Am I Happier as Myself?
Creating Four Affective Virtual Environments to Investigate the Relationship between Embodiment and Emotion in VR

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Figure 1: We systematically designed four virtual environments to induce emotions of (A) calmness, (B) happiness, (C) sadness and (D) fear. Self-reported measures of emotion were taken to validate the dominant emotions induced in each VE. Self-presence measures were also taken to assess the possible relationship between different emotions and embodiment in VR.

ABSTRACT

Despite the critical role of avatar embodiment and emotion elicitation in the effectiveness of many immersive virtual reality (VR) applications, little is known about how embodiment and emotion may interact to enhance the user's experience within a virtual world. There is a need to investigate this relationship within virtual environments designed to elicit different dominant emotions while minimizing changes between each environment to reduce confounding variables. Therefore, we investigate how to systematically create four affective virtual environments to elicit different target emotions (happiness, calmness, fear and sadness) through relatively minor changes. Following a within-subjects design, 20 participants were immersed in each environment, after which subjective measures of emotion were collected to validate the success of each environment in eliciting its intended emotion. Since the user did not embody a virtual avatar when immersed, we recorded self-presence measures to illuminate the possible interplay between embodiment and emotion. Overall, our results demonstrate that it is possible to induce different emotions intensely through manipulations of the same virtual environment. We discuss how our results can guide future developers in VR design, as well as future studies on embodiment.

1 INTRODUCTION

Given that VR technologies afford extensive avatar customisation, users can embody a wide variety of avatars ranging from highly photorealistic, personalised avatars that closely resemble the user [75, 101, 115] to entirely distinct figures [7, 64]. A user's avatar refers to their self-representation within a virtual environment (VE) [118], and existing literature has thoroughly explored how we can enhance the user's sense of embodiment towards their avatar in VR, in which they feel as though the avatar's body is their own [42, 84]. This is frequently researched by manipulating various avatar characteristics, such as appearance [38], to examine their impact on induced sense of embodiment. For instance, users perceive highly personalised, photorealistic avatars as more visually appealing and embody them more readily compared to avatars of lower photorealism and personalisation [101, 124]. This knowledge is important because enhanced avatar embodiment has been shown to not only increase user engagement and enjoyment [13, 36, 91] but also the sense of presence within a virtual world [106, 115]. Multiple studies have shown that user emotion similarly affects the user's experience [57]. Despite this, little is known about how embodiment may interact with emotion to further optimise these user benefits.

Emotions are a critical component of human nature, affecting human perception, decision-making, cognition, and many other psychological processes [95]. Consequently, they have been subject to extensive research in numerous fields, and are commonly modelled using Russel's Circumplex Model of Affect [100, 107]. In this model, emotions are composed of two main dimensions: valence and arousal [100]. Valence refers to the extent to which a given emotion is positive or negative, while arousal refers to the level of intensity associated with the emotion [10]. For instance, fear is considered to be of negative valence but high arousal, while calmness is of positive valence and low arousal [100]. Notably, it has been shown that the arousal of the dominant emotion experienced in VR positively correlates with the user's sense of presence [58]. Presence, defined as the user's subjective feeling that they are truly in the VE [104], is fundamental to the effectiveness of all VR applications [116]. Given that emotional intensity has been demonstrated to be central to the formation of presence, even more so than technical factors such as visual realism of the VE [59], it is essential to study how we can enrich the user's emotional experience in VR. However, while existing literature highlights a possible relationship between enhanced embodiment and emotional intensity [40], there still lacks a thorough investigation into the relationship between embodiment and emotion in VR.

Multiple studies suggest that virtual embodiment may modulate user emotion. According to the Proteus Effect, the characteristics of a user's avatar can affect their behaviour, attitude, and cognition [97]. Importantly, avatar embodiment is often noted as a threshold value for this effect to occur [6, 78, 119]. Thus, given the close relationship between emotion and cognition, the degree of virtual embodiment may also influence user emotion. Some studies suggest that enhanced virtual embodiment should increase emotional arousal, regardless of valence [60, 40, 98]. However, few studies have examined the reverse relationship, exploring how user emotion may contribute to embodiment. Those who have suggest that embodiment correlates positively with positive valence, but not with arousal [82]. Thus, the relationship between embodiment and emotions of different valence and arousal in VR appears complex, and remains unclear. This may be due in part to only a small subset of emotions being investigated when studying this relationship, such as solely happiness [98]. Also, the VEs used are often highly simple, resulting in generally low intensity of emotion felt by users [40, 98]. Whether the relationship would become more pronounced in more emotionally intensive VEs is yet to be explored.

Moreover, with an increased focus towards the creation of a metaverse, it is likely that more users will readily embody avatars that can closely resemble themselves in VR [19, 101]. Since it is highly important that users also feel a large sense of presence and enjoyment within the virtual worlds they find themselves in, it is crucial to investigate how emotion and embodiment may interact to further optimise the user's experience. Clearly, it is also important to investigate this interaction through emotionally enriching VEs that elicit different emotions, as the relationship may differ [82]. Targeting emotions at different extremities of the circumplex model is suitable for this, since this gives four emotions each with different levels of valence and arousal. We pose the following research questions:

- **RQ1** How can we create four versions of a virtual environment that elicit target emotions at the extremities of the Circumplex Model?
- **RQ2** What is the relationship between embodiment and emotion intensity in VR?
- **RQ3** How does this relationship change based on the dominant emotion in a virtual environment?

To address RQ1, we systematically designed four VEs, each intended to elicit a dominant emotion at the different extremities of the circumplex model: happiness (positive valence, high arousal), calmness (positive valence, low arousal), fear (negative valence, high arousal), and sadness (negative valence, low arousal) [100]. 20 participants experienced each VE, after which we took subjective measures of emotion to determine the dominant emotion elicited. Our results suggest that it is possible to evoke intense user emotion within users, even when afforded no interaction. We also discuss possible future work and guidelines for creating affective VEs, given that some VEs elicited similar levels of each emotion. For instance, we found that the Happy VE and Calm VE elicited similar levels of happiness and calmness. To discuss RQ2 and RQ3, measures of self-presence were taken after the participants experienced each VE. Since participants were not embodied in an avatar in each VE, self-presence was measured as it not only describes how embodied a user feels in their avatar but the extent to which they feel as if their self has been extended into the VE [77]. Overall, we contribute to existing HCI literature through:

(1) Providing guidelines to both VR developers wanting to creating emotionally intense VEs, and researchers seeking to study a variety of different emotions under controlled, laboratory conditions.
(2) Evidence that when the user is not embodied in an avatar in VR, user sadness predicts self-presence, while high arousal emotions do not affect self-presence.

2 RELATED WORK

In psychology, embodiment broadly refers to our experience of owning a body, within which we feel located (sense of self-location), have full control over its movements (sense of agency), and feel that it is our body, and not another's (sense of body ownership) [60, 74]. Understanding how different factors may contribute to our sense of embodiment, as well as our ability to distinguish our body from those of others, is a central question in human psychology [60, 112, 105]. Consequently, a vast range of literature has explored how we can induce a sense of body-ownership towards objects external to ourselves [61]. This research dates back to 1998, where Botvinick and Cohen observed that participants felt as though a rubber hand was their own when it was synchronously stroked with their real hand, which was hidden from view [14]. Interestingly, it has also been shown that more intense emotional stimulation, whereby a user's hand is stroked either pleasantly or more painfully, results in an enhanced sense of embodiment towards the rubber hand [21, 22]. Although these studies provide evidence that a user's affective state plays a role in embodiment, existing research regarding embodiment in VR has primarily focused on how to enhance embodiment through the manipulation of different avatar characteristics [105], such as the avatar's size [62, 73]. Few consider the role of the user's emotion.

Nevertheless, numerous studies have demonstrated that virtual embodiment plays a crucial role in many VR applications, such as entertainment [13], health [27, 90], and social interaction [55, 72], where users can meet online and interact in virtual worlds. Notably, the success of many of these applications also lies in their ability to emotionally engage the user, such as the need for therapeutic VR to be calming [27]. Therefore, understanding the interplay between a user's affective state and embodiment is not only crucial within psychology but also highly beneficial to VR developers. This knowledge would allow us to provide further guidelines on improving the effectiveness of applications. For example, suppose we understand that enhanced embodiment enhances user fear. In that case, game developers may focus on increasing user embodiment, possibly through more personalised avatars, to elicit more stress in players. Moreover, in this section we first provide an overview of our current, vast understanding of the specific avatar characteristics that enhance embodiment before reviewing existing research on the role of emotion. Subsequently, we look at how researchers have used VR to evoke different emotions to understand how we should best explore the interplay between emotion and embodiment. Finally, we discuss self-presence in relation to embodiment, since we have taken this measure in order to discuss RQ2 and RQ3.

2.1 Avatars Characteristics and Embodiment

Prior work has extensively studied the interaction between various avatar characteristics and user embodiment [45]. Notably, many support the use of photorealistic, personalised avatars in VR given that such avatars appear to enhance embodiment and presence [101, 115]. In these studies, avatar personalisation refers to the extent the avatar resembles a specific user's appearance [26], while avatar photorealism refers to the quality of the avatar to resemble an actual human [124]. Recently, Salagean et al. [101] employed photogrammetry methods to produce highly personalised, photorealistic avatars for participants to embody. Photogrammetry involves using a rig of cameras to create 3D scans of each participant, from which highly photorealistic avatars can be created and then personalised [1]. Using real-time motion capture to allow the avatar to move synchronously with the user's body, participants in [101] observed their avatar through looking at a virtual mirror while completing a range of different motions. Allowing users to see their avatar move synchronously with their virtual body through a virtual mirror like this is often noted as being highly important in inducing embodiment in VR [46, 56]. Moreover, [101] found that participants reported an increased sense of embodiment towards more personalised, photorealistic avatars when compared to avatars of lower photorealism and personalisation. Similarly, participants in [115] also felt an increased body ownership towards personalised avatars over generic avatars, while reporting a significantly higher sense of presence too.

A secondary focus of [101] was to understand how users perceive these personalised, photorealistic avatars in comparison to less personalised avatars of lower photorealism. Notably, all types of avatar were rated equally as eerie by participants. This supports findings that recent advancements in computer graphics are allowing for 3D generation of virtual avatars that overcome the Uncanny Valley, where users find human-like simulations unsettling [52]. Users also felt a larger degree of familiarity towards photorealistic, personalised avatars and rated them as more visually appealing. Moreover, [101] corroborates existing studies that advocate for avatars that highly resemble the user in order to optimise the user experience, as it results in enhanced presence, embodiment and a more positive avatar perception [69, 115, 124, 125]. Given this large understanding of how different avatar characteristics can affect embodiment, researchers are increasingly interested in how avatar embodiment may also influence user cognition, behaviour, and perception (the Proteus effect) [97]. For example, [7] suggests that embodying an elderly avatar in VR can reduce implicit age bias, while numerous other studies demonstrate that embodying a dark-skinned avatar can reduce implicit racial bias [5, 93]. These findings demonstrate a clear relationship between embodiment and cognitive processing, further suggesting there may also be a link between embodiment and emotion [40].

2.2 Embodiment and Emotion

Multiple studies demonstrate that virtual embodiment can modulate emotional arousal in VR, particularly when placing the user under stress. For instance, participants in [18] reported increased feelings of anxiety in avoiding virtual knives when they felt increased embodiment towards a virtual hand. It has also been shown that when users feel increased embodiment towards an artificial arm, they may exhibit an increased galvanic skin response when threatened by, for example, a virtual knife [49] or needle [31]. These studies suggest that enhanced embodiment towards external objects can lead to increased emotional arousal, specifically for stress, when those objects are threatened. More recently, Gall et al. [40] examined how heightened embodiment of a virtual hand influences emotional responses to stimuli of both positive and negative valence. In VR, participants were presented with 20 2D pictures from the International Affective Picture System (IAPS), a database of images designed to induce specific emotions [80]. After viewing each image, participant emotion was measured using the SAM scale, a common pictorial questionnaire used to measure the valence and arousal of an experienced emotion [15]. Results indicated that when participated viewed the images while feeling an enhanced sense of embodiment towards the virtual hand, they felt slightly higher arousal and valence in response to the pleasant images. Similarly, while there was no significant difference in valence towards unpleasant images, participants reported a small, but still statistically significant, increase in arousal towards these images during enhanced embodiment. This study further suggests that enhanced embodiment can intensify emotional arousal to stimuli in VR.

It is worth noting that although the authors in [40] found that increased embodiment can intensify emotional responses to stimuli in VR, they also found that this effect was small. However, this may have been because the stimuli presented to participants evoked only a moderate emotional reaction. Specifically, the 2D images were presented out of context, and held little relevance to participants. Therefore, in further investigating the interaction between embodiment and emotion, it is important to create a more emotionally intense experience for the users in order to understand if the effects found in [40] would be larger and more prominent.

More recently, Radiah et al. [98] investigated the influence of avatar personalisation on users' emotional experience in VR. The authors explored the impact of embodying personalised, gender-matched avatars in comparison to non-personalised avatars of a different gender on user happiness in VR. Participant avatars were generated using Ready Player Me, an online tool allowing for quick generation of personalised avatars from user photos [3]. In embodying each avatar, participants were seated in front of a table and faced a virtual mirror in VR. Happiness was induced through the autobiographical recall method [81], whereby participants recalled happy memories while seated in front of the virtual mirror. Measuring emotion using the SAM scale, participants reported increased valence and arousal as well as a greater sense of embodiment when embodied in personalised, same-gendered avatars. Moreover, this study focuses on the impact of avatar personalisation on embodiment and user happiness in VR, not explicitly exploring how enhanced embodiment itself may have affected emotion. Nevertheless, it provides valuable insight into how increased avatar embodiment, through avatar personalisation, may enhance user happiness.

Furthermore, the previous studies mentioned solely focus on a causal relationship of embodiment on emotion. Interestingly, few consider the reverse relationship despite suggestion that affective state plays a crucial role in our sense of embodiment [17, 102]. Mottelson and Hornbaek [82] provided evidence that a user's affective state can have an impact in their sense of embodiment in VR. In their study, participants embodied various avatars, ranging from from those with enhanced smiles and upright postures, known to elicit positive emotions such as joy [29, 76, 89], to those with frowns and hunched postures in order to induce negative emotions. Their results suggest a positive correlation between positive emotional valence and virtual embodiment, while there was no significant relationship between emotional arousal and embodiment for positive valence emotions. Importantly, embodiment of avatars with a frown and worse posture did not elicit negative emotions as strongly as desired. Therefore, further exploration is needed to determine if there may be a similar relationship between embodiment and emotions of negative valence, such as sadness. Nevertheless, these results suggest that as users feel more embodied, their emotional valence increases for positive emotions, and vice versa. This study highlights that we should also consider a user's emotional state when attempting to understand the factors that contribute to our sense of embodiment in VR.

2.3 Emotion Elicitation

Though providing valuable evidence of an interaction between embodiment and emotion, it is important to note that many existing studies have primarily used simple, static VEs in studying this relationship (as seen in [40, 82, 98]). Modern VR, on the other hand, is increasingly capable of placing the user within realistic and dynamic virtual worlds that are capable of eliciting a strong emotional response [58]. However, instead of using the VE itself, existing studies on embodiment and emotion have made use of various other mood induction procedures (MIPs) that have often resulted in the use of stimuli that often evokes low emotional intensity in VR. Examples include the affective 2D photos used in [40], while [115] notes that some participants felt as though they were already in a happy mood, and so felt unaffected by the autobiographical recall method. As a result, this may have led to a weaker relationship being found between emotional intensity and embodiment. Therefore, it is not only now crucial to investigate embodiment and emotion through creating an enriched emotional experience for participants, but we need to do so in VEs more representative of the virtual worlds users will be immersed in. Investigating the relationship this way could not only make the suggested interplay between embodiment and emotion more clear, but we would also be able to better inform VR developers, since we would be using environments more comparable to those that they would be creating.

Due to the fundamental role of emotions in daily experiences, understanding how we can intentionally elicit different emotions in controlled laboratory settings is crucial for research that aims to further understand human emotion [79]. As a result, many researchers have designed different VR scenes to elicit intense, yet specific, emotions. Examples range from gloomy hospitals designed to induce sadness [28] to eerie, abandoned houses used to elicit fear [70]. While we know we can use highly varying VEs to induce distinct emotions, it is also important to explore how we can manipulate a single VE to elicit different emotional responses. This would allows us study embodiment in relation to a variety of different emotions while minimising confounding variables as much as possible.

While previous studies have shown that manipulating similar VEs can induce different emotions in VR, this has primarily been explored through the creation of different park scenarios [8, 33, 37]. However, while suitable for their investigation, this involved introduction of elements that would prove unsuitable when attempting to study the relationship solely between emotion and virtual embodiment of an avatar. For instance, although [33] created five virtual parks, the authors created a bright, quiet park filled with birds chirping to induce joy, but to induce anxiety non-playing avatars were introduced within a darker lit park. For our case, however, a human agent would introduce too many confounding variables that could impact both emotion [4, 85] and embodiment [16]. As such, this would be unsuitable to include in such an investigation without introducing more variables into this relationship, such as the role of social interaction on sense of embodiment [16]. Likewise, [8] made use of a narrative, by telling participants the history of the virtual park. However, narrative, too, may interact with embodiment [63].

Overall, then, there is a lack of knowledge on how we can make systematic, consistent manipulations of a VE, particularly through appearance, sound design, and environmental objects, that can evoke emotions of different valence and arousal. Such knowledge would allow us to explore the interplay between embodiment and emotion in a highly controlled manner. Recently, [96] explored how one could manipulate affect in a VR exergame through differences in game mechanics, lighting, and colour scheme. They successfully induced emotions of happiness, stress, calmness and sadness across four versions of a VR cycling exergame. Gamification has been demonstrated as a reliable way to evoke intense emotion, evoking joy through achievement, for example [50]. For our purpose, however, we need to investigate whether we can elicit intense emotion through sound design, colour and environmental objects alone.

2.4 Summary

Despite suggestion of a connection between affective state and user embodiment, there exists only a small amount of literature that explores this topic. Clearly, in order to build on existing aforementioned research on embodiment and emotion in VR (e.g. [40, 82, 89, 98]) there is now a need to explore the possible relationship across emotions of different valence and arousal, within VEs systematically developed to induce each emotion with as minimal possible changes between each VE as possible. This project, then, focuses heavily on the development and validation of four affective VEs that can be used to thoroughly explore the relationship between embodiment and emotion. We are primarily concerned with how manipulations in VE sound design, lighting, colour scheme, and environmental objects can alter the induced emotion. Given that we have seen how the inclusion of a virtual body may modulate emotional intensity, it would be unsuitable to include a virtual body, then, for users when analysing the effect of each VE in inducing different emotions. This, of course, would be required to explore RQ2 and RQ3 thoroughly, but only once we have a set of validated VEs in inducing emotions at the extremity of the circumplex model. For our purpose, however, we can use self-presence as a way to discuss RQ2 and RQ3, which describes the extent to which users feel as though they are part of the VE [47].

Existing literature has discussed how, even without a virtual body, embodied experiences are still created through visuomotor synchrony between the user's head movement and what they see in VR, given that they are viewing the environment from a first person-perspective [35, 121]. Indeed, [35] discuss how self-presence and body-ownership measures are conceptually similar, although the former addresses how one feels located within the environment, while the latter is specific to location with respect to a body. Nevertheless, they suggest that presence correlates with embodiment. Similar to the relationship between embodiment and emotion, few have investigated the relationship between self-presence and emotion. [57] recently found that fear and happiness both predicted self-presence, while relaxation did not, although the user was not embodied in a virtual avatar. While these results suggest that that high-arousal emotions are highly important in constructing self-presence, they may also suggest that high arousal-emotions can affect user embodiment. Overall, then, in this project we focus on the need to create four VEs that elicit different emotions to thoroughly address RQ1, which would allow us to thoroughly explore embodiment and emotion. However, in this project, we discuss RQ2 and RQ3 solely through measure of self-presence.

3 DESIGN OF AFFECTIVE VIRTUAL ENVIRONMENTS

To investigate RQ1, we created four affective VEs each designed to induce an emotion at an extreme of the circumplex model. We can refer to each of these VEs by the emotion they are intended to induce: **Happy**, **Calm**, **Sad**, and **Fear**. Each VE was developed using Unity (version 2022.3.14f1), and simulates a realistic bedroom environment, with surrounding nature, using assets purchased from the Unity Asset Store [86, 87, 88, 110]. A realistic asset was chosen given that an increasing number of users will be able to embody photorealistic avatars in VR, and as such it is likely that many future studies will also investigate embodiment with respect to avatars of high fidelity [101]. It is important that the fidelity of the user's avatar remain consistent with the realism of the VE. Otherwise, a mismatch in graphic quality between the user's avatar and the VE may negatively affect user experience in VR, decreasing presence but also increasing the likelihood that participants feel unsettled when viewing their avatar [114]. A VE that simulated a bedroom was also partly chosen due to the need to for a large realistic mirror needed in investigating embodiment. This virtual mirror is needed based on prior work that suggest that it is an essential element in inducing embodiment [46, 83].

All four VEs were designed to mimic each other as closely as possible, while only changing specific design elements intended to induce the desired emotion. These changes were guided by existing literature on emotion elicitation in VR, i.e. [24, 33, 109]. Moreover, each VE varies by lighting, colour scheme, sound design, and environment objects. In the following sections, the design of each VE is described in detail in order to understand the specific design choices made. Importantly, these VEs were developed in within a team of two, myself and another student at the University of Bath. Therefore, appendix A contains a detailed table noting my contribution to each VE. Figure 2 displays each of the four developed VEs.

3.1 Happy VE and Calm VE

Numerous studies reveal the use of nature as a means to induce positive emotions [25, 28, 92, 109]. For instance, Panic et al. [92] describe how to foster emotions of positive valence through environmental setting, noting that VEs that expose users to natural scenery significantly increases positive emotion, while reducing negative ones. Similarly, [109] describe the important of creating VEs predominantly illuminated by sunlight when inducing positive emotions. [109] also emphasises the need to embed indoor scenes with plenty of greenery, decorative flowers and clean natural furniture, such as wooden shelves, to increase positive valence. So, both the **Calm** VE and the **Happy** VE feature a blue skybox, and the bedroom is primarily lit from light through the bedroom windows, creating the impression that it is a bright, sunny day. Notably, in the **Calm** VE, although it was still daytime, the lighting was less bright, and of a warmer tone [9]. Through the bedroom windows in both VEs, the user could see plenty of trees and flowers. Both bedrooms also featured clean wooden floors and clean, white bedroom furniture. These features ensured that users were immersed in an environment full of nature and sunlight.

Existing literature reveals the role of brightly coloured flowers, such as red and yellow, in inducing happiness, while blue and white flowers are often seen as more calming [123]. Therefore, to differentiate in terms of arousal, the **Happy** VE contains an array of different brightly coloured flowers (red, yellow and pink) that are both present in and outside the room, while the **Calm** VE only features white and blue flowers. To further differentiate in arousal, a monochromatic gray colour scheme was used in the bedroom of the **Calm** VE [117] while the **Happy** VE contained a bright yellow feature wall due to its common association with joy [32, 44, 109]. This yellow colour was specifically chosen according to [24]. Thus, a light green bed cover was chosen for the **Happy** VE, given that we wanted to introduce increased variety of colour to increase happiness [44], while also keeping the VE aesthetically pleasing [109, 120]. Moreover, horizontal mood lines are often used in design to convey peace [111]. Therefore, the bedding in the **Calm** VE remained white in keeping with the monochromatic colour scheme, but contains thin black horizontal lines that follow the direction of the tiled, wooden floor. Both positive valence VEs contained a rotating ceiling fan, but this rotated significantly faster in the **Happy** VE given a suggested relationship between increased dynamism and arousal [23, 43, 103].

Music and sound can have significant effects on a person's emotional state, and many have investigated how music can be used to induce different emotions [30]. In each environment, specific music and atmospheric sound was purchased online and chosen depending on the emotion we intended to induce. The music in the **Happy** VE was cheerful and upbeat, played in major mode with a tempo chosen to be in the range of 120-150 beats per minute (BPM). Music of this mode and BPM range has been shown to increase happiness [34, 39]. Contrastingly, in the **Calm** VE, while the music was still in major mode the tempo was much slower, being between 90-120BPM, in order to decrease emotional arousal [34, 39]. Specifically, the instrumental of 'Lever de la lune' was played in the **Happy** VE [122], and 'Grace' was played in the **Calm** VE [48]. Lastly, both

Figure 2: The four affective VEs created for the study, designed to induce (A) calmness, (B) happiness, (C) sadness and (D) fear. Note that the fear VE (D) appeared much darker to participants, but the brightness has been increased here to better show the features of the room.

VEs contained ambient noise of birds chirping, though more frequently in the **Happy** VE, given its shown effect on increasing emotional valence [33, 92].

3.2 Fear VE and Sad VE

The development of negative valence VEs was informed by the same literature used in creating the positive valence VEs. To elicit negative valence, both the **Fear** VE and **Sad** VE feature dim lighting and a dark coloured skybox, and the colours in the room were also much darker and less saturated [109, 117, 44]. The **Sad** VE also features a very low saturated, soft blue lighting from the lamps in the room chosen from [24], which relates this hue to not only negative valence, but low arousal. In both VEs, the furniture, walls, flooring and bedding appear to be much more filthy than the VEs designed to induce positive valence, with cracks and mould along the walls [109].

To elicit high arousal, it is worth noting that many designers use gore to evoke fear and stress in horror games [94]. Therefore, the **Fear** VE contained bloodied stains and hand-prints throughout the room in order to evoke feelings of death and threat [28, 71]. The blood decals used were downloaded from [41]. It is also mentioned in [109] that video games often make users feel imprisoned in an environment to evoke heightened stress. Thus, there are blinds over every window in the **Fear** VE, which restricts view to the outside in an attempt to make users feel more confined within in the room. Both VEs were also relatively static. In the **Sad** VE, the ceiling fan did not rotate, and the trees viewed from outside the window, which were bare and dying, did not lightly sway as they did in the positive valence VEs. This was done to induce low arousal and evoke further feelings of sadness through reduced dynamism [28]. The **Fear** was also relatively static in comparison to the positive valence VEs, containing no rotating ceiling fan, while the movement of the trees was restricted from view by the blinds. Although low dynamism can be used to induce low arousal, in environments of apparent threat this stillness is often perceived as eerie and builds tension that something is about to jump out [20]. Flickering lights were also added to the **Fear** VE to add to this building tension [65], increasing arousal.

In terms of sound design, the **Fear** VE contains quiet, eerie music in minor key, and is much less melodic than the music featured in the positive valence VE to further induce negative valence [34]. The hooting of owls can also be heard infrequently within this environment, as recommended by [33]. In the **Sad** VE, the music chosen was also in minor key and its tempo was in the range of 90-120BPM, key characteristics of music that induce both low valence and arousal [34, 39]. Specifically, 'Follow Me Nowhere' plays in the **Fear** VE [113], while 'Redemption - Stripped Version' plays in the **Sad** VE [108]. The appearance and sound of heavy rain is also featured in the **Sad** VE, given it's past use in eliciting low arousal and negative valence [96].

4 METHOD

In order to investigate RQ1, validating each VEs effectiveness in inducing the target emotion, we conducted a within-subjects experiment with one independent variable: $Emotion_{VE}$ describes the dominant emotion that each VE was designed to induce, with levels Happy (H), Calm (C), Fear (F), and Sad (S). After each VE was experienced, we took subjective measures of emotion and self-presence. In the following sections we look at the materials, procedure, hypotheses and participants of the experiment.

4.1 Materials

4.1.1 Virtual Environments. Participants experienced all four VEs described in section 3 using the HTC Vive HMD. This headset had a refresh rate of 90Hz and dual OLED panels with a resolution of 1440 x 1600 pixels per eye (2880 x 1600 pixels combined) and a field of view of 110°. The HMD was powered by a desktop computer running Windows 11 with an AMD Ryzen Threadripper PRO 5975WX processor with an NVIDIA GeForce RTX 4090 GPU and 128GB of RAM.

4.1.2 Questionnaires. Numerous studies reveal that direct questions are a reliable measure to assess discrete categorical emotion [58, 96, 99]. Therefore, replicating the methodology of [96], participants were administered 11-point rating scales (0-10) to assess Excitement, Happiness, Contentment, Calmness, Boredom, Sadness, Stress, and Fear after they experienced each VE. For instance, a user's level of excitement was measured through answering 'how excited did you feel?', with 0 indicating they did not experience this emotion at all and 10 indicating they strongly experienced this emotion. User emotion was also assessed through the Affective Slider, a validated continuous, pictorial scale that measures valence and arousal [11].

After experiencing each VE, participants were also administered the self-presence sub-measure of the MPS [77] questionnaire to assess self-presence. This is a scale which has been validated by both its authors and subsequent experiments [47]. Overall, the full scale contains 15 items answered on a 5-point Likert-scale (from 1 = completely disagree, to 5 = strongly agree), and is increasingly popular as it measures multiple components of presence. Specifically, it assesses physical presence (the sense that virtual objects in the VE are real), social presence (the sense that encounters with avatars in the VR are real social interactions) and self-presence (the sense of being a part of the VE) [2]. Particularly, we administered the sub-measure for self-presence in this experiment. This includes questions such as Q3: "I felt like my real arm was projected into the virtual environment through my virtual embodiment" and Q4: "I felt like my real hand was inside of the virtual environment". Moreover, all used questionnaire items are well-established and validated in literature, and each item has been assessed on the scale recommended by the authors. Full details of the questionnaire can be found in the Supplementary Materials.

4.2 Procedure

Participants were first greeted by the experimenter and presented with an information sheet describing the study, informing them that they would be experiencing four VEs that each simulated a bedroom. Participants were not informed of the purpose of the study, or that each VE was designed to induce a dominant emotion. This is important as priming participants by informing them about the emotion that a VE is designed to induce may modulate the intensity of the emotion experienced. For instance, informing a user that they are about to enter a creepy VE may enhance fear [53]. Therefore, users were not informed of the purpose of each VE. Nevertheless, participants then completed a VR screening sheet to ensure they were able to take part in the study, before giving informed consent. These forms can be seen in the provided Supplementary Materials.

Participants were then assisted by the experimenter in wearing the HTC Vive headset, ensuring optimal user comfort. Then, while seated, the participant was immersed in one of the four affective VEs. They started in each VE facing the direction of the mirror on the carpet at the end of the bed. Participants were also informed that they could freely move their head and look at the different elements in the VE, before being immersed in the VE. After 1 minute and 30 seconds, the user was taken out of the VE and took their headset off. They were then instructed to complete the subjective emotion questionnaire items, followed by the completion of the self-presence questionnaire. All questionnaire items were displayed and completed on a tablet provided to the participant by the experimenter, and were completed using the QuestionPro online questionnaire system.

After completion of the questionnaires, participants placed the headset back on, before experiencing a different affective VE and repeating the same process again. The order in which each participant experienced the four affective VEs was determined through use of a counter-balanced Latin square with four conditions (one for each affective VE). This was done to reduce any order effects and carry over effects. After all four VEs were experienced, with each questionnaire completed after each experience, participants completed a demographics questionnaire. Participants were then thanked for their participation, and informed about the purpose of the study through a debrief sheet (see Supplementary Materials). The experiment took on average 30 minutes to complete.

4.3 Hypotheses

Given that each VE was designed to induce a different emotion at different extremities of the circumplex model, we have the following set of *a priori* hypotheses that address RQ1:

H1 The Happy VE will elicit higher happiness ratings than the Calm, Fear, and Sad VEs.
H2 The Calm VE will elicit higher calmness ratings than the Happy, Fear, and Sad VEs.
H3 The Fear VE will elicit higher fear ratings than the Calm, Happy, and Sad VEs.
H4 The Sad VE will elicit higher sadness ratings than the Calm, Happy, and Fear VEs.
H5 The positive valence VEs (Happy, Calm) will elicit higher valence ratings than the negative valence VEs (Fear, Sad).
H6 The high arousal VEs (Happy, Fear) will elicit higher arousal ratings than the low arousal VEs (Calm, Sad).
H7 The Happy VE will elicit higher happiness ratings than calm, fear, and sadness ratings.
H8 The Calm VE will elicit higher calm ratings than happy, fear, and sadness ratings.
H9 The Fear VE will elicit higher fear ratings than happy, calm, and sad ratings.
H10 The Sad VE will elicit higher sadness ratings than happy, calm, and fear ratings.

Note that the following hypotheses first address comparisons between VEs (H1-H6), which compare each VE's induction of one of the desired emotions (happy, fear, sad, calm) as well as valence and arousal ratings between VEs. Subsequently, H7-H10 look at comparing the effect that a single VE has on 8 different affect measures (excited, happy, content, calm, bored, sad, stressed, fear) in order to determine the dominant emotions induced in each VE. In addressing RQ2 and RQ3, we are primarily concerned here with the affect of different dominant emotions on a user's self presence. Guided by existing literature, we propose the following *a priori* hypothesis:

H11 Fear ratings within the Fear VE, and happy ratings within the Happy VE, will predict self-presence.
H12 Calm ratings within the Calm VE, and sad ratings within the Sad VE, will not affect self-presence.

4.4 Participants

Twenty participants took part in the experiment (eight males, 11 females, one non-binary), who were aged 20-23 ($M = 21.6, SD = 0.82$), and were all students of the University of Bath. None worked with the researchers of this project. All participants were recruited through word of mouth. Most participants had used VR occasionally (*Occasionally* = 12, *Never* = seven, *Daily* = one). This study received ethical approval by the University of Bath Research Ethics Committee (Ethics Code: 4588-4592).

5 RESULTS

This section provides an overview of the analysis strategy and main study results for RQ1, RQ2 and RQ3. Statistical analyses were carried out using JASP 0.18.3 and Prism 10.2.2. The JASP and Prism files used to perform the analyses can be found in the Supplementary Material. To address RQ1, repeated-measures ANOVAs were used to to analyse the effect of $Emotion_{VE}$ on affective ratings between each VE (H1-H6) and within each VE (H7-10). According to Shapiro-Wilk tests that were applied to all measurements, the normality assumption was violated in multiple instances. However, repeated-measure ANOVAs were used since they have been shown to be robust to violations of normality [12]. If Mauchly's test indicated a violation of the sphericity assumption, Greenhouse-Geisser corrected results have been reported. This correction is commonly recommended if the estimated epsilon is less than .75 [67], as was the case for all statistical analyses presented here. All tests for significance were made at the $\alpha = 0.05$ level. In this section all p-values that are below .05 have been marked with a '*', while p-values that are less than .001 have been marked with a '**'. In the event that the repeated measures ANOVA showed a significant main effect of $Emotion_{VE}$ on the intended affective ratings (happiness, calmness, sadness, and fear), post hoc tests were carried out using Holm correction. In this case, the effect size, Cohen's *d*, has also been provided to further demonstrate the magnitude of the observed effects [66]. Furthermore, all graphs show the 95% confidence interval of the means. Lastly, in addressing RQ2 and RQ3, multiple linear regression with enter method was used to predict self-presence from its interaction with the dominant emotions experienced within each affective VE.

5.1 Comparison of Affective Ratings between Affective VEs

5.1.1 Happy Ratings. The repeated-measures ANOVA revealed a significant main effect of $Emotion_{VE}$ on happiness ratings between VEs ($F(3, 57) = 61.89, p < .001^{**}, \eta^2 = 0.765$). Post-hoc tests revealed that the Happy VE elicited significantly higher happiness ratings than both the Fear VE ($t = 11.011, p < .001^{**}, d = 2.843$) and the Sad VE ($t = 9.034, p < .001^{**}, d = 2.333$). However, these post hoc tests also revealed that there was no significant difference in happiness ratings between the Calm and Happy VE ($t = 1.035, p = 0.305$). These findings partially support H1, since they reveal that the Happy VE was successful in inducing higher happiness when compared to the VEs designed to induce negative valence, but there was not a noticeable difference in happiness when compared to the Calm VE.

5.1.2 Calm Ratings. The repeated-measures ANOVA revealed a significant main effect of $Emotion_{VE}$ on calm ratings between VEs ($F(3, 57) = 38.042, p < .001^{**}, \eta^2 = 0.667$). Post-hoc tests revealed that the Calm VE elicited significantly higher calm ratings than both the Fear VE ($t = 9.142, p < .001^{**}, d = 3.029$) and the Sad VE ($t = 4.844, p < .001^{**}, d = 1.605$). However, there was no significant difference in calm ratings between the Happy VE and Calm VE ($t = -0.156, p = 0.876$). These findings partially support H2, as the Calm VE successfully induced significantly higher calm ratings than both negative valence VEs, but there was not a noticeable difference in calmness when compared to the Happy VE. Given the overlap between happy and calm ratings in the Happy and Calm VE, deeper analysis was carried out across VEs to determine further differences in affective ratings, specifically for emotions of positive valence but different arousal (excited, and content). A repeated measures ANOVA revealed that there was a significant difference in excited ratings across VEs ($F(3, 57) = 13.289, p < .001^{**}, \eta^2 = 0.412$). Notably, the Happy VE elicited significantly higher excited ratings than the Calm VE ($t = 2.710, p = 0.027^{*}, d = 0.678$). However, although a repeated measures ANOVA revealed differences in contentedness ratings across VEs ($F(2.628, 49.923) = 46.311, p < .001^{**}, \eta^2 = 0.709$), there was no significance between

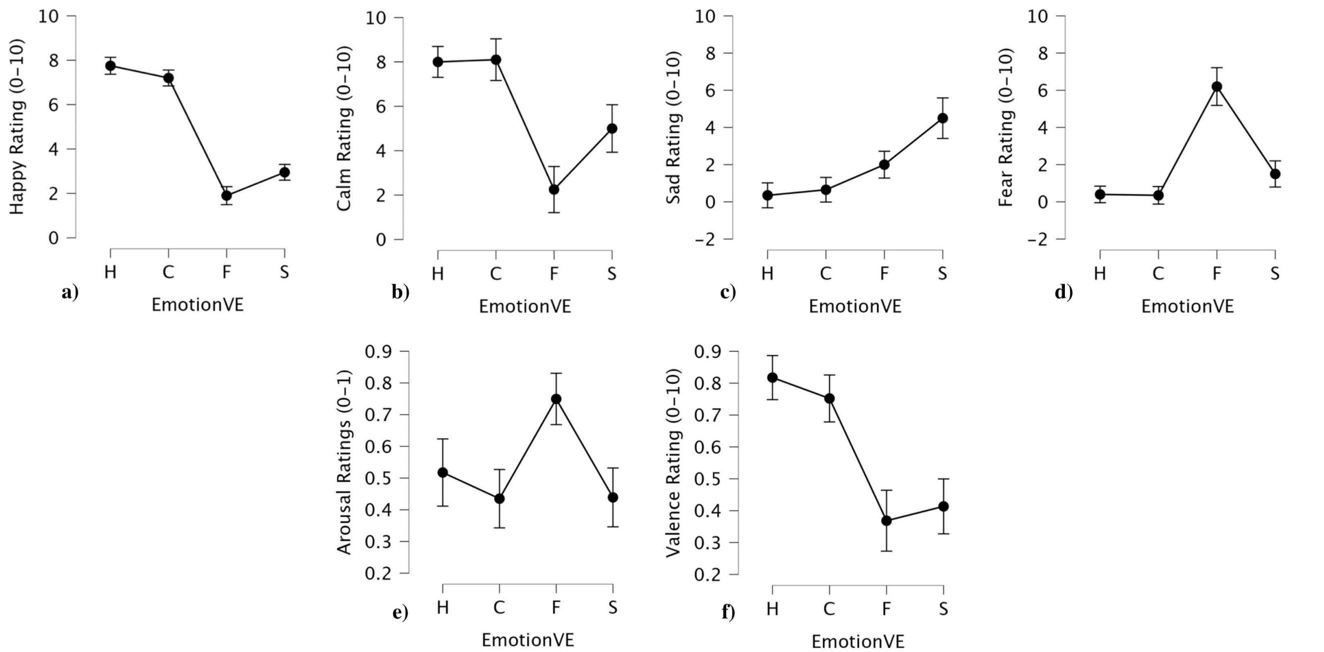

Figure 3: a) Affective ratings of happiness reported in all conditions, as manipulated through $Emotion_{VE}$. b) Affective ratings of calmness reported in all conditions, as manipulated through $Emotion_{VE}$. c) Affective ratings of sadness reported in all conditions, as manipulated through $Emotion_{VE}$. d) Affective ratings of fear reported in all conditions, as manipulated through $Emotion_{VE}$. e) and f) show affective ratings of arousal and valence, respectively, as manipulated through through $Emotion_{VE}$. Error bars represent confidence intervals on all 6 graphs.

contentedness ratings between the Happy VE and Calm VE ($t = 0.243, p = 0.809$). Overall, then, these results show a clear overlap between the elicited by both the Happy VE and Calm VE, even if the Happy VE was considered as more exciting.

5.1.3 Fear Ratings. The repeated-measures ANOVA revealed a significant main effect of $Emotion_{VE}$ on fear ratings between VEs ($F(1.735, 32.962) = 69.560, p < .001^{**}, \eta^2 = 0.785$). Post-hoc tests revealed that the Fear VE elicited significantly higher fear ratings than the Happy VE ($t = 12.321, p < .001^{**}, d = 3.579$), the Calm VE ($t = 12.427, p < .001^{**}, d = 3.610$), and the Sad VE ($t = 9.984, p < .001^{**}, d = 2.901$). These findings fully support H3, and it appears that the Fear VE was very successful in eliciting significantly higher levels of fear than the other affective VEs.

5.1.4 Sad Ratings. The repeated-measures ANOVA revealed a significant main effect of $Emotion_{VE}$ on sadness ratings between VEs ($F(1.808, 34.347) = 24.154, p < .001^{**}, \eta^2 = 0.560$). Post-hoc tests revealed that the Sad VE elicited significantly higher sadness ratings than the Happy VE ($t = 7.625, p < .001^{**}, d = 2.016$), the Calm VE ($t = -7.074, p < .001^{**}, d = 1.870$), and the Fear VE ($t = 4.593, p < .001^{**}, d = 1.214$). These findings fully support H4, showing that the Sad VE elicited significantly higher levels of sadness than the other affective VEs.

5.1.5 Valence Ratings. The repeated-measures ANOVA revealed a significant main effect of $Emotion_{VE}$ on valence ratings between VEs ($F(2.022, 38.421) = 34.557, p < .001^{**}, \eta^2 = 0.645$). Post-hoc tests revealed that the Happy VE elicited significantly more positive valence ratings than both the Sad VE ($t = 7.313, p < .001^{**}, d = 2.170$) and the Fear VE ($t = 8.128, p < .001^{**}, d = 2.411$). Similarly, the Calm VE also elicited significantly more positive valence ratings than the Sad VE ($t = 6.127, p < .001^{**}, d = 1.818$) and the Fear VE ($t = 6.942, p < .001^{**}, d = 2.060$). These findings fully support H5, showing that both the VEs designed to induce positive valence successfully elicited significantly higher positive valence than both VEs designed to induce lower (negative) valence.

5.1.6 Arousal Ratings. The repeated-measures ANOVA revealed a significant main effect of $Emotion_{VE}$ on arousal ratings between VEs ($F(3, 57) = 10.974, p < .001^{**}, \eta^2 = 0.366$). Post-hoc tests revealed that the Fear VE elicited significantly higher arousal ratings than both the Sad VE ($t = 4.921, p < .001^{**}, d = 1.288$) and the Calm VE ($t = 4.984, p < .001^{**}, d = 1.305$). However, there was no significant difference between arousal ratings between the Happy VE and the Sad VE ($t = 1.244, p = 0.589$) or between the Happy VE the Calm VE ($t = 1.308, p = 0.589$). These results only partially support H6, since only the Fear VE was successful in eliciting significantly more emotional arousal than the VEs designed to induce low arousal.

5.2 Comparison of Affective Ratings within Affective VEs

5.2.1 Happy VE. The repeated-measures ANOVA revealed significant differences between affective ratings in the Happy VE ($F(2.206, 41.906) = 95.217, p < .001^{**}, \eta^2 = 0.834$). Post-hoc tests revealed that the Happy VE elicited significantly higher happiness ratings than both sadness ratings ($t = 14.276, p < .001^{**}, d = 4.488$) and fear ratings ($t = 14.279, p < .001^{**}, d = 4.458$). Notably, happy ratings were also significantly higher than ratings for boredom ($t = 10.417, p < .001^{**}, d = 3.275$) and stress ($t = 13.793, p < .001^{**}, d = 4.336$). However, there was no significant difference between happiness ratings and calm ratings ($t = -0.482, p = 1.000$). These findings do not fully support H7, since it is clear that the Happy VE induced relatively similar levels of both happiness and calmness.

5.2.2 Calm VE. The repeated-measures ANOVA revealed significant differences between affective ratings in the Calm VE ($F(2.681, 50.931) = 74.706, p < .001^{**}, \eta^2 = 0.797$). Post-hoc tests revealed that the Calm VE elicited significantly higher calm ratings than both sadness ratings ($t = 13.282, p < .001^{**}, d = 4.108$) and fear ratings ($t = 13.817, p < .001^{**}, d = 4.274$). Calmness ratings were also significantly higher when compared to affective ratings of lower valence, such as stress ($t = 13.282, p < .001^{**}, d = 4.108$) and boredom ($t = 10.875, p < .001^{**}, d = 3.364$). However, there was no significant difference between calm ratings and happiness ratings ($t = -1.605, p = 0.666$). Similar to the Happy VE, these findings show that the Calm VE elicited dominant emotions of both happiness and calmness, which does not support H8.

5.2.3 Fear VE. The repeated-measures ANOVA revealed significant differences between affective ratings in the Fear VE ($F(2.547, 48.392) = 10.416, p < .001^{**}, \eta^2 = 0.354$). Post-hoc tests revealed that the Fear VE elicited significantly higher fear ratings than happy ratings ($t = 5.761, p < .001^{**}, d = 1.765$), calm ratings ($t = 5.292, p < .001^{**}, d = 1.621$), and sad ratings ($t = 5.627, p < .001^{**}, d = 1.724$). Fear ratings were also significantly higher than the affective ratings of other emotions considered to be of lower arousal or higher valence, such as boredom ($t = 5.694, p < .001^{**}, d = 1.745$), contentment ($t = 5.292, p < .001^{**}, d = 1.621$), and excitement ($t = 4.153, p = .001^{*}, d = 1.273$). Moreover, these results suggest that the dominant emotion induced in the Fear VE was one of fear, fully supporting H9.

5.2.4 Sad VE. The repeated-measures ANOVA revealed significant differences between affective ratings in the Sad VE ($F(3.096, 58.821) = 8.301, p < .001^{**}, \eta^2 = 0.304$). Post-hoc tests revealed that revealed that the Sad VE elicited significantly higher sadness ratings than emotions typically of high arousal, such as fear ($t = 4.379, p < .001^{**}, d = 1.333$), stress ($t = 4.087, p = .002^{*}, d = 1.244$), and excitement ($t = 4.598, p = .001^{**}, d = 1.399$). However, sadness ratings were not significantly higher than happy ratings ($t = 2.263, p = 0.329$), calm ratings ($t = -0.730, p = 1.000$), or ratings for boredom ($t = 1.606, p = 0.966$). Overall, these results results reveal that the Sad VE induced the most overlap in emotion among participants. However, these emotions were typically of low arousal, inducing dominant emotions of calmness, sadness and boredom. These results do not fully support H10.

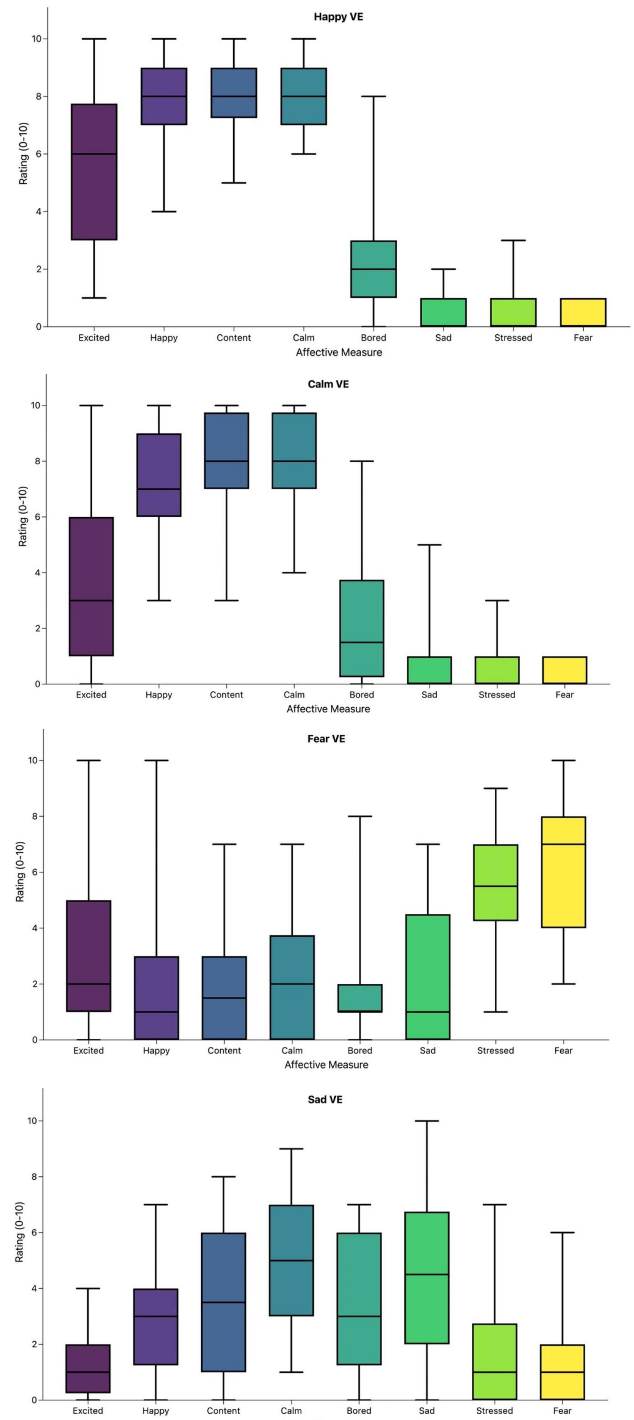

Figure 4: Box plots that show the measured affective ratings (excitement, happy, content, calm, bored, sad, stress, and fear) across each of the four designed VEs: Happy, Calm, Fear and Sad

5.3 Emotion and Self-Presence

5.3.1 Happy VE and Fear VE. A multiple linear regression with enter method was used to predict self-presence in the Happy VE from its interaction with affective ratings for calm and happiness in this VE, given that these were the dominant emotions experienced. The model revealed no statistically significant amount of variance in self-presence due to these chosen predictors ($F(2,17) = 2.216, p = 0.387, R^2 = 0.207$, *Adjusted* $R^2 = 0.133$). A second multiple linear regression with enter method was used to predict self-presence in the Fear VE from its interaction with the affective ratings for fear and stress in this VE. The model revealed no statistically significant amount of variance in self-presence due to these chosen predictors ($F(2,17) = 0.502, p = 0.614, R^2 = 0.056$, *Adjusted* $R^2 = -0.055$). These results suggest that increased happiness and fear were not predictors for self-presence. These results do not support H11.

5.3.2 Calm VE and Sad VE. A third multiple linear regression with enter method was used to predict self-presence in the Calm VE also based on its interaction with affective ratings for calm and happiness. Similarly, the model revealed no statistically significant amount of variance in self-presence due to these predictors ($F(2,17) = 1.758, p = 0.202, R^2 = 0.171$, *Adjusted* $R^2 = 0.074$). Lastly, a fourth multiple linear regression with enter method was used to predict self-presence in the Sad VE from its interaction with the affective ratings for sadness, calmness, and boredom within this VE. The model explained a statistically significant amount of variance in self-presence ($F(3,16) = 3.538, p = 0.039^{*}, R^2 = 0.399$, *Adjusted* $R^2 = 0.286$). This indicates that approximately 39.9% of the variance in self-presence in the Sad VE can be explained by the affective ratings of boredom, calm and sadness that were given in this VE. However, the affective rating for sadness was the only significant predictor ($\beta = 0.491, t = 2.449, p = .026^{*}$). These results do not support, and even partly contradict, H12.

6 DISCUSSION

Our study investigated the ways in which we can systematically induce different emotions within a VE, in order to better explore the connection between embodiment and emotion across a range of emotions with different levels of valence and arousal. In this section we discuss our findings for each research question while highlighting future work where appropriate.

6.1 RQ1: Affective VE Design

The design of the VEs were influenced by existing literature that describes how to elicit emotion through manipulations of visual setting, sound and environmental objects [24, 28, 34, 109]. Our results show varying levels of success in strongly eliciting the intended emotion within each VE. Particularly, the Fear VE was highly effective in eliciting the desired emotion. This is evidenced by significantly higher fear ratings in comparison to the other VEs, as well as significantly higher fear ratings when compared to the positive valence or low arousal affective measures within the VE itself. Thus, the results highly validate the design choices made in eliciting fear within users. However, while the Happy and Calm VE successfully induced high positive valence, there was no significant difference in calmness and happiness ratings between, and within, either VE. This is clearly demonstrated visually by figure 4. This was likely due to the fact that happy VE did not induce high emotional arousal. That is, while the Happy VE elicited strong levels of happiness, it was not exciting and intense enough to also reduce feelings of calmness. Interestingly, previous work has similarly found that it is more difficult to induce highly arousing positive emotions than highly arousing negative emotions solely through visual appearance and sound alone [28].

Moreover, many note that strong emotional intensity can often be induced in virtual worlds through interaction with agents, animated characters or objects that the user can interact with [51, 54, 68]. Although human agents would introduce too many confounding variables on emotion, as previously mentioned, multiple studies have validated an animal, such as a jumping dog, as a means to elicit a dominant emotion of happiness within a VE [58]. Inclusion of a similar agent could make the Happy VE more intense, and hence reduce the experience of calmness. However, being able to distinguish more clearly between happiness and calmness in the Calm VE appears to present a more interesting problem. This is because high levels of calmness often co-occur with increased levels of happiness, given that these emotions, though differing in emotional arousal, are still very similar to each other [96]. Nevertheless, the Happy VE, Fear VE, and Calm VE all successfully elicited high ratings for the desired affective measures, despite the mentioned overlap. This is impressive given that users within virtual environment were afforded no interaction, and given no goal within the environment. Therefore, these results highly encourage the use of virtual environment design as a way to evoke strong emotion when studying embodiment and emotion in the future, rather than making use alternative mood production procedures that may evoke relatively low emotionally intensity [40].

While the results reveal that the Sad VE elicited significantly more sadness than the other VEs, when considering each VE's ability to induce high ratings for the intended emotion the Sad VE induced comparatively low ratings of sadness. The Sad VE also appeared to induce the most overlap between different affective measures, particularly for calmness, boredom and sadness, with no significant difference between any of these measures. Considering specific design elements, many studies have noted that the rain can induce relaxation and positive valence, which could have contributed to the similar levels of calmness within the Sad VE [33]. Nevertheless, without the rain the Sad VE would have been highly static, and as a result may have increased boredom. Similar to the Happy VE, the introduction of an agent may be highly beneficial in distinguishing between sadness and other emotions. Through the introduction of an agent, such as a whimpering dog, the environment could more clearly create an atmosphere of gloom and misery, as is recommended when inducing sadness [8, 28, 33].

Overall, this study joins a limited body of work that aims to induce varied emotions through highly controlled manipulations of a VE [96]. Existing research often focuses on the creation of drastically different VEs to evoke different levels of arousal and valence [28]. While still highly valuable to VR developers, these approaches offer less insight into the ways in which we can study different emotions in controlled conditions in VR, where it is essential to minimise possible confounding variables.

6.2 RQ2 and RQ3: Self Presence and Emotion

Self-presence was not predicted by scores for happiness, calmness or fear when this was the dominant emotion experienced within the VE. However, in the Sad VE, user sadness was shown to be a predictor of self-presence. These findings suggest that sadness may contribute to self-presence, especially when the user does not have a body in VR. This builds upon previous findings that discuss high arousal emotions being key to the formation of self-presence [57], as these results also suggest that user sadness can affect their self-presence too. This is particularly interesting, and further research would be required to explore these effects further, given that role of different emotions, specifically sadness, in self-presence has received little attention. However, these results indicate that negative emotional valence may contribution to self-presence in VR. This may reflect a possible role of negative valence emotion in embodiment, given that previous studies have demonstrated how positive valence positively correlates with embodiment[82]. However, to study this in depth would require participants to virtually embody an avatar within VR.

7 LIMITATIONS AND FUTURE WORK

We acknowledge that there are limitations to this work. One limitation appears from the study using a within-participants design, which meant that participant responses may have been influenced by the emotion elicited by the previous VE. We attempted to mitigate this through counterbalancing. The time spent answering questionnaires after each experience would have also reduced these effects given that these periods would not have been emotionally intense, and placed the participants back within an emotionally neutral state before experiencing the next VE. Another limitation appears from the fact that, although we successfully show that manipulation of sound design, colour, and environmental objects can intensely elicit different target emotions, this may be limited to a users only spending a short duration of time within the VE. Particularly, users were immersed for only 90 seconds in each VE, as we suspected that a longer time would have resulted in boredom given that no interaction was afforded. Future work should seek to add appropriate user agency that would result in participants being able to spend longer in the VE without feeling bored.

Also, while we can show that the combination of the used design elements contribute to the intense elicitation of most of the target emotions, we can not distinguish between the specific design elements that contributed most to this elicitation. It would be highly interesting to understand the specific design choices that contribute most in eliciting each emotion. For example, [109], which helped guide our development of the affective VEs, systematically investigates different guidelines for evoking positive and negative emotions. They find that using signs of past violence, through blood stains present in a VE, is highly effective in inducing negative emotions, while including dense fog in the environment is not as effective. Further work should seek to also separate guidelines that also differentiate by emotional arousal, given that this appears to have received less difficult challenge currently.

With respect to embodiment and emotion, since participants were not embodied in virtual avatars in the experiment, another limitation of this project is that we can only draw inferences of the possible relationship through self-presence. A clear avenue for future work is to investigate questions such as RQ2 and RQ3 using environments similar to the ones created in this project, while participants are embodied in virtual avatars. Given that an increasing number of users will be embodying photorealistic, personalised avatars in VR [101] future work should seek to explore the interaction between the embodiment of such avatars with the user's affective state, as well as with generic avatars that bare little resemblance to the user.

8 IMPACT

The main contribution of our work is through the manipulations of each VE, serving as guidelines that can be taken and applied to many applications in which intense emotion elicitation is desired. Given that VR is still a relatively new medium, such an insight is valuable to developers still learning how to best use VR to engage their users [105]. These environments also give valuable guidelines to researchers wanting to study a variety of different emotions under controlled laboratory conditions. Through the design choices highlighted in the creation of the affective VEs, researchers can elicit intense emotional reactions without using traditional mood production procedures, such as pictures, within simpler VEs that are less representative of modern VR worlds.

9 CONCLUSION

In conclusion, we developed a set of four affective VEs systematical designed to elicit different target emotions. Overall, this study provides evidence that we can elicit intense, yet specific, emotions within virtual environments without the use of traditional mood induction procedures. We also found that user sadness may contribute to self-presence within VR. The results of this study suggest that emotions of high arousal may not predict self-presence, specifically when the user is not embodied. Nevertheless, this study provides a clear way to thoroughly explore this relationship through the use of virtual environments as a powerful method of mood induction.

10 INDIVIDUAL CONTRIBUTION

As the affective VEs were developed with another student, the following contribution percentages highlight my level of involvement in the development of each VE: Fear VE (60%), Happy VE (50%), Sad VE (40%), Calm VE (50%). A more detailed breakdown including each feature can be found in Appendix A.

Word Count: 9753

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A AFFECTIVE VIRTUAL ENVIRONMENTS CONTRIBUTION

Aspect	Fear VE
Weather Conditions	**Black skybox simulating night.**
Lighting	Majority of lighting is artificial, flickering, coming from lamps.
Room Appearance	**Dark grey, dirty walls with bloodied handprints and splatters.**
	Dirty wooden floor with blood splatters.
	Dirty wooden furniture.
	Soiled carpet with stripes against floorboard direction.
	Worn, dirty bedding.
	Static, dirty ceiling fan.
	Blinds down, restricting view from outside.
Outside Appearance	**Restricted view to outside through shutters.**
Sound Design	**Owl hooting.**
	Music playing from radio
Overall Contribution (%)	60%

Figure 5: Fear VE Contribution - The features highlighted in bold represent the features I implemented.

Aspect	Sad VE
Weather Conditions	Gray skybox, fog, heavy rainfall
Lighting	Dim, unsaturated lighting, with slight blue hue.
Room Appearance	**Dark grey, dirty walls. Visible mould and cracks along walls.**
	Dirty wooden floor.
	Dirty wooden furniture.
	Soiled carpet with stripes against floorboard direction.
	Worn, dirty bedding.
	Static ceiling fan.
	Dirty open curtains, clear view to outside.
Outside Appearance	Minimal nature, trees are bare and dying.
Sound Design	**Sound of heavy rain.**
	Music playing from radio
Overall Contribution (%)	40%

Figure 6: Sad VE Contribution - The features highlighted in bold represent the features I implemented.

Aspect	Happy VE
Weather Conditions	Light blue skybox simulating early afternoon with high sun position
Lighting	**Bright sunlight through windows, simulating sunny day.**
Room Appearance	Bright yellow feature wall, other walls are off-white.
	Clean wooden floor.
	Clean white furniture.
	Clean, plain carpet.
	Pastel green bedding.
	Rapid rotating ceiling fan.
	No curtains, clear view to outside.
	Green plants and bright red and yellow flowers.
Outside Appearance	Abundant greenery, with yellow, red and pink flowers, swaying.
Sound Design	**Plenty of birds heard loudly chirping from outside.**
	Music playing from radio
Overall Contribution (%)	50%

Figure 7: Happy VE Contribution - The features highlighted in bold represent the features I implemented.

Aspect	Calm VE
Weather Conditions	Blue skybox simulating late afternoon with lower sun position.
Lighting	Low-intensity, warmer sunlight, and warm white internal lighting.
Room Appearance	**Grey feature wall, off-white walls.**
	Clean wooden floor.
	Clean, white furniture.
	Gray, clean carpet.
	White bedding, black horizontal stripes.
	Slowly rotating ceiling fan.
	No curtains, view to outside.
	Green plants as well as white and blue flowers indoors.
Outside Appearance	Abundant greenery, with blue and white flowers, swaying.
Sound Design	**Birds heard quietly chirping from outside.**
	Music playing from radio
Overall Contribution (%)	50%

Figure 8: Calm VE Contribution - The features highlighted in bold represent the features I implemented.