The Impact of Interaction and Agency on Eliciting Fear in Virtual Reality

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ABSTRACT

Emotion elicitation in virtual reality is a pertinent field of study for exposure therapy in psychology. Virtual environments (VEs) often use multiple scripted visual, audio or tactile cues to induce emotions during these experiments. Interaction plays a large role in modern VR technology, and it is surprising that there is a lack of studies that relate interaction and its ability to elicit emotion. This review focuses on research that has been conducted in relation to fear, and the degree to which their virtual environments heighten immersion and evoke fear in users. We investigate how we define immersion as the underlying link to fear response, and how to measure abstract concepts like immersion and emotion in users. The psychology of fear is investigated and associated with non-interactive and interactive VEs, which are then contrasted and discussed. We then introduce the topic of agency, and its psychological relation to interaction, among the prospects of agency as the leading component in a VE that evokes a fear response in users. It is found that a questionnaire with associated number scales and physiological measurements on the autonomic nervous system (ANS) of participants are sufficient in measuring immersion and fear respectively. Methods used in both types of VEs are effective in eliciting emotion through combinations of tactile, visual and audio cues, and in interactive environments a loss of control presents an even higher level of fear elicitation. The lack of research in this topic creates a difficult climate to properly evaluate interaction, agency and their link to eliciting fear, but remains a promising field of research for future studies.

CCS CONCEPTS

• Computing methodologies -> Computer graphics -> Graphics systems and interfaces -> Virtual reality

KEYWORDS

Virtual Reality, Immersion, Interaction, Agency, Fear, Autonomic nervous system, Scripted Cues.

1 Introduction

VR has long been concluded as an effective medium for emotion elicitation in both therapy – to help individuals overcome certain emotional hardships – and as a form of entertainment in the gaming industry by use of different emotion arousal techniques in virtual environments. Research in this field often refers to the philosophical concepts of presence and immersion, defined by Slater [1], as a driving factor to evoke emotions in a user. For the purposes of this review, we define and combine both concepts to simply be referred to as immersion, a sense of feeling if one is "*really there*" in the virtual environment, to avoid inconsistencies across studies that refer to one or the other. Studies indicate that immersion is directly proportional to emotional response, such that when immersion in the VE is heightened, so is the users' emotion [4, 5, 6]. For the VE to elevate immersion in the user, scripted visual cues in scenes designed to specifically target certain emotions are used – which is no longer a novel approach in fear elicitation.

A largely unexplored branch of this field lies in interaction in the VE as a technique to evoke fear more effectively than traditional scripted cues. Interaction with both virtual agents in the VE and the environment itself around the user aims to present a unique argument that interaction could be the most pertinent method of evoking fear and other emotions in VR. The existing studies which show that interaction increases immersion in the VR experience could further pose a question on the concept of control and agency - and if allowing users freedom of control in the environment could result in a greater or lesser response of fear. Although control is not explicitly explored in the papers presented in this review, we attempt to extract a level of control used in studies that do use interaction as a medium for evoking fear – and if this control does heighten immersion and thus a fear response. Understanding the psychological implications of interaction as compared to simple arousal triggers in the VE could result in systems that treat mental health issues that encompass fear and anxiety in a more effective and user-controlled manner.

When developing a system in VR that is specifically designed to evoke fear, there is a need to formally define emotions and, importantly, define ways of measuring such emotions. In conjunction with the psychology of fear and the computer science sphere of VR, the theory of interaction and its effect on the mind must be explored to quantify emotion. Participants who are exposed to VEs and virtual entities should be examined in terms of past and present psychological and physical health to produce accurate results before such studies occur. The two methods for eliciting fear that currently exist - scripted visual cues and interaction with VREs - are closely examined, contrasted and discussed in relation to control. Interaction with the environment, virtual agents or both, and finally supernatural experiences in the VE, are also provoked to gain an understanding their pertinence in the field – and if overall interaction in VEs is beneficial in developing therapeutic experiences in users.

2 Measuring Immersion and Emotion

For the purpose of this review, to avoid confusion set by an extremely varied use in research of the two distinct definitions defined by Slater, presence and immersion is categorized as immersion. Presence is fundamentally "the sense of being" in a virtual environment or rather feeling as if you are *really there* [1]. It is the subjective experience of VR; one where, if the user is very present in the virtual environment, should feel more engaged in the virtual world rather than the physical. Since this inherits the subjective sense of the virtual world, presence is often studied in relation to evoking emotion. Immersion represents the characteristics of the technology used in the VR experience and how it affects the illusion of being in a real environment [1]. This is an objective view; governed by how sophisticated the hardware is that drives the virtual world. To portray the results of studies in this review, we follow Mütterlein's definition of immersion that correlates both terms. Immersion is a subjective psychological experience that is influenced or "restricted" by the technological capability of the VR system [2]. Therefore, in papers that correlate presence or immersion to evoking emotion, these papers simply heighten immersion rather than either presence or immersion. This creates a better understanding and unit of measuring the impact of the techniques used in papers to elicit emotion.

Intuitively, immersion is correlated to emotion. Without looking at past studies, one could assume if the user is more immersed, they experience more feeling. This is consistent with past research [8, 9, 10]. Measuring immersion often involves questionnaires that ask the user to what extent they were present or immersed in the experience, which are then, but not always, quantified into a number range. Peperkorn et al. [7] found that this method of questionnaire and scale is effective and sensitive to acute changes in measuring presence. Hvass et al. [9] opts to use the Slater-Usoh-Steed (SUS) questionnaire [10] that assesses presence based on three questions:

"(1) The subject's sense of 'being there' - a direct attempt to record the overall psychological state with respect to an environment;

(2) The extent to which, while immersed in the VE, it becomes more "real or present" than everyday reality;

(3) The 'locality', that is the extent to which the VE is thought of as a "place" that was visited rather than just as a set of images."

They then use their own scale of 1-7 for participants to answer these questions. Since most papers in this review use varied methods, my preferred method is simply a questionnaire with a number correlation.

While emotion is too an abstract human concept, there have been varied approaches to measuring and correlating data for feeling emotions. Viewing emotions in themselves are categorized by Peperkorn et al. [7] into two distinct perspectives: dimensional and discrete. These categories can be simplified by associating valence (state of pleasure) and arousal (state of surprise) to the discrete emotion (e.g. Happy, sad, angry, scared). For example, a user who is attacked by a monster in a virtual world can describe an encounter as a displeasuring (low valence), surprising (high arousal) and scary experience. Hyass et al. [9] uses this approach with an associated number and reassures its reliability. In contrast, Peperkorn et al. [8] simply uses a number range from 0 – 100 to record a user's feeling of fear. There is also use of the Positive and Negative Affect Schedule [11], designed by Waston in 1988 [13], which comprises of 10 positive and 10 negative words that can be used to describe an experience. In this review, my preferred method of measuring emotion would be to scale dimensional and discrete emotion as Hyass et al. [9] did.

Non-interactive VEs [7, 8, 12] all use scripted visual cues or present the user to simply exist virtually in the environment to elicit fear. Methods used to measure immersion and emotion in VEs that use interaction could slightly differ from that of visual cues and non-interactive VEs. For example, Mütterlein [2] introduced a novel approach in which he collaborated with a VR center to not only provide a widespread diversity of people for data collection, but also present a unique questionnaire that correlates immersion, presence and interactivity. Chen et al. [14] uses specialized pupil eye tracking and an Arduino setup to capture the change in pupil dilation of the user in the VE. Significant changes in pupil dilation relate to the level of emotion experienced in the VE, and interaction among other methods are used to evoke the emotions. The study could suggest if there is a change in dilation of the pupil, then the user must be eliciting an emotion and with a certain intensity. Both methods, in contrast, represent two entirely different techniques. The only reliable explanation on what method to use to record such abstract data, is develop a technique that is similar to existing methods and attempt to analyze effectiveness as compared to other studies.

While questionnaires with associated units for immersion and dimensional emotion scales of measurement prove to be reliable, fear as an emotion and how to measure fear specifically has also been studied in the past. Fear measurement can involve examining of the autonomic nervous system (ANS) as the driver to develop accurate results. The ANS is split into two sub-categories: the parasympathetic and sympathetic nervous systems. Parasympathetic stimulates the "rest and digest" body response such that heartbeat slows, pupils constrict, and stomach activity is stimulated. Sympathetic is the onset of the "flight or flight" response where heartbeat increases, pupils dilate, and airways relax. Thomson et al. [15] uses this method in a VR study, and develops strong evidence that fear produced a sympathetic activation in subjects, and a withdrawal in parasympathetic activity. To measure such responses, and conclude that fear does engage the sympathetic ANS, participants were fitted with electrodes and respiration belts. ECG (Electrocardiography) measure the electrical signals of the heart through placement of the electrodes on the skin. These signals can then be recorded and processed by pattern recognition software or algorithms to produce a trend that explains distinct heart activity.

Since the sympathetic nervous system engages bodily responses as mentioned above, fear study should rely on this use of physiological measurement (e.g. electrodes [15], pupil tracking [14]) to accurately define a fear response. This is further reliable as, since emotion is abstract, changes in the body that can be accurately examined and provide results, create concrete evidence in physical fear response, and thus can correlate to psychological fear response.

3 Methods

3.1 Psychology of Fear

To fully understand how fear is evoked in virtual environments, and why scripted cues or interactivity in these virtual worlds are designed in specific ways, investigating the underlying psychology of fear is required. While we know that fear can be recorded in individuals through oral or physical feedback in response to being exposed to fear environments, there are reasons to develop methods in certain ways as opposed to others to retrieve this feedback and assess its reliability. These reasons are influenced by factors such as our brain development in evolutionary psychology and past trauma.

The evolutionary development of fear in humans is rooted in the innate struggle of “survival of the fittest,” and its underlying process of natural selection. Threats from predation and the retention of positive characteristics from successful responses to survival challenges – or *adaptions* [3] – are carried through ancestral genes, and fear, or rather what makes us scared, is predefined through these adaptions [4]. Cosmides and Tooby [3] use the example of being alone at night where humans and ancestors perceive the presence of other humans or predators; the fear of being “stalked.” This cues a mental response and behavioral adaption of an increased attention to possible threats, a need to protect yourself, and heightened awareness of the environment. In a virtual environment, dark settings and presenting the user as alone are often used in conjunction with threats - as threats are inherently the cause of feeling scared - to simulate this response of a need to protect one’s self, either through weapons [20], or running away from a monster, such as in *Alien: Isolation* (The Creative Assembly, 2014). Audio is similar in this context too, where evolutionary processing of fear-relevant sounds is presented as a threat, and humans instinctively feel a need to survive [6]. These sounds are either nonlinear, where sound wave frequency exceeds the range of instruments or vocal cords (e.g. human screams), abrupt (e.g. door slam), or ominous (e.g. footsteps when an entity cannot be seen). All these sounds represent the core motif of the fear of the unknown and the perception of that which is not physically present. To further stimulate this fear of the unknown, VEs also use combinations of visual scripted cues such as “jump scares” [12] intended to aggravate a user’s survival behavioral adaption with a dark setting for optimal fear response.

While evolutionary factors suggest methods of evoking more fear, examining the psychological health of the subject before experimentation is imperative to produce objective results when measuring fear. Past trauma and PTSD (post-traumatic stress disorder) are important conditions that require investigation, as sufferers subjected to cues in the VE relating to their trauma can endanger the participant and skew results. Trauma can cause excessive fear responses when the participant is exposed to cues resembling the original traumatic event, a large amount of time after the event occurred [5]. Such cases should be avoided, and those who develop methods used to elicit fear in VEs should understand this possibility before exposure to subjects.

These factors contribute to the successful implementation of mechanisms in VEs that are designed to evoke fear in VR and are found in both non-interactive and interactive environments.

3.2 Non-Interactive VEs and Scripted Cues

Interactivity in VEs is not a saturated topic of discussion in emotion elicitation in VR, rather VEs with scripted cues are abundant in research. Scripted visual cues, one where the virtual entities and objects in the VE are scripted to act on the user during their experience (e.g. a door creak), is a technique that is effective in evoking emotion, and could be considered easier to develop than interactive components in VEs. The VEs presented in this section make use of scripted visual cues or VEs with non-interactive elements in their studies to investigate levels of immersion, emotion or both. We attempt to extract the software and hardware components of the VR experiences to further evaluate the effect of this method, and later contrast this effect with that of VEs with interactive elements. An expected analysis of non-interactive VEs would simply be that these environments would require stronger hardware to induce realism, immersion and thus emotion, rather than software components.

Peperkorn et al. [8] conducted an experiment designed to elicit fear by use of tactile visual cues outside of virtual reality. Participants were presented with a virtual spider that lay on the back of a virtual hand, mimicking that of reality where there was no spider. Without an indication, experimenters placed a dummy spider on the participants’ hands and recorded responses. Such placement of the spider was carefully chosen to mimic that of the virtual world. This was compared against just the isolated virtual environment and the virtual spider, without the dummy. Hardware used in the experiment was a Z800 3Dvisor commercial VR system developed post 2005. The study was conducted in 2013, and such a VR system is older than the currently existing Oculus Development Kit at the time which yielded a much higher resolution-per-eye than the Z800s 800 x 600 resolution. While it can be assumed that higher pixel density yields more realism, and thus more immersion, the experiment only refers to the significance of phobic versus non-phobic participants and what method was the most effective. Fear and immersion ratings were the highest for phobic participants in the study and had the greatest positive correlation. Immersion was highest in combined tactile and visual cues, which indicates tactile cues can result in evoking a higher fear response.

Another spider-fear related experiment [7] focused heavily on stereoscopy, contextually the illusion of depth in the VE, and found that participants exposed to higher stereoscopy resulted in higher levels of immersion. A Powerwall, a large, high resolution display, was used as the virtual environment. While this experiment is not virtual reality in the sense of an HMD (head-mounted display), the Powerwall was placed in front of the participant close enough to be immersed in a FOV that covers the participant's entire vision. The graphical fidelity of a Powerwall, since it is further away than HMD lens is to an eye, has an extremely high resolution, and 3D stereoscopy on Powerwall mimics a 3D virtual world in a headset. Useful data from this study is that of stereoscopy, and that greater illusion of depth, combined with high-resolution displays, results in higher immersion and thus a fear response.

While these two experiments are slightly more linear – both cases involved simply viewing a virtual object with no freedom of choice, movement or interaction – Hyass et al. [9] attempt to present an environment that integrates all three of these notions. Participants used an HMD, the Oculus Development Kit 2 (DK2), which supports a higher resolution pixel density and resembles that of an HTC Vive, a modern VR system that is widely used in studies and games for an immersive experience. Participants were given tasks to complete in a virtual world where they could walk around a virtual environment and freely move their heads to explore the environment. The study focuses on realism as a driver for fear response and immersion. To modify the sense of realism, the texture resolution and polygon count of models were adjusted, and results were recorded. Auditory stimuli involved auditory cues and ambient noise that intended to scare the user (e.g. radio static, echoing footsteps and refrigerator hums). Visual scripted cues such as a door slam were also triggered at certain points through the experiment. The environment is dark, atmospheric and intended to feel eerie. Higher geometric realism – where models were mapped with a higher polygon count and higher texture resolution – resulted in increased immersion and fear elicitation.

Wu, Weng and Xue [12] expand on this idea of an open and immersive environment, and introduces four scenes designed to evoke certain emotions, combined with a powerful hardware set designed to develop the best sense of immersion possible. Participants are required to be seated in a system that contains an HMD and a seat that allows air, motion and audio stimuli. Users could not interact with the scene and are simply taken through the scenes without control of where to explore in the VE. The camera that pans through each scene is at eye-level to the participant. The fear scene is presented with four different types: imaginary, unknown, threatened and height.

Each scene contained different scenarios with different scripted cues and stimuli:

Imaginary moved through a dark corridor with ambient imminent terror music, meant to develop a fear of what is to come. Sounds included eerie background noise, approaching footsteps and slamming doors. Unknown moved through the same corridor, but various scripted visual and audio stimuli such as rats, zombies and crows would suddenly appear in front of the user. The users' seat would also jerk or sweep under the users' feet to induce a sense of realism. In threatened, virtual entities such as ghosts and zombies would either appear or run towards the observer. Finally, in the height scene, the observer falls down an endless tunnel, and the seat controlled the user as they tilted around in the scene.

It was found that visual stimuli are more effective in evoking emotion than auditory and tactile, while all three stimuli developed a higher sense of immersion for the participant and designing an environment that combines all components increases a sense of reality.

These studies were all effective in verifying that tactile, visual and audio cues, along with the design of the environment contribute to a level of immersion and fear response in users. However, none indicate that there are some concrete biological responses in participants that affect immersion. Hidaka and Kobayashi [16] also use various scenes to evoke five different emotions, including fear. Heartbeat, skin temperature and breathing rates were analyzed against use of a flat display versus an HMD for emotional correlation. The terms Effectiveness, Efficiency, Satisfaction, Environmental setting and Learnability on a 1-5 scale were used for user evaluation on design of the VEs. But it was found that VR motion sickness and a small sample size skewed results. Both methods found that emotion is successfully elicited through visual and audio stimuli, and an HMD does heighten these emotional responses, but VR sickness caused anomalies in biological response and evaluation data (e.g. users with motion sickness caused changes in heartbeat and skin temperature, and rated satisfaction as lower which is intended for anxiety and stress levels.).

Perhaps the most novel interactivity study involves pupil dilation as a means of measuring emotional impact of stimuli and interactivity in VEs [14]. Advanced eye-tracking hardware and software is used by attaching photo and eye tracker sensors to the inside of an HTC Vive headset, and accurately record the change in pupil dilation throughout a participant experience with five different emotive scenes. The user is placed in a safari trip, where they are just able to move their heads freely and observe animals as the vehicle drives through a scripted route. There is a heart that visually beats on the UI of the display, which the user can always see. When a significant event occurs, the heart will visually beat and provide haptic feedback to the HTC Vive controllers, which the participants are holding during the experience. The fear scene is one where a T-rex sprints towards the observer and forces a surprising and fearful reaction from the user. It was found that haptic-visual cues caused the most change in pupil dilation, and thus evoked more fear. What is interesting is that presence or immersion was not investigated, as pupil dilation was sufficient enough to provide what sort of cues were significant in evoking emotion.

The methods of eliciting emotion, while all containing VEs that are non-interactive and provoke users through scripted visual, audio and tactile cues, are effective in developing a heightened sense of immersion and thus a better fear response. These cues could mimic that of real fear-inducing entities such as spiders and supernatural creatures, sounds that have a psychological association with fear in the user, and visual cues that are meant surprise and induce a frightening experience. Hardware-related fidelity, such as HMD resolution per-eye, stereoscopy, polygon count and texture resolution on models all contribute to realism and immersion, which contributes to eliciting fear effectively.

3.3 Interactive VEs

It is evident that non-interactive VEs can elicit fear if constructed properly and accompanied by technologies that enhance the experience. A largely unexplored field of study is one where fear and immersion is investigated in relation to interactivity, and if interactivity in a VE could develop a fear response on unprecedented levels: where immersion is comparatively higher in these VEs than non-interactive VEs. In this section we attempt to only investigate if the interaction element presented in relevant studies are effective in evoking fear and heightening immersion, more so than traditional methods of assorted cues and realism. It is expected that interactivity will not only do this but also produce novel psychological significance in participants in the study of fear elicitation. It would then further be useful to develop the underlying component of interactivity that does make eliciting emotion easier: a sense of control and what control means psychologically to the observer in a VE.

Mütterlein [2] produced an explorative study that aimed to link telepresence – states of presence reached through a medium [17], interactivity, immersion and satisfaction. The study was successful, having a large sample size and partnership with an often-busy VR center. Participants were presented with two VR experiences, each with varying levels of interactivity. Since the purpose of this section remains to investigate interactivity, we outline one of experiences and what their interactive elements are.

“The body VR” is a VR experience where users are placed in a lab where one can interact with the anatomy of the body [18]. The latter uses hand tracking with controllers linked to the HMD, which allow manipulation of various elements such as choosing which layer of an MRI to view. Another is placing your hand through the model of a body and observing different layers and internal organs of the body. This is generally associated with a panel alongside the model that allows the user to change colours, lighting and surface rendering of the model. While this is not intended to elicit fear or any emotion, Mütterlein found that this sort of hand representation and directly manipulating objects in the world has a positive influence on immersion. Users were found to be more immersed in the environment if they were able to interact with the VE.

Immersion directly influences emotion, as proved by the many studies that find this link in generally non-interactive VEs. Due to the lack of research on the correlation between immersion, interactivity and fear in interactive VEs, there is a need to find research that simply uses interactivity in the VR experience that contributes to fear. The gaming industry of VR is pertinent in this regard. Game developers provide entertainment by integrating fear into horror-based VEs. A survey of 269 college students [19], indicated that interactivity is one of the top fear-inducing elements in video games among music, darkness and the fear of the unknown. Lin [20] conducted a study that aimed to formalize place illusion (PI) and plausibility illusion elements (PSI) as categories of immersion and measure fear response from such elements. Slater [21] defines PI as “being there” or simply presence. PSI refers to illusion that event in the VR experience is actually occurring. Users were placed inside a dark house VE, where waves of zombies approached and attacked the player; who has weapons to protect themselves and a flashlight. The weapon and flashlight are was fully controllable and have to be manually reloaded and switched on respectively. An HTC Vive headset was used, and graphical fidelity was high since the machine used in the experiment consisted of a GTX 1080 GPU, capable of high-resolution rendering. The element that concerns this review is that the PSI element “When I cannot control my weapons” and “When zombies attack me.” Both elements require interaction to subdue fear, and results indicate that when the user cannot control their weapon, their fear response was the highest. This is an interesting note both psychologically and physically in terms of a sense of control and agency, that pressured situations in conjunction with forcing interaction from the user causes heightened fear.

While Lin’s [20] elements of interaction contained just a weapon and a flashlight, research has shown that games where association to the narrative by implementing a first-person control of a player in a virtual world contributes to immersion and a greater fear response [23]. Playing and interacting as a written character in a VE allows a player to identify with the character, such that when that character faces danger, so does the user [23]. The method here would be to create a virtual character and assign meaning to their identity for the participant. This virtual character would then carry the narrative, interacting with the world in various ways as a real person would.

Resident Evil 7: Biohazard (Capcom, 2017), is a horror video game that supports VR and combines both aforementioned methods. Users control a character with an identity who is subjected to the horrors of unknown and known attackers and uses various weapons to defend themselves. Pallavicini et al. [24] study the effects of the game in VR as opposed to traditional flat displays and determine that anxiety response is slightly higher in that of the VR version of the game, and immersion is significantly higher in VR. While this is to be assumed, the video game presents the user with a first-person narrative that contains interaction with doors, characters, weapons, movement, and a variety of audio-visual stimuli that greatly induce fear [24]. Interactive elements combined with the modern graphics of the game and an equally modern VR HMD – one with high resolution-per-eye and FOV - could present a combination of VR systems that heighten immersion and emotional response significantly more than non-interactive VEs. *Alien: Isolation* (The Creative Assembly, 2014), a video game similar to *Resident Evil 7: Biohazard* such that users play as a character they can associate within an environment where they must defend themselves against an attacker through interaction. The game was found by Day [25] to increase immersion simply because it was professionally designed and coupled with an Oculus DK2 modern VR system. Both video games extensively make use of interaction, from opening doors to using various weapons to deter attackers. Since there is a lack of research in interactivity and these methods used to heighten fear response in users in VR, and what exactly is the psychological implications behind such interaction, methods are limited and superficial.

The two methods that remain effective in VEs, mentioned here, are associating character to the player and introducing an agency complex that is designed to elicit fear. While basic interactive elements such as interacting with objects in the VE, controlling weapons, and supporting hand-tracking could also contribute to improving the VR experience, immersion and a fear response.

Ref.	Method	Hardware	Environment	Agency	Results	Usefulness
[8]	Non-interactive	- Z800 3Dvisor - Low resolution display - Head tracking - Low FOV	Basic, low polygon rendering of spider	None	Tactile cues increased sense of immersion of fear response.	- Low hardware specifications not reliable to compare against modern hardware. - Evidence that tactile cues effective in evoking fear response.
[7]	Non-interactive	- Powerwall - Very high resolution - No head-tracking - High FOV	High polygon rendering of spider	None	Stereoscopy and high-resolution results in higher immersion.	- Evidence that high resolution and greater illusion of depth increases immersion.
[9]	Semi-interactive	- Oculus DK 2 - High resolution - Head tracking - Position tracking - High FOV	Explorable house, detailed models	Control movement, freely able to explore environment	Geometric realism and audio stimuli result in higher immersion and fear response.	- Strong evidence that atmospheric environments, audio and visual stimuli create fear response.
[12]	Non-interactive	- Oculus DK 2 - High resolution - Head tracking - Position tracking - High FOV	Guided camera experience through dark corridor, attacked by entities	None	Visual stimuli and cues evoked more fear than tactile and auditory. Realism with all stimuli combined.	- Visual cues are strong fear elicitors.
[16]	Semi-interactive	Not specified.	Basic, low polygon rendering of graveyard with ghost	Control movement, freely able to explore environment	Visual and audio stimuli increase immersion and fear. Motion sickness is a significant issue in recording reliable data.	- Evidence that VR motion sickness plays a role in this field of study.
[14]	Non-interactive	- HTC Vive - High resolution - Head tracking - Position tracking - High FOV	Guided camera experience through safari, attacked by T-Rex	None	Haptic-visual cues increase immersion and fear response the most.	- Evidence that haptic feedback, along with a visual indication on the UI increases fear response.
[2]	Interactive	Not specified.	Fully explorable laboratory	Control hands and movement, independent of any factors.	Interaction increases immersion.	- Evidence that interaction increases immersion.
[20]	Interactive	- HTC Vive - High resolution - Head tracking - Position tracking - High FOV	Fully explorable dark house	Control hand, objects and movement.	VR increases immersion and evokes multiple dimensions of fear.	- Evidence that interaction increases fear response - Forms basis of agency argument

Table 1: Comparison of virtual environments

4 Discussion

While both methods of eliciting fear are effective – the lack of research that observes interactivity as the driver for evoking any emotion is limited. Since this is the case, comparing results from each method is challenging. There are, however, a few key aspects that differentiate each method and develop a keener understanding of which elements should be used when developing a VE designed to elicit fear. A summary of each study can be seen on table 1 on the previous page.

4.1 Hardware and software

HMDs are modern pieces of technology that have several contributing technical factors that influence immersion in the objective sense. Participants who, for example, play a video game that was developed professionally, with modern graphical fidelity, could testify that experiencing the game on an Oculus Rift Development Kit I (2012) and directly afterward with an HTC Vive (2016) provided a higher sense of immersion. This is because of properties such as FOV, resolution-per-eye and refresh rates. According to Abrash [26], these properties are essential in establishing immersion in the user experience. A wider FOV on the display of the HMD resembles that of the real world and seeing more of the virtual world without a vignette creates develops a sense of plausibility illusion [27]. Higher resolution of the HMD presents the image as clearer, since the screen of the display is pressed against the eyes of the participant. A clearer picture also resembles that of reality and seeing individual pixels due to the distance between the eye and the display distracts users from the experience [26]. Refresh rate is the rate of which the screen updates each frame. A higher refresh rate results in a smooth transition when the camera moves in the virtual world, reducing judder – a stuttering effect caused by latency in frame rate or lower refresh rate – which can cause motion sickness U. While hardware capabilities of the VR system encompass any VE, interactive or non-interactive, a more technically advanced HMD combined with, for instance, an object that has a higher texture resolution and can be picked up, could lead to more immersion.

This hardware is limited by the software fidelity of the VR experience. Modern advances in graphics development can create a virtual world that closely resembles that of the real world. There is, although, a limit and balance to degree to this fidelity. While we saw a link with immersion and fear response when creating models in the VE with a higher texture resolution and polygon count [9], applying realism to humanoid models and creatures can create a rift between expected emotional connection and actual emotional connection. This is known as the “uncanny valley” [28]. Users presented with a model that tries to closely resemble that of the real world can evoke a sense of eeriness or even fear in the user. While the term does not directly apply to non-humanoid objects, an interesting further field of study would be investigating the degree of realism of any model in the VE and how that affects levels of immersion and fear response, and if a closer resemblance to the real world could actually counter the expected higher immersion levels because the model is “too realistic.”

4.2 Agency

Interaction remains largely unexplored in evoking fear. We have established that an advanced HMD, a balance of realism, and a combination of stimuli can evoke fear and high immersion levels in users - but this can be applied to both types of VEs, interactive or non-interactive. Lin’s research [20], however, still remains the most reliable study in this review that is in favour of interaction and has prospects to be the driver in investigating interactive VR design. The significance that lack of control in the user evoked the most fear in the user is the important factor here. This barring of agency is also a topic in VR that is not greatly discussed. When a user is presented in a non-interactive environment, and simply are led by a panning camera, they lack a certain degree of freedom. The experiment is controlled. But present the user with virtual hands and VR controllers that can manipulate these hands, there is already a sense of control in their virtual behavior. They can manipulate objects, open doors, use weapons; the limits are endless since developers can program the hands to interact with any virtual object. Combine this with freedom of movement, and the user can govern the sequence of events and choices made of the VR experience. Autonomy in the virtual environment becomes dictated by the player, and rather is restricted by the developer who created the experience. In evoking fear and heightening immersion, this can be very effective. Agency becomes the inherent quality of the character in a fully interactive environment, where players feel a sense of ownership as their actions drive the narrative of the experience. Introduce an entity such as a monster that is programmed to attack the player, and immediately that sense of agency becomes threatened. The player can no longer move freely about the environment, but rather the monster dictates the players choice. When this autonomy is threatened, the sympathetic nervous system should be engaged, appealing to the bodies “fight or flight” response. While this sort of response is expected from any fright or attack in a VE, it can be assumed that in a high fidelity VE with freedom of choice and interaction, this response would be stronger than that of a guided VR experience. The argument to be made here is if agency in the VE against several design choices would develop more or less of a sense of fear. Madsen [22] investigates this sense of control in a non-VR game, but one that is interactive and guided by player choice. It was found that there was a greater physiological fear response when subjected to a video game that has a greater sense of agency.

Creating a virtual environment that yields all spheres of what was discussed, that is viewed through an HMD with advanced technical capabilities, has a balance of realism and graphical fidelity, and finally is fully-interactive and provides agency to the player, could result in the best VR experience that aims to evoke fear. This forms a comparable structure of the previously reviewed papers. We attempt to tabulate each paper by categorizing each of the above factors and the extent of which they are achieved, with the addition of methods and the aims of each of the studies, in table 1 on the previous page. For each paper, we speculate the level of agency the player has in the VE, and summarize their importance and relevance for this review.

5 Conclusions

VEs in VR are effective in eliciting fear and creating a strong sense of immersion when developed and studied in the correct conditions. These conditions relate to the method used to measure emotions and immersion, the type of environment, the hardware used the experience, and in this review, the interactivity of the VE.

Measuring emotions is varied and is determined by the researchers' preferred method. Questionnaires with associated numbering systems are proven to be effective in measuring immersion in users, while measuring emotions can involve discretely identifying emotions with or without valence and arousal dimensions. Fear should be measured with close examination of the ANS and mental health of the participant for accurate results. Measuring emotion can be static across both interactive and non-interactive environment types. Non-interactive environments rely on visual and graphical fidelity, along with visual, audio and tactile stimuli such as scripted cues to elicit emotions in VR. All types of stimuli elicit emotion successfully, and whichever evokes more of a fear response is dependent on the design of the VE. Interactive environments can contain all non-interactive elements with the addition of agency, which can add a dimension of complexity and possibly a stronger fear response and degree of immersion in VR.

Sense of control and agency is an interesting future topic of study, as there is a lack of research around this field in relation to eliciting fear. There is also a limited number of studies that specifically investigate interactivity as a leading component in evoking a fear response. Further research on this topic could lead to a better understanding of treating phobias and anxiety by the use of interaction as a driver for exposure therapy.

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