delivered by a CBT therapist accredited by British Association for Behavioural & Cognitive Psychotherapies (BABCP) with specialist training in

TF-CBT. As discussed above, the protocol used for the study was a cognitive model for PTSD (TF-CT) developed by Ehlers and Clark (2000). In Figure 2. A diagrammatic summary of a formulation is provided using the TF-CT model to conceptualize Mr. A's PTSD. Mr. A's trauma memory is fragmented (disjointed trauma narrative) and he often reexperiences the events of the assault. This fragmented memory is associated with a range of posttrauma appraisals (Dunmore et al., 1999) regarding his performance ("*Why didn't I see it coming, I am weak, I am vulnerable*"), which has led to feelings of fear (100%) and shame (100%). Beliefs and assumptions have now been altered and "overgeneralized" through this experience whereby

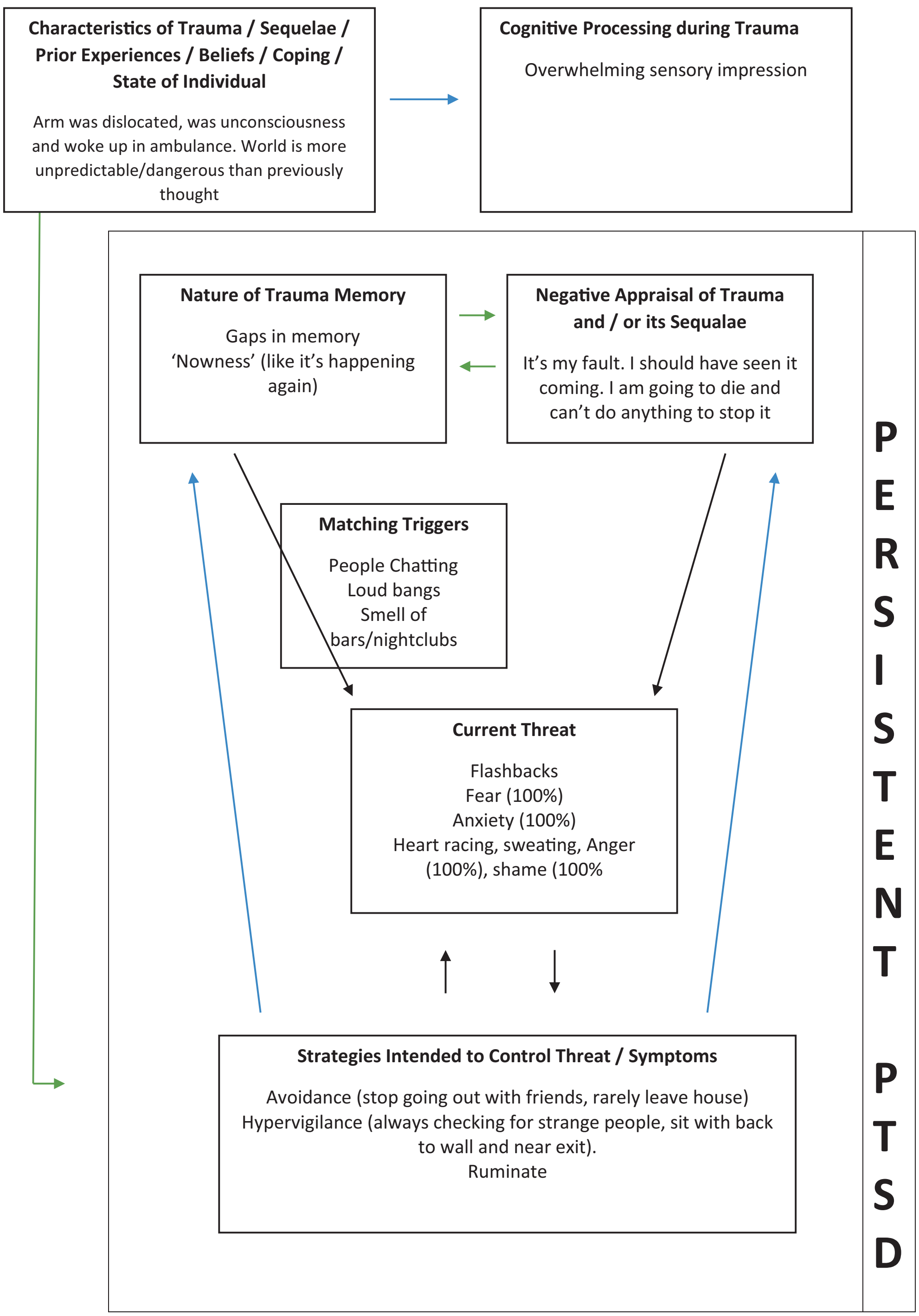

Figure 2. PTSD Formulation (Ehlers and Clark, 2000).

Mr. A sees a potential danger in many actions and interaction. The world is viewed as unpredictable and out of control. As a result, Mr. A has stopped engaging in daily activities over which he feels he has no control (social outings, going to work). He has become hypervigilant to potential threats and rarely leaves the house (avoidance). These behaviors have prevented his trauma memory from becoming updated and integrated within his autobiographical memory structures and thus the cycle of flashbacks, intrusive images, and hyperarousal is maintained (Ehlers & Clark, 2000).

TF-CT Enhanced With VR Photoscan

TF-CT using the Ehlers and Clark's (2000) model was implemented throughout this study. However, sessions that required imaginal exposure, such as a complete reliving of the trauma (Session 4) or updating memory during selected reliving of hotspots (Sessions 5–7), were completed using VR Photoscan technology. In addition to this, VR Photoscan was also used for stimulus discrimination tasks in Session 8 (more detail below). The goal as such was to use VR to enhance existing techniques rather than replace them.

Virtual Environment Creation Using VR Photoscan

To create custom-made virtual environments using VR Photoscan, a simple five-step protocol was developed. As a core aim was to implement the technology within a routine care setting, the creation of the virtual environment had to take place within 1–2 days so as not to disrupt the standard flow or progression of weekly treatment. A therapist wanting to make use of VR Photoscan only requires a mobile phone or camera for pictures and a VR headset to immerse their client in the personalized environment. The headset used in the current study was the Meta Quest 2 (Figure 3).

Table 1
VR Photoscan Protocol

Step	Details
Step 1	Following initial assessment with the participant, the clinician/therapist gathers descriptive data relating to scene where the trauma took place, e.g., precise location, time of day, relevant objects, vantage point, etc.
Step 2	A site visit is conducted (by clinician/therapist) whereby various 2d images are captured (mobile phone or other device) from multiple angles. An audio clip (approximately 3 minutes in length) is also recorded using the voice recorder app on standard mobile devices.
Step 3	Images are uploaded to a secure cloud-based storage centre and accessed by the technology company with a narrative provided by the clinician to highlight salient (environmental) areas of interest.
Step 4	The location images will then be imported into a 3D-software Blender, which enables the sculpting of images into 3D Objects. These 3D-objects are then exported into Unity software where they are created into an environment.
Step 5	This environment is then built as an android package (APK) file and downloaded onto the VR headset.

Table 1 outlines the key steps in this process. The initial step is to gather information in relation to the trauma before the therapist travels to the site to take pictures using a mobile phone device. These images are then shared with a specialized VR production company (ProPeer Solutions Ltd) via a secure cloud trans-

Figure 3. Meta Quest 2 Headset.

fer, who import them into the open-source 3D graphics program, Blender (https://www.blender.org/). This software allows designers to sculpt 3D environments, and in the case of VR Photoscan, the designer overlays the images onto 3D objects to create the virtual scenography. By extruding, scaling, and texturizing the images (e.g., windows, doors, etc.), they can be shaped into 3D photorealistic objects and architecture. These 3D objects are then arranged to create a life-size replica of the trauma site. The virtual environment is then imported into the Unity game engine to enable user navigation and interaction. Once the virtual environment is completed, it is sent via cloud transfer to the therapist, who uploads it onto the headset by connecting to a computer/laptop. The environment is checked for initial accuracy by the therapist to determine if any minor tweaks were made (e.g., objects in wrong place). In addition to this, a "safe space" option (meadow/forest) is provided as an initial landing page. Not only does the user start in this environment, but they could quickly return to the safe space should they require by hitting a virtual watch on their wrist. As such, they could return to a place of safety without removing the headset.

Measures

Primary Outcome (PCL-5)

The primary outcome measure was PCL-5, a 20-item self-report measure that assesses DSM-5 symptoms of PTSD. This was completed by Mr. A at the beginning of each session. DSM-5 symptom cluster severity scores can be obtained by summing the scores for the items within a given cluster and items are rated on a 4-point Likert scale ranging from 0 (*not at all*) to 4 (*extremely*). Total symptom severity score for PCL-5 ranges from 0–80 with a cut-off score of 31–33 indicative of probable PTSD (Blevins et al., 2015). PCL-5 scores exhibited strong internal consistency ($\alpha = .94$), test-retest reliability ($r = .82$), and convergent ($rs = .74$ to .85) and discriminant ($rs = .31$ to .60) validity (Blevins et al.).

Secondary Outcomes

Patient Health Questionnaire (PHQ-9). Alongside the PCL-5, Mr. A completed the PHQ-9 (Kroenke et al., 2001) at the beginning of each session. This 9-item measure is noted by Sun et al. (2020) to be "a simple, rapid, effective, and reliable tool for screening and evaluation of the severity of depression" (p.1). Internal consistency of the PHQ-9 has been shown to be high (Kroenke et al., 2001; Kroenke & Spitzer, 2002).

Posttraumatic Cognitions Inventory (PTCI). The PTCI is a 33-item measured designed to provide information on important appraisals, such as negative self-beliefs, permanent change, and overgeneralized sense of danger (Foa et al., 1999b). The scale is rated on a Likert-type scale ranging from 1 (*totally disagree*) to 7 (*totally agree*) (Beck et al., 2004). It has been previously tested within Northern Irish samples (Hyland et al., 2015) and was shown to have good validity and reliability. The PTCI was administered on three occasions during the treatment (Sessions 1, 6, and 9).

Igroup Presence Questionnaire (IPQ). Sense of presence is an indication of how "real" the environment is perceived to be by the user and as such may have a direct bearing on the exposure stimuli (Bystrom et al., 1999). Presence will be measured using the IPQ (Schubert et al., 2001). IPQ is a subjective measure of presence in VR with high validity and internal consistency ($\alpha = .85$) among virtual game players (Schubert, 2003). The questionnaire includes 14 items rated on a 7-point Likert scale ranging from −3 (*fully disagree*) to +3 (*fully agree*). This measure was given at the end of Session 4 (reliving) when the VR Photoscan environment was used for the first time.

Qualitative Data

A short, semistructured interview was conducted with the client approximately 1 week after the therapy had ended. The interview was 30 minutes in length and was audio recorded and transcribed verbatim. A topic guide was produced beforehand (Appendix A) and included the following: (1) general views on VR Photoscan environment; (2) ease of use; (3) benefits and caveats of using the technology; (4) potential improvements; and (5) quality and accuracy of trauma environment. Data were conceptualized in part using Braun and Clarke's (2006) Thematic Analysis technique, although given the single participant design, it was not analyzed beyond the semantic level (Braun & Clarke, 2006; 2021).

Results

Five of the 10 therapy sessions provided to Mr. A utilized VR Photoscan technology. PCL-5 scores dropped from 64 to 19 by Session 10, while PHQ-9 scores dropped from 18 to 2. See Table 2 for session-by-session overview.

Course of Treatment

Initial assessment was completed in January 2022 (described above) and psychometric scores were 64 (PCL-5), 18 (PHQ-9), and 113 (PTCI) with strong cognitions around self-blame and overgeneralized sense of danger. During the assessment meeting there was also an opportunity for Mr. A to ask questions regarding the use of VR Photoscan technology as part of the therapy. He provided both verbal and written consent that he

Table 2
Session by Session Psychometric Scores

Instrument	Score									
	Session 1			Session 4			Session 8			
PTCI Score	113			88			41			
IPQ				57						
Session Number	1	2	3	4	5	6	7	8	9	10
PCL-5	64	56	57	51	35	33	33	35	20	19
PHQ-9	18	18	17	12	13	7	8	3	3	3

was happy to take part. Below outlines the preexisting TF-CT protocol augmented with VR Photoscan technology.

Session 1: Psychoeducational Material (How the Body Responds When Threatened)

Psychoeducational materials were introduced with a focus on physiological responses to danger (fight/flight mechanism). There was also discussion regarding the relationship between thoughts, emotions, behaviors, and physiological reactions (Padesky, 1993) in relation to PTSD. While Mr. A appeared nervous throughout, he engaged well during this session. There was no discussion regarding the use of VR Photoscan during these early sessions and the standard TF-CT protocol was followed (Ehlers & Clark, 2000).

Session 2: Psychoeducational Material (Trauma Memory and Cognitive Model)

The "filing cabinet" analogy was used during Session 2 to discuss the trauma memory and Mr. A engaged in some flipchart work as part of a collaborative approach (Kuyken et al., 2011). A basic illustration of the TF-CT PTSD model was also introduced. Homework at the end of Session 2 was to complete a written narrative of the assault and identify any areas that are particularly painful or emotional (i.e., hotspots) (Grey & Holmes, 2008).

Session 3: Preparation for Reliving and Introducing VR Headset to Client

During this session Mr. A and the therapist reviewed the trauma narrative together. Further details of the event were collected and care was taken regarding the specifics of the trauma site and any objects (people or architecture) of perceived importance. Google Street view was also used to confirm the exact location of the trauma. The remainder of Session 4 was spent discussing the importance of the reliving activity (Session 4) and introducing the client to the VR headset (Meta Quest 2). The client tried the headset on during this session and was oriented to the controller functions. There appeared a mix of curiosity and apprehension when being introduced to the device; however, Mr. A did remark that being able to see and touch the headset in advance was useful. Homework was to continue to expand on the written narrative.

Building the virtual environment. The next day the therapist travelled to the trauma site (Figure 4) and captured images using a mobile phone camera (Samsung S21). This involved standing at the reported location of the trauma and taking pictures from six different angles (as if capturing the scene as the six sides of the inside of a cube). Additional images (n = 4) were taken of key objects (door, window and signs). Audio (2 minutes in length) was also recorded using the voice-recorder function on the mobile phone. The process took approximately 20 minutes to complete. Images and audio files were then uploaded into a secure cloud database to be accessed by the ProPeer Solutions to be used for the production of the virtual environment. It is important to note that no personal data regarding the traumatic event needed to be (or was) shared with the technology company. As such, they created the environment without any knowledge of what had occurred. The virtual environment was produced within 48 hours after initial upload, including the "safe space" environment, which was peaceful meadow/forest scene.

Session 4: Reliving in Virtual Reality

Before Mr. A arrived, the therapist preloaded the virtual environment so that when the headset was put on, Mr. A would arrive directly into the virtual safe space. The headset was cleaned prior to Mr. A's arrival and the therapist wore a mask and gloves when handling the headset. Mr. A's reliving session was 90 minutes in length. The rationale for reliving was explained again and Mr. A was given an initial 5–10 minutes to orient himself within the virtual safe space before verbally confirming that he was happy to continue. The therapist was able to observe the environment from Mr. A's perspective in real-time by using the "cast" feature on the Meta Quest 2 (see Appendix B) via a mobile device. Mr. A was shown that he could enter

Figure 4. VR Photoscan of Nightclub Environment (incl. safe space).

the trauma environment by tapping his wrist where a virtual wristwatch button was located in the virtual scene. He could also return to the safe space at any stage by tapping the watch again. It was noted that Mr. A's rate of breathing increased during this initial stage with some deep breaths being taking periodically. However, it was unclear if this was in apprehension of the VR experience or the IE process that he was about to undertake. An agreed end point of the trauma was again discussed and agreed before undertaking the reliving. Mr. A stated the end point was when he was in the ambulance, as he knew then he "was safe."

When entering the virtual trauma environment for the first time, Mr. A immediately stated he felt uncomfortable. His Subjective Unit of Distress score (SUDs) was reported as 10/10. Within 2 minutes, he decided to return to the safe space. After asking whether he would like to proceed, he decided to return and the reliving began in earnest. The VR-assisted reliving lasted approximately 30 minutes with a number of pauses taken throughout. The therapist recorded a number of potential hotspots (particularly when being choked and losing consciousness). Occasional prompts were used to guide Mr. A during reliving ("*What is happening? What is going through your mind? How do you feel?*"). Mr. A reported physiological symptoms associated with anxiety, which was also visibly observable during the VR exposure, including sweating, muscle tension, and acting fearfully. Before removing the headset, he spent a short period in the virtual safe space wherein anxiety symptoms started to reduce. Additional notes taken by the therapist while observing Mr. A navigate in the virtual environment stated that he kept his distance from the front door of the nightclub and turned his back at times. This was recognized in subsequent sessions by Mr. A as a form of avoidance. It was also noted that the virtual environment was much larger than the therapy space and therefore Mr. A could only move short distances before having to use joystick to go further. As homework, Mr. A was asked to listen to the audio-tape of this session. Finally, Mr. A was asked to complete the IPQ questionnaire immediately after the session (Table 3).

Sessions 5–7: Hotspots, Challenging Appraisals and Updating Trauma Memory in VR

Subsequent sessions included discussion of the various hotspots and appraisals and the therapist employed a number of standard TF-CBT techniques, such as a responsibility pie chart and conducting behavioral experiments. Interviews with martial arts experts in Brazilian jujitsu and judo were also used to describe different chokeholds, and the likelihood of dying during this type of attack, which helped Mr. A consider new information. Mr. A reappraised that his experience of being choked was similar to that of a "blood choke," where losing consciousness is the result of reduced blood flow. Thus, Mr. A acknowledged that

Table 3
Hotpots and Appraisals

Hotspots	Appraisal/Meaning	Belief Rating
Initial attack whereby I was struck with a glass bottle from behind	I could have prevented this	100%
	I let my guard down	90%
	I'm weak	80%
Being held by both arms and unable to defend myself	I'm useless and helplessness	80%
	No-one is coming to help me	80%
Being choked and slowly losing consciousness	I'm going to die	100%
	It's my fault	100%
	Nobody cares about me	90%
	I'm helplessness	80%

the risk of dying was significantly reduced compared to an "air choke," which affects oxygen supply. Beliefs that he was "going to die" reduced to 15% following this experiment. This decreased further after watching videos of UFC fighting matches where blood chokes were applied and remarking that (a) little medical attention (or urgency) was given to fighters afterwards and (b) once someone loses consciousness in an upright position they become "a dead weight" and therefore he would have fallen to the ground immediately and released from the chokehold. Beliefs subsequently dropped to 5% as Mr. A determined his life was no longer in danger during the trauma. A gradual reduction in PTSD symptoms accompanied these cognitive shifts as seen in other studies (Kleim et al., 2013).

When new information was revealed, and a belief rating subsequently decreased (e.g., "I am going to die" went from 100% to 20%), the updating of this memory was undertaken within the VR environment. This followed the same process as imaginal updating whereby the new information was inserted within the trauma memory through a focused reliving. In regards to the example above, Mr. A returned to the virtual environment and focused on the specific part of the memory where he was being choked and his eyes started to close. He then replaced the phrase/appraisal "I am going to die" with the new information he had learned in order to update the memory. In doing so, he was able to view the images of the trauma and simultaneously (verbally) overlay it with this new information. The process was repeated whenever a shift occurred in key appraisals until a new (updated) account of the trauma was established. While integrating reliving and cognitive restructuring can be difficult, Ehlers and Clark (2000, p. 339) state that by doing this "the nature of the trauma memory often changes . . . and the narrative tend[s] to become more coherent, [whereby] sensory components (e.g., smells, tastes, and vivid images) and motor components (e.g., involuntary movements) tend to fade and the memory loses its here and now quality and becomes more like a normal recollection."

Session 8: Stimulus Discrimination in VR

While Mr. A's psychometric scores had dramatically reduced (Table 2), he still reported being triggered while leaving the house (i.e., when near bars and restaurants and around people who were drunk). Connections were made with what was happening at the time of the trauma, and following Session 7, it was agreed that some stimulus discrimination tasks would be scheduled for the next session. Ehlers and Clark (2000, p. 341) note that reducing the probability of reexperiencing symptoms can be "achieved through better discrimination between those stimuli that occurred around the time of the trauma and those encountered currently." Mr. A permitted some updates to be applied to the VR environment to facilitate this.

By Session 8, the VR environment was updated with additional features that enabled Mr. A to add virtual humans into the environment using a trigger button that he controlled. Additional audio simulating the sounds of crowd noise and nightclub music was also added. Before entering the VR environment, the therapist explained traditional stimulus response techniques based around sensory information. Mr. A was introduced to a number of new smells (scented candles), tastes (mints), and real objects to touch (golf ball) in order to help him break the connection with the trauma memory when triggered. When in the virtual environment, he used one hand (controller) to move and the other hand to hold a scented candle or to eat a mint in order to ground himself.

As Mr. A entered the updated VR environment, he activated the "trigger" button and his SUDs scores rose to 8/10. He was encouraged to move his arms (breaking the feeling of being held) and smell the small scented candle. He reminded himself that he was now safe and was encouraged to repeat this phrase. In addition to trigger stimuli built into the trauma environment, Mr. A also had the ability to alter the environment to assist with breaking the link. This included the fact that his virtual watch now showed the current time and that Mr. A could now change the environment from night to day. Indeed, Mr. A remarked during Session 8 that the daytime "view" was less threatening. Mr. A spent approximately 20 minutes within this environment and his SUDs dropped to 3/10.

Session 9 and 10: Relapse Prevention and Site Visit

The therapy blueprint (i.e., what a client learned in the treatment; Ehlers & Wild, 2020) was completed to support relapse prevention. Moreover, Mr. A reflected upon how dramatic the changes in his life had been since undertaking therapy (he was now employed for the first time in 2 years and had started to socialize again). It was intended that the VR environment would be used on one further occasion in preparation for a site visit but Mr. A stated he felt adequately prepared and that he had visited the scene many times in VR and felt less daunted to do it in person. Mr. A visited the site of the trauma with the therapist and reflected on differences between then and now, as suggested by Murray et al. (2015).

Qualitative Outcomes

A short semistructured interview lasting 30 minutes was conducted with Mr. A approximately 1 week after therapy had concluded. Three main areas emerged during this discussion and are outlined below.

Treatment Effectiveness and Satisfaction

Overall, Mr. A appeared very satisfied with the VR Photoscan environment, although he recalled feeling very uncomfortable the first few times he used it: "*The first time using it sticks out it terms of how I felt . . . but I couldn't believe how much that prepared me for what was to come . . . I couldn't have done it [site visit] otherwise.*" Mr. A also commented on how "real" the environment felt and at times it felt like being "back there." He also suggested that at times he acted within the virtual space in a similar manner to what he would have done in "real life." For example, "*When I went from the forest [safe space] to front of the bar it felt real . . . I was thinking about that night again . . . I felt uncomfortable and nervous and didn't even want to stand close to the door . . . I kept backing away.*"

During the interview, Mr. A also commented on how he started to remember details of the trauma while in the environment—"*I remembered stuff that I didn't remember before . . . there were gaps in my memory and going back into VR environment seemed to help me with this.*" Mr. A stated that he was proud of the fact he was able to visit a bar after his site visit and felt fairly relaxed and credited the stimulus discrimination exercises within the VR environment for helping him with this. Finally, he stated that "*for people with similar trauma to me I think it would be helpful.*"

Ease of Use and Acceptability

The key objective of the study was to explore the acceptability of VR Photoscan technology as applied within a routine care setting. Mr. A did not report any difficulty using the headset, which he found quite intuitive. One barrier he did raise was the office space, which was smaller than the VR environment. This meant he mostly used the controllers when navigating rather physically walking around the room and having this movement reflected in VR. He did not feel this was a major issue for him as his trauma was mainly confined to a small area within the environment (doors and pillars at bar entrance). One interesting observation made by Mr. A was the speed at which VR environment was produced. He stated, "*When VR was mentioned I thought it was going to take weeks to set up as I'd only shown pictures [on Google Street view] the week before. . . it caught me by surprise to be honest.*" Finally, he noted that while he was new to VR, he did use a game console at home. It is possible that being familiar with playing video games and using the controllers may have helped him.

Quality and Design Within the Virtual Environment

Mr. A was also asked questions regarding the quality of VR Photoscan environment. He stated his preconceived ideas as follows: "*It would be like Minecraft characters running about and be all pixelated squares . . . but when I put it on it instantly felt real.*" He continued, "*There's enough quality there that your head will fill in the gaps . . . my mind was filling in the blank spots all over the place and to be honest once I was in the environment I really forgot where I was.*"

Interestingly, he also commented on the smaller details within the environment such as the behavior of virtual humans and background audio: "*The small details were really good . . . the . . . sounds and people with bottles in their hands.*" Mr. A also stated that the gradual approach taken, whereby additional details (people, crowd/bar noise) were added later in therapy, was very helpful: "*I did think if you had have included the trigger information the first time I used it then I would have had a panic attack. It was a good way to ease me in otherwise I might have been on the floor.*" Finally, the inclusion of a safe space was viewed as important as it allowed him to retain "*some level of control over the experience.*"

Discussion

This case study illustrates the application of VR Photoscan technology within a standard TF-CT protocol for the treatment of PTSD. To our knowledge, this is one of only a few studies to implement and adapt the more cognitively oriented Ehlers and Clark (2000) PTSD model for use with VR technology (Donat et al., 2017). There were no missed sessions and after 10 weekly meetings, Mr. A presented with clinically significant reductions in trauma symptoms, as evidenced through PCL-5 scoring, and no longer met the DSM-5 diagnostic criteria for PTSD. Looking back at this case study, a number of strengths and potential improvements can be highlighted: both regarding the use of VR Photoscan, as well as the case study approach. A clear strength of using VR Photocan was the fact that the VR environment assisted reliving by providing a more visceral experience of key hotspots and appraisals. Through this process, Mr. A was able to "link unconnected parts of the trauma experience, retrieve memories that were previously unavailable" and discriminate between then and now (Ehlers & Clark, 2000, pp. 339–340). However, it is important to take care to create an "accurate" representation of the scene of the trauma. Clients will have enough distortions and uncertainties in their trauma memories and do not need inaccurate images to add to the confused memory. Qualitative data also suggested the VR environment provided a more immersive context in which to prepare Mr. A for the site visit, which he thought he would not be able to do otherwise.

Additionally, the cast feature on the headset allowed for the gathering of additional information, as the therapist could see through the "eyes of the user." This led to later discussions regarding "avoidance" and how he behaved during the VR exposure (e.g., moving away from the site of the trauma, looking across the road, etc.). This cast feature is built into the headset and only requires a Wi-Fi enabled mobile phone, tablet, or computer.

While Mr. A reported feeling uncomfortable during the VR exposure, this was to be expected and provides further evidence of the ability of VR Photoscan to recreate real-world trauma environments. However, it also points to the importance of explanation and preparation for the client. For example, if a client dissociates there needs to be a clear, agreed-upon mechanism for withdrawing from the VR environment, similar to how we would use "grounding" techniques in standard application of TF-CT. Nonetheless, Mr. A reflected positively upon the overall experience and reported no issues, including motion sickness, with using or wearing the Meta Quest 2 headset (Bisso et al., 2020). The addition of the virtual safe space was also helpful: Mr. A was able to control his exposure to the trauma site and related triggers.

Finally, the feasibility of VR Photoscan within a routine community care setting was also explored in terms of implementation and cost. The VR Photoscan environment for Mr. A was created within 48 hours and was successfully implemented in place of standard imaginal exposure techniques. There were no disruptions to Mr. A's weekly treatment cycle while the environment was being developed. The resources required to conduct the case study were a Meta Quest 2 headset (RRP £400) and the software to build the environment (approx. £1000). While software development fees will remain a barrier for some, the production time of 48 hours will significantly reduce costs as compared with standard VR environmental builds. To our knowledge, this is one of only a handful of studies to implement VR technology within a local community mental health care setting without the infrastructural support of a specialist laboratory or research center.

Some potential improvements were noted in relation to the room setup, particularly when the VR environment is large. While this was somewhat mitigated by the use of hand controllers to navigate/move, it may be that additional presence and immersion could be gained if the client was able to walk freely around the space without the controllers. This would be particularly important for stimulus discrimination work, for example, if a client felt trapped and "paralyzed" during a trauma, to allow the therapist to prompt him to get up and move around in the present. These technologies may also be useful to assist with imagery work: we often create a scene to enable a victim of abuse to go back into the scene of the trauma as an adult and be assertive against a perpetrator of abuse.

Furthermore, despite the very rapid deployment of the virtual environment, manual labor beyond that of the therapist was still required. Further automatizing the development of these environment may help to further reduce costs and the threshold for clinicians to start making use of the technology.

While results from case reports can be highly biased and lack generalizability (Pannucci & Wilkins, 2010), there are a number of strengths within the current case report which are important to highlight. First, it used mixed methods data collection to provide a more comprehensive analysis of the data. Second, it provides a comprehensive, practical overview of the application of low-cost VR technology within a routine community mental healthcare setting. Third, it combines VR technology with a preexisting cognitive treatment protocol for PTSD, in a field that has largely used more behaviorally oriented approaches, such as prolonged exposure or exposure therapy (Best et al., 2020). Limitations include the case report design and the difficulty in isolating the added value of VR Photoscan to the treatment protocol. As such, the authors cannot definitively state that successful treatment outcomes were due to addition of VR technology. It is also unclear as to whether the trauma type (single incident) played a factor in treatment outcomes—further research would do well to explore this. The safe space created was a generic forest, not a client-specific place; this may limit its usefulness for some, and there is no follow-up longitudinal data to determine whether treatment effect was maintained. Finally, as the treating therapist conducted the posttreatment interview, this may have influenced the findings. As single-subject designs are inherently bias, all findings regarding feasibility and acceptability should be interpreted with caution.

Conclusion

In the current study, VR Photoscan was shown to be feasible as an added component within a cognitively oriented TF-CBT treatment protocol for PTSD. There was a high level of acceptability by the client and minor reported barriers in terms of ease of use. Initial evidence showed that PTSD symptoms reduced after 10 sessions of treatment, although further research is needed with larger samples to verify the overall effectiveness of this approach.

Appendix A. Interview Topic Guide

1. What are your initial thoughts about having a Virtual Reality based treatment?
2. What you see as the advantages of this treatment?
3. What do you see as the disadvantages of this treatment?
4. Who do you think would not find this treatment helpful?
5. What do you see as potential difficulties of using this tool?

Appendix B. Image of Client Wearing Meta Quest Headset

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