MASTER

The influence of visual realism on the sense of presence in virtual environments

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The Influence of Visual Realism on the Sense of Presence in Virtual Environments

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Abstract

Virtual reality is increasingly being used for a wide range of academic, entertainment, training, and therapeutic purposes. The technology allows individuals to be completely immersed in an environment, and interact with it as if the environment is real. If this leads to the individuals feeling as if they are physically present in the environment, it can be said that they experience a high sense of presence: The sense of being there in an environment, whilst being physically situated in another. A high sense of presence is needed in order to make the experience feel real, that is: The individual experiencing the virtual environment should not be conscious of the external environment and the medium needed to navigate through and interact with the environment. But does realism in itself also affect the experienced sense of presence? More specifically, do visually realistic environments that highly resemble a corresponding real environment evoke a higher sense of presence than unrealistic environments?

Earlier research has examined whether visual realism affects the sense of presence in virtual reality applications. However, several contradicting results were found, from which no clear conclusion could be made. The overall lack of consistent findings may be attributed to the realistic environments utilized in prior research not being truly visually realistic, caused by the relatively low computational power available in the past and the lack of user friendly environment design software. This study examined the effects of visual realism on presence and anxiety, replicating and improving the previous research by utilizing a visually highly realistic cliff environment.

Fifty-two participants experienced a visually highly realistic and unrealistic cliff environment, with the order of experiencing the realistic or unrealistic environment first being counterbalanced. They were asked to cross a wooden bridge and count the amount of rocks in the water approximately 30 meters below them. Their experienced sense of presence was measured with the IPQ questionnaire, whilst anxiety was measured by self-reported items, heart-rate, and GSR.

The results showed that increasing visual realism led to an increase in presence. However, only a very small and open to debate effect of visual realism on anxiety was found: The first cliff environment evoked higher anxiety than the second cliff environment, especially if the realistic environment was presented first. The novelty effect however was stronger than the effect of realism, and trait anxiety for fear of heights also influenced self-reported anxiety. The findings indicate that visual realism may indeed positively affect presence, but is of less importance to height-related anxiety.
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1. Introduction

Virtual reality has enabled the immersive and interactive experience of virtual environments, allowing individuals to navigate through the environment using their body movements, as if the environment was real. Each element in the virtual environment can be modified, enabling unlimited creation possibilities in virtual environments. This has been used in diverse applications of academic research, training and entertainment purposes (Bowman & McMahan, 2007; Craig, Sherman, & Will, 2009). For instance, architects can create a 3D model of an existing or envisioned apartment, which potential buyers can view through a head-mounted display (HMD), or 3D models of real-life locations can be used for military training. Another application of virtual reality that has been receiving large amounts of attention in academic research, is the use of virtual environments in exposure therapies. Exposure therapies expose patients to a stimulus that triggers their anxiety, such as standing on a tall building for individuals with fear of heights (acrophobia), or having to give a presentation in front of a large audience when someone suffers from fear of public speaking (Krijn et al., 2004; Price & Anderson, 2012). Virtual reality exposure therapies (VRET) enable gradual and controlled exposure to a stimulus in a safe environment, and have been found to be as effective as traditional exposure therapies (Diemer, Lohkamp, Mülhberger, & Zwanzger, 2016; Parsons & Rizzo, 2008). In this type of application, it is especially important that the person feels as if he or she is physically present in the virtual environment, in order to make the experience feel real (Riva et al., 2007; Slater, 2009). This sense of “being there” in a virtual environment, is called presence (Riva et al., 2007; Steuer, 1992). The more people feel present in a virtual environment, the less they are aware of the external environment and the medium needed to view and navigate through the virtual environment (Lombard & Ditton, 1997). But what determines whether a high level of presence is achieved? If a high level of presence makes the experience feel real, does the effect also appear the other way around; Do highly realistic environments evoke a higher level of presence than less realistic environments?

Earlier research has investigated whether the visual realism of virtual environments—the degree to which the virtual environment visually resembles a possible corresponding real environment (Christou & Parker, 1995)—plays a role in the experience of presence. Some consistent findings are reported in the literature, depending on the type of realism studied. For example, realistic lighting conditions often had positive effects on presence (Slater, Khanna,
Mortensen, & Yu, 2009; Yu, Mortensen, Khanna, Spanlang, & Slater, 2012), whereas realistic humanoid characters typically affected presence negatively (Seyama & Nagayama, 2007). However, several contradicting results have been found even amongst studies with similar research designs (Khanna, Yu, Mortensen, & Slater, 2006), thus research has not provided a clear answer on the influence of visual realism on the experience of presence.

A possible reason for these inconsistent findings is that the majority of these studies have been conducted several years ago, in the period from 1998 until 2009, when limitations in computational power and a lack of user friendly 3D modeling software made it difficult to create truly realistic virtual environments. Especially in virtual reality applications, where each frame needs to be rendered in real-time for both the left and right eye separately, the relatively low computational power, as compared to current standards, made the rendering of complex and thus realistic 3D models infeasible. Additionally, researchers who did not have extensive experience and skills in 3D modelling—which still often may be the case in domains other than computer science and industrial design—had to rely on software that was simple to use, but limited in their possibilities of creating visually realistic virtual scenes. In research on the effects of realism on presence, therefore, the environments used in the realistic conditions were possibly not visually realistic enough to be regarded as highly realistic, as they did not approach photorealism.

Nowadays computational power has increased greatly, such that common consumer grade computers outperform the powerful computers needed for the development of virtual reality applications a few years ago. Additionally, new tools are available to both consumers and academics that do not require extensive experience with 3D modelling; focusing on the easy creation of virtual environments, rather than the underlying technical knowledge needed to make the virtual environment suitable for virtual reality. Combined with the increase in computational power, these tools enable individuals who do not have the technical know-how to create visually realistic environments, whilst delegating the technical implementation to the software. Utilizing these technological advances, the present study aims to replicate and improve the previous studies done on the influence of visual realism on presence, by including a more visually realistic virtual environment than was used in previous research.
1.1. Report structure

First, in section two, the concept of presence will be discussed. Several definitions of presence will be given, to provide a common ground for the rest of the report. Measurement methods and influencing factors will also be discussed.

In the third section, the definition of visual realism will be given along with an overview of developments over time in different media. The focus will then shift to the effects of visual realism on presence in virtual reality, discussing earlier research conducted and the theories underlying its effects.

In the fourth section, the motivation for conducting the study and the research questions are discussed, followed by the description of the experimental method in section five, including sample characteristics, the hardware and software used, and the procedure.

Section six will present the findings of the data analysis, which will then be discussed in section seven, including their relation to other findings, as well as implications for future research.
2. Presence

Virtual reality enables people to experience an unlimited range of environments, including environments that cannot exist in real life. The notion reality in virtual reality, thus does not imply that virtual environments are indistinguishable from real environments, but rather that the environments can be experienced as if they were real. In order to experience this reality, the illusion should be strong enough to let people believe they are physically present in the environment. The sense of being present in an environment, whilst being physically present in another, is called presence (Witmer & Singer, 1998). Presence has also been defined as “the perceptual illusion of non-mediation” (Lombard & Ditton, 1997), and several other definitions exist, but can be generally defined as the sense of “being there in an environment” (IJsselsteijn & Riva, 2003; Sheridan, 1992). This does however not imply that people can only feel present in virtual environments: Other media, such as books or movies, can also provide an imaginary environment that can be perceived as actually existing if the experience is highly engaging. Presence thus does not depend on solely the medium used to provide the experience, but is also dependent on the person’s ability to believe in the illusion. Because presence is a highly subjective construct, there is no clear consensus on how it should be measured.

2.1. Measuring presence

The main subjective method of measuring presence is the use of questionnaires (Laarni et al., 2015; Sanchez-Vives & Slater, 2005). Several questionnaires have been constructed throughout the years, including the Witmer-Singer Presence Questionnaire (PQ; Witmer & Singer, 1998), Slater-Usoh-Steed (SUS) questionnaire (Slater, Steed, McCarthy, & Maringelli, 1998), ITC- Sense of Presence Inventory (ITC-SOPI; Lessiter, Freeman, Keogh, & Davidoff, 2001), and Igroup Presence Questionnaire (IPQ; Schubert, Friedmann, & Regenbrecht, 2001). These questionnaires differ due to the existence of different interpretations of what presence is, but generally a combination of the following components of presence is assessed: Spatial presence (i.e., the experience of being in the environment), naturalness and realism of the interaction with and the environment itself, and involvement with the environment (i.e., whether the environment was engaging). However, because these are subjective measures which require a certain understanding of presence (e.g. What does it mean to be involved with the virtual experience?) by the individuals who experienced the virtual environment—but may not have extensive knowledge of presence or its related concepts and may thus interpret questions
differently, and might be biased by previous judgements of the same stimuli—questionnaires are often used in conjunction with more objective methods, that also enable a deeper understanding of how individuals felt during the experience (Freeman, Avons, Meddis, Pearson, & IJsselsteijn, 2000; Slater et al., 2009).

There are two main methods of objective presence measurement: Behavioral measures and physiological measures (Coelho, Tichon, Hine, Wallis, & Riva, 2006; Laarni et al., 2015). Behavioral measures determine whether individuals behave in the virtual environment as if they were in a real environment: Natural responses indicate a high sense of presence (Freeman et al., 2000). In order to evoke body responses that can be assessed, a stimulus needs to be introduced that would make individuals behave in a predictable way in a real environment, such as crouching to fit through an opening or ducking when an object is thrown towards the individual.

Conversely, physiological measures assess the bodily responses that are not visible from the outside, usually by measuring heart-rate and its derived measures, or galvanic skin response (GSR). As with behavioral measures, a stimulus needs to be introduced that would evoke a natural physiological response in real-life, for instance an increase in heart-rate after being presented with a frightening object. However, the valence of the stimulus needs to be taken into account to determine the psychological meaning, since an increase in heart-rate or GSR does not in itself indicate whether the response is negative or positive (Dawson, Schell, & Filion, 2007). Furthermore, different types of physiological measures assess different types of internal activities. The human body has two autonomous nervous systems which regulate the body’s unconscious activities; The parasympathetic system, which stimulates activities at rest (e.g. eating-related functions), and the sympathetic system, which governs physiological arousal and is linked to emotions (Critchley, 2005). Heart rate is governed by both the parasympathetic and sympathetic nervous system, whereas GSR is controlled only by the sympathetic nervous system (Dawson et al., 2007). GSR is therefore less ambiguous than heart rate, as it excludes emotionally neutral functions of the body at rest, and has been closely linked to the psychological concepts of emotion, arousal and attention (Laarni et al., 2015; Dawson et al., 2007). GSR can be further divided into two components: A tonic, and a phasic component. The tonic component is often expressed by the skin conductance level (SCL), a measure of overall skin conductance over time, and is indicative of a general level of arousal (Boucsein, 2012; Figner & Murphy, 2011). Contrarily, changes in the phasic component measure the responses to
specific stimuli, which are called skin conductance responses (SCR; Benedek & Kaernbach, 2010; Boucsein, 2012). The amplitudes of these phasic changes are often found to be indicative of the arousal evoked by the stimulus (Courtney, Dawson, Schell, Iyer, & Parsons, 2010).

Heart-rate and GSR can thus be used as indications for the arousal felt during the VR experience. However, it should be noted that these measures do not purely measure presence, but rather the emotional state of the individual (Ekman et al., 2012). This makes physiological measures less useful in emotionally neutral environments, since neutral environments generally evoke no, or much smaller physiological responses than emotion-inducing environments (Laarni et al., 2015; Meehan, Insko, Whitton, & Brooks Jr, 2002). However, since emotions and presence are highly related, and the emotion is generally caused by the content of the environment, the measures can be used to indicate the engagement the individual had with the environment. The relation between emotions and presence is discussed in section 2.3.

2.2. Determinants of presence

Having defined presence as the feeling of being in an environment, this definition of presence is independent of virtual reality technology or any other specific media; instead encompassing any media capable of creating an illusion in a person’s mind. If presence can be experienced through a diverse range of media, what determines whether a person feels present and to what degree? There are generally two different determinants of presence: Media characteristics and user characteristics (Coelho et al., 2006; IJsselsteijn & Riva, 2003).

2.2.1. Media characteristics. Media characteristics encompass the content presented and the properties of the available modalities. In this characteristic, virtual reality is different from other media on two important factors: Interactivity and immersion (Schuemie, Van Der Straaten, Krijn, & Van Der Mast, 2001). Virtual reality enables persons to navigate through and interact with the environment, which is not possible in other media. Interactivity allows the person to manipulate the environment, giving the user some control over the environment. Virtual reality may thus provide more possibilities to make an experience engaging, compared to static media, which has been found to affect presence positively (Sanchez-Vives & Slater, 2005; Steuer, 1992; Witmer & Singer, 1998).

Immersion is another aspect that is a main characteristic of virtual reality. Although different definitions of immersion exist, this report uses the definition of immersion as “the description of a technology, and describes the extent to which the computer displays are capable
of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant” (Slater & Wilbur, 1997, p. 605). In other words, the person is completely surrounded by the virtual environment due to system characteristics and the quality thereof. Immersion is thus different from presence, since it entails a description of the technology used, whereas presence is the user’s psychological response to the system (Slater & Wilbur, 1997).

Influential aspects of immersion include field of view, the extent to which a person’s movement are correctly tracked and represented in the virtual environment, frame rate, and stereoscopic presentation, among others (Freeman et al., 2000; Sanchez-Vives & Slater, 2005; Schuemie et al., 2001). The richness and consistency with which the sensory information is presented, have significant impact on a person’s sense of presence: The more consistent and captivating the information is, the higher the experience of presence will be (IJsselsteijn & Riva, 2003; Slater, 2009; Steuer, 1992; Witmer & Singer, 1998).

Increasing the consistency of sensory cues can be achieved by adding more modalities: By combining different but coherent sources of sensory information, the experience will become more reliable and thus more believable, as it approaches the rich sensory stimulation with which the real environment is perceived (Haans & IJsselsteijn, 2012). Aside from the visual modality, the auditory modality is commonly used in media, including non-immersive media, to make the user aware of his surroundings and characteristics of the virtual entities encountered. For example, if a virtual objects looks like a bird, but is a bit different from birds the user usually encounters, letting the entity produce a bird-like sound will increase the likelihood of the user knowing the entity is a bird, along with information about the relative location of the bird. Virtual reality however, as compared to static media, enables the creation of much richer multimodal environments, by incorporating modalities such as haptics and user embodiment, enabling individuals to ‘feel’ the environment and see themselves moving through and interacting with environment, creating a highly immersive experience. The total immersion is further increased by the type of technology used: Head-mounted displays shut out visual cues from the outside world. This does however, not mean that all persons will experience the same level of presence for any given environment. Aside from the form, “quality” factors, such as frame rate, and the content that is presented, user characteristics also play a role in presence, since it is a subjective experience (Lombard & Ditton, 1997).
2.2.2. User characteristics. A general, all-encompassing user characteristic relevant to the experience of presence, is the willingness to believe the illusion created by the virtual environment (Steuer, 1992). Since the virtual environment is never truly real, individuals need to ‘forget’ about the real environment and accept the virtual environment as the place they are currently physically present, suspending their disbelief that the experience is non-mediated (Lombard & Ditton, 1997). To examine which user characteristics play a role in this process, Witmer and Singer (1998) constructed the Immersive Tendencies Questionnaire (ITQ), which measured differences between individuals’ tendencies to experience presence. Cluster analysis of the data obtained through the ITQ revealed three subscales: Involvement, focusing ability, and gaming experience. Involvement was the ability to get involved passively in activities, which were not necessarily mediated by technology. The focus subscale measures whether individuals can concentrate on a task and block out distractions. In virtual reality, this determines whether the person is actively experiencing the real world. Lastly, the gaming subscale measures the frequency with which individuals play computer games and how involved they become while playing them.

2.3. Effects of presence on emotions

If a person’s characteristics influence the level of presence experienced, does presence in turn also influence the person affectively, or is it just a measure of how much people believe to be in a virtual environment? Research has shown that a sense of presence can indeed affect persons’ emotional state and suggests that this is likely a circular process, as the emotional state has also been reported to affect presence (Diemer, Alpers, Peperkorn, Shiban, & Mühlberger, 2015; Riva et al., 2007). In fact, there is some evidence that emotions may influence the experienced presence more than presence influences emotions, as individuals who experienced an emotion-inducing (e.g. fearful or joyful) virtual environment, generally reported a higher sense of presence than those who experienced an emotionally neutral environment (Baños et al., 2004; Bouchard, St-Jacques, Robillard, & Renaud, 2008; Riva et al., 2007). For example, Bouchard and colleagues (2008) exposed participants with snake phobia to two conditions: A neutral environment, and an anxiety-inducing environment, where participants were told snakes would be hidden. Participants reported a higher sense of presence in the anxiety-evoking environment, however: There were actually no snakes in the environment, and the same environment was used for the neutral condition, therefore the degree of immersion was not
changed between the two conditions. Thus, the thought of having to encounter snakes itself, caused the feeling of anxiety and higher presence, which made emotion a more likely predictor of presence, than the immersive capabilities of the equipment. This effect is the strongest when the virtual environment evokes strong emotions, because in neutral or relaxing environments, immersion (e.g. display size) was found to be the main determinant of presence (Baños et al., 2004; Freeman, Lessiter, Pugh, & Keogh, 2005). Additionally, the degree to which anxiety was invoked, often depended on whether phobic or non-phobic participants were used in the experiments, since non-phobic participants experienced less anxiety than phobic participants (Diemer et al., 2016; Robillard, Bouchard, Fournier, & Renaud, 2003).

The underlying theory for these findings, is that there is only a strong relation between emotions and presence when the stimulus is arousing and relevant to the user. In order for a stimulus to be arousing, it needs to be perceived as personally relevant, either visually or by a deeper meaning (Freeman et al., 2005). Phobic individuals are very sensitive to cues depicting their phobia, thus the representations of the phobia-related stimuli made the situation highly relevant to the phobic individuals (Robillard et al., 2003). Because there was a congruence between the individuals’ emotional state and their perceived situation, they likely attributed their feeling of anxiety to the environment, which increased their sense of presence, because the emotion they felt was real (Robillard et al., 2003). The user’s characteristics thus also influence the effects presence has on emotions. However, we can usually not change the user’s characteristics, which brings us back to the importance of immersion, and thus the aspects of the technology that influence the sense of presence.

2.4. Plausibility of virtual environments

If presence is the perceptual illusion of non-mediation, the level of presence that is achieved will be influenced by the individual’s ability to believe in the illusion, and the immersion provided by the mediating technology. If only the system’s characteristics can be changed, what characteristics determine whether a strong illusion is created, or in other words, whether the environment is plausible enough to evoke a high level of presence? As has been described earlier, media characteristics such as frame rate and field of view have been found to affect immersion. These characteristics however, pertain to the technology used to display the virtual environment with. The virtual environment that is presented, also has a wide variety of characteristics, such as the use of a narrative, the amount of objects presented, and colour use.
An overall quality aspect of a virtual environment that affects visual perception and thus the visual illusion created by the VE, is the visual realism of the environment, which determines whether the environment provides the same perceptual information a real-world counterpart would do (Ferwerda, 2003). If a highly believable perceptual experience can be created, will this increase the sense of presence and evoke more natural responses to the virtual environment?

3. Visual realism

Visual realism can be regarded as the degree to which a simulated, artificial world resembles a corresponding real world, that is: How similar the sensory stimulation from the virtual environment is to an equivalent real environment (Christou & Parker, 1995, p. 53). In the real world, the visual system receives light, which has been structured by its interaction with objects in the environment, and projects this as a 2D image onto the retina. The structure of the light provides information about the object properties, which are processed in the brain to perceive the whole scene in 3D. Because the received light is projected as a 2D image and the subsequent image formation process obeys physical laws, virtual environments may provide the same visual stimulation as real environments do: If the objects are similar to their real counterparts and the light interacts with them in a natural way, then the same 2D image projection can be obtained from the virtual environment, which is later transformed back into the corresponding 3D image.

This degree to which an object resembles its real-world counterpart, can be assessed based on the following object properties: Geometry, materials, and lighting (Hagen, 1986). The geometric aspect defines whether the shape of the object is similar to the corresponding real object. In computer graphics, complex curved objects generally need a higher amount of polygons (the pieces of which a 3D model is constructed) than simple rectangular objects. Material properties define whether the surface of the object looks natural. Some types of material can be very simple, defined by a single or a few colors, such as paper, whereas other materials need to have sufficient details in order to look realistic, such as tree bark that often has many different colors, and perhaps some moss. Finally, the lighting component defines whether light interacts with the objects as it would in a real environment. Light interacts with objects depending on their properties, such as their shape or surface smoothness, and depending on those properties, is either reflected or transmitted in varying levels. This process structures the light, providing information about the solidity, depth and structure of the object, among others.
(Christou & Parker, 1995). Therefore, the degree to which the virtual light is simulated correctly, and thus the overall visual realism of the virtual environment, depends on the mathematical implementation of the light structuring process, as well as the geometric and material realism of the object that receives the light.

3.1. Developments in visual realism

If it is known how visually realistically environments can be created, why are not all environments made to be indistinguishable from real environments? The main reason is that an increase in visual realism will always be paired with an increase in needed computational power (Ellis, 1991). Especially the geometric complexity (i.e. amount of polygons) and screen resolution form large bottlenecks in performance (Slater, Steed, & Chrysanthou, 2002). Lighting can also be very complex, if it takes into account multiple properties of the objects, such as smoothness and size. Additionally, a single object may consist of several smaller components that each have a different material, which results in complex lighting instructions for the whole object. However, with the steady increase in computational power, the possibilities for creating realistic environments have increased as well. Entertainment applications, such as computer games, have often strived to create an as visually realistic 3D experience as possible, keeping the computational power of the at that time available mid and high-end consumer grade computers in mind (Masuch, & Röber, 2004). This was needed, as otherwise consumers would not be able to play the games. This also means that games that used to have “cutting-edge” graphics ten years ago, are much less visually realistic than the average games available nowadays. It is interesting to note that this effect is much smaller in media that do not have to rely on the computational power available to consumers, such as movies, because these media are pre-rendered on clusters of high-end computers in the production company. For example, the movie Finding Nemo produced by Pixar Animation Studios, and released in 2003 by Walt Disney Studios, utilized 3000 CPUs running simultaneously at the peak of the rendering process (Quaroni, 2003). The movie featured highly realistic graphics, incomparable to the games available in that time. Figure 1 depicts the developments in visual realism for two popular game franchises, and the Finding Nemo movies. As can be seen in Figure 1, the sequel to Finding Nemo, Finding Dory, released in 2016, was also highly realistic, but the difference in visual realism between the new and old movie, is much smaller than between the new and old versions of the two games.
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*Figure 1. Examples of developments in visual realism in media over time.*

*A: The Deus Ex game franchise, property of Eidos Interactive and Square Enix.*

*B: The Need for Speed (NFS) gaming franchise, property of Electronic Arts.*

*C: The Finding Nemo and Finding Dory movies, property of Walt Disney Pictures and Pixar animation studios.*
3.2. Consequences of the developments in visual realism

The steady increase in visual realism may have consequences for the way individuals perceive and evaluate virtual environments. Because individuals become used to seeing highly realistic media, they may develop certain expectations with regards to visual realism, thus setting the bar increasingly higher for new media that are being developed. If they experience an application that does not meet their current standards, they may evaluate it less positively (Pillai, Richir, & Schmidt, 2013).

The increase in visual realism also sparked a new debate regarding the psychological effects of media. For a long time, there have been discussions regarding the possible negative effects exposure to violent games and movies may have on individuals (Anderson, 1997; Funk, Baldacci, Pasold, & Baumgardner, 2004). Especially games have been suspect to debate, because of their interactive nature, which makes players actually perform the positive or negative actions (Malliet, 2006). Research has found that exposure to violent media may indeed evoke hostile feelings and the accessibility of aggressive thoughts (Anderson, 1997), and decrease prosocial behavior (Bushman & Anderson, 2009). However, most studies have examined short-term consequences, and the debate on whether these negative effects will actually lead to an increase in aggressive behavior in real-life is still ongoing (Markey, Markey, & French, 2015).

The advances in visual realism led to new research on the effects of violent games, because the increase in visual realism might make it more difficult for the player to distinguish the virtual from the real world, that is: Is the player still playing a game, or has the game become reality? This is essentially the same notion of the perceptual illusion of non-mediation, with which presence has been described. Studies have found some evidence that visually realistic violent games increase the sense of presence, as indicated by an increase in physiological arousal and engagement (Barlett, & Rodeheffer, 2009; Jeong, Biocca, & Bohil, 2008), although Bracken and Skalski (2009) only found a positive effect of visual realism on involvement with the content, but not on spatial presence.

3.3. The influence of visual realism on presence in virtual reality

With the increase in computational power and academic interest in developing a wide variety of virtual reality applications, studies have examined the effects of media characteristics on the sense of presence, and found that increased quality aspects, such as frame rate and field of view, generally affected presence positively, as has been discussed in section 2.2.1. However, the
same cannot be concluded for the influence of overall visual realism on presence in virtual reality, with research finding both positive and negative effects on presence. Yet, some consistent findings have been reported in the contexts of illumination and human characters. The following section will describe the findings from previous studies, where visual realism was manipulated in immersive virtual environments, that is: Virtual environments that were experienced through an HMD or a Cave-like system. This is done in order to rule out any differences in experienced presence caused by varying levels of immersion, thus studies involving a single monitor as the display device are not discussed.

3.3.1. Overall visual realism. Several studies have examined the effects of visual realism on presence by manipulating the visual fidelity of the whole environment, mostly by changing the geometric or textural complexity, or both. The majority of studies have shown that the level of realism had no influence on the sense of presence when measured through questionnaires (Dinh, Walker, Hodges, Song, & Kobayashi, 1999; Lee et al., 2013; Lugrin, Wiedemann, Bieberstein, & Latoschik, 2015; Zimmons & Panter, 2003), or when assessed by physiological measures (Zimmons & Panter, 2003; Lugrin et al., 2015), although some studies have found that visual realism increases the sense of presence (Baumgartner et al., 2008; Vinayagamoorthy, Brogni, Gillies, Slater, & Steed, 2004). However, the environments that were used were very diverse, ranging from emotionally neutral to arousing environments. For example, Dinh and colleagues (1999) created an office environment with separate locations, including a reception area, hallways, and office rooms, among others. Participants were asked to look around the rooms, but did not receive any other task, whereas Baumgartner and colleagues (2008) subjected participants to an arousing rollercoaster ride. Despite these differences, most researchers have concluded that even in an unrealistic environment, the human mind may automatically fill in details to make sense of the environment. This theory, along with its counterpart, will be discussed in section 3.4.

3.3.2. Illumination. Studies on the impact of illumination realism in contrast, have generally concluded that improving the illumination realism leads to an increase in presence (Ehrlich, 2014; Slater, Khanna, Mortensen, & Yu, 2009; Yu, Mortensen, Khanna, & Slater, 2012). Slater and colleagues (2009) first examined whether ray tracing, which also renders shadows and reflections, would increase the sense of presence as compared to environments that
received ray casting, where no shadows or reflections were present. They found that both presence and anxiety in a virtual pit room where higher when ray tracing was utilized. Because it was unclear whether this was due to an increase in perceived quality of the light, or due to the visible shadows and reflections, they conducted a second study (Yu et al., 2012). In the second study, the environment utilized either local or global illumination, but shadows and reflections were present in both conditions. They found that the illumination render method did not affect presence, and thus concluded that the increase in presence was most likely caused by the presence of shadows and reflections, which are important cues regarding depth and the location of oneself (Christou & Parker, 1995).

3.3.3. Human characters. Whereas overall visual realism was not considered to have a large influence on presence, and illumination was found to have positive effects on presence, negative effects of visual realism have been found when considering specifically the context of human models. These characters, or sometimes named virtual agents in literature, were designed in varying levels of visual realism, by varying the polygon count or choosing a different visual style, such as cartoonlike or realistic. Studies have shown that when an individual encounters a virtual human, their sense of presence is generally lower when the model is realistic, but does not exhibit realistic behavior (Bailenson et al., 2005; Garau et al., 2003; Vinayagamoorthy et al., 2004). This effect has been called the uncanny valley: When virtual characters appear to be highly realistic, people notice even small deviations from this realism, which would lead to negative affect (Mori, MacDorman, & Kageki, 2012). Generally, people expect that the more a virtual character appears to be realistic, the more realistic it should behave (Seyama & Nagayama, 2007). Therefore, when the effects of visual realism in virtual characters are examined, the behavior of the character also needs to be taken into account. This theory can also be supported by findings that show when a character is clearly not human, no negative effects of increased visual realism on presence are found (Kartiko, Kavakli, & Cheng, 2010).

3.4. Theories on the influence of visual realism

These inconsistent findings reflect the two competing theories regarding how visual realism may affect presence (Slater et al., 2009). The theory that predicts a positive effect of visual realism on presence, is based on the assumption of presence being affected by the immersion provided by the technology used to display and interact with the virtual environment, with immersion being the degree to which the visual fidelity matches a possible real world
The higher the visual fidelity of a virtual environment is, the more difficult it is to discern that an illusory world, rather than a real world, is being perceived (Bouchard et al., 2012; Christou & Parker, 1995). Highly visually realistic environments may therefore be more successful in providing a plausible illusion by taking away the attention from the mediating technology; thus making the experience feel real.

The other theory relies on cognitive processing in human perception and states that visual realism likely does not affect presence (Cummings & Bailenson, 2016; Slater et al., 2009). Different types of objects or constructs, such as cats, trees, and chairs, are stored as mental models, consisting of a set of features that are typical for that particular object (Matlin, 2009). By comparing the set of features extracted from the visual stimulus with the sets that are stored in the mental models, different objects can be recognized. As long as the essential features are present, the cognitive system automatically fills in others details, even if those details are not actually present in the environment (Matlin, 2009; Slater et al., 2002). This means that even an unrealistic representation of an object can be recognized, such as a cartoon character, as long as the important features are easily recognized.

However, this theory focuses on the recognition of objects regardless of their level of visual realism, in order to understand what the virtual scene is supposed to represent. But is the recognition of objects enough to provide a truly realistic experience? For example, if simple but recognizable character models are used in the virtual environment and the users are wearing an HMD, they have no other option than to accept that character as a human in order to make sense of the virtual world, because the HMD filters out any cues from the real world. The users may therefore indeed acknowledge the object exists in the virtual environment, but it does not mean that they felt the experience was truly real, if the lack of intricate details that are naturally present in humans reminds them they are perceiving a mediated environment. It is possible there is a certain threshold that visual realism should pass in order to create a strong visual illusion that makes users forget they are perceiving a mediated environment. Because of the low computational power available in the majority of the previous studies on the effects of visual realism on presence, this threshold might not have been reached yet in academic research.

3.4.1. Comparing the previous findings. One of the main reasons why the findings from the studies cannot readily be compared, is that in each study visual realism was manipulated in a different way: In some environments the polygon count of the 3D models was manipulated, in
others the textures were altered, and in some, both the polygon count and textures were changed to reflect the intended level of visual realism. However, almost no studies reported exactly how the environment was changed, which made it difficult to compare these experiments: What was considered to be an unrealistic environment in one study, might have been regarded as a moderately realistic environment in another study. This may be attributed to the lack of reliable measures of visual realism in computer generated environments.

Rademacher, Lengyel, Cutrell, and Whittled (2001) were among the first to explore which rendering aspects influenced the perceived realism of computer generated images. They manipulated shadow softness, surface smoothness, and the amount of objects and light sources that were present. Images with softer shadows and rougher surfaces were rated higher in realism by observers, than images with harsh shadows and smooth surfaces. Their findings can be used as guidelines when creating realistic environments, but the resulting environments cannot be assessed automatically on their visual realism. Wang and Doube (2011) attempted to incorporate these metrics, while adding colour variance as a metric, to automatically rate images of computer games on their visual realism, but have not yet been used in other studies.

Aside from the lack of methods to assess the visual realism of an environment, it is important to note that most of the studies have been conducted several years ago. Limitations in computational power and the absence of software that enabled the easy creation of realistic environments, made it difficult to create visually realistic immersive virtual environments. The environments used in the research, even in the realistic condition, did not approach the level of visual realism of other media, for example games and animation movies, by far. This is to be expected, because games and movies usually take years to develop, whereas research usually does not have the time needed to create comparable environments. Additionally, immersive virtual environments are even now much more costly to render in real-time than virtual environments that do not require frames to be rendered for each eye separately. Because immersive virtual reality systems have only begun to enter the consumer market in 2014, industry-wide recommendations are being created to enable high performance in immersive VR even when complex environments are used. This will enable current and future research to reach higher visual realism and determine whether there is a threshold that determines whether individuals feel more present in realistic environments.
4. Research aims

There are several reasons why the effects of visual realism should be studied, the first one being that previous research has not provided clear results, possibly caused by the environments that were used not being truly realistic. It should however be known whether visual realism affects presence, because visual realism affects the whole virtual environment, making it a major content characteristic that affects how the environment is perceived and thus the resulting visual illusion, which may influence the sense of presence.

The results that were found in earlier research on the effects of visual realism on presence, may also no longer be subject to replication, because media users have become used to more visually realistic media than were available in the past. Various digital media, such as movies and video games, are increasingly being designed to be as realistic as possible, made possible by the increase in computational power. If people become used to seeing highly realistic virtual media, experiencing a virtual reality application that does not meet their expected level of visual realism, may result in a less positive evaluation of the environment (Pillai et al., 2013). Finally, with virtual reality increasingly being used in diverse applications both within and outside of laboratory settings, such as in consumer gaming and military training, a high level of presence should be achieved to engage the users. This is especially important in virtual reality applications where the user should not be continuously aware that the environment does not exist in real life, for instance in virtual reality exposure therapies. The patient undergoing the therapy should feel the experience is plausible, in order to transfer his advancements in overcoming his or her anxiety obtained in the virtual environment to the real world. If an increase in visual realism increases presence by making the whole experience feel more realistic, then it can be expected that the effectiveness of a virtual reality exposure therapy increases as visual realism increases, resulting in better health care.

4.1. Research questions

The main purpose of the study was to examine whether visually realistic virtual environments evoked a higher feeling of presence than less realistic virtual environments. The expectation was that an increase in visual realism would lead to a higher sense of presence, because of the environment being more visually similar to a corresponding real environment. This would create a stronger illusion of the environment being real, making it less likely that the
user was continuously reminded of the environment being computer-generated. The main research question is formulated as follows:

“Does an increase in visual realism of a virtual environment increase the feeling of presence?”

This study investigated the research question by having participants experience two versions of a virtual cliff environment: A highly realistic and an unrealistic version. The cliff environment was chosen as prior research on VRET treatments for fear of heights has been well documented and found to be effective in evoking anxiety (Diemer et al., 2016). Because emotional states and presence are strongly related, it was also expected that the stronger illusion in the realistic environment would lead to stronger feelings of anxiety than the unrealistic environment. Presence was measured by the IPQ questionnaire, and anxiety was measured by self-reported items and physiological measures (heart rate and galvanic skin response). These measures were used to test the main hypotheses, which were formulated as follows:

- Increasing visual realism increases the sense of presence.
- Increasing visual realism increases the feeling of anxiety caused by fear of heights.

4.1.1. Exploratory research questions. Additionally, we wanted to explore why either environment led to a higher sense of presence or anxiety, if any differences were found. Therefore, participants were asked whether they had noticed any differences between the two environments, and if they did, which differences those were, in order to examine whether any effect of realism could have been a conscious process. It was expected that participants noticed the change in visual realism, because the whole environment was changed to match the intended level of realism. Lastly, we wanted to explore whether increased visual realism was regarded positively, by asking if and why participants preferred either environment. It was expected that participants would prefer a highly realistic version of the same environment, since it would be more aesthetically pleasing to look at. These explorative research questions were formulated as follows:

- Individuals notice the change in visual realism when presented with a less or more realistic version of the same environment.
- Individuals prefer a highly realistic version over a less realistic version of the same virtual environment.
5. Method

5.1. Participants and design

Fifty-two participants (20 women, 32 men) were recruited from the JFS participant database at the Eindhoven University of Technology, ranging in age from 18 to 48 years old ($M = 22.81$ years, $SD = 5.94$). Participants received 5 euros compensation for participating in the study. Because the study relied on the difference in visual realism between the two environments, participants’ visual and stereoscopic acuity was assessed, which resulted in an average visual acuity of 0.93 arcminutes ($SD = 0.22$) and stereoscopic acuity of 95.35 arcsec ($SD = 86.39$) of the sample. Prior experience with virtual reality was assessed by a questionnaire: 19 participants had no prior experience with VR, 24 had experienced VR one or two times before, and 9 had experienced virtual reality three or more times. No participants were excluded completely from data analysis based on their characteristics, although one participant had a much higher fear of heights than others did, and one participant had a high visual acuity. These two participants were excluded during correlation analysis, as described in section 6.1.2.

The study had a 2 (realism: realistic and unrealistic) by 2 (realism of the first environment: realistic first or unrealistic first) mixed factorial design. Realism was a within-subjects factor, whereas the realism of the first environment was a between-subjects factor. The order in which participants experienced the two environments was counterbalanced: Twenty-seven participants experienced the realistic environment first, the other 25 experienced the unrealistic environment first. Each realism condition consisted of two virtual environments: A neutral environment, used for obtaining baseline physiological measures, and a cliff environment. The cliff environment was presented directly after the neutral environment, and matched the neutral environment’s level of realism: Participants in the “Realistic environment first” experienced the realistic neutral and cliff environment first, the others experienced the unrealistic environments first.

5.2. Apparatus

The virtual environment was created using Unreal Engine 4.11.2 and viewed through an Oculus Rift DK2 HMD, which had two displays of 960 x 1080 pixels with a 75Hz refresh rate and 100° Field of View. An infra-red CMOS sensor was utilized for positional tracking of the head, and a Sony DualShock 3 controller was used to navigate through the environment. The software ran on a desktop PC with an Intel Core i7-4770 processor, Radeon R9 270X 2GB
graphics card and 8GB of RAM. The virtual environment was displayed at a fixed framerate of 75Hz throughout the experiment. Participants’ physiological responses were measured with a TMSi Mobi8 device, equipped with a GSR sensor and pulse oximeter.

5.3. The virtual environment

The virtual environment used for the measurement of presence and anxiety consisted of two high cliffs separated 40 meters by a water stream. Figures 2 and 3 depict the cliff environments. A wooden rope bridge placed 30 meters above water level connected the two cliffs. In the water, several smaller rocks were placed that protruded from the water. On some rocks, foliage (grass, moss, or flowers) was added. Before participants experienced the cliff environment, they first experienced a neutral environment, which simulated an open space in a forest. The open space was covered with grass and some small rocks, surrounded by tall trees. This environment was used to make participants comfortable with wearing an HMD, using a controller to move around, and to gather baseline HR and GSR data.

Of both environments, the neutral forest environment and the cliff environment, two versions were created: a highly realistic version and a less realistic version. First, the realistic version was created, using photorealistic 3D models. The mountain models were approximately 8000-10,000 triangles per piece and utilized a texture resolution of 8192x8192 pixels. The wooden bridge had a texture resolution of 2048x2048 pixels. After the realistic environment was created, all 3D models were imported into the Blender 3D modelling software to reduce the triangle count to 20-25% of the original triangle count. This reduced the complexity of the 3D models. Afterwards, smoothing was applied to remove artefacts caused by the reduction of triangles. New textures were also selected for the simpler 3D models. These textures had a resolution of 1024x1024 pixels, and were simpler than the highly realistic textures: They did not contain much detail, such as small rocks, and were not assigned a normal map to simulate bumps and other details. Additionally, they were blurred using a Gaussian blur function in photomanipulation software to further reduce details, but still be recognizable as belonging to rocks. Examples of the realistic and unrealistic textures can be found in Appendix A. The textures of the wooden bridge were simplified to use a single colour. The unrealistic environment

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1 The majority of the mountain models were obtained from Epic Games’ Open World Demo Collection pack. These models were reconstructed from photographs using photogrammetry, and thus looked like real-life objects.
was created by replacing the realistic models with the unrealistic models at exactly the same location, along with the simplified textures. Finally, the water texture was simplified, made opaque, and the water did not flow unlike in the realistic condition.

5.4 Measures

5.4.1. Vision. Visual acuity was measured by a Landolt C test from 5 meters distance. Stereoscopic acuity was measured by a Titmus fly with graded circles and LEA symbols test whilst wearing polarized glasses.

Figure 2. Realistic environment

Figure 3. Unrealistic environment.
5.4.2. Fear of heights. The Acrophobia Questionnaire (AQ; Cohen, 1977) was used to measure trait anxiety in height situations. The Questionnaire consists of 20 situations involving height, such as “Walking on a footbridge over a highway”. For each of the 20 situations, participants indicated their expected anxiety on a scale from “Not anxious at all” (coded by 0) to “Extremely anxious” (coded by 6). The scores per item were summed up to provide a total score ranging from 0-120. The questionnaire is included in Appendix C.

5.4.3. Presence. Presence was assessed by the Dutch version of the Igroup Presence Questionnaire (IPQ; http://www.igroup.org/pq/ipq/download.php#Dutch), and is included in Appendix D. The questionnaire consists of 14 items, divided into 3 subscales and a single item measure: General presence (1 item), spatial presence (5 items), involvement (4 items) and realism (4 items). Each item was assessed on a 7-point Likert scale. Scale reliability per subscale was obtained by averaging the Cronbach’s alpha from the realistic and unrealistic environments. The scale reliabilities obtained in this study were .60 for spatial presence, .75 for involvement, and .54 for realism. Two studies conducted by the Igroup obtained higher reliabilities for the spatial presence and realism subscales, namely .79 for spatial presence, .76 for involvement, and .68 for realism (http://www.igroup.org/pq/ipq/factor.php, n.d.).

5.4.4. Experienced fear. Three items measured the anxiety experienced during the experiment on a scale from 0-10, pertaining to how afraid participants were during the experiment, how likely it would be to fall down from the bridge, and how safe they felt. The measures are included in Appendix D. Scale reliability was 0.69. Additionally, a multiple-item question assessed whether and where participants experienced a physiological response, to explore which aspects of the environment were most anxiety-evoking. Participants could pick one or more of the following options: At no point in time, at the beginning, when they stood on top of the cliff, during the first steps on the bridge, when they looked down to count the rocks with foliage, or at the end of the bridge.

5.4.5. Post-test preferences and differences. A post-test questionnaire assessed which environment participants preferred (no preference / the first environment / the second environment), which environment was scarier (the first / second environment), and whether they had noticed a difference between the two environments. For all three questions participants were asked to write down why they picked their answer. Additionally, a manipulation check was
performed by having participants rate four screenshots of the virtual environment on a scale from 0-10 on realism: Two screenshots of the realistic version, two of the less realistic version. The questionnaire and screenshots are included in Appendix E.1 and E.2.

5.4.6. **Simulator sickness.** Simulator sickness was assessed by the Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993). The questionnaire consists of 15 items, divided into two subscales assessing nausea and oculomotor disturbances.

5.4.7. **Physiological responses.** Heart rate and GSR were measured by a TMSi Mobi8 device. Heart rate was measured in beats per minute (bpm), and GSR was measured in microSiemens (μS), which was divided into a tonic and phasic component afterwards by the use of Ledalab software, as described in section 6.4.2.2.

The intervals used in the analysis of physiological data can be viewed in Figure 4. We did not conduct baseline measures prior to putting on the HMD, since the HMD itself and experiencing the virtual environment are novel stimuli, which may evoke physiological responses, regardless of the level of realism or other stimuli presented in the environment (Dawson, Schell, & Filion, 2007, p. 164). Instead, the period during which participants explored the neutral environment was chosen as a baseline measure. Specifically, the last 30 seconds of this period were used in the data analysis, to account for any short-term physiological responses to the novelty of the environment.

5.5. **Procedure**

Upon arrival at the laboratory, participants were asked to read and sign an informed consent. After they had signed the informed consent, they were asked to fill out a questionnaire with general demographic questions (age, gender), questions regarding prior experience with VR, and the Acrophobia Questionnaire. After they had completed filling out the questionnaire, their visual and stereoscopic acuity was assessed. They were then taken to the room containing the VR setup, and received instructions for applying the GSR sensor and pulse oximeter. Afterwards, the experimenter gave instructions for the task that had to be carried out in the VE and demonstrated how to use the controller for navigation. The participants then put on the HMD and adjusted it when necessary to provide a clear image. Appendix F shows the experimental setup, and Figure 4 shows the task progression per session.
They were given one minute to familiarize themselves with the virtual reality equipment in the neutral environment (an open space surrounded by trees) and the measurement of physiological responses was started. After one minute, a marker was placed in the physiological data, after which the experimenter shortly repeated the task to be conducted in the cliff environment. Participants were then asked to close their eyes, during that period (around five seconds) the cliff environment was loaded and a new marker was placed. They were then asked to open their eyes and begin the task.

In the cliff environment, the goal was to walk over the wooden bridge and count the amount of rocks in the water with foliage on them. To count all the rocks, the participants needed to look down and cross the bridge completely, since some rocks were hidden. After counting the rocks, they had to reach the other cliff and name the amount of rocks with foliage on them. During that time, the experimenter observed the participant’s location and placed a marker when he or she had first reached the bridge and taken two steps. After the task was completed, the experimenter noted the amount of rocks the participant had indicated and stopped the physiological measurement. The participants then took off the HMD and filled out the IPQ questionnaire along with four items assessing their anxiety and physiological responses. The same procedure was then repeated for the other degree of realism in a second session, including the one-minute neutral environment: Participants who started with the realistic environments then experienced the less realistic environments, whereas the others experienced the realistic environments.

After the task had been completed for the second time, the participants were asked to take off the physiological measurement equipment, and to fill out the IPQ questionnaire along with the post-test questionnaire assessing their preferences and experienced simulator sickness. Participants were then debriefed and received the compensation.
6. Results

6.1. Data exploration

To enable subsequent analysis, the dataset was first scanned for any outliers, using z-scores computed from the measurements and visual inspection using boxplots. Three participants had at least one z-score of 3 standard deviations away from the mean, along with at least two other z-scores close to three standard deviations away from the mean on the average presence score and presence subscales. These participants were excluded from subsequent analyses of the presence ratings. One participant did not complete the involvement and realism items for the first environment, and was excluded during the analysis of these items. Two participants were considered to be outliers based on their characteristics: One participant had a z-score of +4.3 for fear of heights, and one participant had a z-score of + 2.5 for visual acuity. They were not considered to be outliers in the self-reported items, and were therefore only excluded during correlation analysis.

6.1.1. Correlations. To determine whether participant characteristics affected presence or anxiety during the experiment, correlations between participant characteristics and the dependent measures were calculated. Table 1 summarizes the significant correlations. Gender was found to correlate with fear of heights ($r = .47$, $p < .001$) and experienced fear during the realistic VE ($r = .38$, $p = .009$): Women indicated higher scores on fear of heights and felt more anxious in the realistic VE. Fear of heights correlated positively with experienced general fear in both the realistic ($r = .39$, $p = .006$) and unrealistic VE ($r = .29$, $p = .048$), and with fear of falling in both the realistic ($r = .51$, $p < .001$) and unrealistic VE ($r = .36$, $p = .014$). Prior experience with VR correlated positively with overall experienced presence ($r = .38$, $p = .007$) and the involvement subscale in the realistic condition ($r = .33$, $p = .021$), but not in the unrealistic condition ($r = .14$, $p = .33$). Including prior experience with VR as an additional between-subjects factor in ANOVA did not reveal an effect of prior experience on presence, nor did it affect the outcomes of the analysis, and was therefore excluded from the reported analysis. Adding fear of heights as a covariate in ANCOVA revealed an effect of fear of heights on reported anxiety, and was therefore included in the analysis of self-reported general fear and fear of falling. Visual and stereoscopic acuity were not found to correlate with any measures, because of which no participants were excluded based on vision.
Additionally, oculomotor disturbances as indicated by the SSQ were positively correlated with experienced fear in the realistic ($r = .29$, $p = .045$), and unrealistic environment ($r = .37$, $p = .010$). Finally, nausea as measured with the SSQ, correlated positively with experienced fear in the unrealistic environment ($r = .29$, $p = .050$).

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Unrealistic VE</th>
<th>Realistic VE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fear of heights (overall)</td>
<td>Fear Fall Presence (overall)</td>
</tr>
<tr>
<td>Gender</td>
<td>.47**</td>
<td>.06 .28 .13 -.15 .38** .18 .08 .06</td>
</tr>
<tr>
<td>Fear of Heights</td>
<td>1 .07 .29* .36* .03 .39** .51** .24 .28</td>
<td></td>
</tr>
<tr>
<td>Prior VR experience</td>
<td>.00 .04 .13 .22 .38** -.10 .08 .25 .25</td>
<td></td>
</tr>
<tr>
<td>Oculomotor (SSQ)</td>
<td>.08 .18 .37* .24 .02 .29* .21 1 .66**</td>
<td></td>
</tr>
<tr>
<td>Nausea (SSQ)</td>
<td>.06 .15 .29* .24 .13 .11 .18 .66** 1</td>
<td></td>
</tr>
</tbody>
</table>

Note:
* $p < .05$ (two-tailed)
** $p < .01$ (two-tailed)

6.1.2. Normality assumptions. To determine whether ANOVA could be used for data analysis, the dependent variables were assessed on normality. All dependent measures were approximately normally distributed, except for the single-item general presence measure, as indicated by inspecting skewness, kurtosis and the SW-test for normality, of the realistic VE with $SW(48) = .839$, and $p < .001$ for the realistic VE, and $SW(48) = .821$, and $p < .001$ for the unrealistic VE.

6.2. Manipulation check

Two manipulation checks were performed at the end of the post-test questionnaire to determine whether the realistic environment was indeed perceived to be more realistic than the unrealistic environment. Four screenshots of the experienced environments were shown and rated on a scale from 0-10 on visual realism: Two of the realistic version, two of the unrealistic
version at the same locations. Participants gave the realistic VE significantly higher scores ($M = 7.21, SD = 0.93$), than the unrealistic VE ($M = 3.23, SD = 1.59$) with $t(48) = 15.43, p < .001, d_z = 2.20$, as indicated by a paired samples t-test. The manipulation was thus successful in that people perceived a difference in realism between the two environments.

Another manipulation check involved whether participants were conscious of the changes in the environments. The first exploratory research question stated that individuals would notice the change in visual realism when presented with a less or more realistic version of the same environment. One measure assessed whether participants noticed a difference, and if they did, what difference it was in an open question. The results were coded into three categories: Not related to realism, realism, and noticed realism before. The not related to realism category was chosen if participants did not notice a difference, or when they answered something very different from realism, such as “the bridge was higher”. The realism category was chosen if participants explicitly chose realism as their answer. Noticed realism before was chosen if participants had answered realism explicitly in previous questions, but chose a different concept for this measure, such as “there was more foliage”. No difference was noticed by 37% of the participants, 43% noticed the difference in realism and provided this as their answer, and 20% noticed realism before but answered something different in this question. The majority of participants thus noticed the difference in realism, although a large part did not notice the difference. A Pearson Chi-Square test indicated there was no effect of whether the realistic or unrealistic environment was experienced first on the notice of change in realism, $\chi^2(2, N = 49) = .027, p = .986$. Based on these results, there are indications that people consciously notice changes in visual realism when presented with the same environment in varying levels of visual realism.

6.3. The influence of realism on presence
In order to determine whether there was an effect of realism on overall presence, the mean scores of the IPQ were calculated for the realistic and unrealistic environment. For this and all subsequent analyses, a mixed-design 2x2 ANOVA was calculated with realism of the VE (realistic and unrealistic) as the within factor, and the order in which the two environments were experienced (realistic first, unrealistic first) as the between factor. The analysis revealed a significant main effect of realism: Participants felt more present in the realistic environment ($M = 3.71, SD = .44$), than in the unrealistic environment ($M = 3.42, SD = .53$), with $F(1, 47) = 14.20$. 
There was neither a main effect of the order in which the environments were experienced, $F(1, 47) = .15, p = .701, \eta_p^2 = .003$, nor an interaction with the order of realism, with $F(1, 47) = .21, p = .65, \eta_p^2 = .004$. This indicates that participants felt overall more present in the realistic environment than in the unrealistic environment. To examine whether there were differences in the type of presence experienced, the analysis was repeated for each subscale of the IPQ. The findings are summarized in Table 2 and full descriptive statistics are available in Appendix G.

### Overview of realism main effects on presence

<table>
<thead>
<tr>
<th>IPQ subscale</th>
<th>Unrealistic VE</th>
<th>Realistic VE</th>
<th>F</th>
<th>p</th>
<th>$\eta_p^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average presence</td>
<td>M 3.42 SD .53</td>
<td>M 3.71 SD .44</td>
<td>14.20</td>
<td>&lt;.001</td>
<td>.232</td>
</tr>
<tr>
<td>General presence</td>
<td>M 4.12 SD .93</td>
<td>M 4.33 SD .92</td>
<td>2.12</td>
<td>.152</td>
<td>.043</td>
</tr>
<tr>
<td>Spatial presence</td>
<td>M 4.01 SD .73</td>
<td>M 4.30 SD .64</td>
<td>7.45</td>
<td>.009</td>
<td>.137</td>
</tr>
<tr>
<td>Involvement</td>
<td>M 3.82 SD 1.14</td>
<td>M 4.19 SD .88</td>
<td>10.00</td>
<td>.003</td>
<td>.179</td>
</tr>
<tr>
<td>Realism</td>
<td>M 2.08 SD .77</td>
<td>M 2.40 SD .78</td>
<td>6.86</td>
<td>.012</td>
<td>.130</td>
</tr>
</tbody>
</table>

#### 6.3.1. General presence

General presence was measured by a single item on the IPQ. A mixed ANOVA revealed no main effect of realism, with $F(1, 47) = 2.12, p = .152, \eta_p^2 = .043$, and no realism order effect, $F(1, 47) = 1.62, p = .209, \eta_p^2 = .033$. However, an interaction with the order of realism was found, with $F(1, 47) = 4.05, p = .050, \eta_p^2 = .079$. Post-hoc LSD tests showed that participants who experienced the unrealistic environment first, felt more present in the realistic environment ($M = 4.33, SD = 0.92$) than in the unrealistic environment ($M = 3.83, SD = 1.09$), with $p = .019$, but this order effect was not present in participants who first experienced the realistic environment. These results, however, must be interpreted with care as the single item general presence measure was not normally distributed.

#### 6.3.2. Spatial presence

Spatial presence was measured by five items, and assessed whether participants felt immersed in the environment. A mixed ANOVA revealed a main effect of realism: Participants felt more present in the realistic environment ($M = 4.30, SD = .64$), than in the unrealistic environment ($M = 4.01, SD = .73$), with $F(1, 47) = 7.45, p = .009, \eta_p^2 = .137$. 
Neither a main effect of realism order, $F(1, 47) = .42$, $p = .519$, $\eta^2_{p} = .009$, nor an interaction effect were found, with $F(1, 47) = 1.61$, $p = .21$, $\eta^2_{p} = .033$. This indicates that individuals felt more spatially present in the realistic environment.

6.3.3. Involvement. Involvement was measured by four items, which assessed whether participants were still conscious of their real surroundings. A mixed ANOVA revealed that participants had a higher involvement with the realistic environment ($M = 4.19$, $SD = .88$) than with the unrealistic environment ($M = 3.82$, $SD = 1.14$), with $F(1, 46) = 10.00$, $p = .003$, $\eta^2_{p} = .179$. There was no main effect of realism order, with $F(1, 46) = .29$, $p = .592$, $\eta^2_{p} = .006$, and no interaction effect, $F(1, 47) = 3.77$, $p = .058$, $\eta^2_{p} = .076$. This finding indicates that participants felt more involved with the realistic environment than with the unrealistic environment.

6.3.4. Realism. Realism was measured by four items assessing the extent to which the environment appeared real. Realism in this subscale was defined as overall realism, including, but not limited to, visual realism. A mixed ANOVA revealed a main effect of realism, such that participants indeed felt the realistic environment was more realistic ($M = 2.40$, $SD = .77$) than the unrealistic environment ($M = 2.08$, $SD = .78$), with $F(1, 46) = 6.86$, $p = .012$, $\eta^2_{p} = .130$. There was no main effect of the order in which the environments were experienced, with $F(1, 46) = .00$, $p = .952$, $\eta^2_{p} < .001$, and no interaction effect, $F(1, 46) = 2.05$, $p = .159$, $\eta^2_{p} = .043$.

6.3.5. Preferences. Aside from the effects of realism on presence, the second exploratory research question also assessed whether individuals preferred a realistic version of the same environment over a less realistic version. One post-test measure assessed which environment participants preferred (the first, second or no preference), and was recoded to none, realistic or unrealistic after data acquisition was completed. The results showed that the majority of the participants (62%) indicated they preferred the realistic environment, 25% indicated they preferred the unrealistic environment and 13% indicated they had no preference. A Pearson Chi-Square test indicated there was no effect of whether the realistic or unrealistic environment was experienced first on preference, $\chi^2(2, N = 49) = 3.77$, $p = .152$.

In order to understand their preferences, participants were asked to give a short explanation in an open question to explain their preference. The answers to the open questions were categorized by the experimenter, based on keywords occurring in the answers. The extracted categories and their frequencies per preference are depicted in Figure 5, on which can
be seen that realism was the most chosen reason why participants preferred the realistic environment, followed by an increase in details and aesthetic preferences. In the unrealistic VE, the most chosen preference category was screen performance. The screen performance category was used when individuals indicated the environment was better or more smoothly displayed. Although all environments were displayed at a frame rate of 75Hz, the neutral realistic environment might have had small frame drops if participants tried to walk into the forest, as rendering for the moving trees was complex. Judging by the low frequency of preferences for the unrealistic environment, the majority of participants did not experience this issue. Based on these findings, there are indications people evaluate realistic environments more positively than unrealistic environments.

![Figure 5. Frequencies of preference categories per level of realism.](image)

### 6.4. Anxiety measures

Anxiety was measured by three questionnaire items after experiencing each virtual environment, and with physiological measures (heart rate and galvanic skin response) during the experiment.
6.4.1. Self-reported measures. The first item assessed general fear. A mixed ANCOVA revealed no significant effect of realism on reported fear, with \( F(1, 44) = .026, p = .874, \eta_p^2 = .001 \), and no effect of the order in which the environments were experienced, \( F(1, 44) = .22, p = .639, \eta_p^2 = .005 \), after controlling for fear of heights. However, an interaction effect was found, with \( F(1, 44) = 4.13, p = .048, \eta_p^2 = .086 \). Additional post-hoc analyses without correction (LSD) revealed no effect of realism order on either the unrealistic environment \( (p = .839) \), or realistic environment \( (p = .265) \), nor an effect of realism for individuals who started with the unrealistic environment \( (p = .208) \), or the realistic environment \( (p = .100) \). The fear of heights trait was found to increase reported fear, with \( F(1, 44) = 5.04, p = .030, \eta_p^2 = .103 \).

The second item assessed whether participants were afraid they would fall down from the bridge. A mixed ANOVA showed there was no main effect of realism, with \( F(1, 44) = .34, p = .564, \eta_p^2 = .008 \), no effect of realism order, \( F(1, 44) = .36, p = .553, \eta_p^2 = .008 \), and no interaction effect, \( F(1, 44) = 2.01, p = .163, \eta_p^2 = .044 \), after controlling for fear of heights. However, trait anxiety was found to increase the fear of falling, with \( F(1, 44) = 12.23, p < .001, \eta_p^2 = .22 \).

The third item which assessed whether participants felt safe in the environment, also showed neither a main effect of realism, with \( F(1, 46) = 3.03 p = .584, \eta_p^2 = .007 \), nor an effect of the order of realism, \( F(1, 46) = .33, p = .570, \eta_p^2 = .007 \), nor an interaction effect, \( F(1, 46) = .017 p = .896, \eta_p^2 < .001 \). These findings indicate that the reported fear did not depend on the level of realism, but whether participants had a fear of heights: Higher fear of heights led to higher fear in the environment.

6.4.2. Physiological measures.

6.4.2.1. Heart rate. Out of 52 participants, four participants’ HR data was removed from the dataset due to measurement artefacts. One participant was considered to be an outlier, as indicated by z-scores > +/- 3, and was not included in subsequent HR analyses. The HR data was analyzed using a customised MATLAB script that computed the average heart rate (in bpm) for each measurement interval.

To determine whether the cliff evoked physiological arousal, a paired samples t-test was calculated, which showed that participants had a significantly higher heart rate when they walked over the bridge in the realistic condition \( (M = 88.04, SD = 13.13) \) than in the neutral environment \( (M = 84.18, SD = 12.39) \), with \( t(46) = 6.58, p < .001, d_z = 0.96 \). The same effect was found in the
unrealistic condition, where participants had a significantly higher heart rate when they walked over the bridge \((M = 86.57, SD = 13.26)\), compared to the neutral environment \((M = 83.72, SD = 13.27)\), with \(t(46) = 4.74, p < .001, dz = 0.69\). Both cliff environments thus led to an increase in heart rate.

6.4.2.1.1. Effects of realism and presentation order. In order to determine whether there was a statistically significant difference in heart-rate between the realistic and unrealistic condition, two deviations from the baseline were computed: The difference between baseline HR and HR in the bridge interval \((HR_{bridge} - HR_{baseline})\), and the ratio \(HR_{bridge}/HR_{baseline}\). Since persons vary widely in their physiological responses at rest, the ratio was expected to be a more valid measure, as it accounts for person characteristics. A mixed-design 2x2 ANOVA with realism of the VE (realistic or unrealistic) as the within factor, and the order of realism in which the environments were experienced (realistic first, unrealistic first), showed that there was no significant difference in HR when comparing the subtracted values, with \(F(1, 45) = 2.85, p = .098, \eta_p^2 = .06\), nor when comparing the ratio, with \(F(1, 45) = 1.94, p = .17, \eta_p^2 = .04\). There was also no main effect of the order of realism when comparing the subtracted values, with \(F(1, 45) = 0.34, p = .560, \eta_p^2 = .008\), nor when comparing the ratio, \(F(1, 45) = 0.53, p = .471, \eta_p^2 = .012\). Finally, no significant interaction with the order of realism was found when comparing the subtracted values, with \(F(1, 45) = 2.23, p = .142, \eta_p^2 = .04\), nor when comparing the ratios, with \(F(1, 45) = 1.73, p = .195, \eta_p^2 = .04\). Based on these findings, the cliff environments did lead to an increase in heart rate, but there was no difference between the realistic and unrealistic cliff environment.

6.4.2.2. GSR. All GSR data were first scanned for any artefacts using the Ledalab add-on for MATLAB (http://ledalab.de/). Small artefacts were corrected in the software, whereas GSR data containing multiple large artefacts that could not be corrected were removed from the dataset, which led to the removal of five participants’ GSR data. The data were then analyzed using continuous decomposition analysis (CDA) in Matlab, which provided two measures of GSR: ISCR (the time integral of SCR) as the phasic component, and SCL as the tonic component (Benedek & Kaernbach, 2010). One outlier with \(z\)-scores of > 3 on multiple GSR measures was detected and excluded from subsequent analyses.

As with the HR analysis, a paired samples t-test was calculated to determine whether the bridge in the cliff environment led to an increase in physiological responses. The results are
shown in Table 3. From these results can be concluded that participants had a significantly higher galvanic skin response in both cliff environments, as compared to the neutral environments.

Table 3.
Differences in GSR between the baseline and cliff environment.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Realism</th>
<th>Baseline M (SD)</th>
<th>Bridge M (SD)</th>
<th>M_{difference}</th>
<th>SD_{difference}</th>
<th>t(45)</th>
<th>p</th>
<th>dz</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISCR</td>
<td>Unrealistic</td>
<td>8.00 (9.59)</td>
<td>18.94 (24.87)</td>
<td>10.94</td>
<td>17.05</td>
<td>4.35</td>
<td>.000</td>
<td>.64</td>
</tr>
<tr>
<td>Tonic</td>
<td>Unrealistic</td>
<td>4.43 (4.24)</td>
<td>4.89 (4.60)</td>
<td>.46</td>
<td>.65</td>
<td>4.84</td>
<td>.000</td>
<td>.71</td>
</tr>
<tr>
<td>ISCR</td>
<td>Realistic</td>
<td>11.41 (22.19)</td>
<td>23.56 (24.04)</td>
<td>12.14</td>
<td>21.46</td>
<td>3.83</td>
<td>.000</td>
<td>.57</td>
</tr>
<tr>
<td>Tonic</td>
<td>Realistic</td>
<td>4.19 (3.73)</td>
<td>4.95 (4.92)</td>
<td>.76</td>
<td>1.77</td>
<td>2.93</td>
<td>.005</td>
<td>.43</td>
</tr>
</tbody>
</table>

6.4.2.2.1. Effects of realism. In order to determine whether there was a statistically significant difference in GSR between the realistic and unrealistic condition, two deviations from the baseline were computed: ISCR (with a minimum SCR amplitude of 0.05 μS) or SCL difference by subtracting the average GSR in the neutral environment from the average GSR in the bridge interval (GSR_{bridge} – GSR_{baseline}), and the ratio GSR_{bridge} / GSR_{baseline}, for ISCR and SCL values. As with HR, GSR varies widely between individuals, and several quantifying methods exist. Most researchers use the difference between the average GSR values, although this does not account for individual differences (Dawson et al., 2007). Dawson and colleagues (2007) recommend expressing GSR as a proportion of the individual’s GSR range, based on their minimum and maximum GSR. However, in this study the range was not obtained, therefore the ratio GSR_{bridge} / GSR_{baseline} was used to account for individual differences.

A mixed-design 2x2 ANOVA with realism of the VE (realistic or unrealistic) as the within factor, and the order of realism in which the environments were experienced (realistic first, unrealistic first) as the between factor, was computed to examine the effect of realism on GSR. The full descriptive statistics can be found in Appendix H. The increase in the tonic
component of GSR, expressed by ratio change in SCL, was found to be significantly higher in the realistic environment (+18%, $M = 1.18$, $SD = .20$) than in the unrealistic environment (+13%, $M = 1.13$, $SD = .14$), with $F(1, 44) = 4.55$, $p = .039$, $\eta_p^2 = .094$, whereas this effect was not found for the difference measure, with $F(1, 44) = 1.37$, $p = .25$, $\eta_p^2 = .00$. The increase in the phasic component of GSR, expressed by ratio change in ISCR, was also found to be significantly higher in the realistic environment (+286%, $M = 3.86$, $SD = 3.51$), than in the unrealistic environment (+151%, $M = 2.51$, $SD = 1.75$), with $F(1, 44) = 5.39$, $p = 0.025$, $\eta_p^2 = .11$, whereas this effect was not found when the deviation was expressed by phasic difference, with $F(1, 44) = .158$, $p =.693$, $\eta_p^2 = .00$. No main effects of the order in which the environments were experienced were found during analysis for any GSR measures.

6.4.2.2.2. Novelty effect. A significant interaction with the order of realism was found for the tonic ratio, with $F(1, 44) = 30.25$, $p <.001$, $\eta_p^2 = .407$, and tonic difference, with $F(1, 44) = 4.58$, $p = .038$, $\eta_p^2 = .094$. Post-hoc LSD tests showed that individuals who first experienced the realistic environment, had a higher tonic ratio during the realistic environment ($M = 1.27$, $SD = 0.20$), than the individuals who experienced the unrealistic environment first ($M = 1.08$, $SD = 0.14$), with $p < .001$, and a higher tonic difference during the realistic environment ($M = 1.27$, $SD = 2.38$), than in the unrealistic environment ($M = 0.26$, $SD = 0.44$), $p = .050$. Finally, a paired samples t-test was computed in order to determine whether changes in tonic GSR between the neutral and the cliff environment differed between the first and second environment participants experienced, regardless of the realism of the environment, or the order of realism. The results are depicted in Figure 6, and revealed that participants had a significantly higher tonic ratio change in the first cliff environment ($M = 1.22$, $SD = 0.18$), than in the second cliff environment ($M = 1.09$, $SD = 0.13$), with $t(45) = 5.30$, $p < .001$, $d_z = 0.78$, and a higher tonic difference in the first environment ($M = 0.89$, $SD = 1.76$), than in the second environment ($M = 0.34$, $SD = 0.57$), $t(45) = 2.13$, $p = .039$, $d_z = 0.31$. 
Overall it can be concluded that the realistic environment evoked a higher increase in GSR than the unrealistic environment when comparing the change in ratio (i.e. percentage change per person from the neutral to the cliff environment). However, the effect size of the interaction with the level of realism of the first VE, indicates that the novelty of the environment had a higher influence on the change in tonic than realism did: Participants’ SCL increased more in the first session than in the second session. This effect was stronger when the realistic environment was presented first.

There are two possible causes for this order effect, the first one being that the tonic level was still heightened during the baseline measures of the second session, which could prevent another high increase, since the SCL was closer to the maximum of the individual’s range. In order to determine whether the baseline values differed between the first and second session, a paired samples t-test was computed. The results showed that the baseline tonic level in the second session was indeed higher ($M = 4.79, SD = 4.14$) than in the first session ($M = 3.84, SD = 3.78$), with $t(45) = 5.46, p < .001, d_z = 0.81$. This was not due the realistic or unrealistic neutral environment being more arousing or individual characteristics, since the baseline tonic level in the first session did not differ significantly between participants who experienced the realistic or unrealistic environment first, as indicated by an independent samples t-test, with $t(44) = 1.45 p =$
.155, \( d_c = 0.21 \). However, in the current study it cannot be determined whether the already heightened tonic level prevented another rise in tonic level, because the participants’ full GSR range was not obtained.

Another possibility is the existence of a habituation effect: Since the two environments only differed with regards to realism and the position and amount of rocks in the water, while the task was the same, the participants knew what they had to do and what would happen, which could have made them feel more at ease.

### 6.4.3. Anxiety-evoking aspects

In order to examine why participants felt more anxious in either environment, the post-test included items assessing which environment evoked more anxiety and why. The realistic environment was chosen by 67% of the participants as the environment they felt more anxious in. Interestingly, for this measure there was no difference between the group that experienced the realistic VE first and the group that experienced the unrealistic VE first, as indicated by a Pearson Chi-Square test, \( \chi^2(1, N = 49) = .50, p = .478 \).

To understand why either environment evoked more anxiety, the open questions were again categorized. The categories and their frequencies can be found in Figure 7. In the realistic environment, realism was the most chosen reason why the environment evoked more anxiety than the other environment, followed by experiencing the task for the first time. For the unrealistic VE, experiencing the VE for the first time was the most chosen reason. When those two measures are summed up overall, 35% of participants found realism to be the anxiety evoking factor, and 29% found the novelty of the VE the most likely cause. This supports the interaction effect between realism and novelty of experience found during analysis. Aside from these two factors, some participants indicated they had more physical responses and generally felt less safe in the realistic environment.
Figure 7. Frequencies of anxiety categories per level of realism.
7. Discussion

This study examined whether visual realism influenced the sense of presence individuals experienced in an immersive virtual environment. Previous studies that examined the effects of visual realism often had contradictory results, which might have been caused by not using truly realistic environments. This study tried to enhance the previous research, by utilizing a more realistic environment than in the majority of previous research. The findings indicate that individuals indeed feel more present in realistic environments than in less realistic environments. In order to determine whether this was actually caused by the difference in realism, we conducted three manipulation checks by assessing the subjective level of realism of the environments, and whether participants had consciously noticed a difference between the environments. The realism subscale of the IPQ and the realism ratings of the screenshots in the post-test questionnaire indicated that the realistic environment was indeed perceived to be more realistic than the unrealistic environment. Additionally, an open question assessing whether participants noticed a difference between the two environments, showed that two-third of the participants explicitly named realism as the difference between the two environments, indicating that the difference in presence could be a conscious process.

Although the main research question was whether the realistic environment evoked more presence than the unrealistic environment, it was also important to examine whether there was an interaction effect between realism and the realism of the first VE, that is: Does the sense of presence in the realistic or unrealistic environment change, depending on whether the environment is presented first or second? If an interaction between realism and the realism of the first presented VE exists, then this would provide evidence that the change in presence would be caused participants being conscious of the change in realism. For example, if the realistic environment was assigned higher presence scores if it was presented as the second environment than when it was presented first, then the increase in presence would likely be caused by participants being conscious of the increase in realism. However, no interaction effect was found for the presence scores, except for the single-item general presence, which indicates that the realistic environment evoked a higher sense of presence, regardless of the order it was presented in. Therefore no conclusions can be made about whether the influence of realism was a conscious or subconscious process. Additionally, no order effects were found, as indicated by the
absence of between-subjects effects, from which can be concluded that the changes in presence were indeed caused by the change in visual realism.

7.1. Individual preferences

To further examine why presence was higher in the realistic condition, a post-test measurement assessed which environment the participants preferred. Analysis showed that 62% of the participants preferred the realistic environment, whilst 25% preferred the unrealistic environment. The most chosen reason for preferring the realistic environment, was the increase in realism, which shows that increased realism can be regarded positively. The second and third most chosen reasons were an increase in detail and aesthetic preferences, with some participants indicating “there was more to look at” in the realistic environment. This may suggest that the realistic environment was more interesting to experience, leading to higher engagement. It should be noted that there was no actual difference in the amount of virtual objects between the two environments. The increase in details was thus caused by the realistic environment using more complex models and photorealistic textures, which showed more variety in features and in colour. Since an increase in colour variance is associated with higher visual realism, the category ‘increase in details’ is likely a related measure of realism (Choi, Luo, Pointer, & Rhodes, 2009; Wang & Doube, 2011). It should, however, be noted that response bias in the post-test measures cannot be ruled out. Since the realism manipulation was successful and participants noticed the difference in realism, it is possible they answered they preferred the realistic environment, to match the experimenter’s expectations (Van de Mortel, 2008).

7.2. Anxiety

Aside from the effect of realism on presence, the influence of realism on anxiety was also examined. Both HR and GSR measures showed that both the realistic and unrealistic cliff environments evoked significant increases in physiological responses, compared to the neutral environments. Further analyses showed that the realistic cliff environment elicited higher changes in SCL and ISCR than the unrealistic environment, but this was not reflected in the HR measures. Previous studies have also indicated that the threshold for HR responses may be higher than for skin responses, which makes HR measures less sensitive to changes in arousal in non-clinical samples (Diemer, Mühlberger, Pauli, & Zwanzger, 2014; Lang, Davis, & Öhman, 2000; Wiederhold, Jang, Kim, & Wiederhold, 2002). However the novelty of the environment was more influential on the tonic level: The first session elicited a higher change in SCL than the
second session, and this effect was the strongest when the realistic environment was presented first. The same interaction effect was found in the subjective anxiety measures, although the post-hoc tests did not indicate which conditions were different from each other, and no effect of realism was present in the subjective measures. These findings indicate that an increase in realism may increase anxiety, but is subject to a novelty effect. This assumption was confirmed by the post-test measures, wherein 35% of participants indicated they were more anxious because of increased realism, and 29% indicated the novelty aspect was most anxiety evoking. Interestingly, no order effect was found for any presence scores. This suggests, contrary to expectations, that anxiety and presence were not strongly related in this study, and that the physiological responses were more indicative of anxiety than of presence.

These findings also indicate the importance of physiological measures when assessing anxiety, since the subjective anxiety ratings were quite low: Scores on the 0-10 scale were mostly in the 1-4 range. Several possible causes exist for this finding, the first being that the majority of participants did not have clinical acrophobia: Research has shown that individuals without acrophobia did not feel more anxious during exposure to a VR height challenge, whilst acrophobic patients felt significantly more anxious, when assessed by subjective anxiety ratings (Diemer et al., 2016). However, they found that both acrophobic and non-acrophobic individuals exhibited physiological arousal, assessed by heart rate and skin conductance level. The same results were found in this study: Individuals with higher acrophobia reported higher fear, but acrophobia was not found to correlate with any physiological measures. It is also possible that the tonic level is less indicative of the currently experienced anxiety than SCR-related measures, because the tonic level can be heightened due to previous exposure to anxiety-inducing stimuli. SCR measures however, indicate the responses to specific stimuli. Although this study did not utilize the sudden presentation of stimuli, the rocks in the water during the counting task were used to make participants look down, and essentially remind them they were high above the ground. When participants were looking at the rocks to determine whether they had foliage on them, they were thus subjected to depth cues, which could have led to an increase in anxiety and SCR. With this interpretation, the realistic environment was successful in evoking higher anxiety, but based on the other anxiety measures, the novelty effect cannot be ruled out.

Another possibility is that the subjective measurement method was not suitable for measuring anxiety. Participants indicated their fear ratings after they had experienced a VE, thus
might have already recovered from anxiety, if experienced. Most research on VRET used 0-10 or 0-100 anxiety ratings during the experience of the VE, in order to find out whether the treatment has effects and whether to continue to the next, more anxiety-inducing location in the environment (Côté, & Bouchard, 2008). Since this study was not designed to have any therapeutic effects, measurement during the VE was deemed inappropriate, as it would distract the participant from the counting task and possibly break presence, caused by hearing a sound from “the real world”. To improve this issue, a different type of subjective fear measure can be administered, such as an anxiety measure displayed inside the VE. However, caution should be taken to prevent a sudden break of flow during the experience.

Finally, a third possibility is that the cliff environment was not successful in evoking strong fearful reactions in non-phobic participants. The bridge was placed at 30 metres above the water level, and the height from which the environment was viewed was made to match each participant’s own body height, thus the 30 metres were geometrically correct. Nonetheless, research has shown that people generally underestimate distances in virtual reality, which would make the bridge look lower than it actually was and thus not successful in inducing high levels of anxiety (Armbrüster, Wolter, Kuhlen, Spijkers, & Fimm, 2008; Grechkin, Nguyen, Plumert, Cremer, & Kearney, 2010; Jones, Swan, Singh, Kolstad, & Ellis, 2008).

7.3. Practical implications

Overall, increasing visual realism increased reported presence in this study and was evaluated positively by individuals. This indicates that it is worthwhile to create realistic environments, to increase presence and user satisfaction. However, the findings from this study indicate that visual realism has a relatively small effect on height-related anxiety, compared to the effects on presence. The level of realism is thus less important when the main goal of a VR application is to induce anxiety caused by fear of heights, such as in VRET applications. It should however be noted that in this study, a ‘natural’, often occurring phobic stimulus (i.e. height) was administered. Although depth cues rely on lighting and shadows to reach a certain perceived depth, and lighting creates more realistic shadows when it interacts with a complex object, simple objects such as cubes are also capable of producing depth cues, which has been demonstrated in previous virtual pit experiments (Meehan et al., 2002; Slater et al., 2009). Visual realism may thus have small effects on height-related anxiety, but possibly has larger effects on
anxiety caused by other phobias, such as any animal phobias, if they are more reliant on the details of the stimulus.

The order effect in the anxiety measures also has implications for research design. Since participants were more anxious in the first environment than in the second environment, a between-subjects experimental design is more suitable for studies examining the effects of a certain experimental condition on anxiety when carryover effects can be expected. If a within-subjects design is used, letting participants wait before continuing to the next environment will lower their anxious state. Another possibility is to change the subsequent environments a bit to make the experience feel less identical. This is however very difficult to achieve without introducing confounding variables.

7.4. Limitations and future research

Previous research provided contradicting results on the influence of visual realism on presence, but some consensus was found when the type of realism was divided into categories, such as realistic lighting having positive effects on presence, but increased realism in human-like characters generally having negative effects on presence, as discussed in section 3.3. This study manipulated overall visual realism and was designed to evoke an anxious response. It is possible that visual realism has different effects on presence in an emotionally neutral environment, thus the findings cannot readily be compared to prior research. Rather, this study proposes that the level of visual realism that can currently be achieved may be high enough to affect presence positively, when compared to less realistic environments.

Visual realism however, is but one of the many aspects that can influence presence: Research has repeatedly shown that presence is not determined by a single factor, but rather by the combination of several, corresponding modalities that form one congruent experience (Slater, 2009). For example, a great amount of research has investigated the effects of haptic feedback on presence and consistently concluded that the addition of haptic feedback increases the sense of presence (Hoffman, Hollander, Schroder, Rousseau, & Furness, 1998; Meehan et al., 2002; Turchet, Burelli, & Serafin, 2013). Another important factor that increases the sense of presence, is embodiment (Schultze, 2010). A person is said to be (partially) embodied in a virtual environment when his body or parts thereof, have a visual representation in the virtual environment. This study did not incorporate haptic feedback or auditory cues, since these modalities are reported to have very strong effects on presence, and may even be more important
than the visual aspect (De Kort et al., 2006; Sanchez-Vives & Slater, 2005). If these modalities would be included, the experienced sense of presence could be moderated by the addition of other modalities, making it more difficult to examine the effects of visual realism by itself. Furthermore, the realism of those modalities would also have to be manipulated to match the realistic or unrealistic environment. Yet in order to create a truly engaging, interactive experience that evokes a high sense of presence, it is needed to combine several modalities and determine whether the level of realism of different modalities affects presence as well.

It is difficult to determine what realism is in different modalities. Few studies on the effects of visual realism on presence reported how they changed visual realism exactly: If the model complexity was changed, by what percentage or amount of polygons? If textures were changed, was it only the resolution of the textures or did colour also vary? It may be practically impossible to compare different studies in an exact way, since model complexity depends on the type of shape that is modelled: A sphere needs much more polygons to look smooth than a cube, which consists of just six faces. In this report, we aimed to report all aspects that were changed between the two environments, but polygon count may very well differ for a similar environment. During the creation of the environment used for this study, we noticed that even highly simplified 3D rock and mountain models looked realistic when a high quality texture was applied. Since great measures were taken to make sure the virtual environment was displayed at the HMD’s native refresh frequency, by removing dynamic objects and some post-processing features that were very costly to render in VR, utilizing simple models with high quality textures may not only make the development of virtual environments easier, but also improve performance by a great amount. Gaming applications often utilize this effect, by pre-computing the surface details of a complex 3D model with high quality textures into a texture map, after which this map is applied to a simpler model that is less costly to render, a process known as texture baking (Brooker, 2012, p. 231). An interesting question for future research is whether the perceived visual realism of a simplified 3D model with high quality textures can approach the same level of perceived visual realism of its complex 3D counterpart.

The lack of a clear definition of realism is even more present in modalities such as the auditory modality: How can the audio quality be changed such that it is realistic or unrealistic? Or does auditory realism depend more on the type of sounds used? For example, the sampling rate of an audio sample can be reduced to make the sample noisier, or the sound emitted when
walking through a VE can simulate a child’s or adult’s footsteps, differing in simulated weight, speed or other characteristics. In order to determine whether overall realism affects presence, guidelines should be constructed from research on human perception and affect, in order to compare findings between different studies and to define what level of realism is needed for virtual reality to provide a truly engaging experience.
References


Freeman, J., Lessiter, J., Pugh, K., & Keogh, E. (2005). When presence and emotion are related, and when they are not. In 8th Annual International Workshop on Presence, September (pp. 21-23).


Slater, M. (2009). Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. Philosophical Transactions of the Royal Society B: Biological Sciences, 364, 3549-3557.


Appendices
Appendix A: Examples of textures used in the environments

<table>
<thead>
<tr>
<th>Realistic texture</th>
<th>Unrealistic texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original size (8192x8192 pixels)</td>
<td>Original size (1024x1024 pixels)</td>
</tr>
<tr>
<td>25% cut-out (4096x4096 pixels)</td>
<td>25% cut-out (512x512 pixels)</td>
</tr>
</tbody>
</table>
Appendix B: Informed consent

Instemming onderzoeksdeelname

Dit document geeft u informatie over het onderzoek ‘Presence in virtual environments’. Voordat het onderzoek begint is het belangrijk dat u kennis neemt van de werkwijze die bij dit onderzoek gevolgd wordt en dat u instemt met vrijwillige deelname. Leest u dit document a.u.b. aandachtig door.

Doel en nut van het onderzoek
Het doel van dit onderzoek is te bepalen in hoeverre mensen zich aanwezig voelen in virtuele omgevingen. Deze informatie wordt gebruikt om de ervaring in virtuele omgevingen te verbeteren.

Het onderzoek wordt uitgevoerd door Yvonne Toczek, student onder supervisie van Yvonne de Kort van de Human-Technology Interaction group.

Procedure
U krijgt straks een tweetal meetapparaten die uw hartslag en huidgeleiding meten, welke u zelf op uw lichaam kunt aanbrengen. Vervolgens zult u een virtuele omgeving te zien krijgen, door het opzetten van een virtual reality headset, waarna u wordt gevraagd enkele vragenlijsten in te vullen.

Risico's
Dit onderzoek brengt geen risico's met zich mee, wel is het mogelijk dat u duizelig kunt worden door het dragen van de virtual reality headset. Indien dit het geval is, steek dan tijdens het experiment uw hand duidelijk omhoog of vertel dat u zich onwel voelt, zodat de headset uitgezet kan worden.

Duur
Het onderzoek duurt ongeveer 25 minuten.

Participanten
U bent geselecteerd omdat u als participant geregistreerd staat in de participanten database van de Human-Technology Interaction group van de Technische Universiteit Eindhoven, of doordat u vrijwillig hebt ingestemd met deelname bij benadering door de uitvoerende.

Vrijwilligheid
Uw deelname is geheel vrijwillig. U kunt zonder opgaaf van redenen weigeren mee te doen aan het onderzoek en uw deelname op welk moment dan ook afbreken. Ook kunt u nog achteraf (binnen 24 uur) weigeren dat uw gegevens voor het onderzoek mogen worden gebruikt. Dit alles blijft te allen tijde zonder nadelige gevolgen.

Paraaf participant: _____
Vergoeding
De vergoeding bedraagt 5 euro (2,00 extra indien u niet op de TU/e of Fontys Eindhoven studeert of werkt).

Vertrouwelijkheid
Bij alle onderzoeken van Human-Technology Interaction wordt gewerkt volgens de ethische code van het NIP (Nederlands Instituut voor Psychologen). Wij delen geen persoonlijke informatie over u met mensen buiten het onderzoeksteam. Er worden geen video- of audio-opnames gemaakt die u zouden kunnen identificeren. De informatie die we met dit onderzoek verzamelen wordt gebruikt voor het schrijven van wetenschappelijke publicaties en wordt slechts op groepsniveau gerapporteerd. Alles gebeurt geheel anoniem en niets kan naar u teruggevoerd worden. Alleen de onderzoekers kennen uw identiteit en die informatie wordt zorgvuldig afgesloten bewaard.

Nadere inlichtingen
Als u nog verdere informatie wilt over dit onderzoek, dan kunt u zich wenden tot Yvonne Toczek (email: y.g.toczek@student.tue.nl). Voor eventuele klachten over dit onderzoek kunt u terecht bij de docent, Yvonne de Kort (email: Y.A.W.d.Kort@tue.nl).

Instemming onderzoeksdeelname

Bij dezen verklaar ik, (NAAM)………………………………………
dat ik dit document heb gelezen en begrepen en dat ik de gelegenheid heb gehad om vragen te stellen. Ik stem ermee in om vrijwillig deel te nemen aan dit onderzoek van de onderzoeksgroep Human-Technology Interaction, Technische Universiteit Eindhoven.

___________________________________________
Handtekening participant

___________________________________________
Datum

Paraaf participant: _____
Appendix C: General demographics and acrophobia questionnaire

Vragenlijst presence onderzoek

Wat is je leeftijd? .......... jaar

Wat is je geslacht? Man / Vrouw

Hoe vaak speel je 3D computerspellen? □ Regelmatig (meerdere keren per week)
□ Soms (enkele keren per maand)
□ Zelden (enkele keren per jaar)
□ Nooit

Heb je eerder al virtual reality meegemaakt? □ Nee, nog niet
□ Ja, 1-2 keer
□ Ja, 3-5 keer
□ Ja, vaker dan 5 keer

Hieronder zie je een aantal situaties met betrekking tot hoogtes. Geef bij de vragen hieronder aan hoe je je in deze situaties zou voelen door een van de nummers bij de situatie te omcirkelen.

0 Helemaal niet angstig, ik zou niet de situatie vermijden

1 Een beetje angstig, ik zou niet de situatie vermijden

3 Redelijk angstig, ik zou proberen de situatie te vermijden

5 Zeer angstig, ik zou het onder geen enkele omstandigheden doen

1. Van de springplank in het zwembad springen

<table>
<thead>
<tr>
<th>Helemaal niet angstig, ik zou de situatie niet vermijden</th>
<th>0</th>
<th>1</th>
<th>2</th>
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<th>6</th>
<th>Zeer angstig, ik zou het in geen geval doen</th>
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</thead>
</table>

2. Over stenen lopen om een beek over te steken

<table>
<thead>
<tr>
<th>Helemaal niet angstig, ik zou de situatie niet vermijden</th>
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<th>Zeer angstig, ik zou het in geen geval doen</th>
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3. Naar beneden kijken van een cirkelvormige trap op enkele verdiepingen hoogte
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<tr>
<th>Helemaal niet angstig, ik zou de situatie niet vermijden</th>
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<th>Zeer angstig, ik zou het in geen geval doen</th>
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<td>4. Op een leunende trap staan ter hoogte van de tweede verdieping van een huis</td>
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<td>Zeer angstig, ik zou het in geen geval doen</td>
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<td>5. In het tweede balkon zitten tijdens een theatervoorstelling</td>
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<td>Zeer angstig, ik zou het in geen geval doen</td>
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<td>6. In een reuzenrad zitten</td>
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<td>Zeer angstig, ik zou het in geen geval doen</td>
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<td>7. Een steile helling op lopen tijdens een bergwandeling</td>
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<td>8. Naar een buurland vliegen met het vliegtuig</td>
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<td>9. Naast een open raam staan op de derde verdieping</td>
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<td>10. Over een voetgangersbrug lopen boven de snelweg</td>
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<td>11. Autorijden over een hoge brug</td>
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<td>Zeer angstig, ik zou het in geen geval doen</td>
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<td>12. Uit de buurt zijn van een raam op de vijftiende verdieping van een gebouw</td>
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<td>13. Glazenwassers zien in een steiger op de tiende verdieping</td>
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<td>14. Over een stoeprooster lopen</td>
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<td>15. Aan de rand van een metroplatform staan</td>
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<td>Zeer angstig, ik zou het in geen geval doen</td>
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<td>16. Een brandladder beklimmen tot de overloop van de derde verdieping</td>
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<td>Zeer angstig, ik zou het in geen geval doen</td>
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<td>17. Over het dak van een tien verdiepingen hoog gebouw lopen</td>
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<td>Helemaal niet angstig,</td>
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<td>Zeer angstig,</td>
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<td>18. De lift nemen tot de vijftigste verdieping</td>
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<td>Zeer angstig, iemand zou het in geen geval doen</td>
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<thead>
<tr>
<th>19. Op een stoel staan om iets van een plank te pakken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helemaal niet angstig, iemand zou de situatie niet vermijden</td>
</tr>
<tr>
<td>Zeer angstig, iemand zou het in geen geval doen</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>20. Over een loopplank lopen om aan boord te stappen van een schip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helemaal niet angstig, iemand zou de situatie niet vermijden</td>
</tr>
<tr>
<td>Zeer angstig, iemand zou het in geen geval doen</td>
</tr>
</tbody>
</table>
Appendix D: Presence questionnaire (IPQ) and fear measures

De volgende vragen gaan over je belevenis van de klifomgeving. Omcirkel het getal dat het dichtst bij je gevoel in de buurt komt. Soms is de schaal omgedraaid, lees daarom bij iedere vraag wat een lage en hoge score inhoudt.

Ik had het gevoel aanwezig te zijn in de computerwereld

Helemaal niet 1 2 3 4 5 6 7 Heel erg

Ik had het gevoel omgeven te zijn door de virtuele wereld

Helemaal mee oneens 1 2 3 4 5 6 7 Helemaal mee eens

Ik had het gevoel slechts plaatjes te aanschouwen

Helemaal mee oneens 1 2 3 4 5 6 7 Helemaal mee eens

Ik had niet het gevoel in de virtuele ruimte aanwezig te zijn

Helemaal mee oneens 1 2 3 4 5 6 7 Helemaal mee eens

Ik had meer het gevoel bezig te zijn in de virtuele ruimte, dan dat ik het gevoel had iets van buitenaf te bedienen

Helemaal mee oneens 1 2 3 4 5 6 7 Helemaal mee eens

Ik voelde me aanwezig in de virtuele ruimte

Helemaal mee oneens 1 2 3 4 5 6 7 Helemaal mee eens

Hoe bewust was je van de echte omgeving (bv. geluiden van buiten, kamertemperatuur), terwijl je je bevond in de virtuele ruimte?

Zeer bewust 1 2 3 4 5 6 7 Helemaal niet bewust
Ik was me niet bewust van mijn echte omgeving

Helemaal mee oneens 1 2 3 4 5 6 7 Helemaal mee eens

Ik lette nog op de echte omgeving

Helemaal mee oneens 1 2 3 4 5 6 7 Helemaal mee eens

Ik ging volledig op in de virtuele wereld

Helemaal mee oneens 1 2 3 4 5 6 7 Helemaal mee eens

Hoe echt kwam de virtuele omgeving op je over?

Heel echt 1 2 3 4 5 6 7 Helemaal niet echt

In hoeverre kwam je ervaring in de virtuele omgeving overeen met je ervaringen in de echte wereld?

Geen overeenstemming 1 2 3 4 5 6 7 Volledige overeenstemming

Hoe werkelijk kwam de virtuele wereld op je over?

Zoals een denkbeeldige wereld 1 2 3 4 5 6 7 Niet te onderscheiden van de echte wereld

De virtuele wereld kwam echter op mij over dan de werkelijke wereld

Helemaal mee oneens 1 2 3 4 5 6 7 Helemaal mee eens

De volgende vragen gaan over je gevoel tijdens het lopen door de klfomgeving. Beantwoord de vragen door een score van 0 – 10 toe te wijzen aan een vraag, waarbij 0 ‘Helemaal niet’ en 10 ‘Heel erg’ inhoudt.

Hoe bang was je tijdens het lopen door de omgeving? ..........................
Dacht je dat je naar beneden zou vallen toen je op de brug stond?  

Voelde je je veilig tijdens het lopen over de brug?  

Voelde je een lichamelijke reactie, zoals een knoop in de maag, bij een of meer van de volgende locaties? Je kunt meerdere locaties aankruisen.

☐ Nee       ☐ Aan het begin, op de rots       ☐ Bij de eerste stappen over de brug  
☐ Bij het naar beneden kijken om de rotsen te telling       ☐ Aan het einde van de brug
Appendix E.1: Post-test questionnaire

De vragen hieronder gaan over de twee klifomgevingen die je gezien hebt. Het zijn voornamelijk open vragen: licht indien mogelijk, je antwoord toe in enkele zinnen.

Heb je een voorkeur voor een van de twee omgevingen?

De eerste  De tweede  Geen voorkeur

Zo ja, waarom?

……………………………………………………………………………………………………………………………………………………
……………………………………………………………………………………………………………………………………………………
……………………………………………………………………………………………………………………………………………………

Welke van de twee omgevingen vond je enger, de eerste of de tweede?

De eerste  De tweede

Waarom vond je de omgeving enger?

……………………………………………………………………………………………………………………………………………………
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Heb je een verschil gemerkt tussen de twee omgevingen? Zo ja, welk verschil?

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Ga verder aan de ommezijde
Op het blad naast je zie je 4 afbeeldingen. Geef een score van 0-10 voor het realisme van de afbeelding, waarbij 0 heel onrealistisch is en 10 niet van het echt te onderscheiden is.

Afbeelding A: .........
Afbeelding B: .........
Afbeelding C: .........
Afbeelding D: .........

De volgende vragen gaan over je welzijn na het zien van de virtuele omgevingen. Sommige personen voelen zich onwel na het dragen van een virtual reality helm. Deze vragen proberen dit in kaart te brengen, zodat verdere onderzoeken de ervaring kunnen verbeteren. Indien je je onwel voelt, meld dit dan ook even aan de proefleider en neem een glaasje water.

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<th>Hevig</th>
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Heb je verder nog opmerkingen over het onderzoek?

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……………………………………………………………………………………………………………………………………………………
Dat waren alle vragen. Heel erg bedankt voor je deelname aan het onderzoek!
Appendix E.2: Screenshots of the environments used in the post-test questionnaire

A

B
Appendix F: Experimental setup
Appendix G: Descriptive statistics presence subscales

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<td>$M$</td>
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Appendix H: Descriptive statistics GSR

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