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Viewpoint

What is Diminished Virtuality? A Directional and Layer-Based Taxonomy for the Reality-Virtuality Continuum

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Abstract

The concept of reality-virtuality (RV) continuum was introduced by Paul Milgram and Fumio Kishino in 1994. It describes a spectrum that ranges from a purely physical reality (the real world) to a purely virtual reality (a completely computer-generated environment), with various degrees of mixed reality in between. This continuum is “realized” by different types of displays to encompass different levels of immersion and interaction, allowing for the classification of different types of environments and experiences. What is often overlooked in this concept is the act of diminishing real objects (or persons, animals, etc) from the reality, that is, a diminution, rather than augmenting it, that is, an augmentation. Hence, we want to propose in this contribution an update or modification of the RV continuum where the diminished reality aspect is more prominent. We hope this will help users, especially those who are new to the field, to get a better understanding of the entire extended reality (XR) topic, as well as assist in the decision-making for hardware (devices) and software or algorithms that are needed for new diminished reality applications. However, we also propose another, more sophisticated directional and layer-based taxonomy for the RV continuum that we believe goes beyond the mediated and multimeditated realities. Furthermore, we initiate the question of whether the RV continuum truly ends on one side with physical reality.

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KEYWORDS

reality-virtuality continuum; diminished virtuality; Apple Vision Pro; VR; virtual reality; reality-virtuality; mixed reality; augmented reality; XR; extended reality; taxonomy; classification; classifications; concept; concepts; conceptual

Introduction

The reality-virtuality (RV) continuum is a concept introduced by Paul Milgram and Fumio Kishino [1] in 1994. It describes a spectrum that ranges from a purely physical reality (the real world) to a purely virtual reality (VR; a completely computer-generated environment), with various degrees of mixed reality (MR) in between. This continuum is “realized” by different types of displays [2] to encompass different levels

of immersion and interaction, allowing for the classification of different types of environments and experiences. The RV continuum helps us understand the varying levels of immersion and interactivity that technology can provide. As technology advances, the boundaries between these immersion levels can become more fluid, and new hybrid experiences can emerge. The continuum is particularly relevant in fields such as VR, augmented reality (AR), and MR, where researchers and developers aim to create more compelling and natural

experiences that bridge the gap between the physical and virtual worlds. We used ChatGPT (OpenAI) [3] to gauge the current state of the RV continuum. According to ChatGPT, the continuum is often divided into several main categories (note,

we adapted the ChatGPT results and enhanced it with concrete examples, where necessary; [Textbox 1](#) [4]). The original ChatGPT transcript is shown in [Multimedia Appendix 1](#) [3].

Textbox 1. Main categories of the reality-virtuality continuum, modified from ChatGPT.

ChatGPT prompt:

- What is the reality-virtuality continuum?

Main categories (modified ChatGPT output):

- Physical reality (real environment): This is the state of the unmediated physical world, where all sensory perceptions are naturally experienced without any technological augmentation.
- Augmented reality (AR): In this category, virtual elements are overlaid onto the real world. AR enhances the user's perception of the physical world by adding computer-generated visual, auditory, or haptic information. Examples include smartphone apps that display digital information on top of real-world views, such as Pokémon GO [5].
- Mixed reality (MR): MR environments combine virtual and physical elements in a way that allows them to interact in real time. Users can manipulate both virtual and real objects, and the distinction between the 2 can be blurred. Microsoft's HoloLens is an example of an MR device that enables users to interact with holographic objects in their real-world environment [6].
- Virtual reality (VR): In VR, users are completely immersed in a computer-generated environment that can simulate various sensory experiences. VR typically involves the use of head-mounted displays and other input devices to provide a sense of presence within the virtual environment [7]. Prominent examples are the HTC Vive and the Meta Quest.
- Augmented virtuality (AV): This term is less commonly used than the others. It refers to scenarios where real-world elements are brought into a virtual environment. For example, capturing real objects or people and placing them into a virtual space. The Varjo XR-3 is capable of providing such a function and is able to make a video stream into the virtual world (VR). A concrete example could be showing a video stream of the (real) smartphone in VR, so the user can answer a text message without actually leaving VR (removing the headset and thus breaking the illusion being in "another world," the simulated virtual environment).

Diminished Reality

What is often overlooked in this concept is the act of *diminishing* real objects (or persons, animals, etc) from reality, rather than *augmenting* the reality with virtual things [8,9]. An introduction to the topic can be found in Cheng et al [10]. A reason for this is that diminishing something from reality needs, in general, a sophisticated understanding of the real scene or environment to make the *diminishing* aspect convincing. In AR, the real world is *just* overwritten with a virtual object. In diminished reality (DR), however, the real-world part that is *augmented* or *diminished* needs to seemingly *fit* to the reality around it. In addition, this should all be performed in real time when a user is walking around the real world, and an algorithm has to do the following (note that the first 3 items are part of the Extent of World Knowledge axis of the taxonomy by Milgram and Kishino [1]):

- Detect and track the real object that has to be removed or diminished;
- Perform geometric modeling of the scene and objects to be added or subtracted (preexisting or captured once or in real time);
- Apply the lighting model of the scene to objects added or to part of the revealed scene when something is removed (preexisting or captured once or in real time); and then
- Combine all the previous points together as the scene description for the rendering algorithm.

All of this has to be done not only in real time but also with very high precision. The inserted virtual object has to fit seamlessly into and make sense with the reality; minor

discrepancies will appear to be a glitch and will be noticed immediately by the user, as we recently observed in a DR user study [11]. In fact, we think that diminution and augmentation require fundamentally different technologies. In our opinion, an augmentation may be needed to alter reality at a certain position with regard to other (real) objects (eg, displaying a patient's tumor as an AR hologram on the patient in front of you, at the real position, such as for needle guidance [12]), but no seamless and semantic fitting is necessary. As soon as a virtual object needs to fit into the scene semantically, we consider this to require diminution. Hence, for augmentation, you *only* need a volume rendering process with some basic options, such as position, size, and transparency. For diminution, however, additional fundamentally different technologies are needed. The scene has to be analyzed and *understood*, and a meaningful replacement has to be generated and *inserted* as an AR hologram. An example could be glasses that are *removed* from a person in front of you.

In summary, the user has to get the impression that the real, diminished object does not exist at all in reality [13]. Besides sophisticated algorithms, this course of action needs a considerable amount of computing power. Fortunately, there has been tremendous progress in both areas during the last years, with deep learning-based approaches and GPUs that can run these kinds of algorithms, even in real time. As a result, DR has already found its way into some applications [5], such as virtual furniture removal for redecorating purposes (eg, IKEA Kreativ [14]). Other possible applications for DR include the following:

- Privacy enhancing: In a live video feed, certain objects or information can be blurred or removed in real time to protect sensitive or private data.
- Training and education: DR can be used to remove distractions in a learning environment or highlight specific items to focus on.
- Therapeutic applications: For someone with a phobia of spiders, a DR system could recognize spiders in the person's field of view and diminish or replace them with less threatening images to reduce anxiety. Additionally, sensory overload, a feature of autism, could be diminished with a DR system, to reduce overstimulation.

Directional and Layer-Based Taxonomy

Nevertheless, for all these aforementioned reasons, we think that DR needs to be more prominent on the RV continuum, as shown in [Figure 1 \[15\]](#), without delving deeper into the broad topics of mediated reality [9] or even multimediated reality [16]. This will not only assist in the decision-making for hardware (devices) and software that are needed for new DR applications but also help unfamiliar users to get a better understanding of the entire extended reality (XR) topic (note that we are addressing this revision to the continuum purely from an application or user point of view [POV], not from the POV of an MR researcher or engineer). An example application for DR could be the real-time anonymization of a face via XR. There is a huge difference if a device detects the eye area and *simply*

inpaints a black bar over the eyes (without considering the surrounding facial area) or inpaints the eyes with *different* or *meaningful* ones that fit perfectly to the surrounding facial area. The black bar approach can probably be performed on a current smartphone, whereas the second approach needs much more sophisticated hardware and computing power, with an integrated GPU that can run a trained, deep inpainting neural network in real time (note that a user with an XR headset would move around in general, which also changes the POV on the face to be anonymized, so the inpainting algorithms also has to be executed continuously in real time). In this context, we also think that the upcoming Apple Vision Pro will push the limits in DR, because it is a video-see-through device that can enable DR to reach its full potential [17]. In fact, the *Digital Crown* hardware of the Apple Vision Pro, which also exists for the Apple Watch, should enable us to seamlessly *walk* along the whole RV continuum (back and forth) and bring medical DR applications to reality, which are still almost nonexistent currently [18]. A potential example of the photo-editing capabilities of newer cell phones as a diminution operation is shown in [Figure 2 \[15\]](#). In this medical example, DR enables the *removal* of a skin tumor virtually from a patient's face before surgery.

Diminished virtuality (DV), however, remains a curiosity, and not even ChatGPT—which has been fed with 300 billion words from books, web texts, Wikipedia, articles, etc [4]—can handle this term as of January 2024 ([Textbox 2](#); the original ChatGPT transcript is shown in [Multimedia Appendix 2 \[3\]](#)).

Figure 1. An updated reality-virtuality continuum where “diminishing” is more prominent to ensure a better understanding. The figure shows a real operation room (OR), which is “real” in the two left columns and computer-generated in the two right columns. In “reality,” a real physician is standing inside an OR without any computer-generated objects. In “augmented reality,” the real physician wears extended reality (XR) glasses in the OR and looks at a computer-generated skull of the patient to be treated. In “augmented-diminished reality,” the real OR table has been removed (but also note that the computer-generated skull is not visualized). On the right side is “virtuality,” that is, virtual reality (VR), where a computer-generated OR with a table and a skull are shown in VR (to a user wearing VR glasses). In “augmented virtuality,” the real physician is shown inside the VR OR. In “augmented-diminished virtuality” (ie, mediated virtuality), the computer-generated OR table is removed, but note that the real physician is still shown. In “diminished virtuality,” the OR table has been removed, but the real physician is also not shown. The “augmenting-diminishing” continuum shows the degree of augmentation and diminution (note that this does not apply for “reality” and “virtuality”). Scenarios where a diminution happens belong to “disrupted reality.” The images within the figure were generated by DALL-E 3 (OpenAI) [15] and then further modified by the authors.

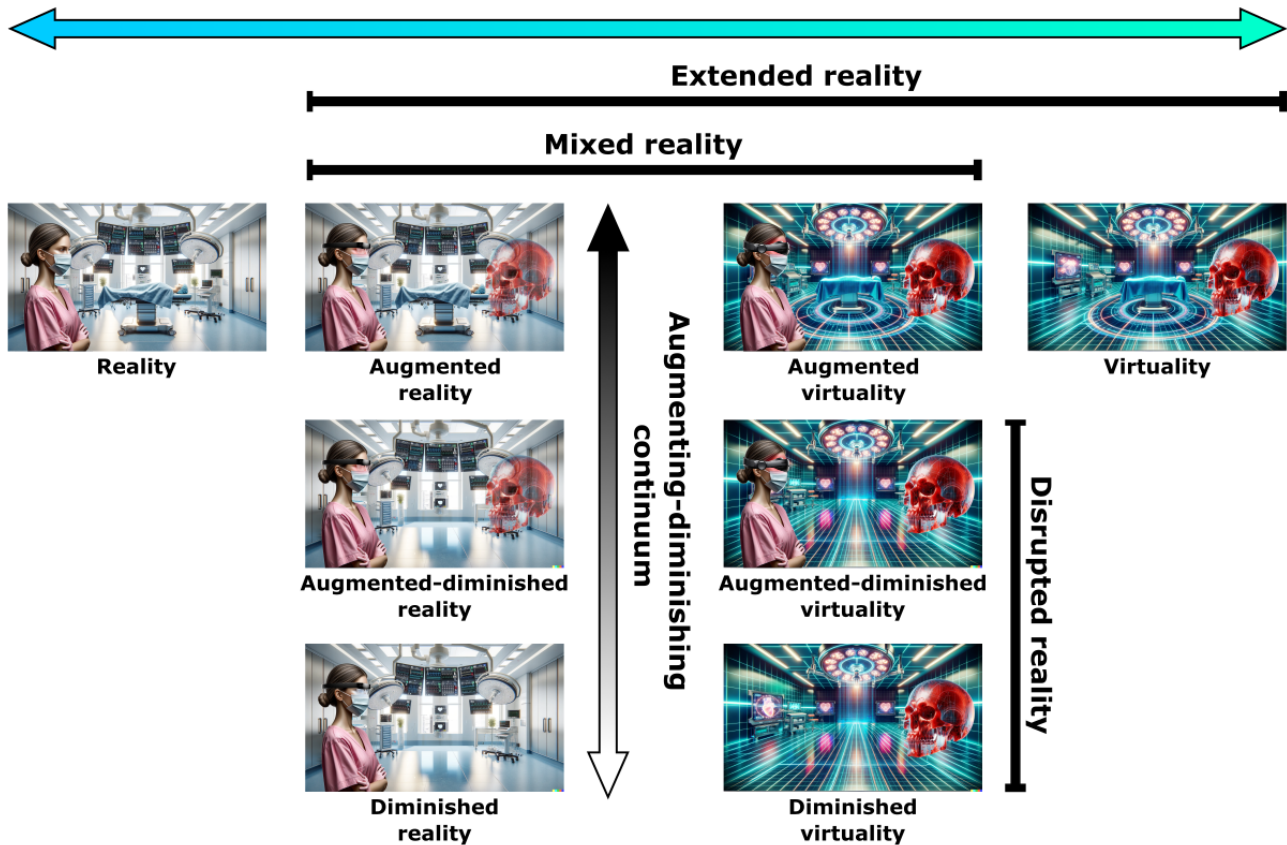


Figure 2. An example of the photo-editing capabilities of newer cell phones as a diminution operation, enabling the “removal” of a skin tumor virtually from a patient’s face before surgery. This figure was generated by DALL-E 3 (OpenAI) [15] and then further modified by the authors.



Textbox 2. Asking ChatGPT about “Diminished Virtuality” (as of January 2024).

ChatGPT prompt:

- What is “Diminished Virtuality”?

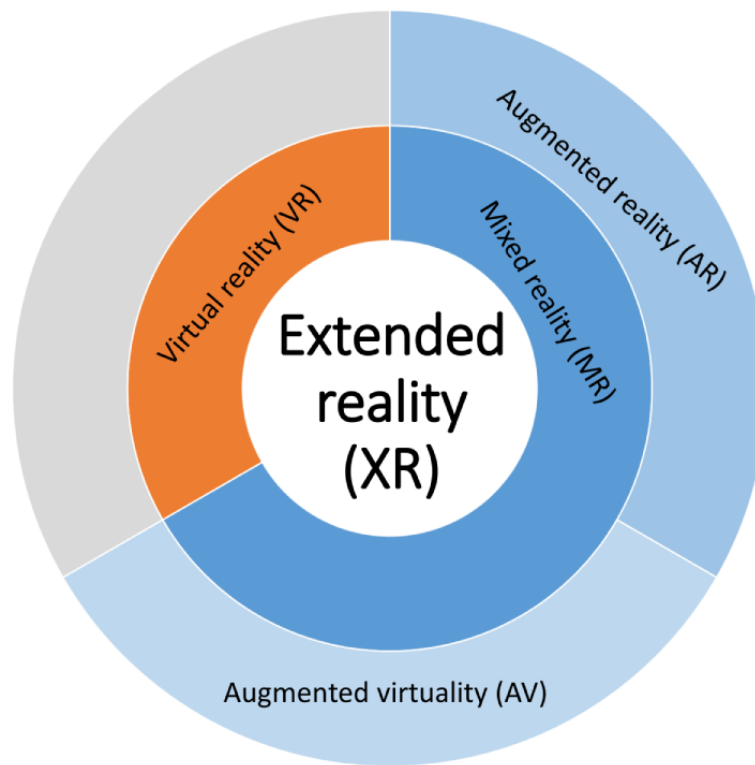
ChatGPT output:

- “Diminished Virtuality” is not a widely recognized term or concept as of my last knowledge update in January 2022. It’s possible that this term has been coined or introduced in a specific context or field after that date, or it may be a term used in a niche or specialized area that is not widely known.
- If you have more context or information about where you came across this term or its usage, I would be happy to try to provide more information or insight based on that context.

DV can perhaps be best imagined as starting on the extreme right side on the RV continuum, which contains only virtual objects (virtual environment and VR), and going along the continuum toward the left to reach diminished virtual elements (see the figure of the RV continuum by Iriqat and Vatansever [19], and note that this is especially of interest for computer-generated structures that are very complex and where only some parts need to be diminished). This should be possible with the *Digital Crown* hardware of the Apple Vision Pro: when fully immersed, the virtuality is reduced to make the real world partly visible. Apple describes scenarios where people might want to increase the pass-through when they intend to interact with a nearby physical object or read text on another device. Another real-world scenario could be a so-called tumor board meeting that is held in VR, where several experts from around the world gather to discuss a rare case and certain virtual elements (images, texts, etc) are diminished because of privacy issues (note that the mixture of reality here is also modifiable): an externally tuned-in expert (who is traveling) can see certain patient information because he or she belongs to the clinic where the patient is located, whereas another externally tuned-in expert who does not belong to the clinic of the patient should not see or hear certain patient information. However, the full potential of DV would unfold when the virtuality is diminished in a way that also fits with the upcoming reality. An example would be a real-world person showing up in VR between virtual objects. Imagine layers of virtual and real context stacked up but still seamlessly interplay with each other for the final output. In fact,

this layer-based concept could also extend to mediated and even multimeditated realities, where, for example, different sounds (real and virtual) interplay with each other, depending on their location and *depth*. “Enaudio” (the “hearing” equivalent to envision) hearing real rain outside in the real world that are mixed with virtual sounds while inside a virtual room. Real and virtual input from different senses could also be mixed; for example, there is a (virtual) hole in the VR room and the (real) rain falls inside this virtual room, generating simulated sounds as they hit virtual objects in the VR room. The same also works for outputs and their combinations; for example, the real voice from someone wearing the headset is mixed with virtual sounds, or real smells are mixed into VR by generating the corresponding virtual objects there. Finally, some could argue whether the RV continuum really ends on *one side* with physical reality [20], because the brain creates reality—comparable to a head-mounted display creating VR—but does not detect it. This could be discussed and explored by the community in the future, and in this regard, we want to propose a diagram of XR that loops back (as opposed to a continuum on a straight line with 2 ends) as an inspiration (Figure 3). In summary, XR is a niche yet growing topic, because more and more consumer devices with better hardware have become available during the last few years. In parallel, artificial intelligence (AI)-based algorithms have made 1 breakthrough after another, which can, for example, be explored to develop novel applications for an intelligent health care metaverse [21].

Figure 3. The extended reality (XR) continuum with its subsections (virtual reality [VR], mixed reality [MR], augmented reality [AR], and augmented virtuality [AV]) folded in an outside-in fashion with a circular representation.



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Conflicts of Interest

BP is an associate editor of the *Journal of Medical Internet Research*. The other authors have no conflicts of interest to declare.

Multimedia Appendix 1

Asking ChatGPT about "the reality-virtuality continuum."

[[PNG File , 303 KB - xr_v1i1e52904_app1.png](#)]

Multimedia Appendix 2

Asking ChatGPT about "diminished virtuality."

[[PNG File , 212 KB - xr_v1i1e52904_app2.png](#)]

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Abbreviations

- AI:** artificial intelligence
- AR:** augmented reality
- AV:** augmented virtuality
- DR:** diminished reality
- DV:** diminished virtuality
- MR:** mixed reality
- POV:** point of view
- RV:** reality-virtuality
- VR:** virtual reality
- XR:** extended reality

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Review

Barriers and Facilitators to the Implementation of Virtual Reality Interventions for People With Chronic Pain: Scoping Review

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Abstract

Background: Chronic pain is a growing health problem worldwide with a significant impact on individuals and societies. In regard to treatment, there is a gap between guideline recommendations and common practice in health care, especially concerning cognitive and psychological interventions. Virtual reality (VR) may provide a way to improve this situation. A growing body of evidence indicates that VR therapy has positive effects on pain and physical function. However, there is limited knowledge about barriers and facilitators to the implementation of VR interventions for people with chronic pain in health care settings.

Objective: The aim of this study was to identify and analyze the barriers and facilitators involved in implementing VR interventions for people with chronic pain.

Methods: We conducted a scoping review of the German and English literature using the MEDLINE, Cochrane Central Register of Controlled Trials, CINAHL, PEDro, LILACS, and Web of Science (inception to November 2023) databases, including quantitative, qualitative, and mixed methods studies reporting barriers and facilitators to the implementation of VR interventions for people with chronic pain, as reported by patients or health care professionals. Two reviewers systematically screened the abstracts and full texts of retrieved articles according to the inclusion criteria. All mentioned barriers and facilitators were extracted and categorized according to the Theoretical Domains Framework (TDF).

Results: The database search resulted in 1864 records after removal of duplicates. From the 14 included studies, 30 barriers and 33 facilitators from the patient perspective and 2 facilitators from the health care professional perspective were extracted. Barriers reported by people with chronic pain were most frequently assigned to the TDF domains environmental context (60%) and skills (16.7%). Most facilitators were found in three domains for both the patients and health care professionals: beliefs about consequences (30.3%), emotions (18.2%), and environmental context (18.2%).

Conclusions: The findings of this review can inform the development of strategies for future implementations of VR interventions for people with chronic pain. Additionally, further research should address knowledge gaps about the perspective of health care professionals regarding the implementation of VR interventions for people with chronic pain.

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KEYWORDS

virtual reality; VR; chronic pain; implementation science; scoping review; barriers; facilitators

Introduction

Chronic pain is defined as persistent or recurrent pain lasting longer than 3 months [1]. Chronic pain is an increasingly prevalent health condition worldwide, as three of the primary

contributors to years lost to disability in recent decades are chronic pain conditions (back pain, musculoskeletal disorders, and neck pain) [2,3]. Estimated pooled prevalence rates for chronic pain in adults vary across studies from 20.5% in the United States [4] to 28.3% in Germany [5], 34% in the United

Kingdom [6], and 48.1% in Chile [7]. High prevalence of chronic pain is not only found in industrial nations but also in low- and middle-income countries, where the prevalence ranges from 13% to 49.4% [8]. Chronic pain affects not only adults but also has a significant prevalence in children, adolescents, and young adults, ranging from 8% to 23% [8-10]. Common consequences of chronic pain include physical disability, psychological distress, and reduced quality of life [3,11]. Furthermore, chronic pain affects relationships and self-esteem and is associated with higher rates of divorce and suicide [12,13]. From a societal perspective, chronic pain places an enormous financial burden on health care systems. In Australia, the financial costs associated with chronic pain were estimated to be ~US \$57.1 billion in 2018 [14]. In the United States, the Institute of Medicine estimated that the annual cost of chronic pain, including medical costs and lost productivity, was US \$560 billion to US \$635 billion in 2010 [15]. In Germany, chronic pain was estimated to cost at least US \$63.7 billion annually [16]. At the same time, the care situation for people with chronic pain is characterized by a shortage of health care specialists, resulting in an inadequate supply of treatments [17], particularly of psychotherapy [18]. In contrast, the guidelines for chronic pain explicitly recommend interdisciplinary multimodal pain management, including cognitive and psychological interventions [19].

Virtual reality (VR) is a relatively new nonpharmacological modality to help people suffering from chronic pain, which can also help to improve the care situation [20]. VR treatment for people with chronic pain includes VR games, mindfulness-based interventions, practical exercises, and visual illusions [21]. A meta-analysis showed large effects of VR interventions on pain (standardized mean difference [SMD] 1.6, 95% CI 0.83-2.36) and body functioning (SMD 1.4, 95% CI 0.13-2.67) in people with chronic pain [21]. Although the mechanisms underlying the observed benefits of VR for chronic pain are not yet fully understood, distraction of the patient and embodiment have been discussed as possible explanations for changes in outcomes [20]. Distraction is based on the limited capacity of people to simultaneously attend to different stimuli [22]. It is assumed that attention that would normally be focused on pain is redirected to the VR experience, thereby reducing or eliminating the perception of pain [23]. Embodiment describes the experience of the virtual body in virtual space and can lead to a change in the perception of the physical body and the body matrix, which can have a positive effect on pain perception and physical activity in people with chronic pain [24]. Other mechanisms, including the gamification of exposure to feared movements through the VR [25] and accelerated time perception in VR [26], have also been proposed to have an influence on chronic pain.

VR can therefore be seen as a promising therapeutic option for people with chronic pain. However, there has been no large-scale implementation of this technology in the health care of people with chronic pain. Previous research has shown that organizational structures and the VR technology itself are barriers to the implementation of VR interventions in various health care settings [27-29]. Regarding the use of VR in physiotherapy, due to technical limitations, lack of protocols

for VR interventions, and patient-related factors, VR itself seems to be the main barrier [30]. Conversely, staff and health care professionals may act as facilitators, as they reduce the anxiety of new technologies and can change patients' attitudes toward VR. Health care professionals are also generally interested in using VR in rehabilitation [28-30]. However, people with chronic pain are a group with unique characteristics and diverse impairments, as they may experience pain-related fears and fear of movement, and often have maladaptive coping strategies, mental disorders such as depression or anxiety [31], or cognitive impairments [32]. Since these factors may influence the implementation of VR interventions, it is essential to identify barriers and facilitators for this population in using VR to derive a targeted implementation strategy.

A systematic implementation strategy is necessary to enable large-scale successful implementation and use of VR interventions for people with chronic pain. This requires a comprehensive review of all known barriers and facilitators. The Theoretical Domains Framework (TDF) offers an approach to systematically examine barriers and facilitators toward the development of an implementation strategy [33]. The TDF is an implementation framework for behavioral change that incorporates 128 theoretical concepts derived from 33 different behavior change theories and organizes them into 14 domains into which the barriers and facilitators can be classified [33]. The findings gained in this way can be used to support implementation efforts. For example, this approach was used to support the implementation of stratified care for people with nonspecific low back pain in Canada [34], and was also used to inform the development and implementation of digital tools in a bariatric surgery service [35].

Therefore, the aim of this scoping review was to systematically identify and categorize barriers and facilitators to the implementation of VR interventions for people with chronic pain. The identified barriers and facilitators will provide a basis for recommendations for the successful integration of VR interventions into clinical practice, future development of VR interventions, and future implementation studies in the field of chronic pain management.

Methods

Study Design and Registration

A scoping review was conducted to comprehensively search and synthesize the published literature on barriers and facilitators reported by patients and health care professionals in implementing VR interventions for the treatment of people with chronic pain. The methodological background for this scoping review is based on the five steps outlined by Arksey and O'Malley [36] and the methodological guidance for conducting scoping reviews published by the Joanna Briggs Institute [37]. Reporting follows the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews) guidelines; the PRISMA-ScR checklist can be found in [Multimedia Appendix 1](#) [38]. The scoping review was registered with the Open Science Framework [39].

Search Strategy, Eligibility Criteria, and Selection of Evidence Sources

A database-specific literature search was conducted in the electronic databases MEDLINE (through PubMed), Cochrane Central Register of Controlled Trials, CINAHL, PEDro, LILACS, and Web of Science on November 1, 2022. A search strategy was developed using the keywords “chronic pain,” “virtual reality,” and “implementation.” The detailed search string for each database can be found in [Multimedia Appendix 2](#). Additionally, one reviewer (AE) screened the reference lists of the included studies.

The search results were combined and uploaded to CADIMA, a web application that assists in conducting and documenting the evidence synthesis process [40], which we used for the selection process. After removing duplicates, two authors (AE and ML) independently screened the titles and abstracts of identified publications.

The initial inclusion criteria for publications were: (1) use of quantitative, qualitative, or mixed method study designs; (2) involves people with any type of chronic pain; (3) the treatment was a VR intervention; (4) published in the English or German language; and (5) reported implementation outcomes. The exclusion criterion was studies involving children (aged <18 years).

Two reviewers (AE and ML) tested the inclusion and exclusion criteria by screening the titles and abstracts of a random sample of 25 publications to ensure consistent use. If agreement was below 75%, the criteria were adjusted [41]. After title and abstract screening, the reviewers (AE and ML) discussed refining the criteria for full-text screening. As a result, the criterion to include only studies that specifically reported barriers or facilitators as reported by patients or health care professionals as implementation outcomes was added. Barriers were defined as any factors that inhibit or negatively influence patients' use of a VR intervention. Facilitators were defined as all factors that enhance or positively influence patients' use of a VR intervention. Barriers and facilitators had to be self-reported by patients or health care professionals. The two reviewers (AE and ML) independently screened the full texts. Disagreements throughout the review process were resolved by discussion between the two reviewers.

Data Charting Process

One reviewer (AE) extracted the data into a custom data template created for the purpose of this scoping review (see

[Multimedia Appendix 3](#)). A second reviewer (ML) reviewed all extracted data and commented on discrepancies, which were resolved through discussion. We extracted study characteristics (title, authors, year of publication, design, population, and sample size), intervention characteristics (setting, type of intervention), and barriers and facilitators (separately for patients and health care professionals). From qualitative studies, all barriers and facilitators reported by patients or health care professionals were extracted. For quantitative studies, barriers and facilitators were extracted if $\geq 50\%$ of participants agreed that this factor had an influence on the implementation of VR interventions [42].

Collating, Summarizing, and Reporting

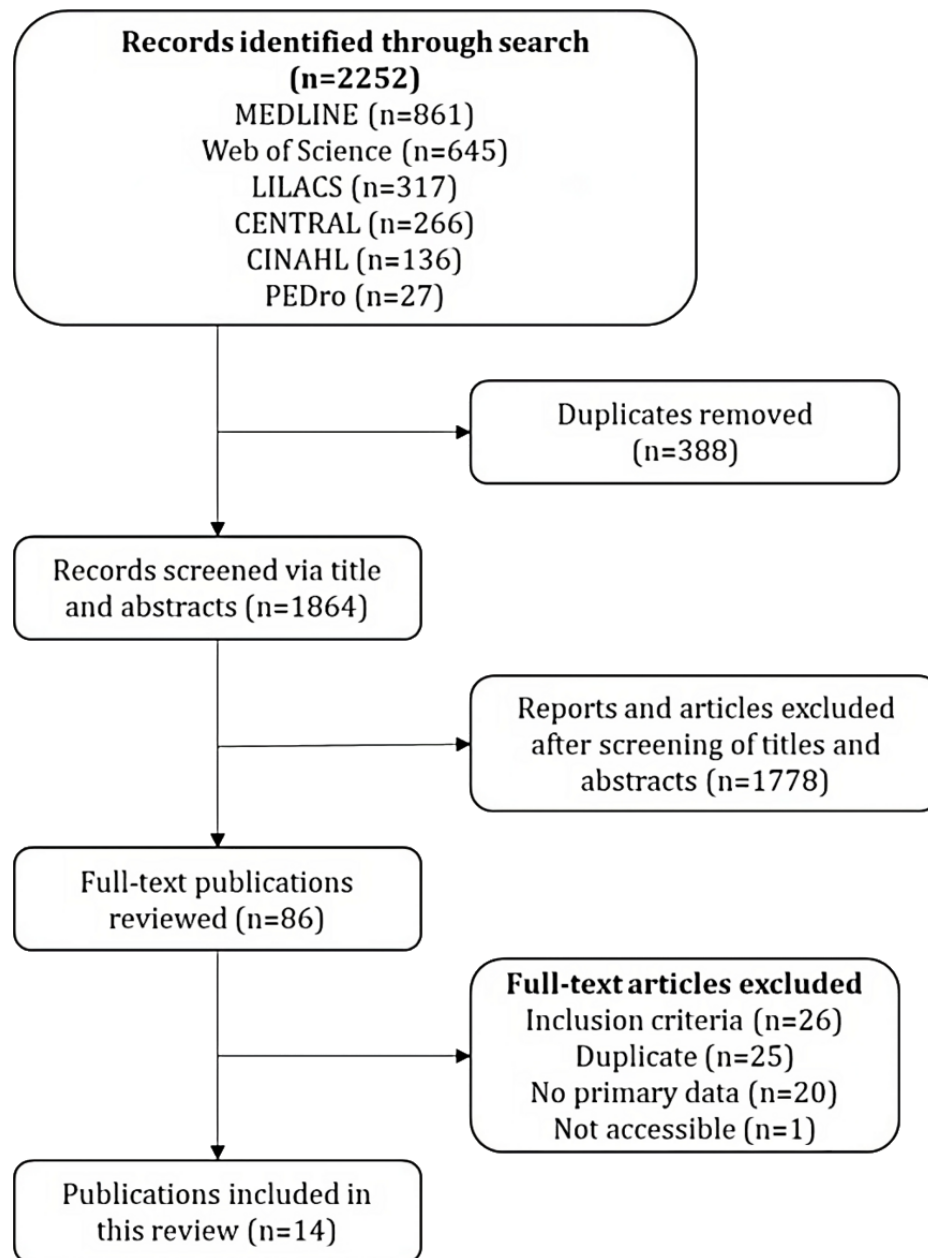
The resulting data were transferred into MAXQDA Plus 2022 (VERBI software, 2021) to code and categorize the barriers and facilitators separately for patients and health care professionals according to the domains of the TDF (see [Multimedia Appendix 4](#)). After coding of the barriers and facilitators by two reviewers (AE and ML), inconsistencies were resolved through discussion. Extracted barriers and facilitators could be categorized in more than one domain.

After evaluation of the number of barriers and facilitators assigned to each domain of the TDF, separately for patients and health care professionals, the most common barriers and facilitators were analyzed to determine underlying themes.

Results

Study Selection

The database search resulted in 2252 publications. After removal of 388 duplicates, 1864 titles and abstracts were screened. Of those, 86 publications met the inclusion and exclusion criteria and were subject to screening of the full text. Among these 86 publications, 72 were excluded because they did not meet the inclusion criteria, were duplicates, did not provide primary data, or were not accessible. Duplicates occurred again in the screening of full texts because the initial removal of duplicates before the screening of titles and abstracts was based solely on the DOI. However, some publications were not recognized by CADIMA in this step due to missing DOIs. Finally, 14 studies were included in the qualitative analysis. The entire selection process is shown in the PRISMA-ScR flowchart in [Figure 1](#).

Figure 1. Flowchart of search and screening results.

Description of Included Studies

Of the 14 studies, there were 8 mixed methods studies [43-50], four qualitative studies [51-54], and two quantitative studies [55,56]. All studies reported barriers and facilitators from the patient perspective, whereas one study also reported barriers and facilitators from the health care professional perspective [53]. The included studies were published between 2013 and 2022, with 9 studies published in 2020 or later [43-46,51-53,55,56]. The sample size of the studies ranged from 7 [49] to 84 [50] participants, with the mean age ranging from 35.86 [49] to 81.85 [55] years. The studies included various VR interventions such as a 5-minute nature relaxation video [46], physically active tasks [43], and specifically developed interventions with guided exercises for focused attention and open awareness [50]. For more information on the

characteristics, study settings, and VR interventions of the included studies, please refer to [Multimedia Appendix 5](#) [43-56].

Overview of Identified Barriers and Facilitators

A total of 65 barriers and facilitators were identified. Among these, there were 30 (46%) barriers and 33 (51%) facilitators from the patient perspective and 2 (3%) facilitators reported from the health care professional perspective. All identified barriers and facilitators are summarized for each TDF domain in [Multimedia Appendix 6](#).

Barriers From the Patient Perspective

The 30 barriers identified from the patient perspective were categorized into six different TDF domains ([Table 1](#)). The other eight TDF domains did not address the barriers identified from the patient perspective.

Table 1. Barriers and facilitators from the patient perspective assigned to Theoretical Domains Framework (TDF) domains.

TDF domains	Barriers (n=30), n (%)	Facilitators (n=33), n (%)
Environmental context and resources	18 (60)	6 (18)
Skills	5 (17)	1 (3)
Memory, attention, and decision processes	2 (7)	0 (0)
Emotion	2 (7)	6 (18)
Beliefs about consequences	1 (3)	10 (30)
Reinforcement	0 (0)	4 (12)
Knowledge	0 (0)	2 (6)
Behavioral regulation	0 (0)	2 (6)
Optimism	0 (0)	1 (3)
Beliefs about capabilities	0 (0)	1 (3)

One of the two most important domains was the *environmental context and resources* (ECR) domain, which included the most barriers from the patient perspective. Three main themes emerged (Table 2). The first was related to the VR devices themselves, with barriers such as the devices being too heavy, too expensive, not detecting all movements, and problems when people with chronic pain were wearing glasses. Furthermore, insufficient support during implementation was perceived as a barrier. The second theme was that the VR software made people with chronic pain feel sick or caused more pain. In addition,

the tutorial of the software was considered to be too difficult. Finally, notable events included technical problems, problems with use due to physical impairments, and patients being in too much pain to use.

Within the domain *skills*, we identified two main barrier-related themes: (1) gaming skills, as the software was too difficult to use and patients without previous experience in playing video games had difficulties controlling the game; and (2) other skills, in which the main barrier was language if the patient's first language was not the same language as that used in the software.

Table 2. Main barrier-related themes from the patient perspective according to Theoretical Domains Framework domains.

Themes	Quote/description	References
Environmental context and resources		
VR ^a devices	"A negative factor was that the VR glasses were heavy to wear"	Glavare et al [45]
VR software	"Yeah, that would really have to be under guidance, yeah. [...] So they [peers] wouldn't be able to do it alone"	Stamm et al [52]
Notable events	"I've got really bad arthritis too at the moment so holding onto those [hand controls] was an issue"	Kelly et al [51]
Skills		
Gaming skills	"I had some trouble figuring out which controls to use to move around so um I've never played computer games before and maybe that had something to do with it. I felt like a total idiot totally frustrated and not able to catch onto what to do"	Garrett et al [48]
Other skills	The exceptions were those whose first language was not English and who described difficulties in understanding game instructions	Tuck et al [43]

^aVR: virtual reality.

Facilitators From the Patient Perspective

The 33 facilitators were assigned to nine different domains of the TDF (Table 1). No facilitators were assigned to the other five domains of the TDF.

The most frequently identified facilitators were categorized in the domain *beliefs about consequences*. A closer look at this domain revealed the following three main themes: (1) positive expectations in regard to therapy effects, (2) the VR interventions are helpful for rehabilitation, and (3) the VR

interventions support doing therapy regularly (Table 3). Among the positive expectations for treatment effects, pain, feelings of anxiety and depression, as well as expectations that VR interventions are superior to conventional therapy were mentioned as facilitators. VR interventions were reported to be helpful for rehabilitation because they improved the mood, well-being, and concentration of people with chronic pain. Similarly, people with chronic pain stated that using VR interventions would increase their adherence with the health behavior and that they would use it on a regular basis.

Table 3. Main facilitator-related themes from the patient perspective according to Theoretical Domain Framework domains.

Themes	Quote/description	Reference
Beliefs about consequences		
Positive expectations	“I had really high hopes...I thought it might actually take my pain away”	Tuck et al [43]
Helpful for rehabilitation	“I’ve taken opiates for 40 years and they don’t work as well as what the virtual reality did”	Kelly et al [51]
Increase adherence	“Especially in the future, you could have thousands of different situations that you could immerse yourself in, for as much time as you want in the day”	Garrett et al [53]
Environmental context and resources		
VR ^a devices	Several participants noted that flexibility in the position of use and brevity of time in the experience had helped manage or entirely avoid such discomfort: “I’m not in as much pain when I’m seated as when I’m standing, so it was quite easy for me to do the movements”	Kelly et al [51]
Supervising therapist	“I think it makes you feel better that it’s a trained physiotherapist. You knew they had that background and it just fills you with confidence a bit more”	Tuck et al [43]
Gamification	“Positive factors were that VR added a dimension of playfulness and gaming to the exercise”	Galavare et al [45]
Emotion		
Fun and enjoyment	The competition against the computer opponents increased engagement and several participants mentioned the feeling of satisfaction they got when they performed well	Mortensen et al [54]
Novel and unknown experiences	“you’re enjoying yourself, you can do things you’ve never experienced before, obviously you’re going to do it”	Kelly et al [51]

^aVR: virtual reality.

One of the second most frequently identified facilitators was ECR, with three main themes: (1) VR devices, (2) a supervising therapist, and (3) gamification. The VR devices serve as a facilitator because they are simple to use for people with chronic pain, easily adjustable, and can be used in different positions. Similarly, a supervising therapist is considered to facilitate the implementation of a VR intervention. The gamification of therapy through VR interventions was also perceived as a facilitating factor by people with chronic pain.

The second most frequently identified facilitator was classified under the *emotion* domain of the TDF. Within this domain, two main themes were derived: (1) fun and enjoyment, in which people with chronic pain reported that VR interventions triggered positive emotions and evoked a high level of satisfaction; and (2) novel and unknown experiences that the people with chronic pain are not able to experience in the real world.

Facilitators From the Health Care Professional Perspective

Only two facilitators from the health care professional perspective were identified, which were assigned to the domains *ECR* and *beliefs about consequences*. Health care professionals indicated that the opportunity to be with the patient during the VR intervention and to be able to intervene in adverse events supports its implementation. Another facilitating factor from the health care professional perspective was that the VR

intervention allows patients to practice everyday situations in therapy, such as working in the garden.

Discussion

Overview

The aim of this scoping review was to identify and categorize barriers and facilitators associated with the implementation of VR interventions for people with chronic pain, using the TDF. From the 14 included studies [43-56], a total of 65 barriers and facilitators from the patient perspective and two facilitators from the health care professional perspective were identified. The main barriers from the patient perspective to use VR interventions for chronic pain were assigned to the domains *environmental context and resources* and *skills*. However, the domains *ECR*, *beliefs about consequences*, and *emotions* also included facilitators that increased the use of VR interventions from a patient perspective. Health care professional perspectives are poorly researched, with only one study [52] found on this topic. To our knowledge, this is the first scoping review summarizing barriers and facilitators to the implementation of VR interventions for people with chronic pain.

Selection of a VR Device

At first glance, a contradictory result of this study is that the *ECR* domain includes barriers as well as facilitators to the implementation of VR interventions for chronic pain. However, since VR devices and VR software emerged as major themes within the barriers and facilitators in this domain, an important

step in implementing VR interventions appears to be the selection of an appropriate VR device and VR software for patients with chronic pain and in consideration of their actual conditions. This decision may be particularly important for people with chronic neck pain, as they may be more sensitive to the weight of VR devices, which could lead to an increase in pain [49]. Although future technological developments of VR devices with lower weight might improve this limitation, the use of VR devices for people with chronic neck pain will remain an individual decision depending on individual tolerance. If these steps are taken carefully, it is possible that the chosen VR device and the VR intervention itself will act as a facilitator in the implementation process. These findings support three proposed aspects to be considered when preparing a VR therapy: the right VR intervention at the right time and with the right patient [57]. These findings are consistent with published recommendations to adopt a participatory approach involving the patients themselves throughout the development process of VR interventions to consider all of the above aspects at an early stage [58].

VR Skills

A second important TDF domain including barriers was *skills*, relating specifically to the patient's gaming skills and language skills. Both can be addressed in software development, such as by participatory developed tutorials or using plain language. These recommendations are partly reflected in the recommendations for the participatory development of VR interventions [58] and are also in line with a previous review, which argued for providing sufficient time to learn and use the new technology for patients and health care professionals [27]. However, our findings emphasize the importance of developing and providing plain-language options in VR interventions for people with chronic pain, potentially due to their shorter attention spans and greater susceptibility to interruption [59], as well as other mental health concerns such as psychological distress [11], anxiety, and depression [31]. For existing interventions, these barriers can be addressed with an implementation strategy. As part of such a strategy, special attention should be given to competencies of health care professionals related to the use of VR to enable them to teach the acquired skills to their patients with individual needs [29]. Additionally, for a successful implementation, it is important that health care professionals are positive about the digital technology [60] and perceive it as user-friendly [61]. Thus, a key aspect of implementing VR in the treatment of chronic pain is adequate training of the health care professionals who will provide the VR interventions to people with chronic pain.

No barriers in regard to game design quality, such as poor graphics or boring games, were reported by people with chronic pain or health care professionals, which was a somewhat surprising finding. Considering the publication dates of the literature retrieved and our own experience with VR interventions, it would have been conceivable that the grade of immersion or perceived difference between the virtual world and the real world could still be experienced as a barrier to using VR interventions.

VR Treatment Expectations

Existing positive expectations regarding pain improvement and rehabilitation facilitate the implementation of VR interventions for people with chronic pain [43,51,53,55,56]. A positive belief in VR interventions seems to result in more satisfaction with the outcome of therapy in general [30] and has an impact on cooperation and outcomes in people with chronic pain in general [62]. When implementing VR interventions for people with chronic pain, this positive belief can be used and facilitated by educating patients about the positive effects of the intervention and presenting best-practice examples.

Another theme that emerged within the domain beliefs about consequences is that VR interventions could increase treatment adherence because VR helps people with chronic pain to improve health behaviors and their ability to focus on tasks [56]. In addition, patients see the possibility that in the future they will be able to choose from many different virtual scenarios in which they can immerse themselves to help with their pain [53].

Lack of patient adherence is a common problem associated with poorer treatment outcomes [63,64] and VR may be a viable option to reduce this problem. Our results are in line with a previous review, which showed that VR can encourage patients to adhere to treatment [30]. VR and its potential impact on adherence may facilitate high-intensity therapy and thereby improve outcomes, as a network meta-analysis showed that high-intensity therapy in particular can have a positive impact on outcomes in chronic pain therapy [65].

The themes fun and enjoyment and having novel experiences provide an explanation for the above-mentioned good adherence to VR interventions. The ability of VR to provide novel experiences for people with chronic pain has also been highlighted in other studies [30]. Furthermore, positive emotions such as fun and enjoyment may themselves have a positive impact, considering that negative emotions are a risk factor for the development and maintenance of chronic pain [66].

Perspective of the Health Care Professionals

In our scoping review, we were only able to identify one study that focused on facilitators from the perspective of health care professionals, who naturally play a crucial role in the implementation of digital interventions [60]. Health care professionals mentioned that VR is a good opportunity to treat people with chronic pain in everyday situations and that they want to be close to the patients during the treatment [53].

Integration With Existing Literature

When comparing the findings of this review with findings from other reviews looking at the implementation of VR interventions in various health care settings [29], rehabilitation [27], and physical therapy [30], it is notable that the identified themes differ only in terms of the details and cover mostly similar topics such as the barrier of appropriate VR interventions and VR devices for the individual patient, as well as the facilitators of having a strong belief in the efficacy of these interventions. This preliminary finding suggests that implementing VR interventions for people with chronic pain is not fundamentally different from implementation in other settings; however, due

to the nature of chronic pain, cognitive and functional impairments should be taken into account. Additionally, since the health care professional perspective is not fully understood, further research on this aspect is necessary.

Limitations

One limitation of this scoping review is that classification of barriers and facilitators into TDF domains may be subjective, although we aimed to minimize subjectivity by standardized procedures using a coding guideline based on TDF domains with two independent reviewers. In this scoping review, barriers and facilitators were ranked according to how often they were mentioned in the included studies. However, this may not necessarily reflect their importance. Barriers and facilitators mentioned only once may nevertheless be the most important factor in a particular implementation setting. In particular, barriers and facilitators in quantitative studies were included if they had more than 50% agreement in the study, whereas all barriers and facilitators mentioned in qualitative studies were included. This may impact the distribution of barriers and facilitators.

The review process did not include a critical appraisal of the studies; although this is not standard practice for scoping reviews, it might be considered a limitation regarding the quality of the evidence. Furthermore, only studies published in German

or English were included. This may limit conclusions about implementation in other countries.

Recommendations

Our findings provide a comprehensive overview of the barriers and facilitators to implementing VR interventions for people with chronic pain in the existing literature. Based on the identified barriers, the development of VR devices and VR interventions should address the perspectives of both people with chronic pain and health care professionals. This could reduce language, cognitive, or physical barriers that are important for patients with specific impairments.

Based on the identified barriers and facilitators, systematic and targeted implementation strategies for VR interventions for people with chronic pain can be developed. For example, the barrier of lack of skills can be reduced by offering targeted training to health care professionals, and positive expectations of VR interventions can be reinforced, such as by displaying a poster about the positive effects of VR in the waiting room. In addition, future research on VR interventions and implementation should pay more attention to the perspective of health care professionals to gain better insight into the values and needs of these critical stakeholders. This can be achieved through an implementation study that includes a formative evaluation of the implementation steps with a focus on health care professionals and their experiences in the process.

Acknowledgments

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Data Availability

The data sets generated and analyzed during this study are available from the corresponding author on reasonable request.

Authors' Contributions

AE, AGS, and CK contributed to conceptualization. AE developed the search strategy and conducted the search. AE and ML screened titles and abstracts and the full text, extracted the data, and categorized the data into domains. AE summarized the domains. AE wrote the original draft; manuscript review and editing were performed by all authors (most notably AGS and CK).

Conflicts of Interest

None declared.

Multimedia Appendix 1

PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) checklist. [[DOCX File, 46 KB - xr_v1i1e53129_app1.docx](#)]

Multimedia Appendix 2

Search strategy.

[[DOCX File, 15 KB - xr_v1i1e53129_app2.docx](#)]

Multimedia Appendix 3

Data extraction sheet.

[[XLSX File \(Microsoft Excel File\), 11 KB - xr_v1i1e53129_app3.xlsx](#)]

Multimedia Appendix 4

Description of domains in the Theoretical Domains Framework.

[\[PDF File \(Adobe PDF File\), 83 KB - xr_v1i1e53129_app4.pdf \]](#)

Multimedia Appendix 5

Description of the included studies.

[\[DOCX File , 23 KB - xr_v1i1e53129_app5.docx \]](#)

Multimedia Appendix 6

Summary of all identified barriers and facilitators according to Thematic Domains Framework domains.

[\[XLSX File \(Microsoft Excel File\), 11 KB - xr_v1i1e53129_app6.xlsx \]](#)**References**

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Abbreviations

ECR: environmental context and research

PRISMA-ScR: Preferred Reporting Items of Systematic Reviews and Meta-Analyses extension for Scoping Reviews.

SMD: standardized mean difference

TDF: Theoretical Domains Framework

VR: virtual reality

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Original Paper

Using Virtual Reality to Reduce Stress in Adolescents: Mixed Methods Usability Study

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Abstract

Background: Adolescent mental health is a national mental health emergency amid surging rates of anxiety and depression. Given the scarcity and lack of scalable mental health services, the use of self-administered, evidence-based technologies to support adolescent mental health is both timely and imperative.

Objective: The goal of this study was 2-fold: (1) to determine the feasibility, usability, and engagement of a participatory designed, nature-based virtual reality (VR) environment and (2) to determine the preliminary outcomes of our self-administered VR environment on depression, mindfulness, perceived stress, and momentary stress and mood.

Methods: We conducted a within-person, 3-week, in-home study with a community-based sample of 44 adolescents. Participants completed surveys of perceived stress, depression, cognitive fusion, and mindfulness at intake, postintervention, and a 3-week follow-up. Participants were invited to use a nature-based, VR environment that included 6 evidence-based activities 3 to 5 times per week. They completed momentary stress and mood surveys 5 times each day and before and after each VR session. Postintervention, participants completed surveys on system and intervention usability and their experiences with using the VR system. Quantitative data were analyzed using descriptive statistics and mixed effects modeling to explore the effect of the VR environment on stress. Qualitative data were analyzed using collaborative thematic analysis.

Results: Participants' use of the VR environment ranged from 1 session to 24 sessions (mean 6.27 sessions) at home over a 3-week period. The 44 participants completed all study protocols, indicating our protocol was feasible and the VR environment was engaging for most. Both the use of the VR system and novel VR intervention received strong usability ratings (mean 74.87 on the System Usability Scale). Most teens indicated that they found the tool to be easily administered, relaxing, and helpful with stress. For some, it offered space to process difficult emotions. The themes *calm*, *regulating*, and *forget about everything* resulted from open-ended exit interview data. Although the Relaxation Environment for Stress in Teens (RESeT) did not significantly affect repeated survey measurements of depression, mindfulness, nor cognitive fusion, it did positively affect momentary mood (pre-intervention: 10.8, post-intervention: 12.0, $P=.001$) and decrease momentary stress (pre-intervention: 37.9, post-intervention: 20.6, $P=.001$). We found a significant reduction in within-day momentary stress that strengthened with increased VR use over time during the study period ($P=.03$).

Conclusions: These preliminary data inform our own VR environment design but also provide evidence of the potential for self-administered VR as a promising tool to support adolescent mental health. Self-administered VR for mental health may be an effective intervention for reducing adolescent stress. However, understanding barriers (including disengagement) to using VR, as well as further encouraging participatory design with teens, may be imperative to the success of future mental health interventions.

KEYWORDS

virtual reality; adolescents; perceived stress; participatory design; depression

Introduction

It is good to like, to have the brain stop for a second and focus on small things. [P98, girl, 16 years old, exit interview]

The Potential for Virtual Reality in Adolescent Mental Health

In a 2018 American Psychological Association survey [1], teens reported worse mental health and higher levels of anxiety and depression than all other age groups. Increased stress causes adverse mental and physical outcomes, including anxiety and depression [2]. However, despite effective, evidence-based treatments for adverse outcomes associated with stress [3], only one-half of teens will receive mental health services due to mental health provider shortages and other barriers to accessing care [4,5]. Even worse, evidence-based therapies are often inaccessible due to cost, time, or the need for a trained interventionist [6]. Therefore, a self-administered, technology-based solution could increase accessibility and scalability of these therapies.

Virtual reality (VR)-based serious games (SGs) for mental health present an opportunity for the translation of effective mental health strategies to an engaging platform [7,8]. VR consists of a head-mounted display that displays simulated environments for exploration and interaction. The immersive and intuitive experience of VR makes it an optimal platform for delivering self-administered SG health interventions for adolescents [9]. Additionally, VR-based SGs are scalable, which could increase accessibility to evidence-based mental health care. VR has been successfully deployed in treating an array of health conditions in adults, including posttraumatic stress disorder [10], phobias [11], and perceived stress in military personnel [12].

The use of VR as an intervention platform for adolescent mental health is an emerging area of inquiry [13,14]. VR has been shown to be acceptable and effective in treating procedural pain, headaches, and public speaking anxiety in adolescents [15-18]. In addition, Björ ling et al [19] found that a nature-based environment reduced stress in teens and that teens will self-administer VR therapeutically. Building on these findings, it has been suggested that existing evidence-based mental health therapies, such as cognitive behavioral theory (CBT), could be translated into a VR environment as an innovative approach to delivering scalable mental health interventions [20]. Although a recent systematic review of clinical trials of mostly computer-based video games found CBT SGs to be more effective than no intervention, true efficacy was clouded by study rigor, and none of the CBT games were VR [21]. In a systematic review of VR environments intended to reduce pain and anxiety in children and adolescents, Ahmadpour et al [22] proposed that future VR interventions explore skill building

and provide dynamic feedback to participants to enable them to be an active participant in managing their own care.

The Importance of Participatory Design

Participatory design (PD) is an approach in which the people who are “destined to use the system play a critical role in designing it” [23]. In PD, the goal is not to simply build systems that address the needs and wants of people. Rather, the hallmark of PD is to establish cooperative and collaborative design relationships that engage users throughout the iterative design process. Research results are often collaboratively interpreted by designer-researchers and the participants who will use the design. For this very reason, gathering data continually during the design and testing phases of development is essential. Such a collaborative approach is thought to result in solutions that address real-world needs and priorities in people’s lives [24,25].

Engaging teens in PD is rare in the design and development of VR, though it is a successful methodology for working with teens in relation to mental health [26-28]. PD is an appropriate approach for designing new technologies with teens due to its meaningful engagement of participants throughout the design process [29,30]. However, engagement is highly variable, and the methods are often iterative and flexible [26]. Examples of engaging teens in co-design for mental health include suicide prevention through social media [27] and stress reduction via a social robot [28]. In fact, co-design with youth specifically for VR has also shown to be successful. Realpe et al [31] engaged youth in the co-design of a virtual environment as a social cognition intervention for people with a first episode of psychosis. Björ ling et al [32] successfully engaged teens in the design of a VR environment aimed to reduce stress.

Our Motivation: A Study of Usability and Experience

As a technology, VR holds the potential to provide immersive experiences and skills training to reinforce evidence-based mental health practices. However, in order to be effective, it must be engaging and usable by teens. Therefore, we designed and developed our VR environment, Relaxation Environment for Stress in Teens (RESeT), using a human-centered, PD approach. We engaged adolescents in each stage of development to ensure usefulness and maximize engagement. Equally important was to empirically measure usability and user experience. Therefore, in our pilot study of our novel VR environment, we explored 2 aims and associated research questions (RQs).

Aim 1

The first aim was to measure the implementation outcomes (feasibility, acceptability, appropriateness, usability, and engagement) of a participatory designed, nature-based VR environment.

- RQ1: How did teens use RESeT, and how did they rate its implementation?
- RQ2: What is the experience of using RESeT?

Aim 2

The second aim was to determine the preliminary mental health outcomes of our self-administered VR environment on depression, mindfulness, perceived stress, and momentary stress and mood.

- RQ3: What effect does RESeT use have on retrospective stress (Perceived Stress Scale [PSS]), depression (Patient Health Questionnaire 9 [PHQ-9]), cognitive fusion (Cognitive Fusion Questionnaire [CFQ]), or mindfulness (Mindfulness Attention and Awareness Scale [MAAS])?
- RQ4: What effect does RESeT use have on momentary stress and mood?
 - RQ4a: Do baseline depression, mindfulness, and stress moderate the effect of [VR environment] on momentary stress over the 3-week intervention?

- RQ4b: Does dosage (frequency and duration of VR use) moderate momentary stress over the 3-week intervention?

Methods

Study Timeline

The prospective, within-person study design utilized multiple layers of measurement. Participants completed surveys at intake, exit, and follow-up as well as within-day momentary measurements of stress and mood and pre- and post-VR measurements. See [Table 1](#) for a summary of the participant activities and measurement over time.

Table 1. Study measurement timeline.

Study activity	Research question (RQ)	Intake	5 times per day during the 3-week intervention	Pre/post-VR ^a use	Exit (at 3 weeks)	Follow-up (at 7 weeks)
Survey instruments						
PHQ-9 ^b (depression)	RQ3	✓			✓	✓
PSS ^c (retrospective stress)	RQ3	✓			✓	✓
CFQ ^d (cognitive fusion)	RQ3	✓			✓	✓
MAAS ^e (mindfulness/attention)	RQ3	✓			✓	✓
SUS ^f /IUS ^g (usability)	RQ1				✓	
IAM ^h , FIM ⁱ , AIM ^j (appropriateness, feasibility, acceptability of intervention)	RQ1				✓	
Interview (user experience)	RQ2				✓	
Momentary instruments						
Stress	RQ4		✓	✓		
Sadness	RQ4		✓			
Affect	RQ4			✓		
Comfort	RQ4			✓		

^aVR: virtual reality.

^bPHQ-9: Patient Health Questionnaire 9.

^cPSS: Perceived Stress Scale.

^dCFQ: Cognitive Fusion Questionnaire.

^eMAAS: Mindfulness Attention and Awareness Scale.

^fSUS: System Usability Scale.

^gIUS: Intervention Usability Questionnaire.

^hIAM: Acceptability of Intervention Measure.

ⁱFIM: Feasibility of Intervention Measure.

^jAIM: Appropriateness of Intervention Measure.

The Development of a Relaxation Environment for Teen Stress

The novel VR RESeT was developed in partnership with teens and the Seattle Public Library. Design of RESeT began by eliciting teen ideas and design principles through PD sessions spanning 2 years with approximately 60 teens at local library

sites. Some of our design-session studies are described in a previous publication [32]. Based upon teen preferences, RESeT was designed as an open, explorable world filled with nature, animals, and calming activities. The activities in RESeT incorporate evidence-based mental health activities stemming from dialectical behavioral therapy [33], acceptance and commitment therapy [34], and mindfulness-based stress

reduction for teens [35]. Each of these therapies have been shown to be very effective in adolescents. Although such self-administered exercises are typically administered in workbooks and worksheets, we incorporated them into the immersive and interactive VR world with teens as our co-designers.

As an example, teens experience “defusion” from negative emotions in the VR environment by placing negative words into a paper boat and releasing the boat out onto a river. As the boat floats away from them, they can reflect on their ability to release negative emotions rather than hold them tightly or be “fused” with them. This process is called *cognitive defusion* [36]. Another example in the environment is building a teen’s capacity for mindfulness through an interaction that invites teens to listen carefully for different birds and look to find where their song is coming from. Integrating these activities was iteratively refined through a series of design sessions (37 teens) and usability testing sessions (9 teens) resulting in a fully

functional RESeT comprised of 6 evidence-based interactions. In addition, the game was designed with arm-swing locomotion where the player swings their arms back and forth to create a natural walking pace in VR. The faster they swing their arms, the faster they move through the environment. Not only is this type of locomotion naturalistic, it has also been shown to improve mood [12].

The RESeT is a natural environment set in winter, consisting of a mountainous border surrounding a snow-covered, tree-filled meadow. A river runs through the meadow, providing a natural border to create an open world feeling for player exploration. A riverboat provides players with a relaxing space in which they can explore and participate in various activities without having a time limit or required objective. Nature sounds and ambient music play in the background through the experience.

Players start the game at a home base location in the middle of the map. See [Figure 1](#) for an illustration.

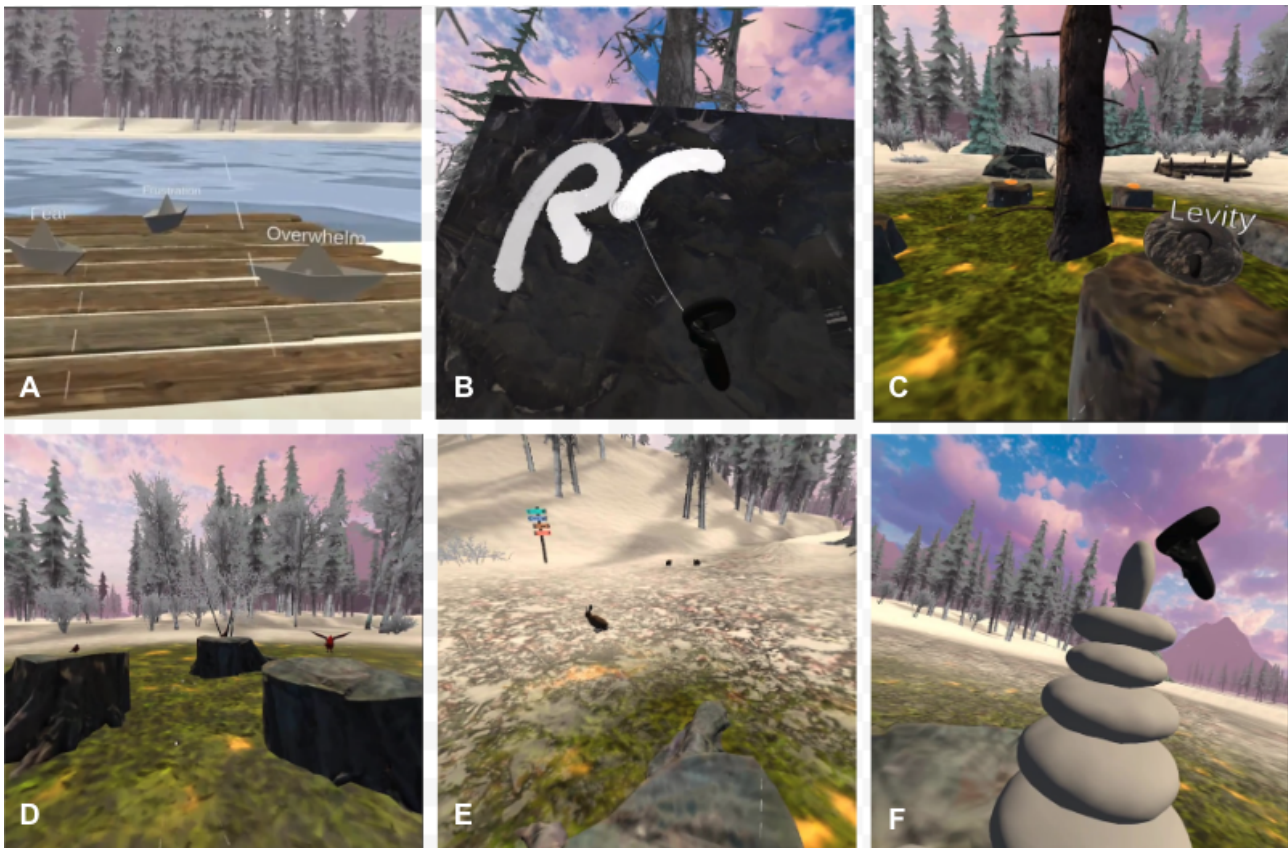
Figure 1. Examples of the (A) controller, (B) wayfinding, and (C) activity navigation.



The environment is designed for seated or standing gameplay using arm-swing navigation intended to feel most like walking. Participants navigate a series of wandering paths and colorful signposts to guide them to 6 clearings, each containing a different activity. See [Figure 2](#) for screenshots during gameplay for each of the 6 activities. In the riverboat activity, players set paper *feeling* boats into the water. Each boat is labeled with a different negative emotion (emotional clarity/cognitive defusion). In the painting activity, players are able to paint on a surface, with their painting slowly disappearing after a short period of time (artful mindfulness). In the scavenger hunt, players search for rocks hidden around the clearing and place

them on stumps when found. Each rock is labeled with a positive word, and when all rocks are found, they change color (visual attention/positive affirmations). With bird search, players search for 3 hidden birds by following the bird’s call. When found, the bird flies to a stump, and when all 3 birds are found, flowers appear (auditory mindfulness). In the rabbit hole activity, players stand still near a stump, and rabbits appear the longer they are standing there (attention/awareness). With rock stacking, players stack rocks on each other to create stacks or other formations (attention/focus). See [Multimedia Appendix 1](#) for a video illustration of the environment.

Figure 2. Screenshots of gameplay illustrating each of the 6 activities: (A) riverboat, (B) painting, (C) scavenger hunt, (D) bird search, (E) rabbit hole, (F) rock stacking.



Ethics Approval

The University of Washington Institutional Review Board approved this study (Study 00003795: Virtual Relaxation Experience).

Recruitment, Screening, and Enrollment

A convenience sample of teens was recruited from April 2021 through June 2021 via social media (Facebook, Twitter), listservs, and snowball sampling. Eligibility criteria included (1) ages 14 years to 18 years, (2) able to speak and read English, (3) have a smartphone with SMS text messaging capabilities, and (4) currently live in the greater metro area. Prospective participants with a diagnosed seizure disorder were excluded from this study due to the risk of VR triggering a seizure.

Research Electronic Data Capture (REDCap) [37], a secure web-based data collection and management system, was used for all participant survey data collection. Prospective participants accessed the REDCap study eligibility screening survey via a QR code or weblink, which described the study aims and associated activities. Eligibility was automatically determined after the individual completed the survey. Those who were eligible were consented within the REDCap system. Participants were informed of the study procedures and phases and that they could disengage at any time. Parents of participants younger than 18 years were sent an email with study contact information.

Upon entering the study, a VR kit was delivered to the participant's home via study staff using a no contact protocol described in a previous study by Sonney et al [38]. Participants

were emailed an enrollment and orientation packet that included a video demonstration of setting up and charging the VR headset. During the study, research staff used text messaging to check in with participants the day they received the VR kit, on day 3, and once a week thereafter. Participants were informed to contact study staff by text if they had any questions.

Instrumentation

Surveys included an investigator-developed questionnaire capturing participant age, grade in school, and prior experience using VR (never, once, 2-5 times, ≥ 6 times) for numerous VR technologies, including standalone headsets, full headsets, and Google cardboard. Participant gender, racial, ethnic, and tribal (if applicable) identities were collected via a write-in option. Standardized surveys focused on implementation outcomes (Aim 1, RQ1) were administered postintervention (Time 2) and included the Acceptability of Intervention Measure, Feasibility of Intervention Measure, Appropriateness of Intervention Measure [39], System Usability Scale (SUS; $\alpha=.85$) [40], and Intervention Usability Scale (IUS) [41]. Surveys focused on mental health outcomes (Aim 2, RQ3) included the PHQ-9 ($\alpha=.89$) [42], PSS ($\alpha=.71-.91$) [43], CFQ ($\alpha=.93$) [44], and MAAS ($\alpha>.80$) [45]. These were administered at intake (Time 1), after the 3-week intervention (Time 2), and 4 weeks postintervention (Time 3). Intake surveys were estimated to take 15 minutes to 20 minutes to complete, and exit surveys were estimated to take 15 minutes to 25 minutes.

Momentary instruments (Aim 2, RQ4) included a 5-time per day momentary survey using SEMA 3 software [46] to gather within-day momentary assessments of stress and mood over the

3-week intervention period. Participants were sent 5 scheduled, within-day mood surveys each day of the 3-week study. Within-day surveys asked 2 questions: “How stressed do you feel right now?” and “How sad do you feel right now?” Participants answered these questions on a sliding scale ranging from no sadness/no stress (0) to extremely sad/extremely stressed (100). In addition, a pre- and post-VR survey was developed that included the same stress scale as the within-day survey. However, it also included an abbreviated Positive and Negative Affect Scale [47] and a comfort scale for post-VR: “How comfortable was your VR session?” (1: not very comfortable to 5: very comfortable). Momentary surveys were estimated to take between 30 seconds and 90 seconds to complete.

Given the potential for participants to forget the self-initiated VR survey, we addressed Aim 1, RQ2 using 2 VR use statistics: VR use frequency (number of sessions) and VR use duration (length of use). These were measured through VR activity metrics downloaded directly from each headset. An analytics system built into RESeT saved a VR use log file with a time stamp and duration for each session. In case the analytics system malfunctioned, the Android OS UsageStatsManager was used to retrieve total app use time from the last 24 hours, 7 days, and 30 days.

Finally, to address Aim 1, RQ2, a semistructured interview examined the participant experience, perceived effect, and feedback related to the protocol and environment (Aim 1). For example, “What did you feel using RESeT?” and “What concerns do you have about using RESeT?” Interviews lasted approximately 15 minutes and were recorded via videoconferencing software. In addition, we asked participants about their likelihood to continue using the environment as well as how they might change the design. The semistructured interview took between 10 minutes and 20 minutes to complete.

Intervention Procedure

Participants were delivered a Quest 2 headset, charger, and customized user manual that included links to troubleshooting and an unboxing video directly to their home. At the start of the study, they were asked to use RESeT for 10 minutes to 15 minutes 3 to 5 times per week. Participants were not further prompted to use the headset nor were they incentivized based upon the amount of headset use during the study. Before each use, they were asked to complete the SEMA presession surveys (stress, affect), explore the RESeT however they desired, and complete the SEMA postsession surveys (stress, affect, comfort). The study team completed weekly check-ins via text message throughout the 3-week pilot and were available for any questions.

At the end of the 3-week pilot, REDCap automatically sent participants the postintervention survey queue, and the study team conducted a semistructured exit interview and scheduled a time to retrieve the VR study kit, which was sanitized and prepared for the next participant. A 3-week follow-up survey queue was automatically sent by REDCap. Participants received digital gift cards after each survey completion. Participants received US \$25 at Time 1, US \$75 at Time 2, and US \$50 at Time 3.

Data Analysis

Quantitative Analyses

All statistical computations were performed in the open-source R software program [48]. Descriptive statistics were used to describe the sample characteristics, survey scores, and intervention use. Longitudinal spaghetti plots were performed to explore time trends and form. A repeated measures ANOVA was conducted to detect group and within-individual differences during survey time points (Time 1-Time 3). Longitudinal mixed effects models with random effects for time, frequency, or duration were computed to detect changes in stress within individuals. A linear regression model with random effects controlled for participant variations was used to measure change in affect and stress resulting from each VR session.

Several models were run to explore whether dosage (number of sessions and duration of use) moderated the change in momentary stress over time. For dosage models, we explored whether changes in stress scores were linear (uniform rate of improvement as dosage increased), quadratic (declining rate of improvement as dosage increased), or cubic (declining and then increasing rate of improvement as dosage increased).

Full maximum likelihood estimation was used, and model building followed a standard procedure [49]. A null model was built first to establish baseline variance for stress over time, followed by longitudinal trend models testing linear, quadratic, and cubic longitudinal trends. These were run on 3 separate sets of models testing longitudinal trends for variables representing number of days since baseline, number of times the VR was used, and number of minutes the VR was used. The best longitudinal trend was selected by model fit deviance statistics using $-2 \log$ likelihood and Akaike information criterion. We tested for possible moderation effects by computing models with each variable and simple interaction between them. Moderation models included possible moderation between stress over time and (1) frequency x duration, (2) baseline PSS, (3) baseline PHQ-9, and (4) baseline MAAS. Significance for moderator terms was determined by t score significance values for covariate estimates.

Post Hoc Groupings

For the purposes of analysis, participants were grouped into depression level and VR use categories based upon their study data. We based 4 mutually exclusive VR use groupings (minimal [<3 sessions], low use [3-4 sessions], moderate use [5-7 sessions], high use [≥ 8 sessions]) upon their self-administered VR use during the study. Depression levels were assessed using the Time 1 PHQ-9 scores. Participants were grouped into mild (PHQ-9 <5), moderate (PHQ-9=5-9), and severe (PHQ-9 ≥ 10) depression levels. We excluded 8 participants from the analyses exploring the effect of the VR environment on surveyed variables (depression, retrospective stress, mindfulness, cognitive fusion) given their low use of the VR headset (<3 sessions). However, all 44 participants were included in the analyses exploring the relationship between VR use and stress over time.

Qualitative Analyses

As part of our mixed methods design, the qualitative data were gathered concurrently with our quantitative instruments and then explored to help contextualize our quantitative findings. Exit interview data were analyzed using a collaborative thematic analysis protocol. Using raw video data from each of the exit interviews, participant VR session logs, and text messaging, the team of researchers engaged in a collaborative, reflexive thematic analysis [50,51]. Analysis began with the extraction of excerpts that felt salient in relation to our research questions around activity in VR, emotional experience, and the effect of VR on stress. From a review of extracted excerpts, open coding was used to create a categorical code book. With the code book, researchers then revisited the data to further contextualize the categorical codes in an effort to represent the depth and breadth of experiences described by participants. This process was repeated until the research team felt we had sufficient evidence to contextualize our study findings.

Results

Participant Characteristics

A total of 118 individuals accessed the eligibility screening, 100 completed the screening, 94 were eligible, and 51 enrolled. Reasons for ineligibility included age older than 18 years (n=4), age younger than 14 years (n=1), seizure disorder (n=1), and out of the geographic area (n=1). After data collection, 7 participants were removed from those enrolled: 2 participants did not complete baseline surveys; 2 did not use the intervention (8% attrition); and although they completed all study procedures and described using the intervention, we found no headset data for 3 participants. Therefore, because we could not objectively confirm use of the headset, these participants were removed from the study. The final sample included 44 adolescents. See [Multimedia Appendix 2](#) for all participant demographic characteristics.

Participants were aged 14 years to 18 years (mean 15.82 years) and in grades 8 through 12 (mean 10.09). Participants identified their gender as boys (n=17), girls (n=23), and nonbinary or

gender fluid (n=4). Participants completed a total of 1651 (mean 45.86, SD 19.24) momentary reports of their stress level and mood during the 3-week study period. The average response rate for random, within-day reports was 33%, which was expected given the randomized schedule. In addition, participants completed 330 pre- and post-VR session logs reporting their stress and affect before and after headset use as well as their comfort level.

RQ1: How Did Teens Use RESeT and How Did They Rate Its Implementation?

Without prompting or using incentives, teens used RESeT, on average, twice a week (number of sessions: mean 6.29, SD 4.51; range 1-24) over the 21-day study period. The average duration of a VR session was 11.5 (SD 6.47; range 1-45) minutes. No significant differences were found when exploring the effect of gender, age, or depression level on VR use nor did we find that VR use affected cognitive fusion, mindfulness, or retrospective stress. We did create post hoc VR use groupings for comparison in our stress analyses. See [Table 2](#) for VR use groupings.

The average usability rating of the VR system (SUS) was good (mean 74.87, SD 11.61); 37 of the 44 participants (84%) rated the system a 68 or higher, suggesting the standalone headset was fairly easy to use without any external support. The average usability rating (IUS) of RESeT was also good (mean 76.92, SD 11.7); 35 of the 44 participants (80%) rated the intervention a 68 or higher, which suggests the VR environment was also fairly easy to use. Intervention acceptability (mean 15.67, SD 3.7), feasibility (mean 15.9, SD 2.95), and appropriateness (mean 15.23, SD 2.99) were all in the high range, suggesting participants found the RESeT content to be appropriate and acceptable. In their session logs, teens reported the environment was moderately comfortable, but reports ranged across the sample (mean 3.43, SD .992).

When asked about the future of RESeT, teens suggested that the VR environment would be most accessible and useful as a school or public library resource, allowing teens to use it on site or to check out the headset for home use when needed.

Table 2. Virtual reality use groups by gender and depression level.

Use (number of sessions)	Gender, n (%)			Depression level (via PHQ-9 ^a), n (%)		
	Boys (n=17)	Girls (n=23)	Other (n=4)	Mild (<5; n=13)	Moderate (5-9; n=11)	Severe (≥10; n=20)
Minimal (<3; n=8)	2 (5)	5 (11)	1 (2)	1 (2)	2 (5)	5 (11)
Low (3-4; n=8)	4 (9)	3 (7)	1 (2)	3 (7)	5 (11)	0
Medium (5-7; n=15)	6 (14)	7 (16)	2 (5)	5 (11)	1 (2)	9 (20)
High (≥8; n=13)	5 (11)	8 (18)	0	4 (9)	3 (7)	6 (14)

^a PHQ-9: Patient Health Questionnaire 9.

RQ2: What Is the Experience With Using RESeT?

General Experience

In their VR Logs, teens reported a small reduction in negative affect, a slight increase in positive affect, and a significant decrease in momentary stress. See [Table 3](#) for full details.

In general, teens enjoyed their experience with the VR environment. Most reported that they liked the audio and visual design. "RESeT helps you chill out with ambient noises and being able to explore" (P1, boy, 16 years old, text message). Overall, teens who engaged in each of the activities most commonly reported liking the rock stacking activity. The least favorite activity was the painting activity.

I really liked the rock stacking. I thought that was nice because you could move the rocks and you could stack them and other places in the area...And, I was a little disappointed by the painting. [P95, nonbinary, 18 years old, exit interview]

We analyzed text message and exit interview data to understand how participants described their experience with RESeT. As a result, 4 key themes emerged: calm, regulating, forget about everything, and some discomfort. Each of these themes is described in detail in the following sections.

Table 3. Key survey outcomes over the study period.

Survey outcomes	Baseline (n=44), mean (SD)	Postintervention (n=44), mean (SD)	3-week follow-up (n=44), mean (SD)	F statistic (df)	P value
Perceived stress	19.7 (5.7)	18.5 (4.1)	17.4 (7.5)	1.9 (2)	.15
Cognitive fusion	28.5 (7.5)	26.9 (7.3)	24.8 (9.1)	0.4 (2)	.65
Depression	9.0 (4.8)	5.8 (4.4)	6.7 (5.4)	1.0 (2)	.38
Mindfulness/attention	3.9 (0.8)	4.2 (0.5)	4.2 (0.8)	1.2 (2)	.31

Calm

Overall, teen participants in the study felt generally positive about the environment. Teens described the environment as “calming,” “relaxing,” and “stress-relieving.” As one teen described:

Kind of makes you calm as a whole—more calm, more relaxed. [P103, boy, 17 years old, exit interview]

Another teen described the following:

I really...definitely noticed feeling a lot more calm and mindful after being in the environment and I thought it definitely has a positive impact, especially when you are depressed or anxious about something. [P80, boy, 14 years old, exit interview]

Regulating

In exit interviews, teens suggested that the VR environment helped them to regulate their moods when overwhelmed or upset. As one teen described:

Mostly I would use it when I was like really upset. And so it helped a lot there. I kind of looked forward to doing it. It changed the way I felt, like mentally and stuff. [P39, 15 years old, nonbinary, exit interview]

Some teens also described emotional regulation or making space for them to process big feelings as a result of the environment, for example:

It has 100% the ability to lower and kind of simmer any really high feelings of emotion. [P96, boy, 16 years old, exit interview]

Forget About Everything

Some teens described it more as a form of escape and distraction from unwanted thoughts or feelings, such as:

It gives teens a space to relax and calm down and just forget about everything happening in the real world. [P116, boy, 15 years old, exit interview]

Some participants mentioned feelings of escapism through the VR environment and that it was a great, but temporary, distraction from current stressors:

RESeT let us transport into another world and I forgot about the environment I was in. It transferred me to a different location. It felt like I was going on a trip so even though I had my worries in my head it felt good to forget about the physical things around me and be somewhere else. I'm going on a trip for 10-15 minutes and it relaxes me. [P71, girl, 16 years old, exit interview]

Some Discomfort

It is important to note that, for some participants, there was some discomfort with the headset causing some nausea or dizziness (n=8) or eye strain (n=3):

Well, when I first started using it, afterwards it hurt my eyes for a little bit, but then, after a while on my eyes got adjusted to it so didn't hurt anymore. [P25, girl, 14 years old, exit interview]

Nausea was typically associated with locomotion. Some described the arm swing motion as nauseating, whereas for others, teleporting induced nausea. Overall, nausea and eye strain seemed to lessen or fully resolve by adjusting the headset or getting used to using VR.

Two participants mentioned headaches as a result of using VR, particularly regarding the arm swing movement causing nausea. There was also some comparison of the environment with a video game, which may explain participants feeling bored when compared with entertainment expectations for a video game:

When I first started using the VR headset I kept on getting giant headaches and got really dizzy because I wasn't used to how VR feels yet. So at that point if I weren't doing a study I personally wouldn't continue using the headset. [P38, girl, 18 years old, text message]

RQ3: What Effect Does RESeT Use Have on the Surveyed Measurement of Retrospective Stress (PSS), Depression (PHQ-9), Cognitive Fusion (CFQ), or Mindfulness (MAAS)?

An analysis of surveyed outcomes demonstrated no significant effect of using the VR environment on retrospective stress (PSS), depression (PHQ-9), cognitive fusion (CFQ), or mindfulness (MAAS) for participants regardless of the amount

of VR use. See [Table 3](#) for details. However, we did see significant changes in momentary stress and affect, as described in the following sections.

RQ4: What Effect Does RESeT Use Have on Momentary Stress and Mood?

When exploring the pre- and post-headset session surveys, teens reported a significant reduction in negative affect, a significant

increase in positive affect, and a significant reduction in momentary stress. See [Table 4](#) for full details.

Mixed effects models of change in momentary stress over the 21-day study period found that a linear time model was a better fit than quadratic and cubic models. Stress decreased by 0.328 points per day over the study ($SE=0.12$, $P=.008$).

Table 4. Effect of virtual reality (VR) sessions on momentary affect and stress (n=44; 330 reports).

Affect and stress	Before, mean (SD)	After, mean (SD)	Estimates (relative to “before” survey)	P value
Negative affect	9.2 (3.6)	6.9 (2.4)	-2.3	.001
Positive affect	10.8 (4.0)	12.0 (4.1)	1.3	.001
Momentary stress	37.9 (27.1)	24.0 (20.6)	-13.3	.001

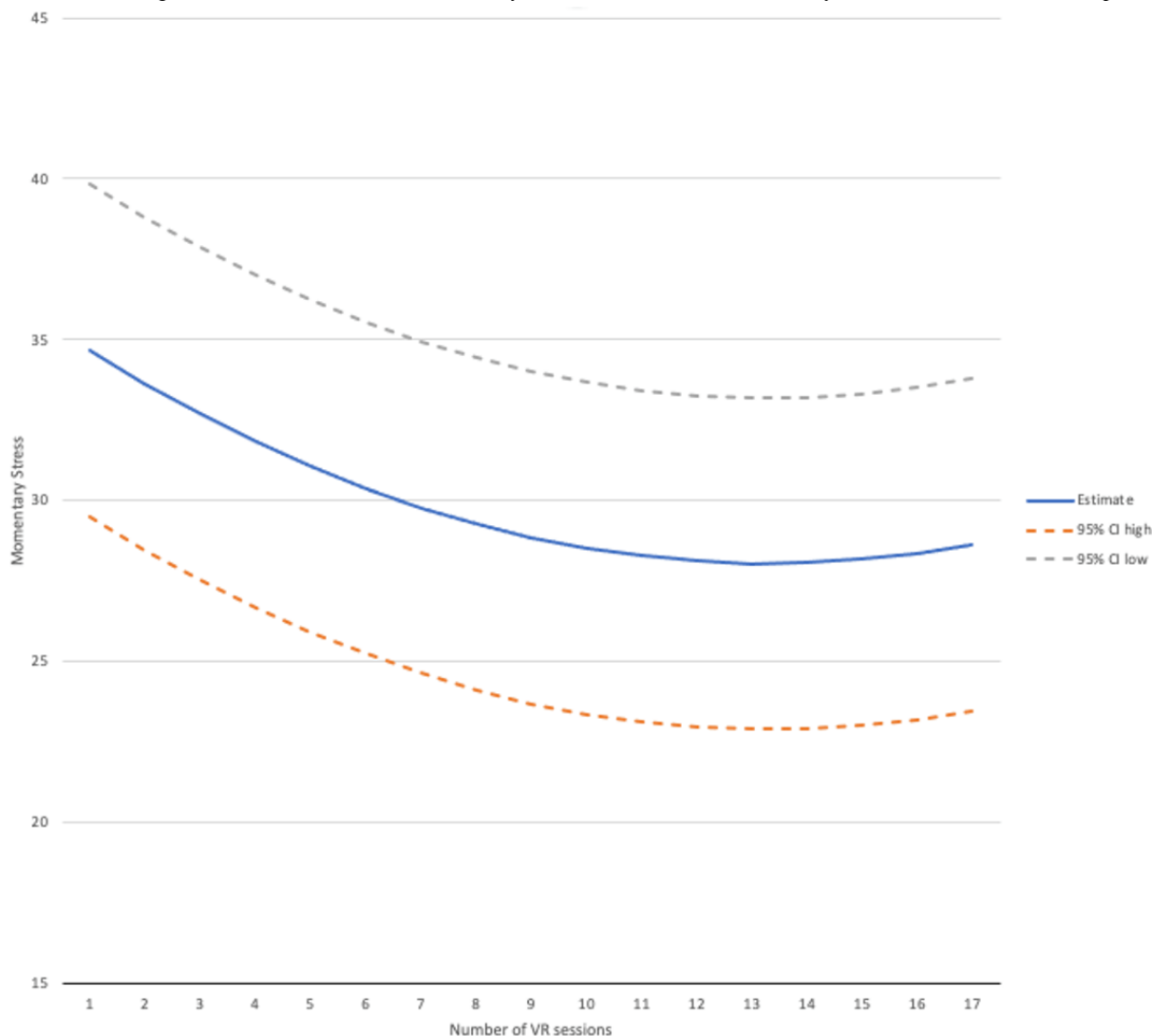
RQ4a: Do Baseline Depression, Mindfulness, and Stress Moderate Momentary Stress Over the 3-Week Intervention?

The rate of decrease in momentary stress score was not significantly moderated by baseline scores of retrospective stress (PSS: interaction=-0.021, $SE=0.021$, $P=.31$), depression (PHQ-9: interaction=-0.04, $SE=0.03$, $P=.14$), or mindfulness (MAAS: interaction=0.14, $SE=0.16$, $P=.38$).

RQ4b: Does Dosage (Frequency and Duration of VR Use) Moderate Momentary Stress Over the 3-Week Intervention?

The best-fitting mixed effects model for frequency of use included both linear and quadratic use frequency, indicating

that there was a stronger association with improved stress scores during the first several uses (linear frequency=-1.08, $SE=0.50$, $P=.03$), which decreased as frequency of use increased (quadratic frequency=0.043, $SE=0.02$, $P=.03$; see [Figure 3](#)). The best-fitting model for cumulative duration of use was linear, though the individual parameter for duration was not significant (linear minutes=0.01, $SE=0.003$, $P=.07$). A model exploring a possible interaction effect of frequency by duration on stress did not find significant effects (frequency x duration=0.001, $SE=0.001$, $P=.61$). See [Figure 3](#) for an illustration.

Figure 3. Predicted change in the stress score, with the 95% CI, by number of uses of the virtual reality (VR) headset over the 3-week period.

Discussion

Principal Findings

It was evident from this study that the VR environment was desirable and a usable system within a self-administered, autonomous home setting. In addition, teens chose to use RESeT repeatedly of their own volition despite its limited interactions. As with our previous studies [28,32], teens confirmed their desire and enjoyment of nature in VR as a stress-reducing environment.

Although RESeT did not significantly affect repeated survey measurements of depression, mindfulness, nor cognitive fusion, it did decrease momentary stress and positively affect momentary mood. This reduction in stress was correlated with the frequency of use, suggesting that self-administered VR environments may be effective to reduce momentary stress. However, the benefit from increased frequency of use tapered off with high use, suggesting that there may be a limit to the impact of RESeT over time. Counterintuitively, although frequency of use was associated with further stress reduction, duration of use was not, suggesting that longer sessions may not be more beneficial. Also likely, it could be that participants

self-regulated their use and ended a session once they felt a reduction in stress, such that long sessions and short sessions had a relatively equal impact.

Comparison With Prior Work

It was not surprising that more stable factors such as depression, cognitive fusion, and mindfulness were not significantly changed by this short-term, self-administered intervention. However, our exit interviews with teens provided strong evidence that, for some teens, the RESeT VR environment provided a place for relaxation as well as emotional regulation. Bond et al [52] found that VR allowed for “safe space to practice” interactions for adults with agoraphobia. It is feasible that VR can also provide a safe space to process big emotions for teens. Although we hoped to see significant changes in cognitive fusion given one exercise (the boat launch) was designed specifically for this purpose, teens did describe experiences of emotional regulation. Computer games have shown significant improvements in emotional regulation in adults [53], and a preliminary study found VR could both improve and measure emotional regulation in adolescents [54]. For this reason, measuring emotional regulation as a result of VR nature environment experiences may be an important factor to consider.

Previously, we conducted a 2-week study exploring a high-fidelity, commercial VR nature-based environment [19]. In the 2-week study, momentary stress was also significantly reduced, suggesting that these types of environments may be effective to reduce momentary stress. In the 2-week study, we also found participants averaged about 6 VR sessions over the study period. This suggests that, perhaps in these self-administered environments, engagement or effect may taper around 6 sessions. Interestingly, similar themes of relaxation and escape emerged from the participants' responses to the VR environment. Granted, both studies explored nature settings, but combined findings suggest teens find nature relaxing and that VR offers an opportunity to escape real-world stressors. Future design research is needed to explore further translation of evidence-based CBT, dialectical behavioral therapy, and acceptance and commitment therapy exercises into immersive VR activities in an effort to understand what types of activities are most engaging and effective.

Limitations and Next Steps

This study was an exploratory usability study of self-administered VR and therefore does not constitute a more rigorous clinical trial. In addition, this study was limited in several ways. First, to establish the effectiveness of RESeT, a control or comparison group, possibly using a well-crafted placebo VR experience, would be necessary. Second, this study was limited in the diversity of its sample (broad range of depression levels) as well as participants' self-selection and ability to self-administer the VR tool. Although each of these factors provides some real-world context about how VR may be used by teens of varying levels of depression, it also limits any generalizability of these data to other samples. Third, the study also lacks controlled data or comparison data to determine the true effect of VR on the measured variables. Fourth, the

participant-level sample size was modest and lacked statistical power to detect small to moderate effects; findings should be viewed as preliminary, consistent with the scope of an exploratory study. Finally, given the probable novelty of VR and short intervention period, teen participants likely experienced a novelty effect, and engagement may have tapered during a longer intervention period.

Further research could explore the VR headset as a community-based tool, such as in a school or library setting, to increase access for teens. VR technology has been found an engaging tool in public library settings [55], which has prompted some public libraries to launch programs to support mental health [56]. As per Kelly et al [57], we included minimal interactions, hoping not to distract participants from mindfulness. However, teens wanted more engagement and interaction; therefore, future evidence-based mental health VR interventions could explore more engaging and interactive activities, as it is likely with a larger platform, more choices, and a more diverse set of activities, teens would be more engaged with the VR platform.

Conclusion

Teens enjoyed and repeatedly used our VR environment, which included 6 evidence-based activities in an open world nature environment, without further incentive. They found the VR system and the RESeT usable, and many reported feeling relaxed or calm as a result. We found that stress decreased over time and that increased VR session frequency further decreased momentary stress. However, we also learned that increased session duration did not improve stress outcomes, suggesting that even brief VR sessions can be effective. These findings indicate that VR is a feasible and likely attractive platform for evidence-based mental health interventions.

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Data Availability

Study data are available upon request.

Authors' Contributions

EAB was the primary investigator who conceptualized the study; oversaw all study procedures, data collection, and data analyses; and led authorship of this manuscript. JS was co-principal investigator of the study; monitored all study procedures, including data collection and management; and shared senior authorship with EAB. SR and SHM helped to conduct and manage the study,

began preliminary analyses, and helped with authoring the paper. HZ and MDP conducted the analyses and authored the analysis section.

Conflicts of Interest

None declared.

Multimedia Appendix 1

RESeT VR Environment Demonstration.

[MP4 File (MP4 Video), 129744 KB - [xr_v1i1e49171_app1.mp4](#)]

Multimedia Appendix 2

Participant Demographics.

[DOCX File , 15 KB - [xr_v1i1e49171_app2.docx](#)]

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Abbreviations

- CBT:** cognitive behavioral theory
- CFQ:** Cognitive Fusion Questionnaire
- IUS:** Intervention Usability Questionnaire
- MAAS:** Mindfulness Attention and Awareness Scale
- PD:** participatory design
- PHQ-9:** Patient Health Questionnaire 9
- PSS:** Perceived Stress Scale
- REDCap:** Research Electronic Data Capture
- RESeT:** Relaxation Environment for Stress in Teens
- RQ:** research question

SG: serious game

SUS: System Usability Scale

VR: virtual reality

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Original Paper

Immediate Impact of an 8-Week Virtual Reality Educational Program on Burnout and Work Engagement Among Health Care Professionals: Pre-Post Pilot Study

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Abstract

Background: Health care professionals globally face increasing levels of burnout characterized by emotional exhaustion, depersonalization, and a reduced sense of accomplishment, and it has been notably exacerbated during the COVID-19 pandemic. This condition not only impacts the well-being of health care workers but also affects patient care and contributes to significant economic burden. Traditional approaches to mitigating burnout have included various psychosocial interventions, with mindfulness being recognized for its effectiveness in enhancing mental health and stress management. The emergence of virtual reality (VR) technology offers a novel immersive platform for delivering mindfulness and emotional management training.

Objective: This study aimed to evaluate the immediate impact of an 8-week VR educational program on burnout and work engagement among health care professionals.

Methods: This nonrandomized pre-post intervention study enrolled 90 health care professionals, including nurses, physicians, and allied health staff, from 3 different centers. Of these 90 professionals, 83 (92%) completed the program. The intervention consisted of 8 weekly VR sessions of 10-13 minutes each, using Meta Quest 2 headsets. The sessions focused on mindfulness and emotional management. The Maslach Burnout Inventory (MBI) and Utrecht Work Engagement Scale (UWES) were used for assessments. Data analysis involved inferential statistical techniques for evaluating the impact on the scales, including paired *t* tests for normally distributed variables and Wilcoxon signed rank tests for nonnormally distributed variables. The significance of changes was indicated by *P* values <.05, with effect sizes measured using Cohen *d* for *t* tests and Cohen *r* for Wilcoxon tests for quantifying the magnitude of the intervention's effect.

Results: The statistical analysis revealed significant improvements in the MBI and UWES indices after the intervention (*P*<.05). Specifically, the MBI showed reductions in emotional exhaustion ($t_{82}=5.58$; *P*<.001; Cohen *d*=0.61) and depersonalization ($t_{82}=4.67$; *P*<.001; Cohen *d*=0.51), and an increase in personal accomplishment ($t_{82}=-3.62$; *P*<.001; Cohen *d*=0.4). The UWES revealed enhancements in vigor ($t_{82}=-3.77$; *P*<.001; Cohen *d*=0.41), dedication ($Z=-3.63$; *P*<.001; Cohen *r*=0.41), and absorption ($Z=-3.52$; *P*<.001; Cohen *r*=0.4).

Conclusions: The study provides initial data supporting the effectiveness of VR-based educational programs for reducing burnout and enhancing work engagement among health care professionals. While limitations, such as the absence of a control group, are acknowledged, the significant improvements in burnout and engagement indices coupled with high participant adherence and minimal VR discomfort underline the potential of VR interventions in health care settings. These encouraging findings pave the way for more comprehensive studies, including randomized controlled trials, to further validate and expand upon these results.

KEYWORDS

virtual reality; burnout; mindfulness; health care professionals; mental health; health promotion; educational intervention

Introduction

Background

Burnout among health care workers is a growing concern that affects professionals worldwide. Burnout is characterized by emotional exhaustion, depersonalization, and a diminished sense of personal accomplishment [1], and it extends beyond transient workplace stress, potentially undermines patient care quality, increases the rate of errors, creates a negative work climate, and contributes to health care costs [1-3]. The prevalence of burnout varies considerably, with a scoping review during the COVID-19 pandemic reporting rates of 4.3% to 90.4% among health care workers, reflecting the significant mental burden and high levels of stress and burnout experienced by frontline health care workers during this period [4]. This review highlighted multiple factors associated with increases or decreases in burnout, including demographic characteristics, psychological conditions, social factors, work organization, and direct COVID-19-related impacts, providing valuable insights for policy makers and health care managers [4].

The COVID-19 pandemic has notably worsened this panorama, causing unprecedented spikes in burnout rates. Data from Spain [5] revealed an increase from 10% before the pandemic to a staggering 50% during the pandemic, with a marked rise in emotional exhaustion and depersonalization, and a decline in personal accomplishment among primary care physicians.

Economically, burnout contributes to substantial costs in the health care system, with estimates in the United States indicating a US \$979 million annual burden related to turnover and reduced clinical hours among primary care physicians alone [6,7]. To deal with this issue, the World Health Organization has underscored the importance of psychosocial interventions, including mindfulness and cognitive behavioral strategies, to enhance mental health and stress management in the workplace [8].

Contemporary research supports mindfulness as an effective intervention against burnout [9,10]. This practice, originally encapsulated by Kabat-Zinn's [11] conceptualization as an intentional nonjudgmental focus on the present experience, is gaining recognition as a cornerstone in the arsenal against burnout among medical professionals [12]. The implementation of mindfulness is corroborated by evidence indicating its significant contribution to bolstering emotional resilience, fostering effective communication, and reinforcing collaborative dynamics in the often high-pressure clinical environment [13-15].

Integration of Mindfulness Practices in Health Care Through Virtual Reality Technology

With the integration of technology into health care, virtual reality (VR) offers a novel platform for mindfulness training. By simulating controlled environments, VR can deepen

mindfulness practices, potentially surpassing traditional methods in improving mood, sleep quality, and cognitive focus [16]. The immersive experiences of VR are known to increase knowledge retention and engagement, making educational interventions more effective [17-22].

The application of VR to mindfulness training presents a unique opportunity for health care professionals to cultivate skills for managing stressors inherent to their profession. Empirical evidence suggests that VR-based mindfulness can yield significant benefits for emotional regulation and stress reduction, thus improving the well-being of health care providers [23-26].

Study Objective and Hypothesis

The objective of this pilot study was to evaluate the immediate impact of an 8-week VR educational program on burnout and work engagement among health care professionals. The study measured changes in the levels of emotional exhaustion, depersonalization, and personal accomplishment as characterized by the Maslach Burnout Inventory (MBI), along with the dimensions of vigor, dedication, and absorption as depicted by the Utrecht Work Engagement Scale (UWES).

The study was guided by 2 hypotheses. The null hypothesis (H0) proposed that the VR educational program would not result in significant changes in burnout or work engagement levels, and any variations could be attributed to random fluctuation rather than the intervention's effect. Conversely, the alternative hypothesis (H1) suggested that the VR program would lead to significant improvements in these measures, reflecting a direct positive impact of the intervention on the professional well-being of participants.

While burnout is recognized as a multifaceted syndrome influenced by a variety of factors, the project posited that a targeted VR program focusing on mindfulness and emotional management might enhance resilience among health care professionals. This resilience, in turn, could modify their perception and coping mechanisms, equipping them with effective strategies to counteract work-related stress. The insights gained from this study are expected to contribute to the development of innovative and more personalized interventions that are tailored to the needs of health care workers [25,26].

Methods

Study Design

In this prospective interventional pilot study, a nonrandomized pre-post intervention design was used to explore the preliminary effects of a mindfulness-based VR educational program in health care professionals.

Participants and Setting

This pilot study enrolled 90 health care professionals, representing a broad range of specialties in the health care sector. The demographic profile of the 83 participants who completed

the program revealed an average age of 46.39 years and a mean professional tenure of 17.57 years. The cohort was predominantly female, with only 7 male participants, reflecting the sex distribution that is common in these centers. The detailed breakdown of professional roles within the cohort is presented in the Results section.

Selection and Enrollment

Recruitment

Recruitment for the study was conducted via an open invitation across 3 health care centers, and the study targeted a diverse group of professionals, including nurses, physicians, administrative staff, nursing assistants, occupational therapists, social workers, psychologists, pediatricians, dentists, and ward assistants.

The first, second, and third centers have been identified in this study as CAP-A, CAP-B, and CSSC, respectively. Informative sessions were held in each center during the recruitment of each group owing to different time periods. During these sessions, all professionals were able to ask questions about VR and the program, and later decide if they were interested in participating. If interested, they were required to send an email to our team to be evaluated for inclusion.

The absence of a control group in this study was a strategic choice, which was influenced by the exploratory nature of the pilot study and resource limitations. This choice and its implications are further discussed in the Limitations subsection. The study's pre-post design without a control group necessitated a sample size that was feasible within the available resources and anticipated participant availability.

Inclusion and Withdrawal Criteria

Health care professionals who were currently employed in the study centers, older than 18 years, and able to commit to the program's full duration were considered for inclusion. Informed consent was required, along with a commitment to complete all questionnaires. Participants were excluded if they had participated in a similar program or received specific training in burnout prevention within the last 12 months, had a long-term absence from work or any situation that prevented regular attendance during the study, or had vertigo, epilepsy, or significant visual/auditory disabilities that precluded the use of VR glasses. Withdrawal from the study was considered when participants had significant intolerance to VR equipment or were absent for more than two sessions. To facilitate participation and minimize dropout, participants were allowed a 2-week grace period after the program to cover any missed sessions.

Sequential Enrollment, Center Allocation, and Attrition

Enrollment and participation were conducted in sequential phases to accommodate the limited number of VR headsets, with only 2 headsets available for the entire study. The initial enrollment occurred at the first center (CAP-A) in February 2022, with 29 participants included and then divided randomly into 3 groups for logistic reasons. The groups completed the program at different times throughout the year, with the final group concluding in December 2022.

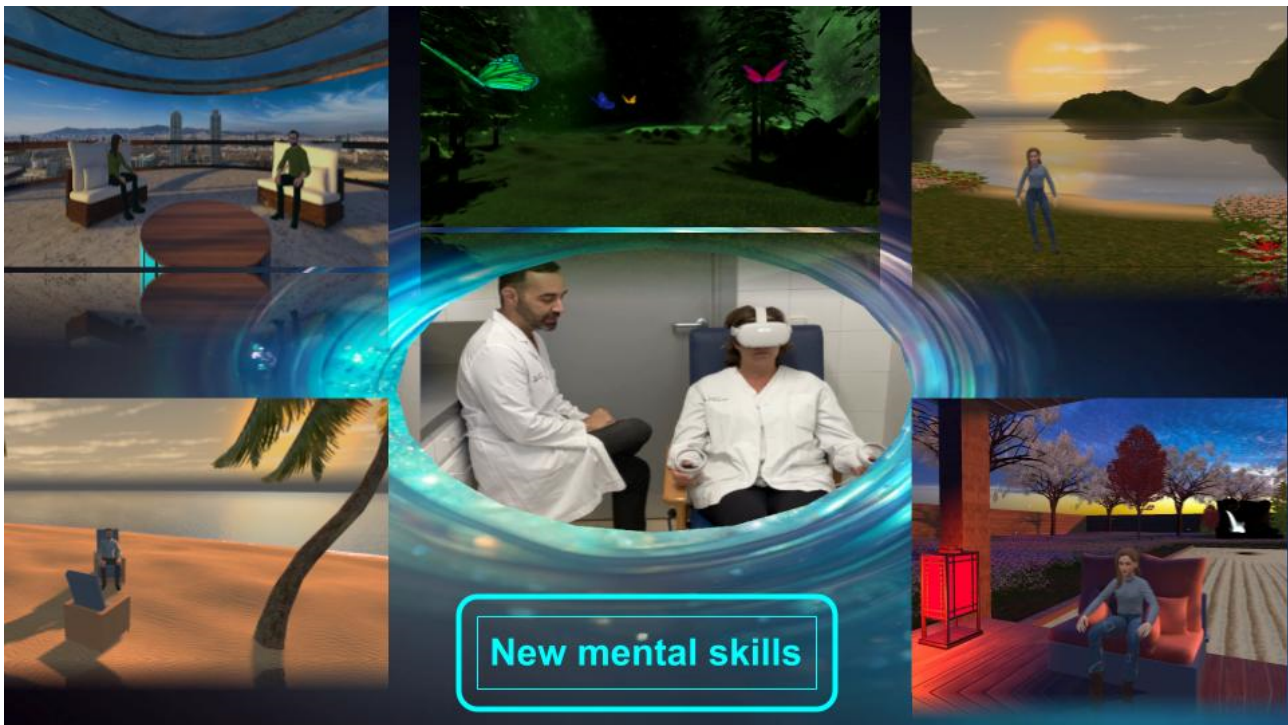
Building on the lessons learned from the initial phase regarding resource utilization and scheduling, the process was refined for subsequent enrollments. In 2023, a more streamlined approach was adopted at the next 2 centers, where all participants were enrolled in a single group per center to simplify logistics. Recruitment for the study was conducted simultaneously at both centers in January and February 2023. At CSSC, 41 participants were included, with 36 participants successfully completing the program between February and April 2023. At CAP-B, 20 participants were initially enrolled, with 14 participants completing the program in April and a small additional group of 4 participants completing the program in October 2023.

Instruments

The intervention was delivered through Meta Quest 2 VR headsets (Meta Platforms, Inc), which were chosen for their cable-free stand-alone functionality and high-quality audiovisual output. The headsets feature hand tracking capabilities that were used in the program to enhance immersion by visualizing users' hands in VR and allowing simple selection of sessions via the menu. The program was developed between April 2021 and January 2022 following a methodical approach based on bibliographic review and guided by the expertise of author NM. It integrated mindfulness and emotional management techniques, which are well-established methods for reducing burnout and enhancing work engagement, and are particularly beneficial in health care settings [9-26]. The VR sessions were developed by author JFC. VR technology was integrated with the author's clinical expertise in mindfulness to create a dynamic learning environment. Unity (Unity Technologies) and Blender (Blender Foundation) were used to construct 3D animations that visually represent and illustrate mindfulness and emotion management techniques. These animations serve as immersive educational tools within VR environments, enhancing the learning experience beyond traditional relaxation sessions. Moran Bueno, who specializes in mindfulness at the University of Barcelona, ensured that the content was scientifically accurate and pedagogically effective. The development process involved iterative feedback from health care professionals, aiming to refine the program's educational impact and comfort. The VR environments were specifically crafted for passive educational engagement, allowing participants to immerse in the program without the need for active interaction or physical movement and thus enhancing the learning experience in a safe and user-friendly manner. The VR program allowed for a more engaging and potentially more impactful learning experience by placing participants in various virtual environments that can enhance the absorption of the techniques taught.

The VR sessions immersed participants in various carefully designed settings, such as a serene beach, calm lake, and peaceful Zen garden. Ambient sounds corresponding to each environment, like the soothing lapping of waves, were incorporated to deepen the sensory experience. This auditory enhancement, in tandem with visual elements, augmented the overall educational and immersive quality for the users. The integration of these sensory aspects aimed to create an optimal learning environment for engaging with the mindfulness and emotional management content (Figure 1).

Figure 1. Some of the virtual reality environments of the educational program. Displayed images from the top middle in clockwise direction are butterflies in a garden, a serene bay, a zen garden, a tropical beach, and a terrace with panoramic views of Barcelona. At the center is an image of a supervised session in progress.



VR Considerations

Although VR is a technological tool with minimal risk, the use of VR headsets, especially for extended periods, can occasionally lead to side effects, such as cybersickness, eye strain, emotional reactions, and physical danger, in some individuals [20,27-30]. These potential effects were carefully considered in the design of the intervention to minimize any adverse outcomes. The potential side effects are as follows [27,30]:

- **Cybersickness:** Symptoms include nausea, balance issues, disorientation, headache, eye strain, and general fatigue, which tend to dissipate shortly after the discontinuation of VR use.
- **Eye strain:** Eye discomfort may occur with extended VR use, although such instances are uncommon given the brevity of typical exposure times in a controlled research setting.
- **Intense emotional reactions:** The compelling realism of VR and the emotion-related content can provoke emotional responses, requiring monitoring.
- **Physical danger:** While rare in a controlled environment, there is a potential risk of physical injury due to loss of spatial awareness while immersed in VR. This includes the possibility of tripping, bumping into objects, or other accidents, particularly if the physical space is not adequately prepared for VR activities.

Mitigation Measures

The project development incorporated strategic measures to address human factors and ergonomic considerations, aiming to minimize VR-induced side effects. These measures, which aligned with current guidelines and best practices, were

meticulously designed to ensure the safety and efficacy of the VR intervention [27-30]. The design aspects are as follows:

- **Session duration:** VR sessions are capped at 10-13 minutes, reducing the risk of cybersickness and visual fatigue [27].
- **Static interaction:** Design of the VR experience for seated participants (minimal requirement for movement) reduces the risks of nausea and physical activity in VR [28,29].
- **Hand tracking:** Incorporation of hand tracking technology allows participants to maintain a sense of agency and immersion in the VR environment without necessitating complex interactions [28,29].
- **Optimization of the VR content:** VR content is carefully designed to avoid overly intense stimuli and to support user comfort. Adjustments to lighting, motion, and frame rates are considered to prevent disorientation and discomfort [27,30].
- **Stress relief features:** Elements, such as biophilic designs, soft colors, and calming music within the VR environment, are incorporated to create a restorative virtual space for users [27].
- **Monitoring and support:** Continuous observation during VR exposure and immediate follow-up after VR exposure permits the research team to identify and mitigate any adverse effects. Participants are advised on headset adjustment and encouraged to take breaks as needed [27,29].
- **User training:** Prior to the initiation of the VR educational program, participants need to undergo a training session focused on VR utilization. This session includes instructions on the proper adjustment of the VR headset, acclimatization to immersive experiences, navigation of the VR interface, and response to potential side effects. The aim is to foster participant independence in managing the VR system and to ensure comfort during use [29].

This approach not only aids in minimizing potential motion-induced discomfort but also ensures a consistent and comfortable experience for all participants. During the course of the research, no VR-related side effects were observed. The only concern reported by a small subset of participants ($n=7$) was discomfort attributed to the weight of the headset. In most instances, this was alleviated, at least partially, by readjusting the headset. Regular check-ins were conducted after the sessions to monitor any adverse effects, and guidance was provided to participants on taking breaks or adjusting the headset position as needed, which further contributed to the positive reception and comfort of the intervention.

Procedure

The program lasted for 8 weeks. A calendar was created, and each participant was assigned a specific day and time every week for their 13-minute VR session. Each session was designed with a clear structure, consisting of 3 phases: preparation, VR experience, and cleanup. In order to ensure a secure and efficient implementation of the program, the sessions were conducted under the supervision of one of the researchers. During the preparation phase, participants were welcomed and assisted with the VR headset adjustment. The role of the researcher included monitoring the implementation for consistency, managing any technical issues, and ensuring that the VR equipment was used safely and effectively.

A key advantage of this VR program is that it constitutes a fully self-contained system. The VR content was directly uploaded to the headsets, thereby eliminating dependency on internet connectivity, an essential feature for accommodating health care professionals operating in environments where internet access may be limited or nonexistent.

Content Overview

Over the sessions, participants engaged with content from the following primary areas:

- **Mindfulness training:** In these sessions, exercises are focused on breath and body scanning, aiming to ground participants in the present moment. By maintaining an attitude of acceptance and nonjudgment, these sessions aim to teach how to foster mental tranquility.
- **Emotional regulation:** In these sessions, participants are introduced to techniques designed to address and manage intense emotions. Instead of suppressing or avoiding discomforting feelings, participants are encouraged to approach them with openness and curiosity, potentially deriving insights and understanding from their observations.
- **Self-compassion:** This area underscores the importance of treating oneself with kindness, especially during challenging times. Recognizing and minimizing the influence of one's inner critic is crucial. Participants are taught to treat themselves with the same warmth and understanding they would extend to a close friend or loved one, promoting a balanced self-view.

Variables

The study evaluated the intervention's impact using demographic and psychometric assessments. Demographic data

collected included age, sex, professional category, and tenure, to understand sample characteristics and control for confounding factors. Psychometric evaluation was performed with 2 established tools: MBI and UWES. These 2 scales were administered on paper before the commencement of the first session and after the conclusion of the last session. Both scales score their 3 subdimensions on a Likert scale from 0 (never) to 6 (daily).

The MBI is an established instrument for assessing burnout in health care settings, and it uses 3 subscales, namely, emotional exhaustion, depersonalization, and personal accomplishment, to capture burnout dimensions. Its high reliability has been confirmed with Cronbach α coefficients ranging from 0.71 to 0.90 in the Spanish health care context, validating its use for this study [31-36].

The subscales are interpreted as follows [36]:

- **Emotional exhaustion:** A score of ≥ 27 indicates a high level of burnout, 19-26 indicates a moderate level of burnout, and < 19 indicates a low level of burnout.
- **Depersonalization:** A score of > 10 indicates a high degree of depersonalization, 6-9 indicates a moderate degree of depersonalization, and < 6 indicates a low degree of depersonalization.
- **Personal accomplishment:** A score of 0-30 suggests a low degree of personal accomplishment, 34-39 suggests a moderate degree of personal accomplishment, and > 40 suggests a high degree of personal accomplishment.

The UWES is a questionnaire that measures work engagement through 3 aspects: vigor, dedication, and absorption, which are defined by high energy, a sense of significance, and deep involvement in work, respectively. Scores on the UWES are calculated as mean values across the items for each dimension. Based on these mean scores, engagement levels are categorized into 5 distinct groups: very low, low, medium, high, and very high. This categorization allows for a nuanced understanding of work engagement among participants. The UWES shows robust psychometric properties for Spanish medical professionals, with a Cronbach α total reliability score of 0.93 and strong subscale consistencies. It has been proven to be effective for correlating work engagement with health outcomes and job stress, making it a pertinent choice for assessing the positive occupational states in the study [37-40].

Ethical Considerations

This study was conducted in compliance with the principles outlined in the Declaration of Helsinki (1964) for research involving human subjects, as evaluated and approved by the Badalona Serveis Assistencials' Research Committee and the Jordi Gol i Gurina Foundation Ethics Committee (approval number: 21/280-P). The committees conducted an ethical review of the project, which included consideration of participant confidentiality, informed consent, and potential risks to participants.

Statistical Analysis

Data Anonymization and Blinding

To protect participant confidentiality while ensuring data integrity, each data set was pseudoanonymized with an identifier code. This measure allowed for an individual response to be tracked without revealing personal information. The principal investigator was the sole individual with access to the decryption key, thus reinforcing the partial blinding of research staff and minimizing potential biases. Statistical analysis was performed with DATAtab (DATAtab e.U.) and SPSS Version 27 (IBM Corp).

Normality Tests

The Shapiro-Wilk test was used to determine the distribution of each variable, a necessary step to guide the selection of appropriate statistical tests for the subsequent analyses.

Inferential Statistical Analysis and Hypothesis Testing

Following the descriptive summary of the data, inferential statistical analyses were conducted to test the study's hypothesis that the VR educational program would lead to significant changes in burnout and work engagement scores. The paired *t* test was applied to normally distributed variables to determine if the mean differences in scores before and after the intervention were statistically significant. For data that did not meet the criteria for normal distribution, the Wilcoxon signed-rank test was used to assess median score differences. All tests set the significance threshold at $P < .05$.

Table 1. Demographic profile of the study participants.

Professional category	Participants, n	Age (years), mean	Age (years), range	Sex (female/male), n	Tenure (years), mean	Tenure (years), range
Nurses	30	44.93	29-56	27/3	18.90	2-34
Physicians	15	50.80	39-63	12/3	15.33	2-32
Administrative staff	13	48.92	35-59	12/1	16.69	1-36
Nursing assistants	7	45.43	27-58	7/0	17.43	1-29
Occupational therapists	7	46.43	41-57	7/0	24.86	18-42
Social workers	3	41.33	40-43	3/0	7.33	1-16
Psychologists	3	39.33	28-47	3/0	17.67	15-21
Pediatricians	2	36.00	33-39	2/0	7.25	3.5-11
Dentists	2	45.00	41-49	2/0	19.00	13-25
Ward assistants	1	57.00	57	1/0	21.00	21
Overall	83	46.39	27-63	76/7	17.57	1-42

Descriptive Statistics

Upon establishing the distribution characteristics of the data set, descriptive statistics summarized the data for the 83

Results

Demographics

Attrition resulted in a final sample of 83 participants who completed the intervention (5 dropouts from CSSC and 2 from CAP-B; CAP-A retained all its participants). The study achieved a high participation rate of 92% (83/90). Attrition was due to personal circumstances not related to the VR system. Specifically, 1 participant was on maternity leave, 3 were on sick leave, and 3 cited time constraints as the reason for withdrawal. Notably, there were no dropouts attributed to discomfort or adverse reactions to the VR technology.

The demographic characteristics of the participants are summarized in [Table 1](#). The final sample consisted of 83 health care professionals with an average age of 46.39 (range 27-63) years. The cohort included 30 nurses, 15 physicians, and individuals with various other roles such as administrative staff and nursing assistants. Female participants represented the majority of the sample, with 76 female participants compared to 7 male participants. The mean tenure was 17.57 years, with individual tenures ranging from 1 to 42 years, reflecting a wide range of professional experience among the participants. These demographic data offer a comprehensive overview of the study sample, highlighting the diversity in age, professional role, and experience within the health care setting.

participants who completed the VR educational program. The analysis provided an initial overview of the results ([Table 2](#)).

Table 2. Descriptive statistics of the Maslach Burnout Inventory and Utrecht Work Engagement Scale items among the 83 study participants.

Variable	Mean	Median	SD	Minimum	Maximum
Emotional exhaustion					
Preintervention	22.67	21	10.88	2	51
Postintervention	17.07	17	9.00	0	42
Depersonalization					
Preintervention	10.04	10	5.07	0	24
Postintervention	7.37	7	4.34	0	20
Personal accomplishment					
Preintervention	29.72	30	8.64	1	47
Postintervention	33.08	34	6.70	17	46
Vigor					
Preintervention	22.90	23	5.91	8	35
Postintervention	24.41	24	5.65	8	36
Dedication					
Preintervention	18.72	19	6.43	6	30
Postintervention	20.36	22	5.88	8	30
Absorption					
Preintervention	19.86	21	6.58	6	32
Postintervention	21.71	23	6.39	6	35

Efficacy of the VR Educational Program

Descriptive Analysis

An analysis of MBI and UWES scores after the VR program reflects a potential impact on participants' professional well-being. [Multimedia Appendix 1](#) presents data indicating a dual effect. There was a reduction in burnout as evidenced by lower emotional exhaustion and depersonalization scores, alongside increased feelings of personal accomplishment. Simultaneously, elevated vigor, dedication, and absorption scores indicated augmented work engagement following the VR intervention.

Following the descriptive analysis, [Table 3](#) provides a detailed breakdown of the distribution of burnout levels among participants both before and after the intervention. The table categorizes participants into low, moderate, and high levels of burnout for each of the following 3 MBI subscales: emotional exhaustion, depersonalization, and personal accomplishment. It presents these categories in both percentage and actual number of participants, offering a clear perspective on the shift in burnout levels after the intervention among the 83 health care professionals involved in the study.

Table 3. Distribution of burnout levels among the 83 study participants before and after the intervention.

Variable	High burnout, n (%)	Moderate burnout, n (%)	Low burnout, n (%)
Emotional exhaustion			
Preintervention	27 (33)	24 (29)	32 (39)
Postintervention	10 (12)	20 (24)	53 (64)
Depersonalization			
Preintervention	45 (54)	21 (25)	17 (21)
Postintervention	21 (25)	34 (41)	28 (34)
Personal accomplishment			
Preintervention	44 (53)	26 (31)	13 (16)
Postintervention	29 (35)	40 (48)	14 (17)

Statistical Comparisons and Significance

Shapiro-Wilk tests were used to determine the normality of all variables. Emotional exhaustion, depersonalization, personal accomplishment, and vigor, which followed a normal distribution, were analyzed using *t* tests. The nonnormally distributed variables dedication and absorption were analyzed using the Wilcoxon test. Additionally, effect sizes were calculated using Cohen *d* for normally distributed data and Cohen *r* for nonnormally distributed data to quantify the magnitude of observed changes.

Correlation and Effect Size Assessments

Correlation assessments were integral to the analysis in order to evaluate relationships between preintervention and postintervention scores. The Pearson correlation was applied to normally distributed data, and the Spearman correlation was used for nonnormally distributed data, with findings reported in Tables 4 and 5. The Cohen *d* and *r* have been provided to reflect the effect sizes and assess the strength of differences, with statistically significant changes ($P < .05$) in all variables.

Table 4. Summary of preintervention and postintervention analysis results for normally distributed variables.

Variable	Preintervention result, mean (SD)	Postintervention result, mean (SD)	<i>t</i> test <i>t</i> (<i>df</i>)	<i>P</i> value (2-tailed)	Effect size, Cohen <i>d</i>	Pearson <i>r</i>	Pearson <i>P</i>
Emotional exhaustion	22.67 (10.88)	17.07 (9.00)	5.58 (82)	<.001	0.61	0.59	<.001
Depersonalization	10.04 (5.07)	7.37 (4.34)	4.67 (82)	<.001	0.51	0.40	<.001
Personal accomplishment	29.72 (8.64)	33.08 (6.70)	-3.62 (82)	<.001	0.40	0.41	<.001
Vigor	22.65 (5.98)	24.66 (5.50)	-3.77 (82)	<.001	0.41	0.64	<.001

Table 5. Summary of preintervention and postintervention analysis results for nonnormally distributed variables.

Variable	Preintervention result, median (IQR)	Postintervention result, median (IQR)	Wilcoxon test			Effect size, Cohen <i>r</i>	Spearman <i>r</i>	Spearman <i>P</i>
			<i>W</i>	<i>z</i>	<i>P</i> value (2-tailed)			
Dedication	19 (12)	22 (8)	580	-3.63	<.001	0.41	0.73	<.001
Absorption	20 (10)	23 (9.5)	785.5	-3.52	<.001	0.40	0.67	<.001

Epidemiologic Factors

Spearman correlation analysis was employed to explore relationships between age, tenure, and the main study variables, and it revealed no significant correlations. Similarly, point biserial correlation analysis indicated no significant correlations between sex and the study variables both before and after the intervention.

The influence of professional categories on questionnaire outcomes was assessed using η^2 values (Table 6). The η^2 values ranged from 0.01 to 0.24 and indicated the proportion of variance in each measure that can be attributed to the professional category. Higher η^2 values, such as those for

preintervention depersonalization, suggested a more significant variance related to the professional category, while other measures exhibited a lower degree of variance due to professional categorization, reflecting a range of impacts across different professional categories.

The ANOVA analysis provided deeper insights into the intervention's impact, examining changes in the MBI and UWES scores. This analysis encompassed overall changes and variations across different professional categories. Detailed statistical outcomes, including sums of squares, mean squares, *F* values, and *P* values, are presented in Table 7, highlighting the statistical significance of the observed changes.

Table 6. Maslach Burnout Inventory and Utrecht Work Engagement Scale data across different professional categories.

Professional category	Emotional exhaustion, mean (SD)		Depersonalization, mean (SD)		Personal accomplishment, mean (SD)		Vigor, mean (SD)		Dedication, mean (SD)		Absorption, mean (SD)	
	Pre ^a	Post ^b	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Nurses	20.37 (8.78)	18.77 (8.22)	9.97 (4.43)	8.00 (4.10)	30.03 (8.26)	33.73 (7.23)	21.90 (6.83)	23.37 (5.84)	18.57 (6.78)	20.23 (5.66)	19.40 (7.37)	21.37 (6.35)
Physicians	26.13 (12.70)	19.93 (9.90)	10.13 (4.66)	7.80 (4.72)	29.40 (5.59)	31.53 (7.62)	21.60 (5.33)	24.60 (5.26)	18.33 (6.20)	21.60 (5.53)	20.80 (6.11)	24.07 (4.38)
Administrative staff	22.00 (7.97)	15.77 (9.36)	13.15 (3.93)	8.00 (4.81)	27.23 (8.63)	31.23 (5.95)	24.00 (4.93)	27.08 (4.96)	16.38 (6.46)	18.69 (6.13)	19.77 (6.31)	22.31 (7.09)
Nursing assistants	22.43 (10.50)	16.00 (12.49)	11.00 (4.90)	7.71 (4.54)	25.29 (14.28)	32.00 (8.70)	23.29 (6.42)	26.14 (6.15)	20.43 (7.28)	21.43 (6.85)	19.00 (7.79)	22.14 (7.65)
Occupational therapists	17.86 (12.42)	10.57 (4.08)	9.14 (7.36)	4.57 (2.23)	33.43 (6.75)	35.43 (2.64)	25.00 (6.08)	24.57 (4.72)	20.43 (7.74)	21.29 (4.75)	19.00 (6.93)	19.57 (7.59)
Psychologists	36.33 (4.16)	14.33 (6.03)	3.00 (3.61)	3.33 (1.53)	27.67 (10.21)	35.67 (5.03)	22.33 (2.89)	26.67 (1.53)	21.67 (2.52)	22.00 (1.00)	21.33 (9.81)	23.33 (6.35)
Social workers	15.33 (8.08)	11.67 (6.81)	2.67 (2.52)	4.33 (4.51)	35.67 (12.70)	33.33 (8.14)	19.67 (7.57)	23.00 (5.57)	18.67 (10.21)	20.33 (8.08)	20.33 (8.14)	22.33 (6.43)
Pediatricians	43.50 (10.61)	27.00 (5.66)	13.50 (2.12)	11.50 (7.78)	29.00 (5.66)	33.00 (4.24)	23.50 (6.36)	17.00 (4.24)	16.00 (5.66)	12.50 (4.95)	18.00 (5.66)	17.00 (2.83)
Ward assistants	26.50 (20.51)	12.50 (6.36)	10.50 (6.36)	5.50 (3.54)	38.00 (11.31)	38.00 (4.24)	25.00 (9.90)	28.00 (4.24)	23.00 (7.07)	21.50 (4.95)	18.50 (7.78)	21.00 (7.07)
Dentists	16.00 (N/A ^c)	7.00 (N/A)	5.00 (N/A)	8.00 (N/A)	36.00 (N/A)	34.00 (N/A)	26.00 (N/A)	31.00 (N/A)	19.00 (N/A)	27.00 (N/A)	17.00 (N/A)	21.00 (N/A)
η^d	0.47	0.39	0.49	0.35	0.32	0.24	0.23	0.37	0.23	0.31	0.12	0.24
η^{2d}	0.22	0.15	0.24	0.13	0.1	0.06	0.05	0.14	0.05	0.09	0.01	0.06

^aPre: preintervention.^bPost: postintervention.^cN/A: not applicable.^d η and η^2 values indicate the variance due to professional categorization.

Table 7. ANOVA results for preintervention and postintervention measures and professional categories.

Variable	Sum of squares	Degrees of freedom (<i>df</i>)	Mean squares	<i>F</i>	<i>P</i> value
Emotional exhaustion					
Preintervention/postintervention	1302.56	1	1302.56	37.07	<.001
Professional category	2294.19	9	254.91	1.75	.09
A×B	861.83	9	95.76	2.73	.008
Depersonalization					
Preintervention/postintervention	294.22	1	294.22	21.89	<.001
Professional category	567.48	9	63.05	2.33	.02
A×B	126.04	9	14.00	1.04	.42
Personal accomplishment					
Preintervention/postintervention	468.92	1	468.92	12.37	.001
Professional category	656.22	9	72.91	0.86	.57
A×B	168.51	9	18.72	0.49	.87
Vigor					
Preintervention/postintervention	168.01	1	168.01	14.59	<.001
Professional category	360.04	9	40.00	0.72	.69
A×B	131.10	9	14.57	1.27	.27
Dedication					
Preintervention/postintervention	128.41	1	128.41	13.11	.001
Professional category	358.90	9	39.88	0.58	.81
A×B	84.81	9	9.42	0.96	.48
Absorption					
Preintervention/postintervention	208.41	1	208.41	12.78	.001
Professional category	194.98	9	21.66	0.29	.98
A×B	34.49	9	3.83	0.24	.99

Discussion

Principal Findings

In this pilot study, we implemented an 8-week VR educational program focused on mindfulness and emotional management for health care professionals. The results suggest that the program can positively affect burnout symptoms and work engagement in this group. This inference is drawn from the significant reductions observed in burnout symptoms and enhancements in work engagement metrics after the intervention (Tables 2-5 and Multimedia Appendix 1). Complementing the observed reductions in burnout symptoms, the VR educational program also appears to have positively influenced work engagement (Tables 4 and 5). These shifts are especially prominent in the dimensions of dedication and absorption, highlighting the VR program's potential in enhancing aspects of work engagement that relate to a sense of significance and deep involvement in work.

The reduction in score variability after the intervention, as shown in Tables 4 and 5, implies a standardized effectiveness of the VR program in mitigating burnout symptoms. This

uniform decrease in scores like emotional exhaustion and depersonalization scores highlights the VR program's consistent impact across participants. The effect sizes, as analyzed from Tables 4 and 5, reveal a more significant impact of the VR intervention in reducing negative burnout aspects, particularly emotional exhaustion and depersonalization, than in enhancing positive work attributes.

Differential Impact Across Professional Categories

The VR program's effects varied among health care roles, as seen in the η^2 values in Table 6. High variability in emotional exhaustion and depersonalization suggests that roles like psychologists and pediatricians might be more vulnerable to certain burnout aspects. Conversely, measures like vigor and absorption showed more uniform responses across roles. The ANOVA analysis revealed significant variation for emotional exhaustion across categories, emphasizing the need for tailored interventions in health care (Table 7). However, the findings should be approached cautiously due to the limited sample size in some categories, needing further research for conclusive results.

Comparison With Prior Work

The improvement in positive occupational states is a key outcome, given the critical role of engagement in the overall well-being and job performance of health care professionals [41]. The successful application of VR in mindfulness and emotional management training is consistent with existing literature [12,13], underscoring its potential as a vital psychosocial intervention tool in health care settings. This aligns with the findings of Lee and Cha [42], indicating the need for refined VR strategies to balance reducing burnout and boosting work engagement in health care.

Strengths and Implications

This pilot study has significant strengths and yields insights with practical implications for addressing burnout in health care professionals. The low dropout rate reinforces user engagement and the potential of VR as a sustainable educational tool, as observed in other research efforts [14-16,43]. The adherence rate of 92% (83/90) along with minimal reports of discomfort from VR use demonstrates its viability in a clinical setting. These factors are encouraging, especially considering the need for ergonomic consideration highlighted by the ease of resolving discomfort with simple adjustments.

The study's VR intervention was designed with a focus on user comfort, drawing from the mitigation strategies outlined in the VR Considerations subsection of the Methods section. This careful design likely contributed to the positive reception and ease of use reported by participants, underscoring the potential of VR in supporting World Health Organization-endorsed strategies for stress management in clinical environments [8].

Limitations

The promising results obtained in this pilot study must be viewed within the context of some methodological constraints. First, the lack of a control group in the study design precludes a definitive conclusion regarding the causality of observed changes, suggesting that further studies with control groups are necessary to corroborate the VR program's effectiveness. Second, the reliance on convenience sampling poses a risk for selection bias, and future studies may benefit from randomized sampling to ensure broader applicability of the results. Third, the study's participant demographic, with a significant underrepresentation of male participants, reflects the female majority typical in health care settings, particularly in our primary care centers where approximately 79.6% of our health care workers are female according to data provided by our

Human Resources department in November 2023. This gender imbalance limits the generalizability of our findings across all genders. Future research should aim to include a more balanced gender distribution when possible, exploring if VR educational programs have differential effects on various demographic groups. Fourth, the sample size, which is appropriate for a preliminary exploration into VR-based interventions, is nonetheless insufficient for establishing definitive efficacy, underscoring the need for larger more representative studies. Resource-related phased implementation may have introduced variability in delivery, which was mitigated in later stages but could have affected initial participant experience. Future studies should increase the sample size to provide more robust evidence of efficacy. It is also recommended to standardize the implementation process across all phases to minimize variability and improve the reliability of the results.

Conclusions

This pilot study provides initial indications that an 8-week VR-based educational program may positively influence burnout and work engagement among health care professionals. Our findings suggest a reduction in burnout symptoms, as measured by the MBI, and an increase in work engagement, as indicated by the UWES. While the data hint at VR's promise for reducing burnout symptoms and fostering work engagement, the results should be viewed as preliminary. The interpretive value of the findings is limited by the sample size and the absence of a control group, despite the application of rigorous statistical analyses to assess the intervention's impact.

To enhance future assessments and maintain equitable access to potential benefits, subsequent research could adopt a crossover study design. Such a design would involve randomizing participants into initial control and intervention groups, with a subsequent exchange of roles following a predetermined washout period. This methodological approach would allow for a comprehensive evaluation of the VR program's impact by ensuring that each participant acts as their own control, thereby reinforcing the strength of the evidence gathered while ensuring access to the intervention.

This study contributes to the literature on the use of VR technology in education and health care, highlighting the potential of digital health interventions in disease prevention and health promotion, and emphasizing the importance of prioritizing the well-being of health care professionals as a main requirement for the survival of the health care system.

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Data Availability

The data sets generated or analyzed during this study are available from the corresponding author upon reasonable request.

Authors' Contributions

JFC led the development of the study's software, provided technical support for the virtual reality sessions, was responsible for the data curation and project administration, drafted the initial manuscript, and supervised all data collection phases. NM co-conceptualized the study, developed the study's theoretical framework, was responsible for the audio creation for the sessions, and reviewed and edited the manuscript. CGM, LJCH, and FRCC contributed to the supervision of the sessions and participated in data collection, ensuring the integrity of the data collection process. MJC conducted the formal analysis, played a significant role in interpreting the data, and was a major contributor in writing and revising the manuscript. All authors reviewed and approved the final manuscript for submission and participated in the supervision of the sessions, ensuring rigorous oversight throughout the study.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Mean scores of the Maslach Burnout Inventory and Utrecht Work Engagement Scale.

[[PDF File \(Adobe PDF File\), 94 KB - xr_v1ile55678_app1.pdf](#)]

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Abbreviations

MBI: Maslach Burnout Inventory

UWES: Utrecht Work Engagement Scale

VR: virtual reality

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Original Paper

Perspectives of Medical Students and Developers Regarding Virtual Reality, Augmented Reality, Mixed Reality, and 3D Printing Technologies: Survey Study

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Abstract

Background: Emerging technologies, such as virtual reality (VR), augmented reality (AR), mixed reality (MR), and 3D printing (3DP), have transformative potential in education and health care. However, complete integration has not yet been achieved, and routine use is limited. There may exist gaps in the perspectives of these technologies between users and developers, and improvement may be necessary in developing such technologies.

Objective: The purpose of this study was to investigate the gaps in perspectives between medical students and developers in medical education regarding satisfaction and anticipated future use of VR, AR, MR, and 3DP technologies, as well as developers' perspectives on their advantages and current challenges.

Methods: This retrospective survey study was conducted during a 4-hour elective course over a period of 4 weeks. In this course, computed tomography scans of congenital heart disease patients, medical image processing software, head-mounted displays, and a virtual table were used. Student pre- and postsurveys and the developer survey included demographic and other characteristics, satisfaction, and anticipated future use of VR, AR, MR, and 3DP technologies. The advantages and current challenges of these technologies were only assessed in the developer survey.

Results: The study enrolled 41 participants, including 15 first-year medical students and 26 software and content developers. Students were more satisfied than developers across AR, VR, and 3DP in terms of overall satisfaction (VR and AR: $P < .001$; 3DP: $P = .002$), esthetics (VR: all $P < .001$; AR: vividness, $P = .006$ and design, $P < .001$; 3DP: vividness, $P = .001$ and design, $P = .002$), and continuous use intention (VR: repetition, $P = .04$ and continuous use, $P = .02$). Particularly in VR, satisfaction with reality was higher among students than among developers (real world, $P = .006$). Developers anticipated future use of MR for educating medical students and residents, individual and collaborative surgical planning, and performing surgery on patients. In contrast, students anticipated future use of VR primarily for student education, 3DP for resident education and individual surgical planning, and AR for collaborative surgical planning and performing surgery on patients. Developers perceived the inherent capabilities of VR, AR, and MR technologies as strengths, with hardware performance identified as a drawback. For 3DP, the possibility of customized product manufacturing was seen as an advantage, while cost was seen as a disadvantage.

Conclusions: This study elucidated the different perspectives between medical students and developers regarding 3D technologies, highlighting the discrepancy in potential applications and challenges within the medical field. These findings will guide the integration of 3D technologies in education and health care to fulfill the needs and goals of both medical students and developers.

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KEYWORDS

medical student; developer; virtual reality; augmented reality; mixed reality; 3D printing; perspective; survey

Introduction

Background

In recent years, 3D technologies, including virtual reality (VR), augmented reality (AR), mixed reality (MR), and 3D printing (3DP), have shown considerable potential to revolutionize the fields of education and health care [1-3]. Each of these technologies offers different capabilities. The basic principle of VR involves the immersion of users in artificial environments, providing complete immersion and removing them from their immediate surroundings [4]. On the other hand, the principle of AR involves overlaying digital information onto the real world, allowing interaction between the physical and digital realms [5]. MR goes a step further by merging tangible and virtual worlds [6]. Unlike VR, which fully immerses the user in a virtual environment, and AR, which overlays digital information onto the physical world, MR is defined as a technology that seamlessly merges the physical world with the virtual world, allowing physical and digital objects to coexist and interact in real time [7]. In MR, virtual objects appear to exist in the same space as physical objects, and users can interact with both in a natural and intuitive way. These technologies are commonly experienced using headsets, allowing hands-free viewing of digital information within the user's view. Additionally, 3DP is a method of creating a 3D object layer by layer from a computer-generated design [5]. Beyond these basic principles, these technologies have become powerful tools in facilitating practical training and skill development. Numerous studies have highlighted the importance of integrating these cutting-edge technologies into medical and surgical education [8-10].

VR is versatile with applications in 3D anatomical models, surgical planning, and medical skills practice simulators [11]. It has been actively evaluated for its efficacy in anatomy education and has been often compared with traditional methods like dissection and lectures, as well as modern techniques like 2D images and blended instructions [12,13]. In surgical education, VR can effectively address challenges, such as the shortage of available mentors, optimization of training time, and mitigation of the complexities associated with operative procedures [14]. Additionally, by replicating complex surgical scenarios in a controlled and risk-free environment, VR offers a safe space for trainees to enhance their skills and decision-making processes.

AR has been incorporated into different phases of medical training, and it serves as an essential tool for anatomical instruction, which can assist students during classroom studies, a tool in image-based training simulators, and an interactive platform to improve clinical skills [15]. The integration of AR has revolutionized medical education by providing students with real-time visualizations of complex anatomical structures and creating interactive and immersive learning experiences that deepen their understanding of medical concepts [16]. In addition, AR-based training simulators enable learners to

improve their practical skills and confidence by allowing them to practice medical procedures in a simulated digital environment before performing them in clinical settings [17]. There is a key difference between AR-based training simulators and VR-based training simulators. VR-based training simulators simulate the actual workspace within a 3D modeling environment and involve the handling of virtual objects using controllers. However, AR-based training simulators allow users to interact with digital elements while still being aware of their physical surroundings [18]. This allows for a more seamless integration of virtual elements with real-world objects and scenarios, offering unique training opportunities that VR alone may not be able to provide.

MR has rapidly advanced in recent years, establishing itself as a fundamental research direction within the field of intelligent medicine. There are significant numbers of MR applications in surgical training and planning [19,20]. Previous studies have found that by expanding upon conventional computer-assisted surgical techniques, MR offers significant potential for enhancing orthopedic training and needle insertion skills [3,21]. This transformative impact extends beyond the confines of surgical applications, encompassing the sphere of medical education as a whole. Some pioneering research has demonstrated that MR has the potential to enhance the efficacy of conveying intricate content through remote learning, a modality that remains pivotal in the field of education [22].

3DP provides a tangible and immersive approach to medical and surgical education [23]. 3DP enables the production of objects with very intricate details and offers the versatility to print a model with different materials, including hydrogels, thermoplastics and thermosets, metals, and ceramics [2,24]. In addition, personalized patient-specific 3DP models help students understand variation and pathology, while surgical planning benefits from accurate organ replicas that enhance visualization and reduce errors [25]. Trainees train their hands-on skills on 3D-printed models in a risk-free environment, and educators simulate complex cases for better decision-making [26]. Furthermore, 3DP plays a crucial role in advancing medical research by facilitating the prototyping of medical innovations, including devices and implants, thus shaping the future of the field [27,28].

These technologies have been well developed in recent years, and this is reflected in a variety of medical specialties in medical education and health care. While these technologies have been widely used to complement existing methods, they are increasingly becoming integral tools, particularly in settings where conventional approaches face limitations or challenges. In educational settings that have constraints, such as limited access to cadavers, high costs, concerns about formaldehyde exposure, ethical considerations, and challenges posed by pandemics, these technologies have gradually replaced traditional methods for medical students [29,30]. Similarly, in health care, personalized instruments, along with advancements like bone grafting and customized implants, are replacing

traditional approaches [31]. As they continue to complement and replace traditional methods, they offer innovative solutions to address various challenges and constraints encountered in both education and health care.

In South Korea, after students are accepted into medical school, they typically spend 2 years in premedical education. During this premedical education, they study basic subjects, such as basic sciences, and other fundamental subjects essential for their medical studies. Therefore, the first year of medical school is an appropriate time to introduce these latest technologies. Because students have already established a solid foundation in basic sciences during their premedical education, they are better equipped to grasp the complexities of these technologies and integrate them into their medical education effectively. The current technology curriculum is situated in the context following the completion of the anatomy course and preceding the commencement of the clinical curriculum. Prior to enrolling in this technology curriculum at Seoul National University College of Medicine, students are exposed to heart content in their human anatomy course using these tools. A survey comparing student evaluation of the same content through traditional education versus the use of these tools revealed that the tools were considerably helpful [32].

Theoretical Background

While numerous studies have examined the satisfaction and effectiveness among medical students, residents, and fellows [33-36], complete integration into routine education and health care has not been achieved. These studies have primarily focused on users, with little attention given to the perspectives of developers, who are responsible for creating these technologies. Consequently, the findings offer an incomplete picture. As these technologies continue to evolve in medical education, it becomes essential to understand the perspectives of both medical students and developers regarding the technologies.

Relationship Between Users and Developers

Users and developers are commonly considered 2 distinct groups of people [37]. Due to differences in backgrounds and situations, developers and users often share different and sometimes conflicting interests during the software development process. The root cause of many issues is perceived to be ongoing cultural differences. Other theories suggest that personality differences or even differences in how users and developers think cause these barriers [38]. Developers tend to be achievement-oriented and are intrinsically motivated to develop excellent software, while users are primarily focused on improving efficiency and solving problems [39]. The potential conflict of interest between them can negatively affect the performance of software development. Therefore, a study is needed to understand the gaps in their perspectives regarding the range of tools and techniques, which might support future development. Understanding their perspectives might help in refining the implementation strategies of these technologies in the large scope of curriculum development.

User and Developer Satisfaction and System Success

User satisfaction is one of the most frequently cited factors for measuring system success and one of the most difficult factors to measure [40]. A great deal of research has been conducted to understand the notion of user satisfaction. User satisfaction, as defined by previous researchers, encompasses meeting user needs [41], positive cognitive responses to system use [42], and measurable effects in projects [43]. In education, satisfaction plays a crucial role as a barrier to continuous use and adoption of these technologies [44]. While people may use various technologies without being fully satisfied with them, in the context of education, satisfaction impacts the effectiveness of learning experiences [45]. Students who are dissatisfied with the technologies used in their education may experience hindered engagement, motivation, and, ultimately, compromised learning outcomes [46]. High satisfaction with technology not only correlates with actual experiences of the technology but also enables individuals to anticipate which technologies may be beneficial in future situations. In addition, considering that developers not only represent the core of the development process but also account for the largest cost in software development, it is necessary to investigate developer satisfaction. Ultimately, developer satisfaction is essential for system development success.

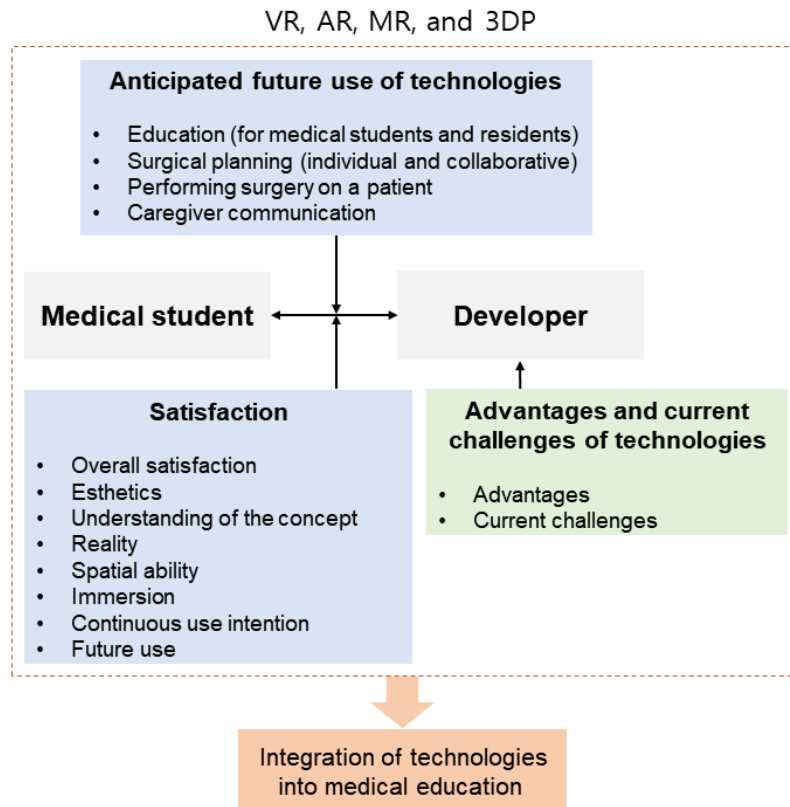
User and Developer Anticipations Regarding Technology

Anticipations of future use in technological development are more than simply descriptions of future products and systems. These anticipations can change the application process of novel technology in medical education as they guide the actions of technology developers [47]. At the same time, extrapolating future technology from past developments can narrow down the potential paths of technological advancement [48]. However, users play a role in shaping the future of technology, as the shape of technology depends on their anticipations of use [47]. To conclude, it is important to consider anticipations for investigating the gap in medical education. We suggest viewing envisaged sociotechnical futures as negotiation arenas between the present and the imagined futures. There is a lack of knowledge on differences in user and developer anticipations regarding the types of technologies that are likely to be widely used in different scenarios. In medical education, there may remain a gap in the anticipated use of these technologies between medical students and developers, and it may be needed to figure out the differences in anticipations to effectively bridge this gap.

Conceptual Framework

This study hypothesized a conceptual framework (Figure 1) in which there is a gap between medical students and developers in terms of satisfaction and anticipated future use of VR, AR, MR, and 3DP technologies, and this gap is associated with the complete integration into medical education. Additionally, from a technological perspective, this study hypothesized that factors related to the advantages and current challenges associated with these technologies from the developers' perspectives could potentially delay the integration of medical education.

Figure 1. Conceptual framework of this study. 3DP: 3D printing; AR: augmented reality; MR: mixed reality; VR: virtual reality.



Study Questions

The aim of this study was to investigate the gap in perspectives between medical students and developers regarding the satisfaction and anticipated future use of VR, AR, MR, and 3DP technologies, as well as developers' perspectives on their advantages and current challenges. The following specific research questions guided this study:

1. What is the difference in satisfaction levels with VR, AR, MR, and 3DP between medical students and developers?
2. What differences exist in the anticipated future use of VR, AR, MR, and 3DP between medical students and developers?
3. What are the developers' perceptions of the advantages and current challenges associated with VR, AR, MR, and 3DP?

Methods

Participants

All participants voluntarily enrolled in an elective course on 3D imaging software and the applications of 3D technology for human anatomy at Seoul National University College of Medicine, Seoul, Republic of Korea, and were voluntarily recruited. In the academic year 2023, 15 first-year medical students and 26 software and content developers with expertise in VR, AR, or 3DP participated in this study.

Curriculum and Study Design

The course and the surveys were designed for educational quality improvement purposes prospectively before actual application of the curriculum. The statistical research was

performed retrospectively after the completion of the curriculum.

Contents and Schedule for the Elective Course

The elective course spanned 4 weeks with 4 sessions, each lasting 4 hours (Table 1). A graphical diagram of the elective course and a workflow diagram detailing the hands-on practice are shown in Figures 2 and 3. During the initial 3 weeks, the curriculum included lectures and hands-on sessions focusing on the application of artificial intelligence (AI) technology in medical imaging. The AI-based image processing software quickly and automatically segmented the anatomical structures, allowing for adequate processing within the first 3 weeks. Only the finer anatomical structures required separate segmentation. The students were divided into 4 groups and used medical image processing software to outline anatomical structures. In this study, heart models were selected owing to complex 3D relationships between components within the thoracic cavity. These heart models were personalized and customized to match the anatomical structure of each patient with congenital heart disease (CHD). The process of creating a 3D reconstruction from a patient's computed tomography scan is shown in Multimedia Appendix 1. The 3D segmented models were constructed for an interrupted aortic arch (Multimedia Appendix 2), Ebstein anomaly (Multimedia Appendix 3), transposition of the great arteries (Multimedia Appendix 4), and major aortopulmonary collateral arteries (Multimedia Appendix 5). The segmented and processed images were then integrated into various tools: VR via Oculus Quest 2 (Meta), AR via HoloLens 2 (Microsoft Corp), and 3DP for physical modeling. In the final week, students presented on the future of medical education and clinical environments, drawing upon tools from the first 3

weeks of the course. In the curriculum management process, faculty members specializing in anatomy education oversaw the development of these tools and modalities. In addition, the course in which these tools were introduced was typically taught

by not only anatomy experts, who use these technologies effectively in anatomy education, but also software developers. Content developers in the course worked with students to create CHD content.

Table 1. Table of contents and schedule for the elective course at Seoul National University College of Medicine, 2023.

Week and time	Topic	Detailed content	Teaching method
Week 1: Medical image-based AI^a technology (n=5)			
1:00-1:10 PM	Presurvey for students	• N/A ^b	Survey
1:10-2:00 PM	Understanding medical image-based AI technology	• N/A	Lecture
2:00-2:10 PM	Rest	• N/A	N/A
2:10-2:30 PM	Use of AI technology in medical imaging; 3DP ^c	• N/A	Lecture
2:30-2:40 PM	Rest	• N/A	N/A
2:40-3:00 PM	Use of AI technology in medical imaging; VR ^d , AR ^e , and MR ^f	• N/A	Lecture
3:00-3:10 PM	Rest	• N/A	N/A
3:10-4:50 PM	Learning the functions of medical image processing software	• N/A	Lecture and hands-on practice
4:50-5:00 PM	Course wrap-up	• N/A	N/A
Week 2: AI segmentation using medical image processing software (n=15; 4 groups)			
1:00-1:50 PM	AI segmentation using medical image processing software	• AI segmentation on cases of CHD ^g patients, including IAA ^h , Ebstein anomaly, TGA ⁱ , and MAPCA ^j	Hands-on practice
1:50-2:00 PM	Rest	• N/A	N/A
2:00-2:50 PM	AI segmentation using medical image processing software	• AI segmentation on the abovementioned cases	Hands-on practice
2:50-3:00 PM	Rest	• N/A	N/A
3:00-3:50 PM	AI segmentation using medical image processing software	• AI segmentation on the abovementioned cases	Hands-on practice
3:50-4:00 PM	Rest	• N/A	N/A
4:00-4:50 PM	AI segmentation using medical image processing software	• AI segmentation on the abovementioned cases	Hands-on practice
4:50-5:00 PM	Course wrap-up	• N/A	N/A
Week 3: VR, AR, and 3DP experience (n=15; 4 groups)			
1:00-4:30 PM	VR experience	<ul style="list-style-type: none"> • Anatomy structures • Pediatric CHD model, including IAA, Ebstein anomaly, TGA, and MAPCA (patient-specific model) • Digestive process • Respiratory process • Muscle movement 	Group rotation experience
1:00-4:30 PM	AR experience	<ul style="list-style-type: none"> • Pediatric CHD model, including IAA, Ebstein anomaly, TGA, and MAPCA (patient-specific model) • Kidney cancer model • Brain tumor model 	Group rotation experience

Week and time	Topic	Detailed content	Teaching method
1:00-4:30 PM	3DP experience	<ul style="list-style-type: none"> Pediatric CHD model, including IAA, Ebstein anomaly, TGA, and MAPCA (patient-specific model) Simulator model for surgery training 	Group rotation experience
1:00-4:30 PM	3DP lab tour	<ul style="list-style-type: none"> 3DP lab Production process lab 	Group rotation experience
4:30-4:50 PM	Rest	<ul style="list-style-type: none"> N/A 	N/A
4:50-5:00 PM	Course wrap-up	<ul style="list-style-type: none"> N/A 	N/A
Week 4: Presentation (n=15; 4 groups)			
1:00-1:30 PM	Group 1: Presentation and discussion	<ul style="list-style-type: none"> N/A 	Presentation and discussion
1:30-1:40 PM	Rest	<ul style="list-style-type: none"> N/A 	N/A
1:40-2:10 PM	Group 2: Presentation and discussion	<ul style="list-style-type: none"> N/A 	Presentation and discussion
2:10-2:20 PM	Rest	<ul style="list-style-type: none"> N/A 	N/A
2:20-2:50 PM	Group 3: Presentation and discussion	<ul style="list-style-type: none"> N/A 	Presentation and discussion
2:50-3:00 PM	Rest	<ul style="list-style-type: none"> N/A 	N/A
3:00-3:30 PM	Group 4: Presentation and discussion	<ul style="list-style-type: none"> N/A 	Presentation and discussion
3:30-4:00 PM	Rest	<ul style="list-style-type: none"> N/A 	N/A
4:00-4:20 PM	Postsurvey for students and developers	<ul style="list-style-type: none"> N/A 	Survey
4:20-4:40 PM	Group photo	<ul style="list-style-type: none"> N/A 	N/A
4:40-5:00 PM	Course wrap-up	<ul style="list-style-type: none"> N/A 	N/A

^aAI: artificial intelligence.

^bN/A: not applicable.

^c3DP: 3D printing.

^dVR: virtual reality.

^eAR: augmented reality.

^fMR: mixed reality.

^gCHD: congenital heart disease.

^hIAA: interrupted aortic arch.

ⁱTGA: transposition of the great arteries.

^jMAPCA: major aortopulmonary collateral arteries.

Figure 2. Graphical diagram of the elective course. 3DP: 3D printing; AR: augmented reality; MR: mixed reality; VR: virtual reality.

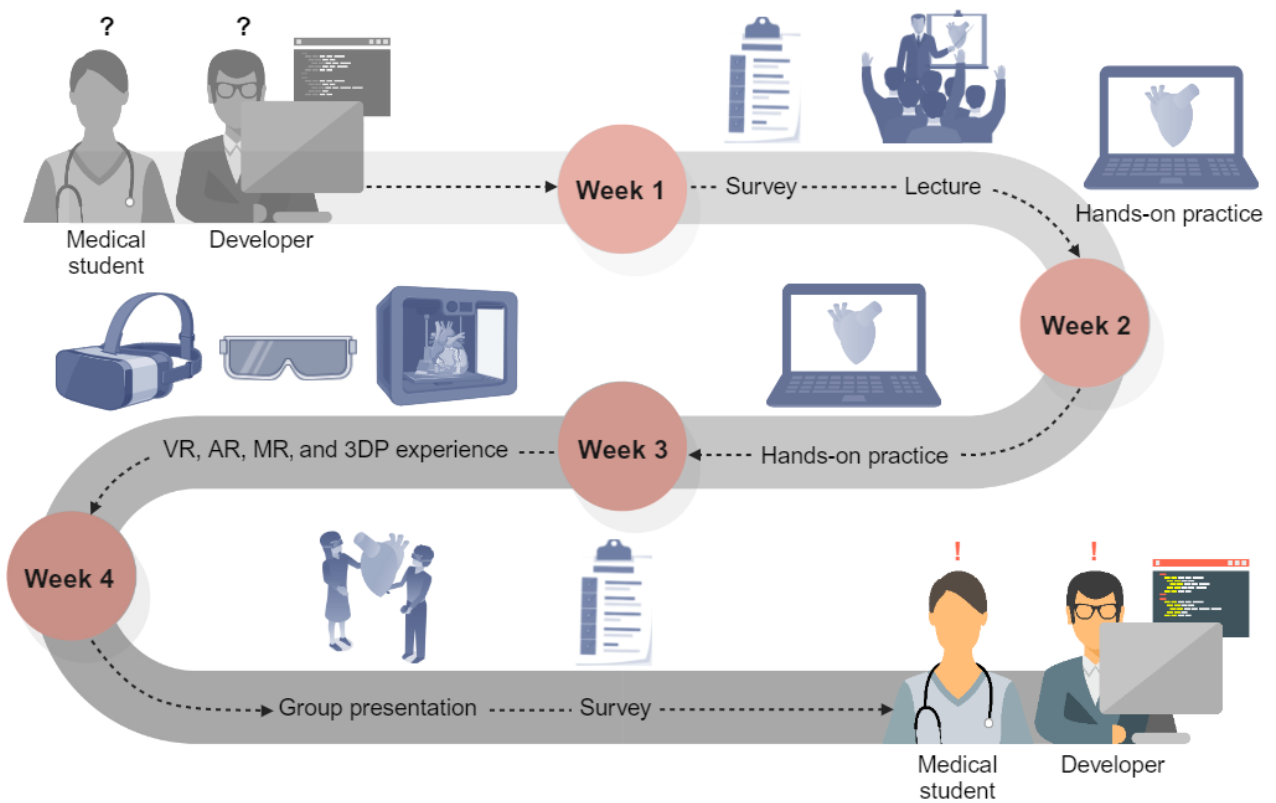
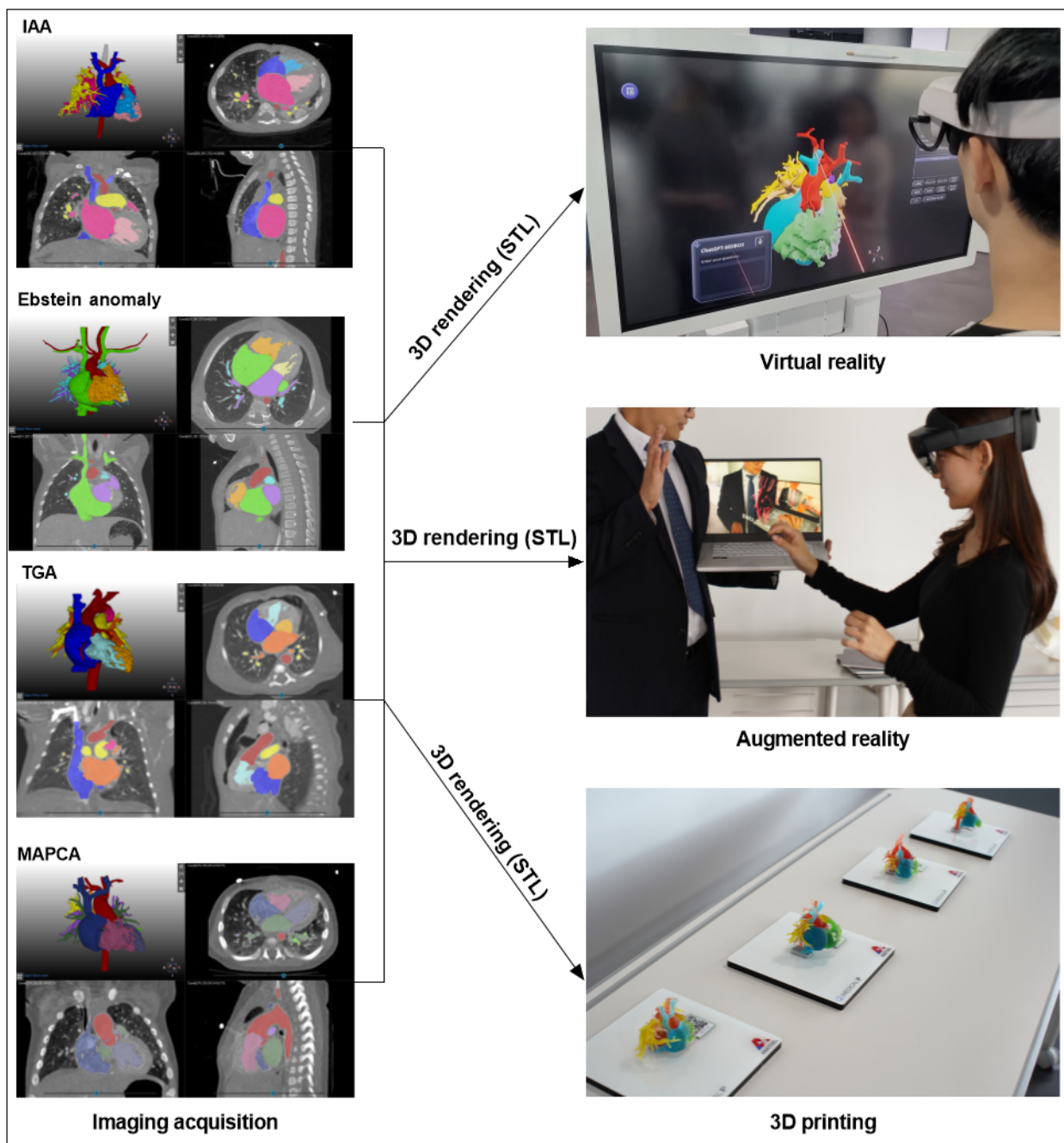


Figure 3. Workflow diagram of hands-on practice for the elective course. Segmented and refined 3D congenital heart disease models are used for not only virtual and augmented reality but also 3D printing. IAA: interrupted aortic arch; MAPCA: major aortopulmonary collateral arteries; STL: standard tessellation language; TGA: transposition of the great arteries.



Devices and Software

This study employed a virtual dissection table (MDBOX, MEDICAL IP Co, Ltd), a VR headset (Oculus Quest 2), an AR headset (HoloLens 2), and medical image processing software (MEDIP PRO, MEDICAL IP Co, Ltd).

Student Pre- and Postsurveys

The students’ survey consisted of pre- and postsurveys. The presurvey included questions about demographic information and prior experience with 3D medical technologies. The majority of previous studies used 5-point Likert scale–based questionnaires to assess user satisfaction, device usability,

perceived engagement, and the influence on anatomy education [49]. Therefore, in the postsurvey, students used a 5-point Likert-type scale to indicate their overall satisfaction and satisfaction levels with VR, AR, and 3DP across 7 categories, which were organized into 2 subscales each (Multimedia Appendix 6). The 7 categories included esthetics, understanding of the concept, reality, spatial ability, immersion, continuous use intention, and future use. The use of new technologies in education is considered to be about experiences that include esthetic enjoyment as well [50]. Moreover, well-designed and esthetically pleasing content is more likely to engage users and improve their overall experience [51]. Clarity and comprehensibility of the content are crucial for users to

effectively grasp concepts. 3D models provide users with the flexibility to explore structures from desired angles, thereby facilitating deeper comprehension and learning [52]. In education, aspects of spatial ability can be enhanced through experience, suggesting the potential for facilitating users' learning of 3D structures [53]. Previous studies have found a correlation between spatial abilities and assessment of anatomy knowledge, with spatial training being shown to improve spatial abilities [54]. In these technology-rich educational environments, immersion has been identified as one of the primary drivers of student learning [55]. Continuous use intention is an important factor for the successful adoption of technology [56]. Additionally, satisfaction with technologies expected to be used in clinical areas or their potential for substitution was also investigated. To further explore students' thoughts and insights through their presentations, students were asked questions about their expectations regarding the use of these technologies in various situational scenarios in the future. These questionnaires were prepared using Google Forms (Google LLC).

Developer Survey

The developers took a single survey, which included demographic information, department affiliation, and years of professional experience. Similar to the student postsurvey, developers rated their overall satisfaction and satisfaction levels with VR, AR, and 3DP using a 5-point Likert-type scale across the same 7 categories organized into 2 subscales each. The survey also inquired about their expectations regarding the integration of these technologies into various medical settings within 5 years. Furthermore, the survey included questions exploring only developers' perspectives on the advantages and challenges of VR, AR, MR, and 3DP. These questionnaires were prepared using Google Forms (Google LLC).

Statistical Analysis

Statistical analyses were performed using SPSS software, version 26 (IBM Corp) and Prism, version 9 (GraphPad). Differences in satisfaction levels between students and developers for VR, AR, and 3DP were assessed using independent *t* tests. Statistical significance was determined at $P < .05$. Owing to the possibility of a type I (false positive) error resulting from the multiple comparison analyses, we applied Bonferroni correction. After Bonferroni correction, most

of the associations were not considered significant, with the adjusted significance level set at $P < .003$.

Ethical Considerations

This study was approved by the Institutional Review Board of Seoul National University College of Medicine (E-2307-030-1447). The study was entirely retrospective (using existing student and developer surveys), and the requirement for informed consent was waived.

Results

Participants

In this survey study, we recruited 15 first-year medical students and 26 software and content developers who participated in a 4-week elective course that combined lectures and hands-on sessions. The data collection started on May 22, 2023, and ended on June 19, 2023.

Demographic and Other Characteristics of Medical Students

The demographic and other characteristics of the 15 medical students are provided in Table 2. Their mean age was 21.5 (SD 1.5) years, and there were 12 (80%) male students and 3 (20%) female students. All students were familiar with VR, and 14 (93%) students were aware of AR and MR. However, 14 (93%) students had difficulty distinguishing between these technologies. Regarding VR content, 11 (73%) students engaged with it 1-3 times a month, with 8 (73%) engaging for educational purposes and 5 (46%) engaging for gaming. AR content was less frequent, with 5 (33%) students experiencing it 1-2 times a year, mainly in gaming (4/5, 80%) and education (2/5, 40%). 3DP content was used 1-2 times a year for educational purposes by 9 (60%) students. Moreover, 11 (73%) students used VR-based medical content, with 6 (55%) students focusing on heart-related content (heart VR education was previously provided in the anatomy curriculum) and 5 (46%) using unknown content. None had prior experience with AR-based medical content, but 2 (13%) students had experience with 3DP-based medical content. Of these 2 students, 1 (50%) used a pediatric cardiac model and 1 (50%) used content of unknown nature.

Table 2. Demographic and other characteristics of medical students (n=15).

Characteristic	Value
Age (years), mean (SD)	21.5 (1.5)
Gender, n (%)	
Male	12 (80)
Female	3 (20)
Please select all the options you have heard of among VR^a, AR^b, MR^c, and 3DP^d, n (%)	
VR	15 (100)
AR	14 (93)
MR	14 (93)
Can you distinguish between VR, AR, and MR? n (%)	
No	14 (93)
Yes	1 (7)
Have you ever experienced VR content? n (%)	
No	4 (27)
Yes	11 (73)
If you have experienced VR content, how often did you experience it?^e, n (%)	
Everyday	0 (0)
3-4 times a week	0 (0)
1-2 times a week	0 (0)
1-3 times a month	11 (100)
1-2 times a year	0 (0)
If you have experienced VR content, please select all the experiences you had^e, n (%)	
Game	5 (46)
Travel	0 (0)
Movies or television shows	0 (0)
Music (eg, concerts and music videos)	0 (0)
Education	8 (73)
Art galleries	0 (0)
Have you ever experienced AR content? n (%)	
No	10 (67)
Yes	5 (33)
If you have experienced AR content, how often did you experience it?^e, n (%)	
Everyday	0 (0)
3-4 times a week	0 (0)
1-2 times a week	0 (0)
1-3 times a month	0 (0)
1-2 times a year	5 (100)
If you have experienced AR content, please select all the experiences you had^e, n (%)	
Game	4 (80)
Travel	0 (0)
Movies or television shows	0 (0)
Music (eg, concerts and music videos)	0 (0)

Characteristic	Value
Education	2 (40)
Art galleries	0 (0)
Have you ever experienced 3DP content? n (%)	
No	6 (40)
Yes	9 (60)
If you have experienced 3DP content, how often did you experience it?^e, n (%)	
Everyday	0 (0)
3-4 times a week	0 (0)
1-2 times a week	0 (0)
1-3 times a month	0 (0)
1-2 times a year	9 (100)
If you have experienced 3DP content, please select all the experiences you had^e, n (%)	
Game	0 (0)
Travel	0 (0)
Movies or television shows	0 (0)
Music (eg, concerts and music videos)	0 (0)
Education	9 (100)
Art galleries	0 (0)
Have you ever experienced VR-based medical content? n (%)	
No	4 (27)
Yes	11 (73)
If you have experienced VR-based medical content, what is the name of the content? (If unknown, please write "unknown")^e, n (%)	
Heart	6 (55)
Unknown	5 (46)
Have you ever experienced AR-based medical content? n (%)	
No	15 (100)
Yes	0 (0)
Have you ever experienced 3DP-based medical content? n (%)	
No	13 (87)
Yes	2 (13)
If you have experienced 3DP-based medical content, what is the name of the content? (If unknown, please write "unknown")^e, n (%)	
Pediatric cardiac model	1 (50)
Unknown	1 (50)

^aVR: virtual reality.

^bAR: augmented reality.

^cMR: mixed reality.

^d3DP: 3D printing.

^eOnly the subgroup of students who experienced either VR, AR, or 3DP.

Demographic and Other Characteristics of Developers

The demographic and other characteristics of the 26 developers are shown in Table 3. Their mean age was 28.2 (SD 4.5) years,

and there were 7 (27%) male developers and 19 (73%) female developers. There was no bias in their expertise. The developers were individuals with backgrounds in software and content development and had various degrees and majors (Multimedia

Appendix 7). Among the 26 developers, 15 (58%) were associated with VR, 4 (15%) with AR, and 10 (39%) with 3DP. Regarding their years of professional experience, most developers had 1 year of experience (9/26, 35%), followed by

less than 1 year of experience (4/26, 15%); 4 and 5 years of experience (each 3/26, 12%); 2, 3, and 8 years of experience (each 2/26, 8%); and 7 years of experience (1/26, 4%).

Table 3. Demographic and other characteristics of developers (n=26).

Characteristic	Value
Age (years), mean (SD)	28.2 (4.5)
Gender, n (%)	
Male	7 (27)
Female	19 (73)
Which departments are you affiliated with? n (%)	
VR ^a	15 (58)
AR ^b	4 (15)
3DP ^c	10 (39)
How many years of experience do you have? n (%)	
No experience	0 (0)
Less than 1 year	4 (15)
1 year	9 (35)
2 years	2 (8)
3 years	2 (8)
4 years	3 (12)
5 years	3 (12)
6 years	0 (0)
7 years	1 (4)
8 years	2 (8)
9 years	0 (0)
More than 10 years	0 (0)

^aVR: virtual reality.

^bAR: augmented reality.

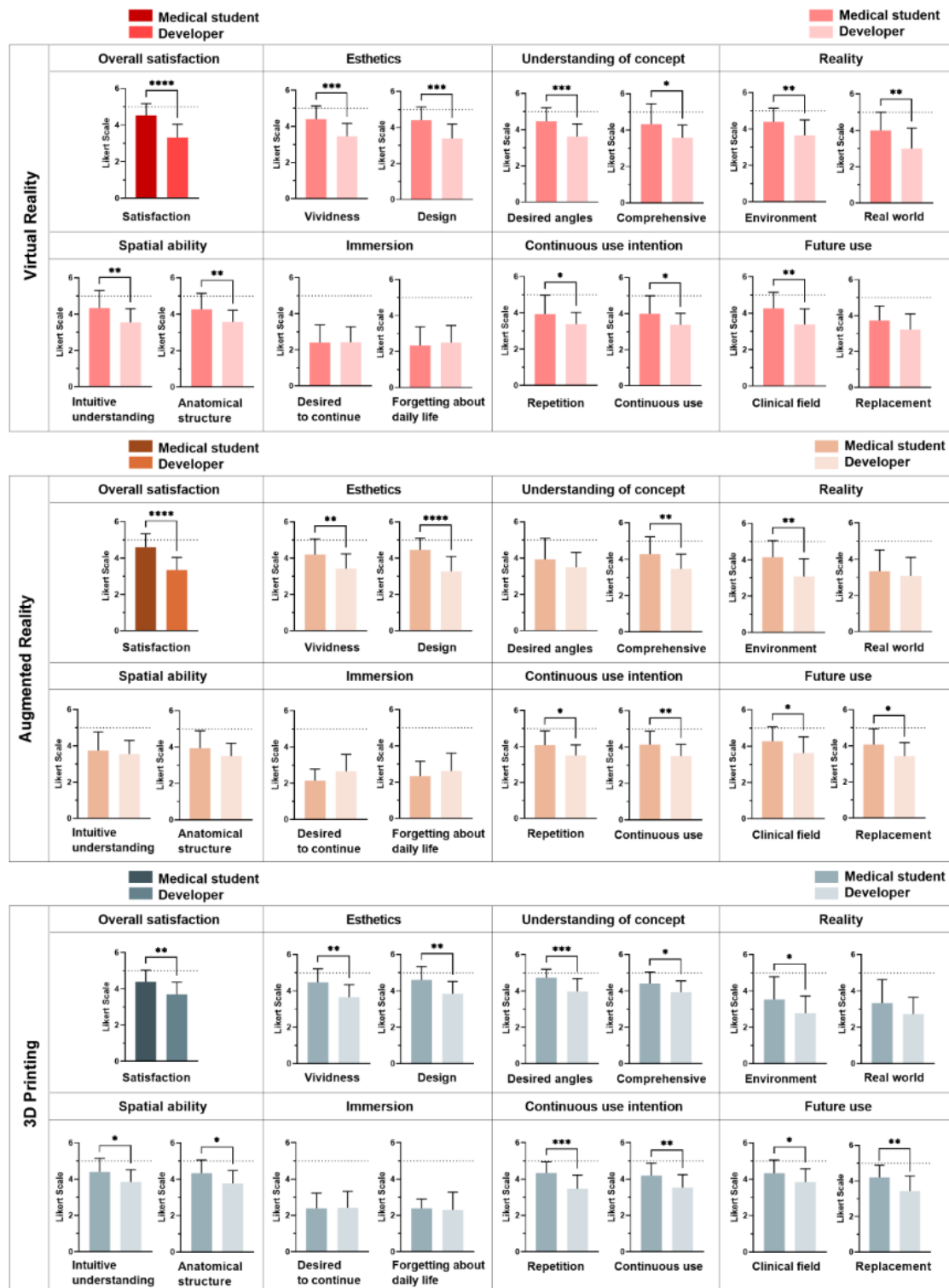
^c3DP: 3D printing.

Levels of Satisfaction With VR, AR, and 3DP Between Medical Students and Developers

Levels of satisfaction with VR, AR, and 3DP among medical students and developers are shown in Figure 4 and Tables S1-S3 in Multimedia Appendix 8. The satisfaction results are presented in terms of overall satisfaction and the following 7 categories: esthetics, understanding of the concept, reality, spatial ability, immersion, continuous intention, and future use. Specifically, 2 questions were included in each category. In terms of esthetics, the vividness and design of the content were considered. For understanding of the concept, questions assessed how easily

participants understood the content and if they were able to learn effectively. Reality focused on whether participants felt a sense of realism within the content and its surroundings. Spatial ability questions evaluated participants' satisfaction to intuitively grasp the structures and understand the relationships between different structures. Continuous use intention investigated participants' desire to repeatedly engage with the content and continue its use. Future use included specific inquiries about the potential application of these technologies in clinical settings and their potential to replace conventional methods.

Figure 4. Medical students' (n=15) and developers' (n=26) levels of satisfaction with virtual reality, augmented reality, and 3D printing have been ranked on a 5-point Likert-type scale (1=very dissatisfied to 5=very satisfied). Participants were asked about their overall satisfaction with virtual reality, augmented reality, and 3D printing, as well as their satisfaction with 7 categories organized into 2 subscales. * $P<.05$, ** $P<.01$, *** $P<.001$, **** $P<.0001$.



Overall satisfaction with VR, AR, and 3DP was significantly higher among students than among developers. There was no significant difference in satisfaction with immersion in VR, AR, and 3DP between medical students and developers. In the case of VR (Figure 4 and Table S1 in Multimedia Appendix 8), the satisfaction levels of students were significantly higher than those of developers in esthetics (vividness: 4.52 vs 3.31; design:

4.40 vs 3.38), understanding of the concept (desired angles: 4.47 vs 3.62; comprehensive: 4.33 vs 3.58), reality (environment: 4.40 vs 3.65; real world: 4.00 vs 3.00), spatial ability (intuitive understanding: 4.33 vs 3.54; spatial perception: 4.27 vs 3.58), continuous use intention (repetition: 3.93 vs 3.39; continuous use: 4.00 vs 3.39), and future use (clinical field: 4.27 vs 3.39). However, after Bonferroni correction to adjust for

multiple variables, only overall satisfaction ($P < .001$), esthetics (vividness and design, $P < .001$), and understanding of the concept (desired angles, $P < .001$) remained statistically significant.

Similarly, in the case of AR (Figure 4 and Table S2 in Multimedia Appendix 8), the satisfaction levels of students were significantly higher than those of developers in esthetics (vividness: 4.20 vs 3.42; design: 4.47 vs 3.27), understanding of the concept (comprehensive: 4.27 vs 3.46), reality (environment: 4.13 vs 3.08; real world: 4.00 vs 3.00), continuous use intention (repetition: 4.07 vs 3.50; continuous use: 4.13 vs 3.50), and future use (clinical field: 4.27 vs 3.61; replacement: 4.07 vs 3.42). However, after Bonferroni correction to adjust for multiple variables, only overall satisfaction ($P < .001$), esthetics (design, $P < .001$), and reality (environment, $P = .002$) remained statistically significant.

In the case of 3DP (Figure 4 and Table S3 in Multimedia Appendix 8), the satisfaction levels of students were significantly higher than those of developers in esthetics (vividness: 4.47 vs 3.65; design: 4.60 vs 3.85), understanding of the concept (desired angles: 4.73 vs 3.96; comprehensive: 4.40 vs 3.92), reality (environment: 3.53 vs 2.77), spatial ability (intuitive understanding: 4.40 vs 3.85; spatial perception: 4.33 vs 3.77), continuous use intention (repetition: 4.33 vs 3.46; continuous use: 4.20 vs 3.54), and future use (clinical field: 4.33 vs 3.85; replacement: 4.20 vs 3.42). However, after Bonferroni correction to adjust for multiple variables, only overall satisfaction ($P < .001$), esthetics (vividness, $P = .001$; design, $P = .002$), understanding of the concept (desired angles, $P < .001$), and continuous use intention (repetition, $P < .001$) remained statistically significant.

Anticipations for the Future Use of VR, AR, MR, and 3DP Between Medical Students and Developers

Future usage expectations of VR, AR, MR, and 3DP between medical students and developers are illustrated in Multimedia Appendix 9. Students expected VR and AR to be the most frequently used technologies in medical education (8/15, 53% and 5/15, 33%, respectively), while MR and 3DP were less anticipated. In contrast, 10 (38%) developers predicted MR to be the most widely used technology, followed by 3DP, with VR and AR having low expected use. In educating residents, 7 (47%) students anticipated 3DP to be the most widely used technology, followed by MR, VR, and AR. Moreover, 11 (42%) developers expected MR to be the dominant technology, followed by 3DP, AR, and VR.

For individual surgical planning, 7 (47%) students expected 3DP to be the most widely used technology, followed by VR, AR, and MR. Moreover, 11 (42%) developers anticipated MR to be the most widely used technology, followed by 3DP, VR, and AR. In collaborative surgical planning, 6 (46%) students anticipated AR to be the most widely used technology, followed by MR, VR, and 3DP. Moreover, 12 (46%) developers expected MR to be the dominant technology, followed by 3DP, AR, and VR.

For surgical procedures on patients, 8 (53%) students expected AR to be the most widely used technology, followed by VR,

MR, and 3DP. Moreover, 14 (52%) developers anticipated MR to be the most widely used technology. In explaining medical information to patients' caregivers, 13 (87%) students anticipated 3DP to be the most widely used technology, followed by VR and MR. Moreover, 10 (38%) developers anticipated 3DP to be the most widely used technology, followed by MR, AR, and VR.

Developers' Perceptions of the Advantages and Current Challenges in VR, AR, MR, and 3DP

The developers' views on the advantages and current challenges of VR, AR, MR, and 3DP are presented in Multimedia Appendix 10. Regarding VR, developers highlighted immersion (11/26, 42%) and the expansiveness of space (8/26, 31%) as key advantages. However, none reported providing experiences similar to real environments as a VR advantage. The main challenge was hardware performance (4/26, 31%), followed by a lack of proactive content production, user-friendliness, and pricing and health issues.

Regarding AR, developers considered engagement in AR (11/26, 42%) as its main advantage, followed by recognizing interactivity and appreciating its ability to provide experiences similar to real environments. None of them reported refining information in AR as an advantage. The main challenge was hardware performance (10/26, 38%), followed by user-friendliness, a lack of proactive content production, and issues related to price and health.

Regarding MR, developers highlighted the integration of real and virtual spaces as the primary advantage (13/26, 50%), with 19% (5/26) noting the provision of realistic virtual spaces. Interactivity and the innovativeness of the experience were also reported. None reported refining information as an advantage. Hardware performance was the primary concern (11/26, 42%), followed by user-friendliness, a lack of proactive content production, and issues related to price and health.

Lastly, regarding 3DP, the primary advantage was the possibility of customized product manufacturing (21/26, 81%). Some developers recognized high accuracy and texture fidelity, and reported increased creative freedom and fast product production. However, none mentioned new design possibilities as an advantage. The primary challenge was manufacturing costs (18/26, 69%), followed by long printing times, difficulty in creating complex models, limitations of materials, and low durability of printed objects (all 2/26, 8%).

Discussion

Overview

Our study aimed to investigate the gaps in perspectives between medical students and developers regarding satisfaction and the most anticipated future use of 3D technologies in medical education. This study offers insights into the differences in satisfaction levels between medical students and developers. This study also provides insights into how anticipations for the use of these technologies differ between medical students and developers across different situational scenarios, as well as how these technologies might be used in specific specialties or areas

of medicine. Additionally, this study sheds light on developers' viewpoints regarding the advantages and challenges associated with these technologies, with the aim of understanding their applicability and limitations in industrial settings.

Principal Findings

The results of this study provide unique evidence that medical students have a higher level of overall satisfaction than developers across VR, AR, and 3DP technologies (Figure 4), which implies that there might be a stronger alignment between the satisfaction and experiences of students with these technologies. It is also noteworthy that medical students were more satisfied than developers with esthetics and the intention to continue use among the 7 categories in VR, AR, and 3DP technologies (Figure 4). We assume that students had positive experiences with the liveliness of technology and design through this course, and based on this experience, they will have high expectations for the future in terms of the vividness and design of these technologies. We believe that students had higher satisfaction with the intention to continue use compared to developers because, as users, they perceive that these technologies yield greater learning effectiveness when used repetitively in the learning environment.

The extent of satisfaction difference between medical students and developers varied across VR, AR, and 3DP. Regarding VR, the difference in satisfaction between medical students and developers was the greatest for esthetics and conceptual understanding (desired angle). This difference could be attributed to the experience students had during the course. Students would have experienced higher satisfaction by interacting with the CHD model they created in the course, such as by rotating the CHD model they created to the desired angle in virtual space, understanding the structure, and applying color. We speculate that esthetics showed the largest extent of difference in AR because students experienced higher satisfaction than developers as the design made it easy for them to recognize and interact with the CHD models they created when presented in a real-world environment. Regarding 3DP, the difference in satisfaction was the greatest for concept understanding (desired angle) and continued use intention (repetition). The patient-customized CHD model could be rotated at any desired angle in real space, and it is assumed that continuous repetition helps students understand complex anatomy.

This study found that when comparing all categories with each technology, medical students were more satisfied than developers in reality (real world) only within VR (Figure 4). Based on the findings of the study, it can be inferred that VR technology, particularly in its current state of hardware development, offers medical students a more realistic and satisfying experience compared to developers. On the other hand, developers may be less satisfied with the current state of technology when considering both the current state of technology and the potential for future technological advances in the industry. This may be because developers who actively participate in the industry are aware of the substantial difficulty needed to increase the realism of VR. In addition, AR showed no significant difference in satisfaction between medical students

and developers in terms of understanding of the concept (desired angles) and spatial ability (Figure 4). Therefore, we conclude that VR might offer a more immersive and satisfying experience for medical students based on current hardware technologies, while AR appears to offer a more balanced perception in terms of conceptual understanding and spatial awareness.

One of the key findings of our study was that there was a gap in anticipations between medical students and developers in 6 situational scenarios regarding the anticipated future use of technology, with the exception of 1 situational scenario (Multimedia Appendix 9). Situational scenarios in which the perspectives differed included educating medical students and residents, individual and collaborative surgical planning, and performing surgery on a patient. In these scenarios, developers perceived MR as a more promising technology. In contrast, medical students perceived VR primarily for student education, 3DP for resident education and individual surgical planning, and AR for collaborative surgical planning and performing surgery on a patient. This discrepancy between the 2 groups is likely from variations in exposure and practical experience with these technologies. Although students experienced VR, AR, and 3DP in their elective course, they were not exposed to MR. Despite the limited exposure to MR among medical students, we can speculate on their perspectives regarding its future use based on their experiences. Medical students may see VR primarily for undergraduate education because of its immersive and interactive nature, allowing for realistic simulations [4]. They may see 3DP as beneficial for resident training and individual surgical planning because of its hands-on nature, allowing them to create physical models that can enhance their understanding of anatomical structures and medical conditions. This perception could be attributed to its potential for customized product manufacturing, which could potentially facilitate clearer communication of medical information to nonexperts. This result is consistent with the results of previous studies, which tended to report positive correlations between the use of 3DP and resident education and explanation to patient caregivers [28,57-59]. Regarding AR, medical students may see it as suitable for collaborative surgical planning and performing surgery on a patient because of its potential to overlay digital information onto the real surgical environment, providing surgeons with real-time guidance and information during procedures. This aligns with existing research on its benefits in specific surgical procedures, such as spine and orthopedic surgeries [60,61]. Our study implied a potential interest in exploring the application of AR in the surgical field among medical students. These findings of our study emphasize the need to align technological advancements with the expectations of both medical students and developers. By meeting the expectations of both groups, these technologies can be smoothly integrated into medical education.

This study highlights an interesting alignment in perspectives between medical students and developers, particularly in the situational scenario of explaining to a patient's caregiver. In this scenario, both groups showed potential interest in 3DP for conveying complex medical information to a patient's caregiver. Additionally, considering that students and developers in this study participated in creating patient-specific 3D-printed heart

models and that students gave group presentations with this technology, it can be inferred that personalized 3D-printed models are helpful in patients' caregiver communication. Previous studies demonstrated that the use of personalized 3DP models can further enhance patient understanding by providing tailored visual representations of individual patient anatomy and medical conditions [57,62,63].

This exploration of varying expectations will offer insights into how these technologies are anticipated to shape the future of medical training, patient care, and medical research. Several potential applications can be envisioned based on our research findings. In medical education for medical students and patients, VR, MR, and 3DP could be used for anatomy learning, medical research, simulation training, and procedural skills practice. VR can be used for virtual simulations of procedures like suturing, catheterization, and intubation, as well as clinical scenarios like patient assessments and diagnostic procedures. MR is expected to enhance anatomical learning and hands-on procedural training by combining virtual and real-world elements. It will overlay digital models onto physical specimens, which are generated from 3DP, and enable realistic simulations with them. Our speculation involves the use of AR, MR, and 3DP in surgical planning. Based on patient-specific medical imaging data, it is anticipated that surgeons will use patient-specific 3DP models to physically review and plan surgical approaches before the actual surgery. Alternatively, they may use AR and VR for surgical simulations to plan the procedure in advance. We also speculate that AR and MR will be used in specialties, such as neurosurgery, cardiovascular surgery, etc. Surgeons can use AR holograms of the heart or lungs to visualize complex cardiac anatomy during surgery and to orient and localize the target tumors or lesions. MR-guided interventions can facilitate minimally invasive procedures, such as transcatheter valve replacement, by providing real-time imaging guidance and navigation. VR and 3DP are expected to benefit patient care. We speculate that VR will help manage pain and reduce stress during treatment, while 3DP will allow for personalized models, improving the understanding of patient conditions and treatments.

While the majority of developers perceived the inherent capabilities of VR, AR, and MR technologies as strengths, an interesting aspect of our findings is that none of them mentioned providing experiences similar to real environments as a strength of VR technology or cited the refinement of information in AR technology (Multimedia Appendix 10). We infer that developers perceive providing experiences similar to real environments and refinement of information as technically challenging at present or as areas requiring further development and thus fail to recognize the benefits of each technology. In fact, modeling of environments, especially in the medical field, requires the creation of high-quality 3D objects [64]. Reaching highly realistic and natural photorealistic rendering and animations in full 3D can be exceedingly challenging and costly in terms of both time and money [65]. Therefore, we speculate that in addition to the advantages of each technology that developers currently recognize, additional improvement and development are needed for aspects of each technology that developers are not aware of at present.

This study identified a concern regarding developers' limited attention to health issues, although there is a high prevalence of computer vision syndrome as an occupational disease in the 21st century (Multimedia Appendix 10). Additionally, the focus of developers on hardware performance over health issues indicates concerning results where technical priorities overshadow user well-being. To address this, developers must adopt a more holistic approach that balances technical advancements with user safety. This includes integrating health considerations into the design and development process, implementing safety features, and conducting thorough user testing to mitigate health-related issues [66]. By prioritizing both technical excellence and user welfare, developers will enhance the overall ethical standards of these technologies and contribute to a safer and more responsible technological landscape.

Regarding 3DP, our results showed that developers perceived the practical aspect of manufacturing customized products as an advantage of 3DP over the creative aspect of new design possibilities. This finding is consistent with previous studies reporting that customization allows for printing parts with geometries tailored to each print, which can be particularly useful in patient-specific fabrications for personalized medicine, where the layout matches a specific patient's anatomy [67]. As a significant challenge, the developers in this study and several other studies recognized high manufacturing costs [68]. However, in general, 3DP has been applied in the medical field. Therefore, this study suggests the need for continued research and development efforts aimed at optimizing the cost-effectiveness of 3DP technology without compromising on its advantages.

Limitations

This study has several limitations. First, this study was conducted in a single institution with a relatively small sample size. Further studies should be conducted and compared across multiple medical schools. Second, this study was limited by the exclusive focus on first-year medical students and developers involved in the course. While this provided valuable insights into the perspectives of these specific groups, the exclusion of residents, fellows, and senior medical professionals may limit the generalizability and applicability of our findings. Participants from diverse backgrounds should be included in further studies. Third, owing to the voluntary nature of student participation in the course, participant selection was not conducted. Consequently, our study results may be influenced by the higher proportion of male individuals than female individuals in the student group, potentially resulting in a dominance of male perspectives in the outcomes. Fourth, students having difficulty distinguishing between VR, AR, and MR experiences may have influenced the accuracy of the self-reported engagement with these technologies. Future studies should consider incorporating educational interventions to enhance students' understanding of various immersive technologies before administering surveys on technology usage. Lastly, it was not possible to validate the instruments used in this study, and we used a limited number of questionnaire items to measure the levels of students' and developers' satisfaction with the elective course. Despite these limitations, this study might help to understand differences in

satisfaction levels between medical students and developers, as well as discrepancies in their perceptions of future technological advancements.

Conclusion

The roadblock for better integration of VR, AR, MR, and 3DP technologies in medical education is the gap in satisfaction levels and future anticipations between medical students and developers. Our study found that VR, AR, and 3DP technologies showed differences in satisfaction levels in the categories of esthetics and continuous use intention. In particular, in VR,

differences in satisfaction levels regarding reality (real world) emerged as a major obstacle to integration into medical education. Medical students and developers had different anticipations of the future use of technology regarding education, surgical planning, and surgery. Furthermore, insights from industry developers indicated that hardware performance poses a challenge for VR, AR, and MR, while high manufacturing cost is the primary concern for 3DP. Recognizing and understanding these discrepancies and current challenges can help developers tailor their strategies and innovations to better meet the expectations of technology users.

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Data Availability

The data used or analyzed in this study are available from the corresponding author upon reasonable request.

Authors' Contributions

YHY made substantial contributions to conceptualization, data curation, formal analysis, investigation, methodology, resources, software, validation, visualization, writing—original draft, and writing—review and editing. DHS contributed to conceptualization, data curation, formal analysis, investigation, methodology, project administration, supervision, validation, and writing—review and editing. HJC contributed to conceptualization, methodology, project administration, supervision, formal analysis, validation, and writing—review and editing. All authors approved the final version of the manuscript for submission.

Conflicts of Interest

None declared.

Multimedia Appendix 1

The process of creating a 3D reconstruction from a patient's computed tomography scan.

[[MP4 File \(MP4 Video\), 92202 KB - xr_v1i1e54230_app1.mp4](#)]

Multimedia Appendix 2

The heart of a patient with an interrupted aortic arch.

[[MP4 File \(MP4 Video\), 32727 KB - xr_v1i1e54230_app2.mp4](#)]

Multimedia Appendix 3

The heart of a patient with Ebstein anomaly.

[[MP4 File \(MP4 Video\), 33538 KB - xr_v1i1e54230_app3.mp4](#)]

Multimedia Appendix 4

The heart of a patient with transposition of the great arteries.

[[MP4 File \(MP4 Video\), 15565 KB - xr_v1i1e54230_app4.mp4](#)]

Multimedia Appendix 5

The heart of a patient with major aortopulmonary collateral arteries.

[[MP4 File \(MP4 Video\), 30007 KB - xr_v1i1e54230_app5.mp4](#)]

Multimedia Appendix 6

A survey on satisfaction with virtual reality, augmented reality, and 3D printing technologies.

[\[DOCX File , 28 KB - xr_v1i1e54230_app6.docx \]](#)

Multimedia Appendix 7

The educational background of the software and content developers in this study.

[\[DOCX File , 17 KB - xr_v1i1e54230_app7.docx \]](#)

Multimedia Appendix 8

Average satisfaction differences in virtual reality, augmented reality, and 3D printing between students and developers.

[\[DOCX File , 52 KB - xr_v1i1e54230_app8.docx \]](#)

Multimedia Appendix 9

Medical students' (n=15) and developers' (n=26) anticipation of the use of technologies in various medical contexts within 5 years. The pie charts present percentages.

[\[PNG File , 241 KB - xr_v1i1e54230_app9.png \]](#)

Multimedia Appendix 10

Developers' perceptions of the advantages and current challenges of virtual reality, augmented reality, mixed reality, and 3D printing.

[\[PNG File , 335 KB - xr_v1i1e54230_app10.png \]](#)

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Abbreviations

- 3DP:** 3D printing
- AI:** artificial intelligence
- AR:** augmented reality
- CHD:** congenital heart disease
- MR:** mixed reality
- VR:** virtual reality

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Original Paper

Brain Activation During Virtual Reality Symptom Provocation in Obsessive-Compulsive Disorder: Proof-of-Concept Study

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Abstract

Background: Obsessive-compulsive disorder (OCD) is a psychiatric disorder characterized by obsessions and compulsions. We previously showed that a virtual reality (VR) game can be used to provoke and measure anxiety and compulsions in patients with OCD. Here, we investigated whether this VR game activates brain regions associated with symptom provocation.

Objective: In this study, we aim to investigate the neural regions that are activated in patients with OCD when they are interactively confronted with a symptom-provoking event and when they are performing compulsive actions in VR.

Methods: In a proof-of-concept study, we investigated brain activation in response to the VR game in 9 patients with OCD and 9 healthy controls. Participants played the VR game while regional changes in blood oxygenation were measured using functional magnetic resonance imaging. We investigated brain activation in relation to OCD-related events and virtual compulsions in the VR game. Due to low statistical power because of the sample size, we also reported results at trend significance level with a threshold of $P < .10$. Additionally, we investigated correlations between OCD severity and brain activation.

Results: We observed a trend for increased activation in the left amygdala ($P = .07$) upon confrontation with OCD-related events and for increased activation in the bilateral amygdala ($P = .06$ and $P = .09$) and right insula ($P = .09$) when performing virtual compulsive actions in patients with OCD compared to healthy controls, but this did not attain statistical significance. The amygdala and insula activation did not correlate with OCD severity.

Conclusions: The findings of this proof-of-concept study indicate that VR elicits brain activation in line with previous provocation studies. Our findings need to be replicated in a study with a larger sample size. VR may be used as an innovative and unique method of interactive symptom provocation in future neuroimaging studies.

Trial Registration: Netherlands Trial Register NTR6420; <https://onderzoekmetmensen.nl/nl/trial/25755>

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KEYWORDS

virtual reality; obsessive-compulsive disorder; VR; symptom provocation; MRI; neuroimaging; OCD

Introduction

Obsessive-compulsive disorder (OCD) is a chronic, debilitating disorder characterized by obsessions, recurring involuntary thoughts that are frequently linked to compulsions—mental or physical acts to control provoked emotions of fear or restlessness. The obsessions and compulsions are often

accompanied by feelings of anxiety and uncertainty and cause a high level of suffering [1]. OCD has a 2%-3% lifetime prevalence and is associated with significant impairment in social and occupational functioning [2].

An OCD diagnosis is usually based on an interpretation of clinical signs and symptoms as retrospectively expressed by the patient. Assessment by a clinician while patients are actually

experiencing symptoms in the consulting room may provide a more realistic image of the symptoms and improve the diagnostic process. This can be achieved by symptom provocation [3].

Virtual reality (VR) is one way of achieving symptom provocation in patients with OCD. There are numerous examples of studies that have investigated the use of VR to provoke OCD symptoms in order to improve an OCD diagnosis or provide targeted treatment. For example, Laforest et al [4] showed that exposure to a virtual contaminated toilet in a VR immersion chamber led to an increase in anxiety and heart rate in patients with OCD with contamination fear compared to that in healthy controls.

Furthermore, in a systematic review and meta-analysis by Dehghan et al [5], it was found that VR environments were capable of significantly increasing anxiety, disgust, uncertainty, washing urges, time spent on checking, and the number of checks in patients with OCD compared to healthy controls.

In 2 former studies, we investigated an interactive VR game designed to provoke and assess OCD symptoms in a controlled and standardized way [6,7]. Figures 1 and 2 show a schematic outline and screenshots from the VR game. The VR game is designed to actively confront patients with OCD-related events

in a standard household environment. It is a first-person-perspective game composed of video images of an actual house. Patients are asked to carefully check the house, which is left behind in a hurry by a friend. They walk through the house in a preset order and are confronted with 15 OCD-related events (eg, turning off the gas stove). Patients are asked to solve these events and subsequently check or repeat the events as often as desired (for full details, see van Bennekom et al [7]). We showed that this VR game, when played on a laptop screen, was able to provoke higher levels of anxiety and virtual compulsions in patients with OCD than in healthy controls [6,7].

In this study, we modified the VR game to enable performance inside a functional magnetic resonance imaging (fMRI) scanner. In contrast to traditional “passive” fMRI symptom provocation tasks mostly using images, written verbal stimuli, emotional faces, or neurocognitive tasks with emotional interference [8,9], this VR game is interactive and realistic and therefore actively immerses patients whilst inside the scanner. This allows us to gain insight in to blood oxygenation level-dependent (BOLD) derived brain activation while patients are confronted with OCD-related events and while they perform virtual compulsive actions. To our knowledge, this is the first study using a VR game with fMRI for symptom provocation in OCD.

Figure 1. A 3D map of the house indicating obsessive-compulsive disorder-related items. 1: locking the gate (start); 2: locking the front door (start); 3: switching off the television; 4: extinguishing the candle; 5: organizing pencils; 6: closing the window; 7: cleaning the breakfast table; 8: turning off the gas stove; 9: organizing the cans; 10: cleaning the sink; 11: hand-washing after using the toilet; 12: switching off the flat iron; 13: organizing hazardous substances; 14: locking the front door (end); and 15: locking the gate (end).



Figure 2. Screenshots from the virtual reality game.

Recent meta-analyses of fMRI, positron emission tomography, and single-photon emission computed tomography studies underline several brain regions involved in the pathophysiology of OCD. Abnormalities in cortico-striato-thalamo-cortical pathways—circuits connecting the cortex, striatum, basal ganglia, and thalamus—are involved in the pathophysiological substrate [10]. In a recent meta-analysis of fMRI, positron emission tomography, and single-photon emission computed tomography studies conducted by Thorsen et al [9], brain activation during symptom provocation was compared between patients with OCD and healthy controls. They found higher levels of activation in the bilateral amygdala, right putamen, orbitofrontal cortex (OFC) extending into the anterior cingulate cortex (ACC) and ventromedial prefrontal cortex, and middle temporal and left inferior occipital cortices during emotional processing in patients than in healthy controls. In patients with OCD with a higher rate of comorbidity with anxiety or mood disorders, they found more pronounced activation in the right putamen, amygdala, and insula. Another preceding smaller meta-analysis of neuroimaging symptom provocation studies in OCD, conducted by Rotge et al [11], also found an increased likelihood of activation in 19 clusters in patients with OCD compared to healthy controls. These included the OFC, ACC, precuneus, and thalamus. Although paradigms have been developed to induce the urge to check in patients with OCD [12], to our knowledge, no provocation procedures to induce actual checking behavior have been applied in fMRI studies before.

Because our VR game represents a new and innovative technique for fMRI symptom provocation, we decided to perform a proof-of-concept study with a limited sample size. In this study, we aim to investigate the neural regions that are activated in patients with OCD when they are interactively confronted with a symptom-provoking event and when they are

performing compulsive actions in VR. Moreover, we aim to investigate whether activation in these regions is related to OCD symptom severity. We hypothesized that (1) playing the VR game inside a fMRI scanner would lead to increased brain activity within the OFC, ACC, amygdala, right putamen, and right insula in patients with OCD compared to that in healthy controls, and (2) a positive correlation exists between the degree of brain activation and the severity of OCD in patients.

Methods

Participants

We recruited 9 patients with OCD from December 2017 to March 2020 at the Psychiatric Outpatient Department of Amsterdam University Medical Center by means of information letters provided by their treating clinicians. Patients were also recruited through the Dutch OCD website Dwang.eu [13]. This sample size is in line with recommendations for proof-of-concept fMRI studies [14]. All included patients had a primary diagnosis of OCD, as determined by a psychiatrist and confirmed by the Mini-International Neuropsychiatric Interview in accordance with the DSM-IV (Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition) criteria [15]. We aimed to assess a clinically relevant group of patients with OCD including those with (mild to moderate) comorbid psychiatric disorders, under the condition that OCD was the primary diagnosis. We recruited 9 age- and gender-matched healthy controls through advertisements at the Amsterdam University Medical Center and by emailing individuals who formerly participated in research projects at our department. The healthy controls were free of any current mental disorders, as validated with the Mini-International Neuropsychiatric Interview. We excluded subjects with a history of severe neurological or cardiovascular disorders, psychotic disorder,

bipolar disorder, intellectual disability, and alcohol or substance abuse during the last 6 months. Furthermore, the use of medication potentially influencing cerebral blood flow, uncorrected hearing or vision problems, and irregular sleep/wake rhythm were exclusion criteria, as well as other contraindications for scanning with a magnetic resonance imaging (MRI) scanner.

Ethical Considerations

The study was approved by the Medical Ethics Committee of the Academic Medical Center of the University of Amsterdam (case number NL59652.018.16). All participants provided written informed consent before enrollment.

Procedure

The procedure of fMRI scanning was carried out at the Spinoza Centre for Neuroimaging, Amsterdam, the Netherlands. On the test day, trained clinical researchers obtained clinical and demographic data using questionnaires. After that, participants practiced controlling the VR game through manual button boxes in a mock scanner. For baseline measurements, they first watched a calming movie with nature scenes inside the scanner. Finally, they played the VR game during an fMRI scanning session. Trained technicians at the Spinoza Centre for Neuroimaging performed the scanning procedure in the presence of a trained researcher.

Patient and Public Involvement

Patients or the public were not involved in the design, conduct, reporting, or dissemination plans of our research.

Assessments

Clinical Data

Trained clinical researchers assessed OCD severity using the Yale-Brown Obsessive Compulsive Scale (Y-BOCS) and OCD subtype using the related Y-BOCS Symptom Checklist (Y-BOCS-SC) [16], in combination with an expert's opinion. They measured anxiety and depression symptoms with the Hamilton Rating Scales for anxiety [17] and depression [18]. Finally, the sense of presence was measured with the Igroup presence questionnaire [19].

VR Game

The setup of the VR game is described and illustrated in detail in our pilot study [7]. In short, it concerned a first-person-perspective video game based in a house with 15 OCD-related events. Participants walked a set route through the house and were confronted with all these events in a preset order. At every event, after confrontation, participants were asked if they wanted to correct and then check an event, or if they wanted to proceed to the next event without intervening. Checks could be repeated as often as desired. At each event, participants rated their emotional responses including anxiety, tension, uncertainty, and urge to control on a digital 0-10 visual analog scale (VAS) after confrontation, correction, and checking. The VR game's output scores included the VAS scores and the number of virtual compulsive actions performed.

For this study, we edited the output data of the VR game to allow communication with the fMRI scanner. After 35 minutes, both the game and scanning process were automatically stopped.

Participants could see the white projection screen behind the head through a mirror fixed at a 45° angle to the head coil (standard MRI equipment). The VR game provides an immersive virtual reality "feel" because it has a first-person perspective and is projected close to the eyes in the scanner. The participant operated the VR game by means of 2 manual button boxes.

Acquisition of Images and Preprocessing

MRI scanning was performed using a 3.0T MRI scanner (Philips) using a 32-channel SENSE head coil. Scanning included a high-resolution T₁-weighted structural scan for anatomical reference (repetition time=6.9 milliseconds, echo time=3.1 milliseconds, voxel size=1.20 mm isotropic, flip angle=8°, and 150 transverse slices). Additionally, at least 496 (range 496-883) BOLD scans were acquired using a T₂*-weighted gradient multiecho echoplanar imaging sequence [20], with the following parameters: repetition time=2375 milliseconds, echo time=9/26.4/43.8 milliseconds, flip angle=76.1°, field of view=224 × 224 × 122 mm³, voxel size=2.8 × 2.8 × 3.0 mm³, matrix size=76 × 73, slice thickness=3 mm, slice gap=0.3 mm, number of slices=37, acquired in foot-head order. There was a maximum time frame of 35 minutes for playing the VR game inside the scanner.

We performed imaging analysis using Statistical Parametric Mapping (version 12; Wellcome Trust Centre for Neuroimaging). Data preprocessing consisted of realignment of images with respect to the middle volume, slice timing correction, coregistration of echoplanar imaging data to structural T₁ data, normalization to Montreal Neurological Institute space (3 mm isotropic), and spatial smoothing using an 6-mm full width at half maximum Gaussian kernel. We checked for motion artifacts; for a patient with OCD, we had to omit the final 25% of the VR game scans, due to excessive motion artifacts (ie, >5-mm framewise displacement).

Data Processing and Statistical Analysis

Clinical and VR Game Data

Demographic, clinical, and VR game data were analyzed using SPSS (version 26; IBM Corp). The VAS score of each emotional response upon confrontation with an OCD-related item was averaged for the 15 items. We performed Bonferroni correction to correct for testing of multiple emotional responses. Because of the small sample size, nonparametric tests were used to compare patients with healthy controls. We used the Mann-Whitney *U* test to compare continuous data (age and emotional responses) and Fisher exact tests for comparing categorical data (sex, nationality, schooling, and number of compulsions), including categorized questionnaire scores, because original scores did not qualify as continuous due to their limited distribution. Furthermore, in the group of patients with OCD, we calculated the reduction in emotional responses by subtracting the VAS score after the last compulsive action from the VAS score at confrontation. We used a 1-sample Wilcoxon signed rank test to assess the reduction in emotional responses after performing compulsive actions. The α value was set at .05 for significance.

Neuroimaging Data

Functional MRI data were analyzed using Statistical Parametric Mapping software (version 12) [21]. We performed individual subject analyses within the context of the general linear model, using delta functions convolved with a canonical hemodynamic response function to model events of interest. To enable this first-level analysis, we subdivided the events in the game in confrontation, correction, checking and, VAS rating events (Figure 3), which were contrasted with short time frames in the game during which no specific events took place. This resulted in a total of 10 regressors.

On the second-level between-group comparison, we conducted an independent samples *t* test to determine whether the OCD-related events in the VR game influenced brain activation differently between patients with OCD and healthy controls.

Figure 3. Events in the virtual reality game. VAS: visual analog scale.



Results

Demographic and Clinical Data

Demographic and clinical data of the study participants are shown in Table 1. Patients showed significantly more obsessive-compulsive and depressive symptoms; however, anxiety symptoms (assessed using the Hamilton Rating Scale for Anxiety) and mean scores of the Igroup Presence Questionnaire did not categorically differ significantly between patients and healthy controls ($P=.21$ and $P=.17$, respectively).

We investigated group interactions using a priori regions of interest (ROIs). We defined the bilateral amygdala, OFC, ACC, right putamen, and right insula as a priori ROIs. We used a threshold of 0.01 (0.05 divided by 5; corrected for multiple ROIs) for significance. To accommodate the low statistical power due to the small sample size, we also reported results at a trend significance level with a threshold of $P<.10$. We corrected for multiple comparisons at the voxel level (family-wise error) using a small-volume correction for ROIs, which were based on the automatic anatomical labeling atlas [22], using the WFU Pickatlas tool [23]. To determine correlations of Y-BOCS scores with fMRI data in SPSS, we used Marsbar [24] to extract parameter estimates from the bilateral amygdala and right insula in patients with OCD. To determine correlations of the fMRI data with the Y-BOCS scores, the Spearman correlation coefficient was used.

Patients with OCD had a mean Y-BOCS score of 23, which indicates moderate symptom severity. All patients had symptoms from multiple OCD dimensions. The most common dominant dimensions included perfectionism or symmetry for 44.4% ($n=4$) and taboo thoughts (aggressive or sexual intrusions) for 33.3% ($n=3$) of patients with OCD. Five patients with OCD were treated with a selective serotonin reuptake inhibitor (SSRI) or serotonin and norepinephrine reuptake inhibitor (SNRI), and 4 patients were unmedicated. Four patients experienced comorbid disorders including generalized anxiety disorder, depression, and social anxiety.

Table 1. Demographic and clinical data of patients with obsessive-compulsive disorder and healthy controls.

Characteristics	Patients (n=9)	Controls (n=9)	<i>P</i> value
Age (years), mean (SD)	29 (8.0)	29 (8.5)	.97
Male sex, n (%)	4 (44)	4 (44)	>.99
Dutch nationality, n (%)	8 (89)	9 (100)	>.99
Tertiary education, n (%)	3 (33)	5 (56)	.64
HAM-A ^a score, mean (SD)	12 (7.5)	1 (2.0)	.21
HAM-D ^b , mean (SD)	11 (4.5)	1 (2.1)	.002
Y-BOCS ^c score, mean (SD)	23 (2.8)	0 (0)	<.001
IPQ ^d score, mean (SD)	1.97 (0.96)	1.53 (0.75)	.17

^aHAM-A: Hamilton Rating Scale for Anxiety.

^bHAM-D: Hamilton Rating Scale for Depression.

^cY-BOCS: Yale-Brown Obsessive Compulsive Scale.

^dIPQ: Igroup Presence Questionnaire.

VR Game Data

The provoked emotional responses when playing the VR game are shown in Table 2. These represent the difference in mean VAS scores at confrontation over all 15 items and VAS scores

at the baseline measurement. Playing the VR game provoked significantly more anxiety, but not tension, uncertainty, and an urge to control in patients with OCD compared to healthy controls. Furthermore, patients with OCD showed significantly more compulsive behavior in the VR game than healthy controls;

patients performed a mean of 0.46 (SE 0.14) compulsions per event, healthy controls performed a mean of 0.07 (SE 0.02) compulsions per event ($P=.03$). Finally, in patients with OCD, we found a significant reduction in anxiety (mean 1.54, SE 0.60;

$P=.001$), unrest (mean 3.09, SE 0.77; $P=.008$), and uncertainty (mean 1.72, SE 0.61; $P=.01$) but not in the urge to control (mean 2.16, SE 0.86; $P=.02$) after performing virtual compulsive actions.

Table 2. Provoked emotional responses during the virtual reality game measured using the visual analog scale (VAS).

	VAS scores of patients with obsessive-compulsive disorder (n=9), mean (SE)	VAS scores of controls (n=9), mean (SE)	U value	P value
Change ^a in anxiety	1.01 (0.38)	0.13 (0.30)	12.0	.01
Change in tension	0.78 (0.72)	0.21 (0.35)	36.0	.73
Change in uncertainty	1.47 (0.57)	-0.03 (0.19)	19.0	.06
Change in the urge to control	1.58 (0.63)	1.31 (0.37)	38.0	.86

^aDifference between scores at baseline and at confrontation.

Neuroimaging Data

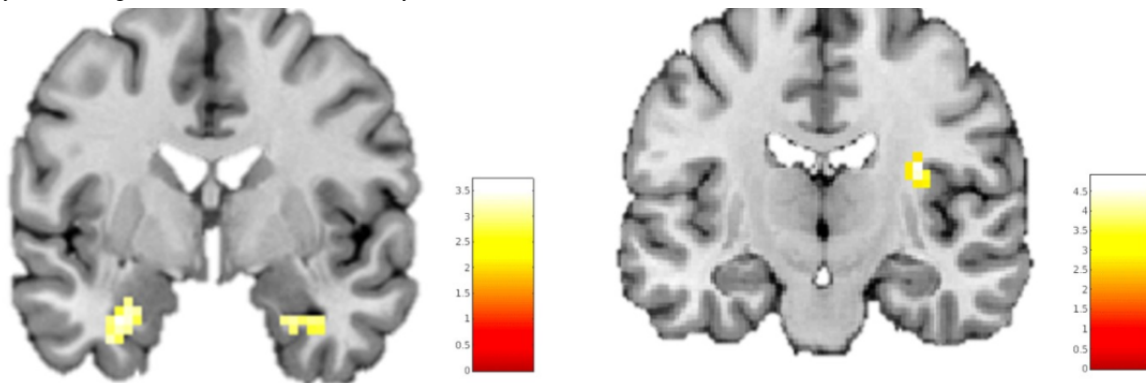
Since 4 patients were unable to finish the VR game within 35 minutes, patients with OCD were exposed to a mean total number of 13.89 (SD 1.27) events during the VR game scan, whereas all healthy controls were exposed to all 15 (SD 0) events. After correction for multiple comparisons, there were no significant differences in brain activation between patients with OCD and healthy controls when playing the VR game. However, during confrontation with the OCD-related events in the game, a larger increase in left amygdala activity was observed in patients with OCD than in healthy controls at the trend level (Figure 4; peak voxels: x, y, and z=-27, -4, and -25;

$T=3.24$; $P_{fwe,svc}=.07$). When performing the virtual compulsive actions, a larger increase in left amygdala (Figure 5A; peak voxels: x, y, and z=-27, -4, and -22; $T=3.61$; $P_{fwe,scv}=.06$), right amygdala (Figure 5A; peak voxels: x, y, and z=30, -4, and -28; $T=3.27$; $P_{fwe,svc}=.09$), and right insula (Figure 5B; peak voxels: x, y, and z=33, -19, and 20; $T=4.61$; $P_{fwe,svc}=.09$) activity was observed in patients with OCD than in healthy controls at trend level. Task-related activity in the ROIs OFC, ACC, and right putamen was not significantly increased in patients with OCD compared to that in healthy controls. Finally, healthy controls showed no areas of increased BOLD response upon confrontation with OCD-related events or when performing virtual compulsive actions compared to patients with OCD.

Figure 4. Results of analysis of regions of interest. Trend significant cluster of hyperactivation in the left amygdala in patients with obsessive-compulsive disorder (OCD) compared with healthy controls during confrontation with OCD-related events. Montreal Neurological Institute coordinate: y=-4.



Figure 5. Results of analysis of regions of interest. Trend significant clusters of hyperactivation in patients with obsessive-compulsive disorder compared with healthy controls during performance of virtual compulsive actions, in the left and right amygdala (A; Montreal Neurological Institute [MNI] coordinate: $y=-4$) and right insula (B; MNI coordinate: $y=-19$).



Correlation Between Y-BOCS Scores and Brain Activation

Based on the aforementioned results, we focused on the correlation between amygdala and insula activation and Y-BOCS scores in patients with OCD. Upon confrontation with OCD-related items, there was no significant correlation between left amygdala activation and the Y-BOCS score ($r_s=-0.542$, $P=.13$). When performing virtual compulsive actions, there were no significant correlations between left amygdala ($r_s=-0.192$, $P=.65$) or right amygdala ($r_s=-0.419$, $P=.30$) and right insula ($r_s=-0.467$, $P=.24$) activation and Y-BOCS scores.

Discussion

Principal Findings

In this study, we performed an fMRI scanning session during a VR game for OCD, allowing us to examine brain regions upon confrontation with virtual symptom-provoking events and compulsions. We replicated findings from our previous study, showing that this VR game provoked more anxiety and virtual compulsive actions in patients with OCD than in healthy controls [6]. In the patient group, we also found a decrease in negative emotions following compulsive actions. Our results confirm that the VR game can provoke anxiety and virtual compulsions, which modulate negative emotions. We found no significant differences in brain activation between patients with OCD and healthy controls. The results show increased activity in the bilateral amygdala and the right insula at the trend level. We found an increase in left amygdala activity upon confrontation and an increase in bilateral amygdala and right insula activity with compulsive actions in patients with OCD. Contrary to our hypothesis, we did not find differences in brain activity in the OFC, ACC, and right putamen.

Comparison to Prior Work

The increase in left amygdala activity in response to confrontation is in line with previous symptom provocation studies [9]. The amygdala is involved in the detection of salient events and the mediation of negative emotions such as fear and anxiety [25,26]. The activity is associated with increased attention toward events and provoked feelings of anxiety. The laterality of the amygdala's response may be explained by fear

modulation of the left amygdala in response to learned, subject-dependent, aversive stimuli, in contrast to fear modulation by the right amygdala in generally aversive stimuli [27]. Increased bilateral amygdala and right insula activity during virtual compulsive actions is in line with previous provocation studies [9]. In our study, we observed brain activity while participants actually performed virtual compulsions. This is unique, since other studies use pictures, emotional faces, or written words to provoke symptoms. Our approach is a good example of an ecologically valid experiment that shows engagement of the amygdala and insula.

Thorsen et al [9] found pronounced right insula activation in studies with comorbid anxiety or mood disorders. In another study, the right insula was activated in response to disgust-inducing pictures in patients with contamination fear [28]. Indeed, the insula is suggested to play a role in processing disgust, and, in particular, the contamination/washing dimension of OCD is associated with higher disgust sensitivity [29]. Furthermore, Luigjes et al [30] found increased insula activation during risk processing in risk-averse patients with OCD, mainly in those with the doubt/checking dimension of OCD. The disgust and high risk-related virtual compulsions in our VR game (eg, washing hands after touching a dirty toilet or turning off a running flat iron) could have contributed to right insula activation.

In contrast to former studies, we did not find a difference in activity in the OFC or ACC. Most neuroimaging symptom provocation studies found increased activity in the OFC and ACC [9,11]. In one study, hypoactivation of the left ACC was observed in response to a handshake from a dirty virtual avatar in patients with OCD [31]. Furthermore, we did not find a correlation between the degree of brain activation and severity of symptoms. These results are nevertheless consistent with those of the meta-analysis of Thorsen et al [9]; the latter did not find a correlation between amygdala or insula activity and symptom severity.

Limitations

Our study has a few limitations. First, since this is a proof-of-concept study, we decided to recruit a small sample of 9 patients with OCD and 9 healthy controls, leading to limited statistical power. This impedes drawing definite conclusions regarding the ability of the VR game to activate the OCD-related

neural regions in patients compared to healthy controls. This could also explain why only trend-level activation patterns were observed in the amygdala and insula.

Second, in our group of patients with OCD, 5 patients used a SSRI or SNRI and 4 experienced a comorbid anxiety or mood disorder. Thorsen et al [9] found a negative correlation between SSRI use and right amygdala activation, and more pronounced right amygdala and less pronounced left amygdala activation in studies with more comorbid anxiety and mood disorders. Hence, in our results, both medication use and comorbid disorders could have affected left and right amygdala activation. Third, we used the “neutral” scenes (eg, the camera turning toward a wall) as contrast in the analyses during the game, and we cannot exclude the premise that participants already anticipated new events during the neutral scenes. If anything, this would have led to less pronounced activation patterns in the OCD-related brain regions in response to OCD-related events than to neutral events. Finally, 4 out of 9 patients with OCD indicated that their specific obsessions and compulsions were not triggered by the VR game. This indicates that the VR game, despite its comprehensive design, is not able to trigger OCD in all patients, possibly because the VR game did not represent all OCD dimensions. Indeed, studies have found distinct patterns of brain activation with OCD dimension-specific picture sets [32] or fully individualized picture sets [8].

Conclusions

In this proof-of-concept study, the VR game activated the bilateral amygdala and right insula at the trend level in patients with OCD, especially when performing virtual compulsions. Since this was a proof-of-principle study with 9 patients, it is

important to replicate these results in studies with a larger sample size. Our results suggest that immersive symptom provocation, with the possibility to conduct virtual compulsive actions, may allow us to study brain regions in patients with OCD in a more ecologically valid context, and, as such, can be seen as a stepping stone toward more research in this area. In particular, the possibility to observe brain activation when performing virtual compulsive actions might teach us more about the involved brain regions in this complex process that has proved difficult to study in an MRI scanner. So far, the VR game was not able to activate the whole OCD circuit including the OFC and ACC, possibly due to limited power because of the small sample size.

To our knowledge, this is the first study among patients with OCD using an innovative and interactive VR game entailing multiple OCD dimensions for symptom provocation inside a MRI scanner. New possibilities arise, for example, with the development of MRI-suitable head-mounted displays, to gain even higher levels of presence and immersion inside the MRI scanner. Furthermore, new VR technology allows for personalization of the virtual environment to the OCD dimension, which may improve power to detect brain regions [8]. Further research with larger sample sizes is needed to determine whether using a virtual environment on a head-mounted display that can be adjusted to OCD subtypes will lead to increased activation of neural regions related to OCD. If activation of OCD-related neural regions can be achieved during confrontations with events and while performing compulsive actions in a VR environment, this suggests the feasibility of exploring the neural basis of near-real-life OCD symptoms. This approach could yield deeper insights into the complex pathological foundations of OCD.

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Data Availability

The data sets generated or analyzed during this study are available from the corresponding author on reasonable request.

Authors' Contributions

MJvB drafted the manuscript, led the investigation and formal analysis, and supported the conceptualization of the study. GvW and WBB supported the formal analysis and reviewed and edited the manuscript. JL led the development of the study methodology, supervised the study, and reviewed and edited the manuscript. DD conceptualized and supervised the study, and reviewed and edited the manuscript.

Conflicts of Interest

GvW received research funding from Biogen, Bitbrain, and Philips for unrelated work. The other authors declare they have no conflicts of interest.

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Abbreviations

ACC: anterior cingulate cortex

BOLD: blood oxygenation level-dependent

DSM-IV: Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition

fMRI: functional magnetic resonance imaging

MRI: magnetic resonance imaging

OCD: obsessive-compulsive disorder

OFC: orbitofrontal cortex

ROI: region of interest

SNRI: serotonin and norepinephrine reuptake inhibitor

SSRI: selective serotonin reuptake inhibitor

VAS: visual analog scale

VR: virtual reality

Y-BOCS: Yale-Brown Obsessive Compulsive Scale

Y-BOCS-SC: Yale-Brown Obsessive Compulsive Scale Symptom Checklist

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Original Paper

Virtual Reality for Basic Life Support Training in High School Students: Thematic Analysis of Focus Group Interviews

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Abstract

Background: High-quality and engaging cardiopulmonary resuscitation (CPR) training of both health care professionals and members of the public is necessary to provide timely and effective CPR to maximize survival and minimize injuries. Virtual reality (VR) is a novel method to enhance CPR engagement and training. However, a near-peer mentoring framework has not been applied in such training to date.

Objective: The purpose of this pilot qualitative study was to understand the acceptability and feasibility of using VR technology to introduce basic life support (BLS) to high school students reinforced by near-peer coaching.

Methods: Dyads of high school students underwent BLS training in CPR using a VR experience reinforced by the near-peer mentoring model. Focus group interviews were performed following the intervention. The interview sessions were recorded, transcribed verbatim, and subjected to thematic analysis. VR software data were analyzed after five cycles of chest compressions between the two participants.

Results: The overwhelming responses from the three dyads of high school students indicated positive acceptance of learning CPR using VR. Analysis of emerging themes revealed three main categories of barriers and facilitators: (1) motivation to learn CPR, (2) CPR learning modality, and (3) coaching CPR content. These themes supported the theoretical framework of an "intention-focused" paradigm leading to acquiring the skills needed to perform CPR and ultimately increasing the chances of a bystander performing CPR.

Conclusions: This study highlights the potential for training a unique population to increase bystander effects using novel VR technology coupled with a near-peer mentoring method. Further research is warranted to measure the outcome of the knowledge attained and the intention to perform CPR by high school students who participate in CPR education using VR and a near-peer mentoring method.

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KEYWORDS

virtual reality; mixed reality; technology; basic life support; cardiovascular pulmonary resuscitation; near-peer mentoring; education; high school students

Introduction

Sudden cardiac arrest (SCA) is an uncommon phenomenon in youth; however, according to the Centers for Disease Control

and Prevention, approximately 2000 healthy people under 25 years of age in the United States die each year due to SCA [1]. Regardless of one's age, the survival odds of SCA outside of a hospital setting are low, which is likely related to the low

bystander cardiopulmonary resuscitation (CPR) rates [2,3]. Therefore, it is important to increase the general public's awareness and knowledge levels of CPR to consequently increase the number of bystanders who may initiate CPR in an emergency situation [4]. Educating and engaging adolescents in life-saving maneuvers such as CPR is a crucial step in increasing the lifelong ability and motivation to take actions in an emergency [5,6].

High-quality and engaging CPR training of both health care professionals and members of the public is necessary to provide timely and effective CPR to maximize survival and minimize injuries [7]. Traditionally, CPR training has occurred in an in-person group setting utilizing CPR mannequins. Due to the COVID-19 pandemic, this traditional approach of CPR training shifted toward a focus on smaller group sizes to minimize hands-on simulation activities. Virtual reality (VR) is a novel method to enhance CPR engagement and training, which has shown rapid growth since 2019 [8,9]. The immersive VR training induces a greater sense of presence and agency when compared to traditional CPR training, and may be more effective in increasing the intention and initiative to perform CPR in real-world emergencies [10]. Such VR technology enhancements have been particularly well received by the "technology natives" of the younger generation [11]. A systematic review identified the current gap of this field as the lack of educational programs rated at 3-4 on the Kirkpatrick model, which is a method of evaluating the results of training and learning programs [12]. This highlights the importance of continued development and improvement in simulation education, particularly in the context of CPR training. While there is a growing interest in leveraging novel technologies for CPR training, few studies have assessed their potential [13].

Near-peer mentoring is a learner-centered model, where the pairing of mentors and mentees close in age and developmental stage allows for mentors to draw on personal experiences to connect with mentees. This facilitates connections and reflections integral to the experiential learning process [14]. However, the relationship between CPR training and use of VR technology based on a near-peer mentoring framework has not yet been investigated, particularly in the high school population.

To fill this gap, our primary objective was to assess the feasibility of VR technology as a novel learning modality for CPR training and to apply the near-peer mentoring model in this CPR training among adolescents. Toward this end, we evaluated the relationship between the following three domains: CPR, VR, and near-peer mentoring. Our secondary objective was to collect and document the lived experiences of adolescents upon experiencing VR to obtain basic skill sets associated with CPR.

Methods

Recruitment

High school students were recruited from participants of Camp Children's Hospital Los Angeles (CHLA), which is an annual,

week-long health care career exploration summer camp for high school students between 15 to 17 years of age in Los Angeles County. The VR-based CPR sessions were offered as a voluntary option. The study was conducted in the Las Madrinas Simulation Center at CHLA.

The target number of participants to recruit for this qualitative pilot study was not established a priori. According to Creswell [15], between 5 and 25 interviews for phenomenological studies were reported to be appropriate. In addition, Morse [16] specified recruiting at least 6 participants for phenomenological studies. Neither of these studies included the rationale for the indicated numbers.

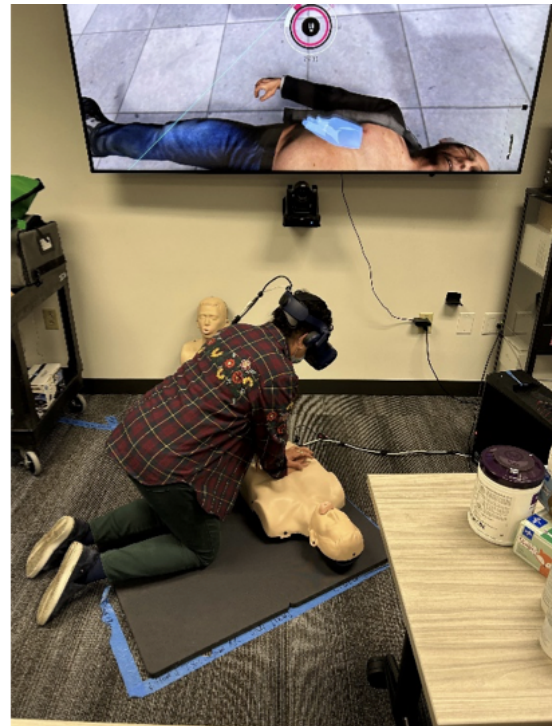
Ethical Considerations

The protocol and participant-facing materials underwent review by the CHLA institutional review board, and approval was obtained prior to any data collection (case number CHLA-22-00230). Informed consent and assent were obtained from the identified participants and their respective parents prior to the day of the study. Participants were not offered compensation. Consents and assents were electronically obtained via the Research Electronic Data Capture (REDCap) system where corresponding participant IDs were created. The identifiers were removed during the transcription process and the recordings were destroyed once transcription was completed.

Data Collection

Dyads of high school students underwent CPR training using a VR-based hybrid simulation platform (CBS, TetraSignum). Prior to the VR session, each dyad watched approximately 30 minutes of didactic content delivered by a virtual avatar instructor. Following the didactic portion, the students took turns and had an opportunity to perform hands-on CPR on a quality CPR (QCPR) mannequin. Next, the VR software data, which scored five cycles of chest compressions between the two participants, were analyzed. We used a Vive Pro (HTC) hardware system, which enabled simulcasting the VR user's view to a screen for others to watch. The VR software superimposes a virtual avatar over the location of the mannequin to simulate a human in cardiac arrest. This QCPR technology uses wireless sensors embedded in the mannequin to measure the effectiveness of core CPR components [17]. The steps of the CPR consisted of (1) a check response, (2) a call for help, (3) a check for breathing, (4) five cycles of chest compressions and rescue breaths, and (5) using an automated external defibrillator. This experience was reinforced by the near-peer mentoring model as a pair (Figure 1). The sessions were immediately followed by approximately 45 minutes of focus group interviews led by the research team. The debrief interview sessions used open-ended questions addressing the domains of interest and the participants' lived experiences. The interview sessions were recorded, transcribed verbatim, and analyzed.

Figure 1. Dyads of campers underwent basic life support training using a virtual reality–based hybrid simulation platform.



Phenomenology

Phenomenology is a type of a qualitative research method with roots in psychology and philosophy. Phenomenology is best applied to understand the lived experiences of individuals where the focus is exploring [18,19]. In our study, participants interested in a career in health care intentionally chose the VR CPR tract as part of their day. Accordingly, this study aimed to gain insight as to “how individuals make sense of the world to provide insightful accounts of their subjective experience” [18], and to gain understanding of the phenomenon of introducing the contents of basic life support (BLS) and CPR using VR and near-peer mentoring to high school students.

Data Analysis

The interview sessions were recorded and transcribed verbatim. An interdisciplinary team of medical researchers used a thematic analysis approach as described by Braun and Clarke [20]. The first three authors (HJM, CA, and ROLBB) read the transcripts to understand the students’ perceptions and acceptability of using VR to learn CPR with a near-peer mentoring model. Next, the transcripts were coded systematically across the three team members and combined for reflexive thematic analysis [21]. The three research team members, including two research nurses (HJM and ROLBB) and a physician (CA), analyzed the focus group data using constant-comparison analysis. This approach allows for richer interpretations of meaning, particularly across multidisciplinary research members. Constant comparison also allowed for refining, defining, and naming themes. Once codes were created, they were grouped into barriers and facilitators, and then broader themes were identified by circling back to the near-peer mentoring model and the intersection between VR

and CPR. Finally, the thematic auditors (DRL and TPC) reviewed the identified themes for any discrepancies.

Results

Recruitment

This pilot study launched over the summer of 2022. We recruited a total of three dyads of 6 high school students from a total of 31 students participating in the CHLA camp. The parents of the 6 participants provided consent and individual participants provided assent to be interviewed to share their lived experiences of learning CPR using VR and acting in the role of “coach” based on the near-peer mentoring model. The cohort comprised 2 boys and 4 girls with a mean age of 16.5 (range 15-17) years. Of note, this was the first on-site camp since the COVID-19 pandemic; therefore, there was a smaller total group of campers selected for that year, ultimately leading to a smaller sample size for this study.

Data Saturation

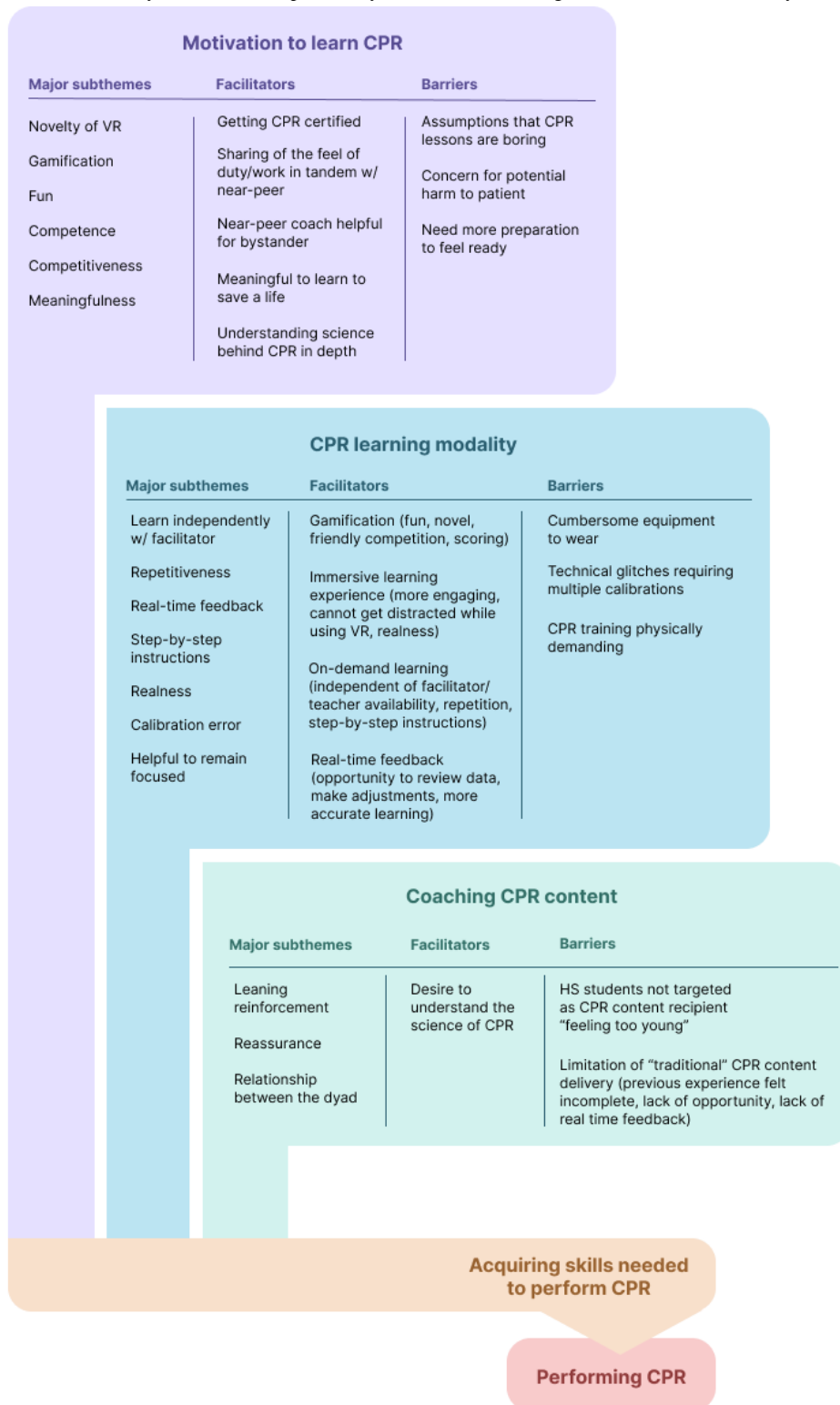
Data saturation in a qualitative study is defined as the collection of qualitative data to a point of “sense of closure,” because there are no new insights obtained and the data yield redundant information [19,22]. Attempts were made to have the campers return to campus after the camp had been completed; however, since the students were back at school, we were unable to recruit additional participants.

Themes

Main Themes Identified

During the qualitative analysis process, three themes were identified: (1) motivation to learn CPR, (2) CPR learning modality, and (3) coaching CPR content (Figure 2).

Figure 2. Summary of the thematic analysis. CPR: cardiopulmonary resuscitation; HS: high school; VR: virtual reality; w/: with.



Motivation to Learn CPR

Motivation to learn CPR was defined by themes arising from the individuals’ expressed extrinsic and intrinsic motivation to learn. Participants reported the novelty of VR and the engaging space of the simulation center to be a motivating factor in learning CPR. Our method of learning was unique when compared to the traditional method of a CPR class and its preconceived notions because it created “a more engaging space

for kids to be more interested in CPR.” Furthermore, the gamification of learning by VR was considered to be fun, and even peers who may not have an interest in health care would also be interested since VR would “automatically assumed to be fun because it’s a game.” The final scores provided by the software served as positive feedback of competence and elicited competitiveness as a source of encouragement in the participants’ ability to achieve success. Lastly, many of the

participants reported that it was meaningful to be able to learn how to save a life.

CPR Learning Modality

The learning modality of CPR was defined by themes arising from the method, medium, or delivery of the CPR learning via VR and peer coaching. The participants reported that being able to learn independently without having a facilitator or teacher supervision would allow them to repeat the learning process at their own pace (eg, “you keep practicing, eventually it’ll become second nature”) and that when faced with an emergency, one would feel more prepared to assist. The real-time feedback from the avatar trainer and the in-person peer coach was considered to be helpful. In addition, the ability to address concerns such as “Are we going at the right pace?” “Are we going too slow?” “Is the pressure right?” on a real-time basis enabled immediately making changes and adjustments in real time as needed. The step-by-step instructions helped to reinforce the knowledge. One camper shared, “I like that it went step by step because it helped to absorb the information easier.” There was also feedback regarding the avatar often moving out of sync with little or no time for the participant to reflect. For instance, “it was like after you finish check response and then he just quickly moved on to the next one. Maybe just a little bit time to reflect...” Lastly, the realness of the VR simulation and tactile hands-on learning modality helped participants to be better prepared when compared to the traditional lecture-based or passive online modules: “I liked it was more accurate. I like that it put me in a real-life situation and, I felt like it made me more prepared.” The participants also shared calibration error to be a source of distraction in learning, which occurred when the mannequin’s sensor and the participant’s hands were not calibrated correctly. Lastly, use of VR enabled the participants to remain focused while learning, because “you weren’t looking around or getting distracted by anything,” since while the headset is on, the participant is engaged in the “VR world” and is therefore unable to become distracted.

Coaching CPR Content

Coaching CPR content was defined by themes arising from the dyads’ experiences of serving as a coach and being coached as a pair. Although the pair started by watching the 30-minute introduction training videos together, many participants shared that being able to coach after having the opportunity to go through the program first helped them to feel more confident in coaching. The comments offered as a coach served as additional learning reinforcement, as stated by one participant: “whatever I said to her stuck in my mind, so I was able to remember that for when I went.” The presence of the coach also provided a sense of reassurance because participants “felt reassured like I wasn’t being pressured to do everything and then forgetting anything.” Working in tandem in CPR training impacted the pair’s perception of the responsibility of a “scary situation” to be less daunting. An important factor to be mindful in assigning of the pair was assessment of the relationship between the dyad:

If I had just met someone, maybe I wouldn’t be as comfortable telling them what to do or what not.

Probably just the relationship with people would be the biggest aspect of coaching.

Recommendations for Future Projects Provided by Participants

Helpful ideas for future iterations of the VR-based CPR trainings included adding options of different major metropolitan cities, background music, and personalization of avatars. Moreover, participants suggested expanding the trainings to include a pediatric population, ranging from infants to toddlers to school-aged children. Lastly, they suggested using a more seamless VR technology to impose less of a burden associated with the headset.

Discussion

Our findings show that it will be valuable to leverage the currently available VR technology to promote CPR education for high school students. Moreover, purposeful inclusion of a near-peer mentoring approach can have a synergistic contribution to the training and result in a positive learning experience. The themes identified in our study build upon the existing theoretical framework proposed by Panchal et al [23], termed the “intention-focused model for bystander CPR performance,” which allows gaining an understanding of the determinants of bystanders’ decision-making process. The proximal domains preceding the intentions start with the bystander’s demographic characteristics, including gender, age, personality traits, and education level. These baseline demographic variables then lead to their “beliefs,” categorized by “attitudes,” “perceived norms,” and “self-efficacy,” in performing CPR. These beliefs then result in the “intention” to perform CPR, bolstered by the “skills needed to perform CPR” as a determinant of behavior, which ultimately leads to the action of performing CPR.

Therefore, the themes unveiled from our qualitative data analysis were consistent with the intention-focused model for the bystander CPR performance framework. Our research design of phenomenology and documentation of the “lived experiences” of the participants expanded upon the demographic characteristics and beliefs associated with CPR prior to this new learning experience. The main purpose of this VR CPR project was to equip the participants with the knowledge and skills needed to perform CPR. The three major themes unveiled from our analysis add to the preceding themes leading up to the “skills needed to perform CPR” in the intention-focused model, which were (1) motivation to learn CPR, (2) CPR learning modality, and (3) coaching CPR content.

The motivation to learn CPR is a new domain that is distinct from the previously identified “attitudes,” “perceived norms,” and “self-efficacy” about performing CPR. Self-determination theory is a motivational theory of personality, development, and social process that examines how individuals are driven and depicts motivation on a continuum [24]. Notably, our participants were highly motivated individuals who are interested in future careers in health care. In accordance with the framework of Panchal et al [23], it will be important to introduce a moderating factor to motivate high school students

to be intrinsically motivated where the motivation's root stems from interest, enjoyment, and satisfaction.

The overwhelming positive feedback received by the participants in regard to learning CPR via VR is consistent with prior research showing a link between novelty and curiosity [11,25,26], where "when a novel stimulus affects an organism's [brain] receptors, there will occur a driving stimulus producing response called curiosity" [26]. Our novel approach to the learning and delivery of CPR content may have steered the "attitudes" and "perceived norms" about performing CPR in a positive direction. A scientific statement by the American Heart Association noted that novel methodologies and digital platforms (ie, gamified learning, social media, and crowdsourcing) do not necessarily improve response and performance; however, novelty allows for the potential to reach a larger population with various types of learners [27]. Likewise, although this pilot study did not measure the changes in the "intention to perform CPR," based on the feedback provided by participants, this approach has the potential to reach and create interest in high school students.

Since the VR CPR learning modality would allow for learners to repeat the learning sequences independently in their own time, as one participant stated, "if anything like this were to happen, you would be able to do it." A similar study from 2016 that evaluated multiplayer virtual training in medicine among 12 Swedish medical students found that virtual training may result in "erroneous self-beliefs" affecting future clinical practices [11]. This study points to the importance of future studies to measure the "intention to perform CPR" and assessment of the efficacy of VR-based training compared to traditional training methods [13].

There was a similar study evaluating the influence of near-peer mentoring in CPR workshops on medical students' knowledge and satisfaction [28]. Similar to the findings with our high school students, the previous study reported the benefits of this type of mentorship to be helpful in that the peers have similar levels of experience, and they are more familiar with the educational needs and better understand the learning process and potential areas for confusion [28].

The selection of inherently motivated high school students with career aspirations in health care may have posed a bias, thereby limiting the generalizability of the study, in addition to the small sample size of 6 participants. In addition, consistent with the design of this pilot study, it can be difficult to present generalizable findings of phenomenological research due to the highly individual records of lived experiences. Lastly, although we did not collect measures specifically evaluating changes in intentions to perform CPR in the future, previous studies have indicated that a bystander who had experienced CPR training was up to 6 times more likely to perform CPR when witnessing an out-of-hospital cardiac arrest [3,29,30]. Although outside of the scope and aims of this study, we did not collect any data to measure the quality of the CPR. Nevertheless, it is still meaningful that the students were trained on the sequences of BLS.

Our findings show that it is feasible to leverage a novel technology such as VR to enhance the CPR learning experience. Particularly for high school students, learning CPR using VR served as a source of motivation, which was fostered by the unique modality of learning in the presence of a near-peer coach. These benefits could contribute toward training a future generation who will be more confident to perform CPR as a bystander in an emergency situation.

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Data Availability

Data for this study, which comprise the transcription files and coding from the first 3 authors, may be made available upon request to the corresponding author.

Conflicts of Interest

None declared.

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Abbreviations

BLS: basic life support

CHLA: Children's Hospital of Los Angeles

CPR: cardiopulmonary resuscitation

QCPR: Quality CPR

REDCap: Research Electronic Data Capture

SCA: sudden cardiac arrest

VR: virtual reality

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Original Paper

Factors Associated With Risky Drinking Decisions in a Virtual Reality Alcohol Prevention Simulation: Structural Equation Model

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Abstract

Background: Risky alcohol consumption among adolescents is a significant public health concern in most Western countries. Various motives and factors (eg, sensation seeking, gender, reduced self-efficacy) known in the literature are associated with risky drinking decisions in real life. Efforts to tackle risky drinking decisions in real life through skills training to deal with social pressures have been successful. However, interventions of this nature require significant resources. Technological solutions, such as virtual reality (VR), offer advantages, as they enable immersive experiences that replicate real-life scenarios. However, a question persists pertaining to the fidelity of real-world behaviors within virtual environments.

Objective: This study is exploratory and aims to ascertain if the established drinking motives and factors for risky drinking decisions are transferrable to the virtual environment in the simulation game VR FestLab and to uncover determinants linked to risky drinking decisions within the simulation.

Methods: The study analyzed data from the intervention arm of a cluster-randomized study of 161 Danish students aged 14-18 years who tested the virtual alcohol prevention simulation VR FestLab. At baseline and before playing VR FestLab, independent variables such as age, gender, alcohol consumption, use of other drugs, sensation seeking, drinking refusal skills, knowledge of blood alcohol concentration, and refusal communication skills were recorded. The dependent variable, virtual risk decisions, was measured immediately after the gameplay. Confirmatory factor analysis and structural equation modeling were used to examine the latent variables in relation to virtual risk decisions. Moderation analyses for age and gender in relation to the latent characteristics and the primary outcome were also conducted.

Results: The data indicate that 73.9% (119/161) of the participants engaged in binge drinking at least once in their lifetime. The confirmatory factor analysis demonstrated a good fit of the items for their respective constructs; therefore, they were adopted without modification in the structural equation model. The data suggest that individuals with prior alcohol experience are 4 times more likely to engage in virtual risk decisions within the simulated environment (odds ratio 4.31, 95% CI 1.70-10.84; $P=.01$). Knowledge and awareness of blood alcohol concentration were associated with a lower chance to engage in virtual risk decisions (odds ratio 0.32, 95% CI 0.11-0.93; $P=.04$). However, no significant associations were found between virtual risk decisions and other latent variables. Gender and age did not moderate the associations.

Conclusions: The immersive and lifelike properties of VR partially reflected risk-related decisions. However, it remains unclear which factors favor the mapping of real-world behaviors in virtual simulations. Therefore, future research should address the mechanisms underlying behavioral dynamics in virtual simulations and explore the translation of virtual behaviors into real behaviors to gain a comprehensive understanding of the potential of virtual simulations for alcohol prevention.

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KEYWORDS

alcohol; prevention; virtual reality; risk behavior; structural equation model

Introduction

Alcohol prevention continues to represent a pertinent public health concern worldwide [1]. Despite witnessing a reduction on a global scale since the establishment of the Millennium Development Goals in 1995, alcohol consumption still contributes to 5% of disability-adjusted life years and 5% of total fatalities [2]. Furthermore, harmful alcohol consumption is pivotal in over 200 diseases and injury conditions [3]. Notably, alcohol prevention remains significant, particularly among adolescents, as indicated by the latest European School Survey Project on Alcohol and Other Drugs report, which reveals that approximately 80% of students aged 15-16 years have experimented with alcohol at least once [4]. Denmark surpasses the European average, with roughly 92% of adolescents having consumed alcohol at least once in their lifetimes [4].

To effectively deter premature substance use among adolescents, targeted alcohol prevention programs prove indispensable [5]. In this context, it is important to consider the motives underlying risky consumption patterns among adolescents. A systematic review conducted by Adan et al [6] revealed an association between risky drinking behavior and specific personality traits. For instance, binge drinking was correlated with increased impulsivity and sensation seeking [6], while Stautz and Cooper [7] and Percy et al [8] established an association between high sensation seeking and an increased likelihood of heavy episodic drinking. Other studies have identified binge drinking as particularly linked to male gender and reduced self-efficacy [9]. Moreover, engagement with other legal or illegal substances, apart from alcohol, correlates with increased risk behavior. Creamer et al [10] demonstrated that using various tobacco products corresponds to heightened risk behavior. Additionally, a correlation exists between cannabis use, drinking-related risk behavior [11], and the frequency of alcohol-related consequences [12].

Given the known drinking motives among adolescents, prevention programs anchored in concepts like inoculation theory [13] and social learning theory [14] advocate for skill enhancement that strengthens resilience against social influences, such as peer pressure for risky behavior. Research involving life skills training in educational institutions underscores the value of cultivating social resistance skills and broader personal and social competencies, leading to decreased cigarette use and enhanced anti-drinking attitudes [15]. Moreover, participants demonstrated higher substance use awareness and skill-related knowledge [15]. Effective refusal communication skills and risk-related knowledge are crucial

components for enhancing the personal and social skills of young people. Refusal communication, which involves the ability to say “no” to substance offers, is essential in reducing substance use and risky behavior. Several studies have demonstrated that individuals with strong refusal skills regarding alcohol misuse exhibit reduced abusive alcohol use [16-18], possess greater knowledge of alcohol misuse prevention, are less susceptible to peer pressure, and have better internal health control [19]. However, in addition to communication skills, it is also crucial for young people to have knowledge about substance use and its effects on the body to assess and avoid risks. Individuals with greater knowledge of substance-related topics may be better equipped to handle risky situations, potentially reducing the likelihood of substance abuse. Various studies have explored the relationship between substance-related knowledge and the reduction of risk behaviors, such as alcohol consumption. Teesson et al [20] conducted a cluster-randomized study in schools and found that combining digital prevention programs that increased alcohol-related knowledge resulted in a reduction in binge drinking. Hasking and Schofield [21] demonstrated that health and alcohol knowledge can strengthen the intention-behavior relationship. Individuals with more alcohol-related knowledge and experience are likely to be better informed about the consequences. Conversely, better-informed adolescents are likely to feel better prepared to minimize the risks of alcohol consumption [21]. Padget et al [22] discovered that increased awareness of the detrimental effects of alcohol on the brain resulted in improved perceptions of harm and subsequent attitudes of alcohol aversion. These improvements had a significant impact on the intention not to use alcohol, but they did not result in a significant reduction in short-term alcohol consumption. Therefore, it is important to note that knowledge about alcohol may be only one of many factors that can influence risk-taking decisions. Risk behaviors are frequently caused by multiple factors, and knowledge about alcohol may only have a partial impact on the development or absence of such behaviors.

Although traditional skills training involving rational alcohol consumption often relies on labor-intensive and costly in-person role-playing, contemporary technological solutions such as virtual reality (VR) have emerged. An intrinsic advantage of VR lies in its capacity to deliver an immersive encounter that faithfully mimics real-life scenarios. By replicating authentic situations, VR prompts participants to enact genuine behaviors within virtual environments [23,24]. Whereas studying real-world behaviors within experimentally controlled settings posed challenges, VR now allows one to scrutinize behaviors within genuine settings and uncover determinants of behavioral intentions [25].

The convergence between VR and real-life behavior might be attributed to presence and immersion. Individuals immersed in VR experiences can subjectively experience a sense of “being there” in the virtual realm. This sense of presence fosters more authentic and realistic behavioral responses akin to real-world conduct [26]. Alcañiz et al [27] reported that comparable neural mechanisms can be triggered in individuals immersed in a virtual world, paralleling experiences in the physical world. Additionally, the increasing realism and interactivity of VR technology play a role. As VR systems advance, they provide heightened sensory input and feedback, including lifelike visuals, haptic responses, and precise motion tracking. These immersive, lifelike elements contribute to greater congruence between VR and real-life behaviors [28]. Moreover, psychological factors such as social presence and adherence to social norms influence VR behavior, as people replicate real-world behaviors due to a sense of social presence and the desire to conform, even within virtual contexts [29].

The immersive, authentic portrayal of virtual environments implies that genuine risk behaviors are likely to manifest in these settings. This conjecture is supported by the findings that, for example, children exhibiting higher risk behavior in road traffic replicate this behavior in a virtual cycling simulation [30].

Nonetheless, reviews indicate that VR’s role in substance use prevention remains limited [31,32]. Thus, a cocreated virtual alcohol prevention simulation (VR FestLab) was developed in 2020 [33]. The VR FestLab application, an educational game simulation, aims to enhance the refusal self-efficacy of adolescents aged 15-18 years who experience social pressure to consume alcohol. Given the scarceness of VR-based alcohol prevention applications [31,32], this study was exploratory and aimed to ascertain if the established drinking motives and factors for risky drinking decisions are transferrable to VR FestLab. A structural equation model was used to uncover determinants linked to risky drinking decisions within the simulation. To this end, the following hypotheses were formulated for testing:

1. Higher sensation seeking is associated with increased virtual risk decisions in the simulation.
2. Enhanced knowledge and awareness of blood alcohol concentration (BAC), refusal communication skills, and drinking refusal skills are linked to reduced virtual risk decisions in the simulation.
3. Prior alcohol experiences are associated with increased virtual risk decisions in the simulation.

Methods

Study Design

The data were collected as part of a longitudinal study that investigated the efficacy of the VR FestLab application. The comprehensive procedure and outcomes of the primary study can be found elsewhere [34]. To achieve this objective, a total of 13 Danish schools were allocated in a 1:1 ratio to either the intervention or control group. The schools assigned to the intervention group engaged with the VR FestLab application, whereas those in the control group played the VR game First

Steps (Meta Platforms Inc). The data set in this study was derived from the 7 schools that were selected as intervention schools only. Data collection transpired within the school premises between August 2020 and December 2020 and then again from April 2021 to May 2021; the latter period was necessitated by COVID-19 restrictions. For the original study [34], a sample size calculation was performed using STATA 15 with a 2-sample *t* test. This resulted in a sample size of 135 individuals for the control group and 135 individuals for the intervention group to yield an intervention effect of Cohen $d=0.44$, with a power of 0.80 using a 2-sided α of .05. The sample size was calculated based on an estimated intraclass correlation for drinking refusal self-efficacy of 0.01 and 45 students per school. Taking into account an estimated attrition of 35%, 420 participants were planned to be recruited for the study. Further information can be found elsewhere [34].

Participants

To enroll adolescents aged between 14 and 18 years, initial contact was established with the administrations of the 7 schools through email. Once the school administrations granted their approval, the study’s objective was presented to the respective classes, emphasizing the confidential and anonymous nature of data collection. In accordance with the principles outlined in the Declaration of Helsinki, all students were duly informed that their participation was voluntary, and they gave written consent prior to their involvement.

Ethical Considerations

The study adhered to Danish standards for the ethical conduct of scientific studies and was approved by the Research Ethics Committee of the University of Southern Denmark in March 2020 (case no 20/5348; date of approval: January 22, 2020). In accordance with the Ethics Committee of the University of Southern Denmark, parental consent was waived, as it is only mandatory for adolescents under the age of 15 years in Denmark [35].

The Virtual Reality Simulation VR FestLab

The Danish VR application, VR FestLab, immerses users in a 360-degree filmed simulation and was specifically designed for adolescents aged between 15 and 18 years. A total of 128 distinct scenes allows users to engage with diverse simulation sequences. This interactive experience commences at the home of a school friend, where they both join in a birthday celebration. Within this simulation, users can navigate through 2 virtual rooms using eye movements. As they move within these spaces, they encounter various scenes, such as engaging in beer pong or participating in a flirting scenario, wherein they are presented with choices of both alcoholic and nonalcoholic beverages. Adhering to the taxonomy outlined in the Behavior Change Wheel [36], the simulation effectively integrates various behavior change functions, including education, training, modeling, and coercion or incentivization. Notably, individuals within the simulation can interact with role models who demonstrate the refusal to consume alcohol. If the user decides to consume alcohol and accepts an alcoholic drinking choice, the choice results in an incremental increase of a BAC bar,

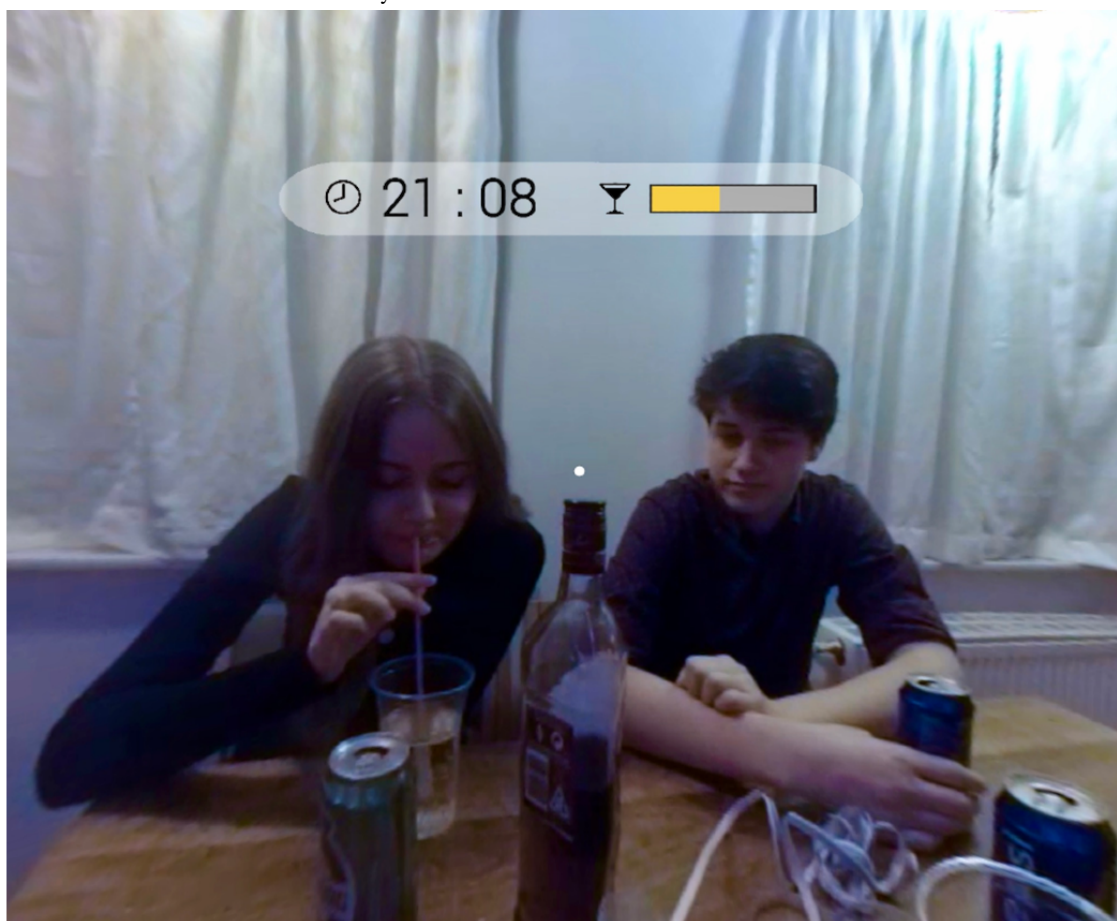
calculated via an algorithm, which is filled in at the top of the screen (see [Figure 1](#), yellow BAC bar at the top of the screen).

This algorithm considers factors like gender, alcohol content in grams, drinking pace, and the average weight of a 16-year-old boy or girl to calculate the BAC [37]. To calculate the exact BAC score, a BAC calculation by Becker and Nielsen [38] was used. The calculation for girls and boys is as follows:



Should the user consume an excessive amount of alcohol within a short span, as determined by the algorithm, they suffer a blackout. This blackout is first portrayed by the camera shaking and a magnifying display of the BAC bar. Following this, within

Figure 1. Screenshot of a scene from the virtual reality simulation FestLab.



Measures

Data were gathered through electronic questionnaires administered during school hours within classroom settings. The questionnaire was developed using the English versions of the respective scales (sensation seeking, drinking refusal skills, refusal communication skills) because no Danish versions were available ([Multimedia Appendix 1](#)). For the other measures (alcohol consumption, other drug consumption, knowledge and awareness of BAC) without existing scales in the literature, the project team created their own questions and items. The English questionnaires were translated to Danish and pretested with 31 students to determine their psychometric characteristics.

the game, the screen turns black, with the user subsequently awakening in a bedroom. In this bedroom, they receive messages that they have blacked out, concluding the simulation.

VR FestLab was pre-installed on Oculus Quest (Meta Platforms Inc) VR devices and handed out to the participants. Before engaging with the simulation, adolescents received instructions on device operation and navigation within the simulation. Following this, adolescents experienced VR FestLab for a maximum of 15 minutes in a classroom session. Depending on the simulation decisions, several rounds could be played during this time. After that, a structured 45-minute group reflection period was moderated by a trained study assistant in the classroom.

Adolescents were tasked with completing the questionnaire before (T0) and after (T1) the intervention. Independent variables, including age, gender, alcohol consumption, other drug consumption, sensation seeking, drinking refusal skills, knowledge and awareness of BAC, and refusal communication skills, were assessed at T0 before the VR FestLab intervention. The dependent variable, virtual risk behavior, was surveyed at T1 following the intervention.

Virtual Risk Decisions

The primary outcome was virtual risk decisions, evaluated through a self-developed question: "Did you pass out at any time during the party?" Answer options were dichotomized (yes/no). Passing out can only be achieved in the simulation

when the number and types of drinks accepted in a given time period resulted in a BAC of 2.0 permille, thus representing several risk decisions. The scenes and participant selections within the simulation were intentionally not recorded nor tracked to afford participants the utmost freedom in their interactions. As a result, the blackout experience in the game could only be assessed verbally. If participants responded affirmatively, it was inferred that the simulation terminated prematurely due to excessive alcohol consumption in a condensed time frame during the simulation.

Age and Gender

Participant gender was dichotomously determined using the question “Are you a girl or a boy? (State what you most identify as right now),” while age was quantified using the question “How old are you?”

Perceived Family Affluence, School Performance, and Health

To gather information on the sociodemographic factors of the participants, the following questions were adapted from the Health Behavior in School-aged Children study [39]: “How well-off do you think your family is?” “What does your class teacher(s) think about your school performance compared to your classmates?” and “Would you say your health is...?”

Alcohol Consumption

Alcohol consumption was estimated with 3 single questions designed by the researchers. The questions “Have you ever drunk alcohol?” “Have you ever been drunk?” and “Have you ever had 5 or more drinks on a single occasion?” could be answered dichotomously (yes/no) by the participants.

Other Drug Consumption

To assess the consumption of substances other than alcohol, 5 customized questions were used. Participants were queried about their usage of cigarettes, hookah, e-cigarettes, snuff, or cannabis. Response options were dichotomized (yes/no).

Sensation Seeking

Sensation seeking was measured using the 8-item Brief Sensation Seeking Scale (BSSS-8) by Hoyle et al [40], which has a Cronbach α of 0.76. Participants answered 8 statements using a 5-point Likert scale, ranging from “strongly disagree” to “strongly agree.” The 8-item scale contains 4 subscales with 2 items each. Subscales, including “thrill and adventure seeking,” “experience seeking,” “disinhibition,” and “boredom susceptibility,” were calculated following the criteria outlined by Hoyle et al [40]. The Cronbach α of the BSSS-8 was 0.76 in our sample.

Drinking Refusal Skills—Social Pressure Subscale

To evaluate drinking refusal skills within the context of peer pressure, the 5-item social pressure subscale of the Drinking Refusal Self-Efficacy Questionnaire (DRSEQ) by Young et al [41], with a Cronbach α of 0.87, was used. Participants responded on a 6-point Likert scale, ranging from “I am very sure I could not resist drinking” to “I am very sure I could resist drinking.” The Cronbach α of the DRSEQ social pressure subscale was 0.88 in our sample.

Knowledge and Awareness of Blood Alcohol Concentration

Knowledge and awareness of BAC was measured using 2 self-constructed items. Participants were prompted to rate the statements “It is easy for me to estimate my own alcohol tolerance” and “I know how much alcohol I can drink before I get drunk” on a 5-point Likert scale, spanning from “strongly disagree” to “strongly agree.”

Refusal Communication Skills

Refusal communication skills were assessed using 2 items drawn from the Alcohol Misuse Prevention Knowledge Questionnaire by Shope et al [19]. Only 2 items from the questionnaire by Shope et al [19] were used because the other questionnaire items do not cover relevant aspects of VR FestLab [34]. Participants were asked to evaluate the statements “If someone offers me a drink of alcohol and I say no, I can make them take no for an answer” and “If my best friends want me to drink beer with them and I don’t want to, I have ways to say no” on a 5-point Likert scale, ranging from “strongly disagree” to “strongly agree.”

Statistical Analysis

Data analysis was performed using the R Studio software package (version 2022.07.2). The 2-step methodology, as outlined by Herting and Costner [42], was used to calculate model fit as the first step and formulate the structural equation model as the second step. Initially, confirmatory factor analysis (CFA) using the lavaan package [43] was carried out to determine the adequacy of the measurement models of the questionnaires. For this purpose, different single-factor models were created and calculated using a diagonally weighted least squares estimator that is suitable for categorical items. Model fit was checked using a chi-square test in combination with other fit indices such as the comparative fit index ($CFI \geq 0.95$), root mean square error of approximation ($RMSEA \leq 0.06$), Tucker-Lewis index (≥ 0.95), and standardized root mean square residual ($SRMR \leq 0.08$) [44].

Subsequently, a structural model with latent variables was calculated to investigate the influence of the constructs (alcohol consumption, other drug consumption, sensation seeking, drinking refusal skills, knowledge and awareness of BAC, and refusal communication skills) on the main outcome (virtual risk decisions) and the correlation of the constructs with age and gender as covariates. In addition, a moderation analysis for gender and age was run. Estimated scores for each latent variable were calculated and subsequently incorporated into a logistic regression model to predict virtual risk decisions.

Results

Participants

A total of 268 students from 7 schools were assigned to the intervention group. Of these, 183 students participated in the baseline survey (T0). The main reasons for dropout between allocation and baseline survey were that 1 complete school (n=36) dropped out, 1 complete school class (n=15) dropped out, and 34 students were not willing to participate or did not

provide consent. After the intervention, 2 additional participants dropped out, resulting in 181 individuals completing the first follow-up questionnaire (T1). The subsequent analysis was based on a complete data set from 161 participants. Additional information on allocation and dropouts can be found elsewhere [34]. To test whether there were differences between respondents at T1 and those who provided complete information at T1 and were included in the analysis, independent *t* tests were conducted for metric variables, and chi-square tests were conducted for nominal and ordinal scaled sociodemographic variables. The analyses showed no differences between the 2 groups in terms of age ($t_{179}=0.61, P=.54$), gender ($\chi^2_1=0.31, P=.58$), and Family Affluence Scale (FAS; $\chi^2_1=0.25, P=.42$). For the chi-square analysis of the FAS between completers and noncompleters,

the prerequisite of cell frequencies above 5 was violated, which is why a Fisher exact test was used.

Sample Characteristics

Table 1 provides an overview of the demographic attributes. Gender distribution was equal, with 78 of the 161 (48.4%) participants being female. The mean age of the sample was 15.6 (SD 0.72) years. Most respondents (143/161, 88.8%) reported low to moderate perceived family affluence, and 62.1% (100/161) rated their perceived school performance as good to very good. Additionally, 79.5% (128/161) reported good to very good health. The majority of respondents (119/161, 73.9%) reported having engaged in binge drinking at some point in their lives.

Table 1. Characteristics of the study population (n=161).

Characteristics	Value
Age (years), mean (SD)	15.6 (0.72)
Gender (female), n (%)	78 (48.4)
Perceived family affluence, n (%)	
Low to medium	143 (88.8)
High to very high	18 (11.2)
Perceived school performance, n (%)	
Good to very good	100 (62.1)
Below average to average	61 (37.9)
Perceived health and well-being, n (%)	
Good to excellent	128 (79.5)
Poor to fair	33 (20.5)
Lifetime binge drinking, n (%)	
Yes	119 (73.9)
No	42 (26.1)

Calculations of Model Fit

The single-factor models generally showed a good fit in the CFA and could therefore be transferred to the structural equation model without adjustments. Sensation seeking provided a mediocre fit, with CFI and RMSEA beyond their cut-offs, while the 90% CI of the RMSEA included the cut-off (see Table 2). The factors “knowledge and awareness of BAC” and “refusal

communication skills” were combined for the CFA for statistical reasons; otherwise, it would not have been possible to determine the fit, as they only contained 2 items each. Finally, the combination of the 2 factors showed high loadings on the individual and superordinate factors, which resulted in good fit values in the CFA. The results of the single-factor models are shown in Table 2 and Figure 2.

Table 2. The goodness of fit indices of the confirmatory factor analysis for single-factor models.

Model	Items	χ^2 test (df)	P value	CFI ^a	TLI ^b	SRMR ^c	RMSEA ^d (90% CI)	P value
Alcohol consumption	3	2.24 (2)	.33	1.00	1.00	0.04	0.03 (0.00-0.16)	.46
Other drug consumption	5	3.02 (5)	.70	1.00	1.00	0.02	0.00 (0.00-0.08)	.84
Sensation seeking	4	7.38 (2)	.03	0.92	0.76	0.05	0.13 (0.04-0.23)	.07
Drinking refusal skills: social pressure subscale	5	19.47 (5)	.01	0.97	0.95	0.03	0.13 (0.08-0.20)	.01
Knowledge of BAC ^e and refusal communication skills	4	1.42 (1)	.23	1.00	0.99	0.02	0.05 (0.00-0.22)	.32

^aCFI: comparative fit index.

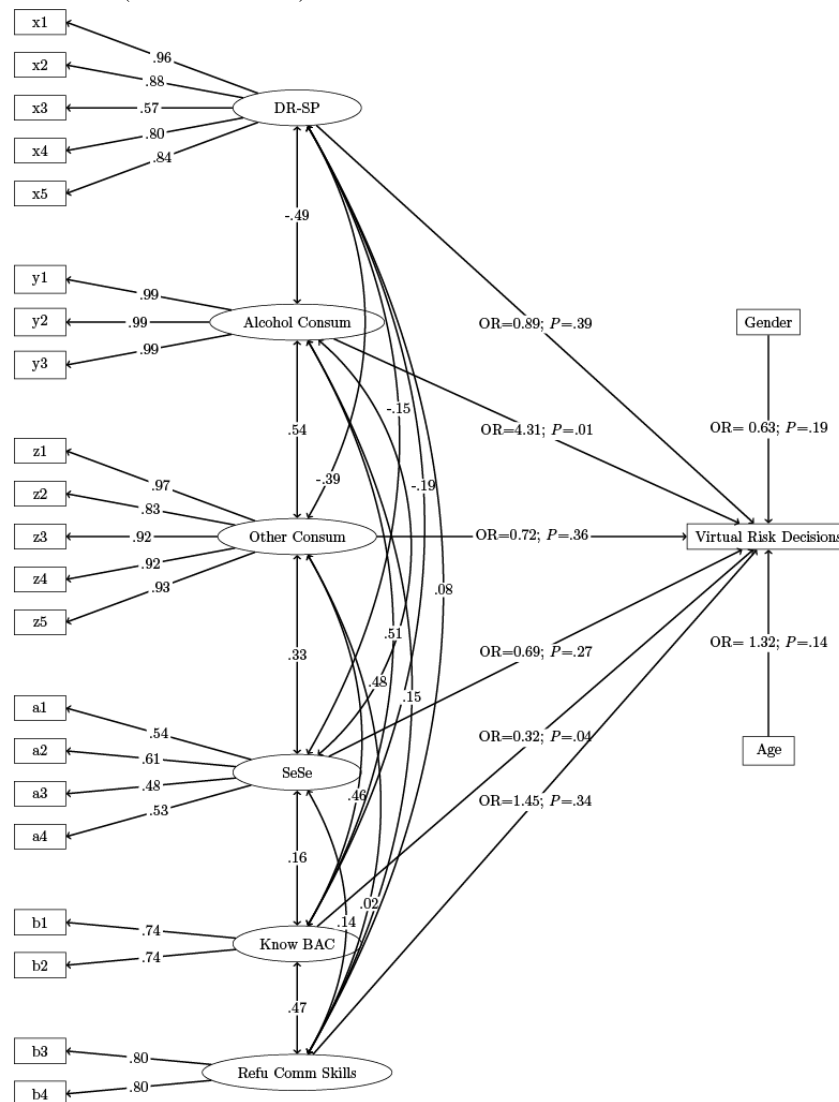
^bTLI: Tucker-Lewis index.

^cSRMR: standardized root mean square residual.

^dRMSEA: root mean square error of approximation.

^eBAC: blood alcohol concentration.

Figure 2. Path model of the relationships between virtual risk decisions and drinking-refusal skills-social pressure (DR-SP), alcohol consumption (Alcohol Consum), other drug consumption (Other Consum), sensation seeking (SeSe), knowledge and awareness of blood alcohol concentration (Know BAC), and refusal communication skills (Refu Comm Skills). OR: odds ratio.



Determinants Linked to Risky Drinking Decisions

A general overview of the bivariate correlations of all variables used in this study can be found in [Multimedia Appendix 2](#). Age and gender were included as covariates without moderation in the structural equation model, as shown in [Figure 2](#). The path model used to test the formulated hypotheses showed an unsatisfying model fit: $\chi^2_{238,161}=422.59$, $P<.001$; CFI=0.94, SRMR=0.12, RMSEA=0.07 (90% CI 0.06-0.08). Nevertheless, we decided to retain the model, because all included measurement models were a priori tested and showed good fit. Due to the explorative nature of the study, the structural model included all possible paths. Therefore, the reason for misfit can be attributed to the cross-loadings of various scales only. As the structural part of the model was the aim of the study, we decided to retain it. [Figure 2](#) shows the tested model. Prior alcohol experiences and knowledge and awareness of BAC were significantly associated with virtual risk decisions in VR FestLab. Participants who reported prior alcohol consumption had a 4.31-fold higher chance of showing virtual risk decisions in the simulation (odds ratio [OR] 4.31, 95% CI 1.70-10.84; $P=.01$). Therefore, hypothesis 3 could be accepted. Apart from that, adolescents with high knowledge and awareness of BAC at baseline were 0.32 times less likely to make virtual risk decisions in the simulation (OR 0.32, 95% CI 0.11-0.93; $P=.04$). Higher social pressure drinking refusal skills (OR 0.89, 95% CI 0.69-1.16; $P=.39$), consumption of other drugs (OR 0.72, 95% CI 0.36-1.45; $P=.36$), sensation seeking (OR 0.69, 95% CI 0.36-1.34; $P=.27$), or refusal communication skills (OR 1.45, 95% CI 0.68-3.10; $P=.34$) showed no significant relationship with virtual risk decisions in the simulation. Therefore, hypotheses 1 had to be rejected, and hypothesis 2 could only be partially confirmed.

Moderation Effects of Gender or Age Regarding Virtual Risk Decisions

Subsequently, we analyzed whether age and gender had a moderating influence on the latent variables. The results of this moderation analysis are presented in [Multimedia Appendix 3](#). All individual moderation analyses for the variables (alcohol consumption, other drug consumption, sensation seeking, drinking refusal skills, knowledge and awareness of BAC, and refusal communication skills) showed no significant moderation. Accordingly, age and gender did not significantly alter the effects of the tested constructs on virtual risk decisions in the simulation. Age and gender also did not significantly influence the dependent variable of virtual risk decisions ([Multimedia Appendix 3](#)).

Discussion

Principal Findings

In summary, the structural equation model exhibited a significant association between prior alcohol experiences and knowledge and awareness of BAC with virtual risk decisions, supporting hypothesis 3. The other initially hypothesized factors (hypotheses 1 and 2), including drinking refusal skills, sensation seeking, refusal communication skills, and consumption of other drugs, did not have significant associations with virtual risk

decisions. Upon exploring moderating factors such as age and gender, no moderation on virtual risk decisions was identified. This study has underscored that prior alcohol experiences are notably linked to virtual risk decisions. Participants who have encountered alcohol and engaged in binge drinking appear to perceive the VR FestLab game as realistically simulating their personal behaviors, leading them to enact these behaviors within the game. Apart from that, it appears that higher knowledge and awareness of BAC is a protective factor and leads to fewer virtual risk decisions in the simulation.

Comparison With Prior Work

These findings align with qualitative insights collected from focus group investigations involving adolescents discussing the simulation [45,46]. Adolescents reported finding the VR simulation remarkably realistic, evoking sensations akin to being present at an actual party [45,46]. The initial participation in VR FestLab possibly aimed to ascertain whether the simulated party aligned with their expectations and whether outcomes matched real-world drinking behaviors. The study's data set does not offer insights into potential variations in behavior between several attempts with VR FestLab. However, it seems plausible that distinct behaviors and strategies would be attempted in subsequent trials, as highlighted by focus group participants in qualitative interviews. The participants expressed the view that VR serves as a medium for experimenting with various behaviors and that repeated engagements with the VR simulation allow for exploring different strategies, such as drinking versus abstaining, while observing the reactions of simulation characters [46]. This points to VR's potential benefit in alcohol prevention, allowing participants to experiment with diverse approaches and behaviors in risky scenarios. This study found a relatively high lifetime prevalence of binge drinking in the group of adolescents aged 14 years to 18 years, at about 73.9% (119/161). In this context, it would be interesting for future studies to investigate the association between previous alcohol consumption and the likelihood of risk decisions in different social environments. These results may also provide hints for further virtual scenarios that can be integrated into the VR FestLab. Hadley et al [47], who combined VR environments with emotion regulation and a risk reduction intervention, also arrived at similar conclusions, indicating that VR, through better simulated contextual cues of risky situations, facilitates the application of different emotion regulation strategies among adolescents. In the real world, such experimentation of behavioral strategies is constrained by the necessity of personally experiencing risky behavior and its consequences, often without the possibility of multiple trials (eg, in the case of blackout).

The hypothesis that individuals with high sensation-seeking tendencies would exhibit elevated virtual risk decisions within the game could not be substantiated by the study's findings. The lack of a significant association between sensation seeking and virtual risk decisions could potentially be attributed to the design of VR FestLab. The game's preventive nature might not have resonated sufficiently with individuals displaying high sensation-seeking behavior. Given that sensation seeking characterizes those seeking diverse, potentially risky experiences [48], the simulated risk behavior in VR FestLab might not have

provided compelling cues for such participants. Participants were aware of the virtual and simulated nature of the risk decisions, possibly leading to the observed absence of virtual risk decisions in the game. This absence could also stem from the absence of personal consequences, such as intoxication, emotional arousal, and sensory perceptions, conveyed through VR FestLab. This lack of stimuli might not engage adolescents with a high sensation-seeking drive. On the contrary, sensation seeking is a multifaceted construct, not exclusively tied to risky behavior. The study by Ravert and Donnellan [49] found that sensation seeking, manifested as a search for stimulation, could also be positively linked to psychological well-being. Furthermore, sensation seeking might have been manifest in nonalcohol-related scenes within VR FestLab (eg, interactions with game characters), rendering the presumed virtual risk decisions unappealing to participants with pronounced sensation-seeking tendencies.

Likewise, drinking refusal self-efficacy skills failed to display an association with reduced virtual risk decisions in this study. Those with higher baseline drinking refusal self-efficacy skills might have opted for less risky drinking decisions within VR FestLab, possibly bypassing activities like beer pong. These observations align with those of the study by Guldager et al [34] that assessed the efficacy of VR FestLab. Although effects were insignificant, a more pronounced increase in drinking refusal skills was noted among participants whose baseline skills lay below the median compared with those above the median. Despite the documented real-world associations between risky behavior and higher drinking refusal skills, drug consumption, and refusal communication skills [50,51], these correlations did not manifest in the virtual world.

Although it was originally hypothesized that higher refusal communication skills would be associated with a reduction in virtual risk decisions, this hypothesis was not supported by this study. It is possible that participants were more exploratory when playing VR FestLab to “just see what happens next” and did not use their refusal communication skills in the simulation to say no to drinking offers. Qualitative interviews with adolescents who played VR FestLab revealed that they felt the peer pressure in the simulation was weaker than in real life [45], which could be a reason why refusal communication skills were not associated with reduced virtual risk decisions in this study.

Apart from that, this study has shown that individuals with higher knowledge and awareness of BAC are less likely to make risky decisions in virtual environments. It is reasonable to assume that those who understand how different drinks affect BAC are less likely to engage in risky decisions in VR FestLab compared with those who cannot accurately assess the effects of BAC. These assumptions are supported by the literature, which indicates that individuals with greater knowledge of low-risk alcohol consumption are more likely to reduce their alcohol intake and make fewer risky decisions [52]. Increased awareness of BAC could enhance risk perception and enable better anticipation and assessment of the consequences of risk decisions. It is possible that individuals without knowledge and awareness of BAC were more willing to experiment in the simulation, leading to an increase in virtual risk-taking decisions. VR FestLab is a prevention program that uses an in-game BAC

bar to illustrate the effects of alcohol-related decisions on BAC. The in-game presentation may help adolescents avoid risky decisions by increasing their knowledge of BAC. Other research [53] using VR in e-cigarette prevention has also shown that virtual prevention simulations can increase substance-related knowledge and harmful perceptions about e-cigarettes.

To our knowledge, this study is the first attempt to examine the relationship between real-life behavior and attitudes and virtual risk decisions in the context of alcohol prevention, making it difficult to contextualize the findings with those of other virtual alcohol prevention studies. The findings illuminate VR's capacity to replicate real-life behavior within simulated environments. Other studies [54-56] using VR in other thematic areas have also concluded that there are links between simulated behavior and real behavior. The combination of prevention and VR within research is relatively novel, necessitating further exploration into leveraging simulated settings for risk behavior prevention and health promotion. Existing studies underscore increasing adoption of VR for prevention and health promotion [57]. Building behavior change interventions and predicting behavioral transformations are challenging in real-world scenarios [58]. Immersive technologies, such as VR, can harness specific attributes like training and realism to facilitate future behavioral change. Nevertheless, the translation of real-life behavior into virtual simulations, along with the potential impact of virtually acquired behavioral patterns on subsequent real-world behavior, remains uncertain. Research suggests that altering an individual's avatar representation in VR influences their behavior and psychological disposition in the real world, an occurrence termed the Proteus effect [24,59]. This phenomenon could also be probed in the context of alcohol prevention, where avatars could shape participants' self-image and preventive behaviors. Addressing these unresolved questions in future studies while delving into the mechanisms at play in virtual simulations could position VR as a valuable asset in prevention and health promotion.

Limitations

In this study, certain limitations must be acknowledged when interpreting the results. First, the applicability of the findings warrants consideration. Participants were drawn from diverse Danish schools, making the results pertinent exclusively to Danish students. Additionally, the recruitment was limited to a specific region within Denmark, implying that adolescents from other regions within Denmark or other countries might exhibit disparate outcomes.

Second, the results should be cautiously approached due to the reliance on self-reported data, which are susceptible to common biases such as respondent bias, extreme responding, and social desirability bias [60]. These potential biases could have influenced and skewed the reported results. The timing of the follow-up data collection (T1), conducted immediately after the intervention, may have influenced the results. Furthermore, this study did not survey risk behaviors that may occur prior to a blackout, such as engaging in sexual activity or driving under the influence of alcohol. Future studies should consider measuring these risk behaviors before a blackout occurs in order to establish a relationship. Specifically, the question about

certain risk decisions may have been biased (eg, experiencing a blackout). The potential for a Hawthorne effect should be considered when interpreting the results, because the students in the intervention group were not blinded and tested the new VR FestLab application. Their knowledge of participation in the study and the aim of VR FestLab can influence their self-assessment of whether they experienced a blackout in the application, which could potentially distort the results. Since there was no content tracking during participants' engagement with the simulation, the navigation patterns within the simulation remain uncharted. Integrating a content log in future analyses could offer deeper insights into participants' usage behavior.

Third, organizational limitations limited the playing time to 15 minutes for each participant. This restriction could have led to variations in the number of rounds played within the simulation, potentially affecting the reported outcomes. Additionally, the controlled setting of the VR FestLab intervention study might have curtailed the expression of extreme behaviors that could

naturally occur among adolescents. This controlled environment may have influenced the observed results.

Conclusions

Despite these limitations, this study illuminates the link between real-life behavior and virtual simulations in alcohol prevention. The significance of prior alcohol experiences in shaping virtual risk decisions underscores the potential of VR to mimic real behaviors. The study highlights VR's potential as a valuable tool for behavior change interventions and health promotion. To harness this potential, future research should delve into mechanisms underpinning behavioral expression in virtual environments. As VR evolves, it presents a promising avenue for health promotion strategies, offering a unique medium to experiment with behaviors in risk-prone scenarios. This research signifies the importance of advancing our understanding of the intersection between human behavior, virtual simulations, and their real-world implications.

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Data Availability

The analyzed data can be accessed from the Zenodo database [61].

Authors' Contributions

CS acquired the funding, provided project administration, and supervised the study. RH, CS, and JDG conceptualized the study, curated the data, and performed the formal analysis. RH, DS, and CS created the visualizations and designed the methodology. JDG, PBL, GM, and CS performed the investigation, and CS, PBL, and GM secured the resources. PBL and GM provided the software. RH, JDG, DS, and CS performed the validation and wrote the original draft of the manuscript. All authors reviewed and edited the manuscript draft.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Investigator-developed questionnaire.

[PDF File (Adobe PDF File), 290 KB - [xr_v1i1e56188_app1.pdf](#)]

Multimedia Appendix 2

Bivariate correlations of all variables.

[PDF File (Adobe PDF File), 212 KB - [xr_v1i1e56188_app2.pdf](#)]

Multimedia Appendix 3

Results of the moderation analyses.

[PDF File (Adobe PDF File), 135 KB - [xr_v1i1e56188_app3.pdf](#)]

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Abbreviations

- BAC:** blood alcohol concentration
- BSSS:** Brief Sensation Seeking Scale
- CFA:** confirmatory factor analysis
- CFI:** comparative fit index
- DRSEQ:** Drinking Refusal Self-Efficacy Questionnaire
- FAS:** Family Affluence Scale
- OR:** odds ratio
- RMSEA:** root mean square error of approximation
- SRMR:** standardized root mean square residual
- TLI:** Tucker-Lewis index
- VR:** virtual reality

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Original Paper

Exploring How Virtual Reality Could Be Used to Treat Eating Disorders: Qualitative Study of People With Eating Disorders and Clinicians Who Treat Them

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Abstract

Background: Immersive virtual reality (VR) interventions are being developed and trialed for use in the treatment of eating disorders. However, little work has explored the opinions of people with eating disorders, or the clinicians who treat them, on the possible use of VR in this context.

Objective: This study aims to use qualitative methodology to explore the views of people with eating disorders, and clinicians who treat them, on the possible use of VR in the treatment of eating disorders.

Methods: We conducted a series of focus groups and interviews with people with lived experience of eating disorders and clinicians on their views about VR and how it could potentially be used in the treatment of eating disorders. People with lived experience of eating disorders were recruited between October and December 2020, with focus groups held online between November 2020 and February 2021; clinicians were recruited in September 2021 and interviewed between September and October 2021. We took a thematic approach to analyzing the resulting qualitative data.

Results: We conducted 3 focus groups with 10 individuals with a current or previous eating disorder, 2 focus groups with 4 participants, and 1 with 2 participants. We held individual interviews with 4 clinicians experienced in treating people with eating disorders. Clinicians were all interviewed one-to-one because of difficulties in scheduling mutually convenient groups. We describe themes around representing the body in VR, potential therapeutic uses for VR, the strengths and limitations of VR in this context, and the practicalities of delivering VR therapy. Suggested therapeutic uses were to practice challenging situations around food-related and weight/appearance-related scenarios and interactions, to retrain attention, the representation of the body, to represent the eating disorder, for psychoeducation, and to enable therapeutic conversations with oneself. There was a substantial agreement between the groups on these themes.

Conclusions: People with lived experience of eating disorders and clinicians with experience in treating eating disorders generated many ideas as to how VR could be used as a part of eating disorders treatment. They were also aware of potential limitations and expressed the need for caution around how bodies are represented in a VR setting.

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KEYWORDS

eating disorders; virtual reality; anorexia nervosa; bulimia nervosa; EDNOS; treatment; immersive; clinicians; qualitative data; psychoeducation; therapeutic; limitations

Introduction

Eating disorders are serious mental illnesses, affecting around 8% of women and 2% of men at some point in their lives [1]. They have substantial physical [2,3] and psychiatric [4] comorbidities, with anorexia nervosa having the highest mortality of any psychiatric illness [5]. Nationally representative population data from England show that rates of possible eating disorders in adolescents almost doubled from 6.7% in 2017 to 13.0% in 2021 [6]. Meanwhile, at 10-year follow-ups, only one-third of those with anorexia nervosa and two-thirds of those with bulimia nervosa have fully recovered [7], and rates of relapse are up to 50% in those with anorexia nervosa [8]. New treatments are thus urgently needed.

Virtual reality (VR), a technology which “immerses users in a fully digital environment through a headset or surrounding display” (p. 3) [9] is a candidate modality for such novel treatments. VR shows promise in treating mental illnesses, with studies demonstrating efficacy in treating phobias, including fear of heights [10] and spiders [11]; anxiety disorders [12]; and avoidance and distress in people with psychosis [13]. Emerging evidence suggests that VR can be useful in the treatment of eating disorders, with a meta-analysis showing reductions in binge frequency and body dissatisfaction in binge-purge and binge-eating disorders [14]. Some evidence also suggests that exposure to a larger version of one’s own body in VR may be a useful addition to the treatment of anorexia nervosa [15,16].

One problem with the currently established treatments for eating disorders is the high rate of dropouts. Even in randomized controlled trials, as many as 40% of participants do not complete treatment for anorexia nervosa [17]. For new treatments to have the best chance of being acceptable to patients, a prerequisite for efficacy, they should be designed in collaboration with the patient group for whom they are intended. To our knowledge, no previous work has explored the perspectives of people with lived experience of eating disorders on the potential use of VR in their treatment.

There is also a longstanding acknowledgment of the difficulty in ensuring that patients receive evidence-based treatments, variously termed an “evidence to practice gap” [18], “implementation problem” [19], or “second translational gap” [20]. This is a particular challenge for complex interventions. To avoid or shorten this gap, it is argued that new interventions should be designed with implementation in mind and that frontline clinicians should also be involved in novel intervention design from the outset. In relation to the growing field of

developing clinical interventions using VR, an international working group of Virtual Reality Clinical Outcomes Research Experts also state that “it is vital to include the patients’ voice early and often in the development of VR treatments” (p. 2), as well as seeking input from health care providers, to design acceptable, feasible, and effective VR treatments [21].

We therefore set out to conduct a series of focus groups and one-to-one interviews with both people with lived experience of eating disorders and, separately, the clinicians who treat them. We explored their thoughts about using a VR environment, including their ideas about the potential therapeutic uses of VR, and any concerns or worries about risks.

Methods

Participants

We recruited participants with lived experience of eating disorders via social media, through the UK eating disorders charity the Somerset and Wessex Eating Disorder Association, and by contacting those on a list of research-interested individuals with eating disorders held by HB. We recruited clinicians with experience in treating people with eating disorders via social media and by snowballing via professional contacts. Potentially interested participants completed a brief online screening questionnaire via SurveyMonkey (SurveyMonkey Inc.; [Multimedia Appendices 1 and 2](#)) to check they met inclusion criteria.

Inclusion criteria for people with lived experience of an eating disorder required that they be aged 16 or over, and have any current or previous eating disorder (eg, anorexia nervosa, bulimia nervosa, binge eating disorder, or other specified feeding or eating disorder). We did not specify that participants must be based in the United Kingdom. We excluded people currently being treated as an inpatient in a hospital. Inclusion criteria for clinicians required that they be a health professional with at least six months’ experience in treating people with eating disorders. Inclusion criteria for both groups required fluency in English (due to a lack of funding for translators) and the ability to access a private space with an internet-enabled device via which they could join an online focus group or interview. We did not require participants to have any previous experience of using VR. We conducted interviews and focus groups online as a result of constraints around in-person research during the COVID-19 pandemic. All participants provided written consent and were offered a £10 (US \$12.5) shopping voucher to thank them for their time.

After recruiting the first 8 eligible participants who were women and who responded to follow-up emails, we excluded subsequent

responders who were women to include men. All eligible clinicians who responded to follow-up emails were included.

People with lived experience of eating disorders were recruited between October and December 2020, and focus groups were held online between November 2020 and February 2021; clinicians were recruited in September 2021 and interviewed between September and October 2021.

Ethics Approval

The study was approved by the Faculty of Health Science Research Ethics Committee, University of Bristol (reference number 7545).

Procedure

We collected brief demographic data, including age, gender (participants were asked “How would you describe your gender?”) and ethnicity, duration of current or previous eating disorder (for people with lived experience of eating disorders), professional background (for clinicians), and duration of experience in treating people with eating disorders (clinicians).

Interview and focus group discussion topics were informed by a topic guide (available in [Multimedia Appendices 3 and 4](#)). We also shared some slides with images of VR headsets and from some VR games and current VR interventions for those with fear of heights and psychosis (see [Multimedia Appendix 5](#)). We used open-ended questioning and follow-up probes to explore participants’ ideas in detail and also allowed them to suggest and discuss issues of importance that were not included in the topic guide. All interviews and focus groups were then conducted via videoconferencing software (Microsoft Teams; Microsoft Corporation), audio-recorded on an encrypted recording device, and transcribed verbatim. Authors HB and LB ran the focus groups together, enabling one of them to monitor the written “chat” function and provide support to any distressed participant if necessary. HB conducted the one-to-one interviews alone.

Analysis

We used a thematic approach, with MRK, HB, and LB all taking part in coding. These coauthors brought differing perspectives and expertise to the data: LB as an associate professor in qualitative mental health research, MRK as a more junior qualitative researcher in health and ethics, and HB as a child and adolescent psychiatrist with research and clinical expertise in eating disorders. HB’s clinical expertise likely influenced the lines of inquiry taken within the interviews and allowed greater probing of the participants, but may have introduced bias. This clinical perspective is likely to have been

counterbalanced by LB and MRK approaching the interviews and analyses from their complementary and nonclinical perspectives. MRK conducted the initial coding of 2 focus groups. Sections of the data from these 2 focus groups were then coded separately by coauthors LB and HB, with high levels of concordance in the coding. LB, HB, and MRK held a series of meetings to finalize the coding frame, and MRK then applied this frame to the final focus group. As the coding frame evolved, codes were grouped to derive themes and subthemes.

MRK then applied the same coding frame to the clinician interviews. Subsections of these interviews were coded by LB and HB, and further meetings were held between HB, MRK, and LB to finalize agreement on these codes. The coding frame evolved through the addition of new ideas from clinician participants and through discussion, we grouped the codes into themes and subthemes. MRK then wrote a descriptive account of the themes and subthemes to explore in detail their content and relationships.

Results

Participant Characteristics

A total of 14 participants contributed to these data: 10 people with lived experience of eating disorders and 4 clinicians ([Table 1](#)). People with lived experience of eating disorders included both people with a current eating disorder and people who have recovered. The length of illness varied from 3 to 20 years. Clinicians came from a range of professional backgrounds and had between 2 and 15 years’ experience of working with people with lived experience of eating disorders. We recruited men and women in both groups.

The screening survey was completed by 31 respondents with lived experience: 5 did not fully complete the survey or supply contact details, 8 did not respond to email invitations to join a focus group, and 8 were women who responded after we had held 2 focus groups with women and were purposively sampling participants who were men. These 21 respondents were therefore not included, and the remaining 10 joined a focus group. Nine clinicians completed the screening questionnaire: 3 did not complete it fully or supply contact details, and 2 did not respond to email invitations.

We held a total of 3 focus groups for people with lived experience of eating disorders: 2 with 4 participants and 1 with 2 participants. As a result of difficulties in finding mutually convenient times, we were not able to hold clinician focus groups and instead held a series of one-to-one interviews.

Table 1. Participant characteristics.

Characteristics	Values
People with lived experience of eating disorders (n=10)	
Gender	
Women, n	8
Men, n	2
Age (years), range	19-37
Ethnicity	
White/White British, n	10
Current eating disorders	
Current anorexia nervosa, n	4
Current bulimia nervosa, n	2
Duration (years), range	3-20
Previous eating disorders	
Previous anorexia nervosa, n	5
Previous eating disorder not otherwise specified, n	1
Duration (years), range	5-16
Recovered from eating disorders, n	
Duration (years), range	0.25-6
Clinicians (n=4)	
Gender	
Women, n	3
Men, n	1
Age (years)	
25-34, n	1
35-44, n	1
45-54, n	1
55-64, n	1
Ethnicity	
White/White British, n	4
Duration (years) of clinical experience with people with eating disorders, range	2-15
Professional background	
Clinical psychologist, n	1
Counselor, n	1
Family therapist, n	1
Mental health nurse, n	1

Themes

Overview

We describe the core themes: Representing the Self, Strengths and Limitations of VR, Potential VR Interventions, and Practicalities of Delivering VR Therapy. Quotes from people with lived experience of an eating disorder are followed by PWLE, and the number indicates their group (members of groups 1 and 2 were all women; and members of group 3 were

men); quotes from clinicians are indicated CL. Most participants reported having tried VR as entertainment, and those who had not reported that they were willing to try it.

Representing the Self

Everyone acknowledged that deciding how best to represent the self in a VR setting was challenging (“one of the really tough questions” [PWLE3]); “need[s] to be very carefully...done” [CL4]).

People with lived experience of eating disorders felt comfortable with a first-person perspective: “I quite like the idea of just it being from my perspective, so just seeing your feet and hands” [PWLE1]; “I was imagining that you wouldn’t see yourself...you’d see what you would normally see if you were walking around” [PWLE2]. Clinicians agreed: “if I had an eating disorder, I’d probably prefer not having my body [in the VR setting], just having my hands” [CL1], also suggesting that this would increase a sense of embodiment: “[if] I just see my hands, that feels more real because when I’m me, I can’t see my body, unless I look down my body” [CL1]. Some people with lived experience of eating disorders highlighted the importance of accuracy and realism to enable them to suspend disbelief, including representing correct skin color and gender even if only representing a hand.

Some people with lived experience of eating disorders were concerned about the possibility of their whole body being represented, for example, from a third-person perspective or in a mirror, which they felt may exacerbate self-criticism and create risk: “maybe I’ll see something on VR that I’ve never seen in real life and it makes me worse...you might go, wow, I really do look shit in that outfit or you know nude or whatever” [PWLE2]; “with eating disorders being the beast they are, anything that would maybe feed into that kind of inner critic, or that sort of obsession with our sort of external appearance, it would have to be handled very sensitively...for it not to risk causing more harm than good” [PWLE1]. They were also concerned about how accurate images might be created: “wouldn’t you have to take full body photos of people...which in itself I think could be quite difficult” [PWLE1].

There was some concern that an accurately represented body might be distracting: “you would then become too focussed on what it looked like, and then ignore the job in hand” [PWLE2], but participants in both groups also discussed that this itself could form part of treatment (see the “Potential VR Interventions” section).

People with lived experience of eating disorders discussed alternative suggestions as to how their bodies may be represented, such as a “cartoon”-type avatar [PWLE2] or animal [PWLE1]. While such alternatives might be useful to avoid “getting hung up” [PWLE1] on one’s image, they were largely dismissed as unrealistic or silly, and possibly preventing engagement: “I think seeing me like a kind of panda pinballing around...I just wouldn’t...feel like I could get on board with it” [PWLE1].

Representing the self in an abstract form was also suggested and again felt to have therapeutic potential (see the “Potential VR Interventions” section): “maybe they could be shapes, maybe they could be manifested in different things, like personifications, emotions...I actually think that could be part of the process” [PWLE3].

Despite prompting, clinicians expressed few views on how representation should be achieved, tending to share the belief that “it’s best to go with their [PWLE] visualisation, because then it has more meaning” [CL1]. However, participants in both groups agreed the actual process of creating a representation of self could be challenging if this presented patients with excessive

choice: “I would be distracted by worrying what my virtual [cartoon avatar] self looked like if it was down to me [to make it] or whether it was down to someone else to generate me then I might get offended” [PWLE1]. One clinician suggested this process could be simplified: “so that we didn’t have endless conversations about choice...there’s a bit of me that would go for a menu of what somebody looks like so they could choose a torso or...a torso or legs or a face...or the menu would just be certain kinds of figures” [CL3]. One clinician also raised the point that it may be important to discuss the process of leaving VR to return to one’s own real body: “we’re not going to be that avatar so, how do we then come back out into the real world and reconnect with who we really are, even the bits we don’t like” [CL1].

Strengths of VR

People with lived experience of eating disorders and clinicians were excited about the potential of using VR in treating eating disorders and felt it may be more engaging than other treatments: “I would be more motivated to do that as my homework than my mood diaries or my thought diaries” [PWLE3]; “I’d be really interested in it, definitely like give it a go, I imagine young people would just engage very well in it” [CL4].

Participants described the strength of creating realistic situations, which nevertheless were not actually real and so could provide a safe space to practice: “knowing it’s not real, but also it’s simulating something that is real so it would be a very good first approach to...expose somebody to something scary” [PWLE1]; “a gentle form of exposure work” [CL3]. One clinician [CL1] wondered if this might be particularly valuable for some groups of patients, suggesting that those who are autistic or anxious may find it easier to engage in a “real” activity than a face-to-face conversation.

Participants noted that in some ways VR was “better” than real life because it is a “controlled environment” [PWLE2 and CL3] and having control—specifically the ability to stop—allows users to explore or confront activities they would not feel able to try in the real world: “you can always turn it off...you’re not going to be halfway round a roller coaster having a panic attack” [PWLE2]; “you can take it off any time” [PWLE3].

People with lived experience of eating disorders suggested VR could also help make therapy more closely related to real life, by making it more engaging and action-based “I find sitting on the couch in the room [in therapy] really tough, I think it’s [VR] something physical to do, a practical thing to do” [PWLE3]. They also suggested that VR might enable therapeutic work to feel more directly connected to real life because it could enable “the therapist [to be] there with you as you’re experiencing those things...rather than...have to remember these situations and then feed them back...that’s a challenge to remember what you’ve actually thought and felt at that moment in time and then be able to share it with a therapist when you’ve got that meeting...three days later” [PWLE2]. Another person with lived experience of eating disorders explained “I’m going to benefit from maybe being in a room with my therapist and having a sort of virtual reality...challenge and her sort of...being able to be there, in the moment...I think it would help me feel like we’ve

had a better understanding of what it actually feels like in that moment” [PWLE1].

Clinicians discussed the possibility of using VR alongside existing treatments “whatever that end goal is I think that it requires picking up on tools that you think are going to work for that particular individual and I just see VR as being a tool”, adding “if it was available you might be kind of picking it off the shelf” [CL3]. Relatedly, they mentioned its potential as a scalable resource, enabling more support than might otherwise be possible in overstretched services: “potentially then, we know that people are getting something additional to what they are currently able to access often in services” [CL2].

Limitations of VR

Some people thought VR headsets might be heavy, uncomfortable, or hard to take off quickly. Some without personal experience of VR were worried about feeling claustrophobic or “panicky” [PWLE2], though this was countered by the experience of others.

Practical concerns about being unable to see one’s surroundings and feeling off-balance were also raised, contributing to fears about feeling unsafe and “vulnerable” [PWLE1 and PWLE2] while using VR; it was felt that individuals’ experiences may increase such feelings. Participants also described potentially feeling self-conscious, a common experience when trying VR in other contexts: “I think you feel like a bit of a dick when you try it on” [PWLE3].

Both people with lived experience of eating disorders and clinicians were concerned that clinicians might not feel confident about using VR technology, and one person with lived experience of eating disorders also suggested VR was “not for everyone”: “I wouldn’t naturally be very interested in VR to be honest and I think it’s maybe for people who are younger than me” [PWLE3].

Participants also talked about technical limitations relating to the suitability of VR in treating eating disorders. Concerns included the quality of graphics, and that VR may be limited to visual and sound worlds, which would not be able to capture the physical sensations involved in experiencing and recovering from an eating disorder: “when I went through recovery...it was physically existing in a bigger body...like the physical sensation of inhabiting a bigger body...I’m not sure that VR could address” [PWLE1]; “it’s kind of bingeing and then not eating anything, it’s that sense of hunger, like you can’t replicate that with VR” [PWLE1]; “for me there’s an additionality of thinking about smells or sounds” [CL3].

Some clinicians discussed the idea that VR not being real might be unhelpful because it could facilitate avoidance of real life: “fuelling more the idea that we can be this virtual reality person that’s not ourself, because we don’t like ourself” [CL1], or avoidance of treatment: “I think with an eating disorder there’s always this kind of temptation to step away, isn’t there? And actually there is a real need to just get on in there and do it [the

treatment] right away” [CL2]. However, clinicians also described this viewpoint as in “tension” with a recognition of the idea that VR could be used as an intermediate step or “tool” for people who are not yet ready to try things out in real life: “[VR] feels more accessible and then, they feel more kind of empowered and strengthened taking it forwards in the real situations” [CL2].

People with lived experience of eating disorders raised the concern that the fact that it is not real might make VR easier to dismiss: “I might be inclined to think, well that was just in VR, in real life it would be totally different” [PWLE1]; “I think it must be really difficult to...apply it because you think well that wasn’t real” [PWLE2].

One person with lived experience of eating disorders also raised the idea of VR being a fad and the possibility that it could be an expensive distraction from the need to train more therapists

Potential VR Interventions

Participants made a wide range of suggestions for potential VR interventions to help and treat people with eating disorders. They agreed treatments would need to vary for each individual: “ultimately it has to have meaning to the person you’re working with” [CL1]; “no pun intended, one size definitely won’t fit all” [PWLE1]. However, suggestions could be grouped according to the type of intervention.

Practicing Everyday Challenges

One common type of intervention discussed by participants was the idea of using VR to “sort of put yourself in that [challenging] situation as an in-between step before you end up doing it” [PWLE2]; or “practicing helpful behaviours or responses to situations...having an opportunity to try out responding in a different way...so...it could feel much easier to access that in the real world” [CL2]. Challenges fell into 3 main groups: food-related scenarios, weight/appearance-related scenarios, and challenging interactions. Examples are presented in [Table 2](#).

Both groups discussed how VR could allow people with eating disorders to practice such challenges in a protected way, to decrease anxiety or “desensitise” [PWLE2] oneself, thus providing an in-between step before going into a real situation “there’s a whole lot of...step-based approaches to end up with sitting in a café having a piece of cake...[in VR] you’re taking away a whole layer of somebody being concerned about the public’s reaction to them” [CL3]. VR might fill an important gap between talking about doing something and actually doing it: “it’s kind of that buffer, that bridge to being exposed to those things in a real world” [PWLE1]; “it could probably lend itself quite well to practising going up to someone and saying, you know, can I have this drink or whatever, like it would be a good sort of in between step, because otherwise...there’s lots of talking and planning around it but there’s nothing in between that can, you know, reduce their anxiety” [CL4].

Table 2. Quotes about challenges and potential VR interventions.

Challenges and specific scenarios	Quotes describing challenges	Quotes relating to the proposed VR intervention
Food-related scenarios		
Cafés	<ul style="list-style-type: none"> going into Costa or whatever and ordering that hot chocolate...those other challenges that are almost kind of like steps before the eating [PWLE2] having to talk to a waiter or...interact in a normal way whilst your brain is feeling anything but normal [PWLE1] 	<ul style="list-style-type: none"> getting used to...where all the cakes are on the counter and not feeling too overwhelmed by that [PWLE2] I will never meet the person who's in this situation as a waiter, therefore I can try saying different stuff and then you can kind of repeat the same situation [PWLE1]
Supermarkets	<ul style="list-style-type: none"> I really struggled with going into a supermarket to pick a sandwich off the shelf...I get paralysed with the indecision and the kind of temptation to look at calorie labels and the knowledge I shouldn't be [PWLE1] I would struggle with not impulsively buying loads of food for binge eating [PWLE3] 	<ul style="list-style-type: none"> making sure like you go down each aisle...when there's like the chocolate aisle or whatever and physically taking one off the shelf, putting it in your basket...trying not to check the calories or seeing other people's responses, actually no one is shouting at you, oh look at the girl, she's got chocolate in her basket...just to get exposure to those sorts of things [PWLE2]
Eating in public	<ul style="list-style-type: none"> eating in front of others...if I'm in work I find that almost impossible because you think everybody's watching you [PWLE2] 	<ul style="list-style-type: none"> the idea of eating a real meal but in an environment created by the VR. With other people around and again that idea of are people going to be watching me...experiencing that a few times will desensitise me to go out and do it [PWLE2]
Portion sizing	<ul style="list-style-type: none"> I don't have a good sense of how much I should be eating or shouldn't be eating [PWLE1] 	<ul style="list-style-type: none"> serve yourself a meal from this thing and then you could then say, okay, the nutrients you're getting from that [PWLE1] you could have a go at dishing yourself up a plate of food...and all of a sudden pull out of the cupboard what somebody might consider to be a normal plate of food and have a conversation [CL3]
Weight/appearance-related scenarios		
Being weighed	<ul style="list-style-type: none"> I'm happy to get on my own scales now...whereas when I was anorexic it was terrible [PWLE3] 	<ul style="list-style-type: none"> having a conversation about how do you feel...looking at those scales being now in your virtual room [PWLE3] perhaps you have an expectation or desire of what you want the number [on the scales] to be and it's not that, or in one scenario it's more than what you expect it to be and how would you feel about that? [PWLE3]
Changing rooms/gyms	<ul style="list-style-type: none"> The environment that I felt was really difficult would be changing rooms...I just feel very self-conscious [PWLE3] 	<ul style="list-style-type: none"> what is it like to go into a gym where everybody is extremely muscular and like how do I feel about that? [PWLE3]
Public places	<ul style="list-style-type: none"> I couldn't walk on the main roads because I thought I was too ugly...I thought...cars...would crash because I was so like shockingly hideous [PWLE3] 	<ul style="list-style-type: none"> you could use VR to kind of emulate that feeling of being in a body and being looked at...the feeling of being observed and how to get through that [PWLE1]
Clothes shopping	<ul style="list-style-type: none"> one of the biggest limitations if you go clothes shopping and obviously there's great big mirrors everywhere... [PWLE2] 	<ul style="list-style-type: none"> with the eating disorder maybe people can wear certain types of clothes or like baggier clothes and actually even trying on like different styles and realising what you might like or what you might like to experiment...kind of finding your own identity slightly more [PWLE2]

Challenges and specific scenarios	Quotes describing challenges	Quotes relating to the proposed VR intervention
Interactions		
Unhelpful comments	<ul style="list-style-type: none"> I find it really hard to know how to respond...where people are talking about say their own weight or their own eating...or...commenting on my weight or my eating [PWLE1] when they go back to school...what they're going to say [about why they've been away]...we tend not to discharge anyone until they've got a plan around that because that feels so difficult for them [CL4] 	<ul style="list-style-type: none"> having your therapist there with you going look, okay, so they've said that that's made me think that what, yeah, how do I work this through [PWLE1]
Asking for help	<ul style="list-style-type: none"> for me, asking for help was really, really, hard [PWLE3] 	<ul style="list-style-type: none"> if we had a virtual reality scenario where I go and they don't give a great response...I can practise how I'm going to respond to that...it could be about easy steps, like level one, you ask for help and somebody does like whatever...and then other situations where it's more difficult...or more confrontational [PWLE3]
Practice skills	— ^a	<ul style="list-style-type: none"> a virtual environment to practise...skills that they have in DBT [dialectical behaviour therapy] would have been great [PWLE3] practice anything in terms of like life skills...I think mostly like communicating within a family...practising for what you want [CL4]

^aNot available.

Both groups also suggested that VR could be used to try out these situations at different levels of difficulty. For example, other avatars in a VR setting could be used to make challenges easier: “maybe you can have someone in the queue before you ordering that and kind of normalising that” [PWLE2], and situations could also be made increasingly challenging: “graded exposure of challenge...depending on what the fear is, is it talking to other people, is it asking for food, is it having the food in front of you. Like any of those number of things you could recreate in virtual reality” [CL4].

VR could also enable discussion about in-the-moment thoughts and feelings about being in a feared situation, in a way that would be more immediate than talking retrospectively in a therapy session: “going as a VR to a restaurant and then you're talking about, how is it making you feel, the fact the person is eating...might be a useful tool” [CL1]; “you could look at a menu and in the session you can kind of go, okay, what's going through your head and you do it as a CBT [cognitive behavioural therapy] thing” [PWLE1]; “being able to expose yourself to kind of challenging situations like that and being able to talk through what your instant thoughts are and then I guess rationalise them a bit more could be helpful” [PWLE2].

Most people with lived experience of eating disorders and clinicians agreed that this could be useful, though a clinician raised a concern: “is it something that would mean they [patients] could practice it and then [be able to do it] or would [it contribute to feeling that] everything has to be done perfect?” [CL4].

Attention

Several people with lived experience of eating disorders described how their attention was affected by their eating disorder, causing them to fixate when in public on, for example, people with particular body types, or food outlets: “it feels very bizarre to me now but like, I remember walking down the high street and it was like I had a zoom cam in my head, like spot the skinniest person in the street, and then I would focus on them all the time and then compare myself to them” [PWLE1].

They suggested VR could be used to help individuals recognize what they were attending to: “I don't know if you can like eyetrack people over the VR” [PWLE2]; “it would be a really useful tool to kind of just confirm that bias” [PWLE2]. Building on this, they suggested VR might then be used to retrain attention: “actually if they're saying...we've just noticed you're looking at this, how about looking at those” [PWLE2]; “it could be a good way of getting rid of those biases and try to see things in a more kind of healthy and realistic way” [PWLE2].

Representing the Body

Body representation was discussed in terms of whether it could be a therapeutic intervention. The suggestions, why they were felt to be potentially helpful, and supporting quotes are presented in Table 3. The ideas comprised representing the body in an abstract way, having a third-person perspective of one's body, or a third-person perspective of one's body at different weights, and comparing self-generated versions of own body with those generated by the clinician. The area was agreed to be complex, with even the act of choosing how one's body should be

represented giving scope for therapeutic discussion around why someone wanted to be represented in a particular way: “if you allowed somebody to choose say their avatar...to get different conversations about the whys and what fors of choice...how do they think somebody would perceive the avatar and why” [CL3].

Table 3. Quotes relating to how representing the body could be therapeutic.

Representation of the body and how it might help	Illustrative data
Abstract/exploratory representation of body	
<ul style="list-style-type: none"> Reduce the importance of shape and size in self-evaluation 	<ul style="list-style-type: none"> loosen up some of the fixed ideas about your body...lessen the importance of how you view your body [PWLE3] what I looked like...was so central to maintaining anorexia that if there was something that could have helped me shake that up or reconceptualise that, that would have been great...if you could represent yourself, like maybe that’s a physical thing or maybe that’s also like I want to be courageous or I want to be strong or...I want to climb a mountain [PWLE3]
Third-person perspective of own body	
<ul style="list-style-type: none"> Understand the severity of the illness 	<ul style="list-style-type: none"> if I could have seen myself from the perspective of another in the past I would have been shocked...about how unwell I looked [PWLE3] I had moments [when unwell with anorexia nervosa] of like stepping out of myself and being, my goodness, I look really unwell, whereas most of the time I thought I was overweight [PWLE3]
<ul style="list-style-type: none"> Change attitude to own body and reduce avoidance 	<ul style="list-style-type: none"> practice the sorts of more positive self-talk...to override some of those really powerful negative comments that come up...but then...being able to step away from it quite easily when it feels too much...A lot of people go through life and just kind of avoid looking at their image...and actually, it’s more helpful to be able to look at yourself...focusing on the things that you do like about your body and challenging your ideas about the bits you don’t like [CL2]
Third-person perspective of own body at different weights	
<ul style="list-style-type: none"> Reduce anxiety about planned weight restoration 	<ul style="list-style-type: none"> seeing yourself as a bigger weight as a kind of like exposure therapy so you can kind of get your head around what that might look like. [PWLE1] ...it would be a good thing for them to see...and...explore...what they see and how they feel about that [planned weight increase] [CL4]
<ul style="list-style-type: none"> Reduce anxiety around small fluctuations in weight 	<ul style="list-style-type: none"> nowadays [in recovery]...I’d find that quite useful actually...it would be interesting to see...this is what you look like with or without like a small weight increment and you can’t tell the difference [PWLE1]
<ul style="list-style-type: none"> Seeing that other people do not react as feared 	<ul style="list-style-type: none"> you could see other people’s responses to you at that normal weight and just witness that actually people aren’t going, oh my gosh, that’s huge, or people aren’t responding at all [PWLE2]
Compare self-generated with VR-generated image	
<ul style="list-style-type: none"> Allow comparisons and discussions 	<ul style="list-style-type: none"> you could ask somebody...to come up with their own image about what they look like and then overlay the comparison, if somebody can tolerate that...I think those are...helpful possible conversations to have [CL3]

Various caveats were expressed. These included the idea that some interventions might not be useful for everyone: “other people might potentially find it triggering” [PWLE3], and that it may be unhelpful to focus too much on appearance “the way we look is just a small part of who we are, and there’s probably other things we want things to be doing alongside” [CL2].

Manipulating the weight of the body representation was particularly controversial. Some people with lived experience of eating disorders felt it would not be helpful, that they would not want to experience it, or that it may be counterproductive. There were concerns from both clinicians and people with lived experience of eating disorders that it might lead to increased rumination about body size, or lead to further disordered eating behaviors or weight loss: “it really could have

triggered...restricting behaviours if it really kind of distressed me...kind of almost like an anxiety thing like just the fear of kind of knowing what you look like” [PWLE2]; “[if] you don’t like what you see and then you go, wow, I don’t want that and then it’s going to push you down the other way so it’s a bit of a risk” [PWLE1].

Another concern was that images of self at a healthier weight might encourage a focus on specific body parts rather than on the overall appearance of looking “well”: “they might just be focussing on, ‘Oh god, there’s no thigh gap’ you know...would they be able to see the glowing skin and the healthy hair..?” [CL2]. Some clinicians also wondered if very unwell patients would be able to make use of it, highlighting that it would need to be used in an appropriate and timely fashion: “for somebody

very much in the grip of anorexia...I can imagine you'd have conversations, 'Well, the computer's wrong'" [CL3]. Another question was how it would be possible to know what one's body would look like at a different weight: "you can't really predict what that would be like just through like a computer algorithm" [PWLE1].

There was general agreement that therapeutic work around body representation would be better done with the support of a therapist: "I would only want to do it with a therapist that I trusted rather than having the option to look at it at home" [PWLE2]. This was partly because people wanted to be supported through the process, and partly because they felt it would be useful for someone else to be in control as repeatedly checking might be unhelpful "like controlling the scales and not going on the scales as often as you might otherwise." [PWLE2].

Clinicians also felt that such an intervention would need to be used at the right time in relation to motivation and recovery: "someone that was coming in in a different mindset and...they really did want to change...then yes, maybe it would work" [CL1], and that if used it should not be a drawn out intervention but "quite time-limited or focused bit of work" [CL2].

Representing the Eating Disorder

One person with lived experience of eating disorders had a previous experience of using an art program in VR as a means of illustrating his eating disorder. In it, he "was trying to simulate what happens when you start eating again after starvation...it was also quite good at communicating to other people as well" [PWLE3]. He explained "I'd lived that in difficult feelings and difficult behaviours and stuff but I hadn't been able to communicate it in words and I think that communicating it visually and using space and colour...was really powerful and therapeutic." Part of what had been helpful was "you have the paintbrush and you are in charge, you have agency...it met some of those core needs about agency" [PWLE3]. Another person with lived experience of eating disorders agreed "this is about creativity and doing something different in the space...I think it would really appeal to me" [PWLE3]. One clinician also suggested VR could be used to help patients separate their eating disorder from their idea of themselves, for example, by creating a representation of the eating disorder in the virtual world: "that classic anorexia externalisation process of having anorexia in the room with you...There might be a place for that as well as the young person" [CL3].

Psychoeducation

People with lived experience of eating disorders described their family members, friends, and clinicians finding it hard to understand what they were experiencing: "so much of the pain in the heart of having an eating disorder is people around you just not understanding" [PWLE1]. They suggested that VR training could help others to understand eating disorders better: "to train therapists or charity volunteers or GPs or family to...get that kind of level of understanding and empathy" [PWLE1]. For example, VR could be used to "show the messages, pinging and pinging with all the influencing thoughts that

we get...the fact that you're focusing on you know skinny people, calorie labels, smells..." [PWLE1].

Clinicians agreed VR could be used to "increase family members' understanding" [CL4] and "help them step into a different position" [CL3]. One clinician suggested VR could be used as part of family-based therapy, to coach parents in skills to support their child so that "the parent can go in more likely to get it right, I guess having had a bit of practice with that beforehand" [CL2]. However, they also wondered what might be lost through the young person not witnessing their parent being coached as would be her normal practice "when the young person sees the parent being coached...sometimes that's really helpful because they know...it's not just coming from the parent...it's the professionals."

One person with lived experience of eating disorders suggested that VR could be used to make learning about eating disorders more engaging for those with the illness too: "I think it would be a really good learning module...actually I find concentrating very difficult so to make learning fun and engaging and dynamic" [PWLE3].

Enabling Therapeutic Conversations With Oneself

People with lived experience of eating disorders raised the possibility of VR enabling them to see themselves from an external perspective which will allow them to support themselves better. It could be a "learning opportunity for you to impart some wisdom so could you kind of visualise, like create yourself, you know, is it that kind of shit that they say...would you say this to other people, what you're saying to yourself" [PWLE3].

Practicalities of Delivering VR Therapy

Overview of Opinions

Participants highlighted practical considerations around the delivery of VR therapy, which would vary according to the precise nature of the intervention. Supportive data for this section are available as [Multimedia Appendix 6](#).

Setting

Opinion was divided as to whether people would rather use VR interventions at home or in the clinic. Arguments in favor of the home environment centered around it being less stressful, especially because one would not need to worry about being observed. However, others preferred the idea of a clinic setting because they felt that a potentially difficult or distressing VR experience could intrude on the safety associated with home, and some questioned whether they would use VR if left to do so independently.

Therapist Presence

Many participants in both groups would want therapist involvement in or alongside any VR, with people with lived experience of eating disorders highlighting that they would need to know and trust their clinician. Others suggested that the therapist's input could be intermittent, with VR providing additional support, for example, between or alongside other therapeutic work.

Timing

The best timing for a VR intervention was agreed to be important, complex, and dependent on the nature of the intervention. Some felt that people with eating disorders may not be able to make use of it if they were significantly underweight or not eating, while others suggested it might be useful for people who were very underweight as it might help to manage high levels of anxiety in relation to beginning treatment. Others felt that VR interventions could be useful at any point, and highlighted that the severity of eating disorder symptoms is not always related to weight. Several participants in both groups raised the patient's current motivation for recovery as important, feeling that this might be the most important factor in whether people would engage with and potentially benefit from VR-based treatments.

Discussion

Principal Findings

Both people with lived experience of eating disorders and clinicians with experience in treating eating disorders were in general positive about the possible future use of VR in eating disorders treatment. They generated a wide range of ideas as to how VR could be used, including to practice challenging situations, retrain attention, represent the eating disorder, for psychoeducation, and to enable therapeutic conversations with oneself. They discussed the complexity of how to represent people's bodies in a VR setting and ways in which this could be done safely and potentially therapeutically. Clinicians and people with lived experience of eating disorders independently suggested similar uses for VR, and the coding framework initially developed for the focus groups with people with lived experience of eating disorders fitted well with data obtained from clinicians.

To our knowledge, this is the first study to explore the views of people with lived experience of eating disorders and clinicians about how VR could be used in the treatment of eating disorders. The focus groups and interviews were extremely rich in detail and explored many ideas in substantial depth. Focus groups included people with several different eating disorder diagnoses, including some with experience of more than 1 diagnosis, and both men and women. We also interviewed clinicians (1 man and 3 women) from a range of professional backgrounds and with varying amounts of professional experience.

Participants highlighted some concerns about the limitations of what is possible in VR, particularly around physical sensations and the sense of smell. In fact, haptics can enable participants to experience physical sensations in a VR setting [9], and it is possible to add an olfactory display to VR to allow the user to manipulate objects in VR and have an experience of smelling them [22].

Strengths and Limitations

Although the study was small scale, we adopted a rigorous approach to data collection and analysis. Credibility was enhanced by the inclusion of 2 sample groups recruited nationally and using multiple sampling strategies to maximize variety in the perspectives obtained. Purposive sampling was

used to ensure that perspectives from men were also included, thus increasing the transferability of the findings. Data analysis was carried out with triangulation between 3 researchers, each with differing backgrounds, and 1 of whom was not involved in data collection. To ensure dependability, the researchers performed independent coding and checking across both sample groups and discussed discrepancies in interpretation to arrive at a comprehensive coding schema that could be applied consistently to the data.

However, we identify the following limitations in the study. First, transferability is limited in relation to ethnicity because both our people with lived experience of eating disorders and clinician samples were limited to people who described their ethnicity as White. This was due to difficulties in recruiting people from other ethnic groups in the time available. It would be useful to expand this work to people from different ethnic groups, and with different cultural backgrounds, in the future, to open up conversations around different cultural experiences of eating disorders and VR. Second, the number of clinicians included was small, again as a result of time limitations. Their input was valuable and is novel in this type of work but it would be useful for future studies to include more clinicians. Third, it is likely that the self-selection among individuals offering to participate may have led to us recruiting participants who were more likely to be positive and enthusiastic about the potential adoption of VR. Lastly, it is possible that findings would have been different had we held interviews instead of focus groups with people with lived experience of eating disorders, and focus groups instead of interviews with clinicians. It is possible that this variation in methodologies meant we collected slightly different data from the 2 sample groups because of the format available to them in which to respond. For example, clinicians' views may have been shaped if they had had the opportunity to interact and reflect with colleagues in situ, and people with lived experience of eating disorders may have been less able to draw on personal narratives in a group setting. Ideally, further research could triangulate these 2 methods of data collection using a mix of the 2 approaches in both sample groups. However, it is notable that the focus groups were small, and we observed individual participants talking in-depth, and also that there was a strong overlap and consistency in the content of themes obtained from the 2 sample groups.

Comparison With Prior Work

Previous work has described a case report of a person with lived experience of eating disorders in the context of her trying VR exposure therapy in which she ate "forbidden" foods [23]. The participant described that she initially perceived the foods as too unhealthy to eat even in a virtual setting, and that she was then able to use the VR environment to practice eating feared foods [23]. However, we have been unable to find previous research which has reported qualitative research findings alongside other results in preliminary trials of VR interventions for eating disorders. We have also been unable to find other qualitative studies exploring the views of people with lived experience of eating disorders around how VR could potentially be used in treating eating disorders, despite the importance of this for ensuring that new interventions are acceptable and

therefore have the potential to be effective in treating eating disorders.

There is also little research on the views of health care professionals on the potential use of VR in treating eating disorders. One survey of practicing cognitive behavioral therapists found that 45% agreed VR could be used for eating disorders (rising to 61% among those with clinical experience of treating people with eating disorders) [24]. They agreed with statements around VR enabling exposure to be tailored to the individual, increasing a sense of control, and making exposure less stressful, and shared concerns we found in our study about whether results would translate into the real world and the ability to use a new technology [24].

Early qualitative work in other areas of VR development for health-related use has found some similar general themes, particularly around the idea of VR as being novel and enjoyable [25,26]. When health care professionals are asked about potential applications for VR, they have many ideas [26].

Some qualitative work has explored the experience of people with other mental health conditions while undergoing VR interventions. These report several themes in common with our findings, such as the VR environment feeling “easier than the real thing” (p. 9) [27] or a good place to practice situations “so you cannot make a fool of yourself” (p. 4) [27]. Relatedly, they describe the potential usefulness of VR in reducing anxiety [28] and building confidence [27,28]. Caveats are also consistent, particularly the concern that it might not be for everyone, and

that benefits might not translate out of a VR environment [27]. Participants were also keen to highlight that the use of VR would need to be supported by someone with whom the patient had a trusting relationship [28].

Implications for Research and Practice

Both people with lived experience of eating disorders and clinicians in our study expressed interest and enthusiasm in the development of interventions using VR to supplement and improve the treatment of eating disorders. This work has highlighted a number of possible interventions that could be developed using VR, including psychoeducation, experiencing challenging situations, attention retraining, and seeking to make therapeutic use of the different ways VR enables one to experience one’s own body. We recommend that such interventions are co-designed with people with personal experience of eating disorders, to maximize their usefulness for this group and reduce the risk of unintended harms. Such novel interventions will subsequently require rigorous evaluation in the form of clinical trials to test their efficacy.

Conclusions

People with personal experience of eating disorders and clinicians who are experienced in their treatment both see many potential roles for VR-based interventions in their treatment, although they are also clear that there is a need for caution and ongoing co-design in their development, particularly around how bodies are represented in a VR setting.

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Data Availability

Data are available to bona fide researchers on request via the University of Bristol Research Data Storage Facility (deposit doi: 10.5523/bris.lpf0ek7zcnxb26yzhe8a5khhbx).

Authors' Contributions

HB, IPV, LB, and LMT researched the literature and conceived the study. HB, IPV, LB, JB, and LMT were involved in protocol development and gaining ethics approval. HB recruited participants. HB and LB collected the data. MRK, HB, and LB were involved in data analysis. HB wrote the first draft of the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Screening questions for people with lived experience of eating disorders.

[[DOCX File, 22 KB - xr_v1i1e47382_app1.docx](#)]

Multimedia Appendix 2

Screening questions for clinicians.

[[DOCX File, 22 KB - xr_v1i1e47382_app2.docx](#)]

Multimedia Appendix 3

Topic guide for people with lived experience of eating disorders.

[[DOCX File, 23 KB - xr_vli1e47382_app3.docx](#)]

Multimedia Appendix 4

Topic guide for clinicians.

[[DOCX File, 23 KB - xr_vli1e47382_app4.docx](#)]

Multimedia Appendix 5

Powerpoint images shown to participants.

[[PPTX File, 5103 KB - xr_vli1e47382_app5.pptx](#)]

Multimedia Appendix 6

Practicalities of delivering virtual reality therapy for people with eating disorders.

[[DOCX File, 17 KB - xr_vli1e47382_app6.docx](#)]

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Abbreviations

VR: virtual reality

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