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Bachelor thesis
Bsc Artificial Intelligence

Measurement of presence in virtual reality and the factors that influence presence

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Abstract
Virtual reality (VR) is a booming subject. From slick new videogames to futuristic applications for societal problems, the options are seemingly endless. But how can we use VR in our daily lives? Before we can answer this question, we must understand how VR works and how we can so fully immerse ourselves in its virtual environments. One's sense of presence within a virtual environment dictates whether or not we can interact within it as if it were real. Therefore, this thesis aims to answer a twofold question: what are the factors that influence the rate at which presence is experienced in virtual reality? And how is presence measured? This thesis gives an overview of 16 factors that influence presence and 13 measurement techniques, which are analysed and a recommendation for future presence research is given.

Keywords: Presence, immersion, Virtual Reality (VR), Virtual Environment (VE), Head-mounted Display (HMD)

Contents

1.1 Introduction

There are many different interpretations of the concept of 'presence'. Presence can be simply defined as *the sense of being somewhere* and the specification of that 'somewhere' distinguishes different forms of presence (Bulu, 2012; Draper et al. 1998). The specific form of presence that will be discussed in this thesis is presence within virtual reality (VR) as defined by Lee (2004) and Slater (2003). Virtual presence differs from presence in real life in that a person in a virtual environment (VE) is cognitively aware that they are not actually in the VE. Despite this knowledge, a high level of presence would mean that such a person would still react as if a virtual environment is real. From this point onward the word 'presence' will be used to indicate presence within a virtual environment. Previous research shows that when presence is high, test subjects regard the VE as reality and therefore take any task in the VE quite seriously, which could have positive implications for skill acquisition, as well as therapeutic purposes (Sanchez-Vives & Slater, 2005). The use of a VE when compared to conducting training, therapy or experiments in vivo could be used to circumvent a large swath of constraints, be them of technical or economical nature. Circumventing these constraints makes it a worthwhile endeavour to find out how to achieve high presence.

Training is an example of a task for which VE's can be used. People can train tasks in a virtual environment that would have been very expensive, dangerous or even impossible to carry out in real life, i.e. disarming bombs, war tasks on a battlefield or even reparations on the outside of a space station (Slater, 1994; Whitelock et al., 1996). It is hypothesized that the greater the presence of the person in virtual training, the more potential to learn more this gives the person, as argued by Slater et al., (1996) who claim that the sense of presence in the virtual environment contributes towards more natural behaviour in the VE, which improves performance. Research by Welch (1997) confirms findings by Slater et al. (1996), namely that higher presence in virtual training correlates with better performance, and potentially even information retention.

The correlation between presence and performance implies that higher presence leads to better VR training, which has a great potential societal relevance. Take for instance the training of a surgeon. As it is unwise to have unskilled students practise on living humans, they train on cadavers. However, it would be better if a realistic training could be designed in such a way that the students can practise in VR. A strong virtual training could approximate real operations, which could give medical students the opportunity to practise their highly important tasks in a safe, cheap way and without them having to worry about potentially harmful repercussions in case the students make mistakes. Medicine is not the only field where VR training could be highly useful. Military skills could be safely trained, dangerous engineering tasks, bomb dismantling, whatever the subject might be; if it is dangerous, expensive or even impossible in real life it might be useful to work on skill acquisition in VR instead.

Besides training purposes, there are other highly relevant uses of VR. Schuemie et al. (2001) name the fact that virtual experiences can evoke the same emotional reactions as real experiences as one of the most important consequences of presence. This consequence points towards potential therapeutic uses of virtual reality, for which we review the concept of exposure therapy. Exposure therapy is a method of behavioural therapy that aims to lessen the burden of anxiety by exposing a patient gradually to what triggers their anxiety. Previous research on the exposure therapy in VR showed that people reacted in VR as if they were truly exposed to their fear (Krijn et al., 2004; Price & Anderson, 2007). Virtual Reality Exposure Therapy (VRET) is much cheaper than exposure therapy in vivo as well as easier to set up at a convenient location for both therapist and patient and has been shown to be effective (Sanchez-Vives & Slater, 2005).

Considering skill acquisition and therapy as two of many potential applications of virtual reality to enhance people's lives, understanding how presence was measured in previous research and what influences the rate at which it is experienced is exceptionally useful. For future research and future uses of VR in task training, this knowledge could be used to achieve a high rate of presence for the test subjects, trainees and patients.

Besides the significant societal relevance of this topic, there is also a lot of relevance in presence research in VR in the field of Artificial Intelligence. The application of goal-oriented artificial intelligence could be useful in creating believable interaction with the virtual environment, for instance in building virtual characters. The subject of presence in VR is on the intersection of computer science, neuroscience and cognitive psychology and therefore a prime opportunity for multifaceted AI experts to tackle. This thesis could provide a solid base for future VR research, seeing as this thesis will contain a comparison of different measuring techniques and a critical take on what seems to work best when it comes to the study of presence. This thesis could be seen as a stepping stone for further research on presence in the fields of cognitive psychology, computer science, neuroscience and potentially even a combination of all three.

There has already been a lot of research conducted on measuring presence and seeing what influences it, however, it seems as if a clear overview on this has not yet been constructed. Therefore I will attempt to give an objective overview on how the field of presence in VR is situated. Which leads to the question that this thesis aims to answer: 'How is presence measured and what influences the rate at which people experience presence?'

To answer this question, this thesis is divided into five chapters. In Chapter 1 the theoretical framework in which the subject of virtual presence is situated will be explicated. In Chapter 2 the factors that influence presence will be discussed based on previous research. In Chapter 3 the different techniques that are used to measure presence will be discussed. All measurement techniques that are discussed in Chapter 3 and all factors discussed in Chapter 2 will be analysed in Chapter 4. From these different factors and measuring techniques I will conclude on what seems to be the most effective and dependable. Lastly, I will give my own recommendations regarding the future of presence research as well as societal and practical uses of VR in daily life. In Chapter 5 the process and outcomes of this thesis are discussed.

1.2 Theoretical background

Because presence within <u>*virtual reality (VR)*</u> is the subject of this thesis, it is important that only one definition of virtual reality is understood**.** The field of virtual reality is quite new and has therefore undergone big changes in rather short time. A lot of research that mentions virtual reality or even presence within virtual reality actually refers to a simpler form of VR, where test subjects are seated in front of a screen and given slightly different images for both eyes. This is a medium that nowadays would be referred to as three dimensional video. In this thesis, whenever Virtual Reality is mentioned, this refers to a person "entering" a 360 degree wide virtual environment through the use of a head-mounted display or the use of CAVE.

The *virtual environment (VE)* is the location in VR that the test subject or user experiences.

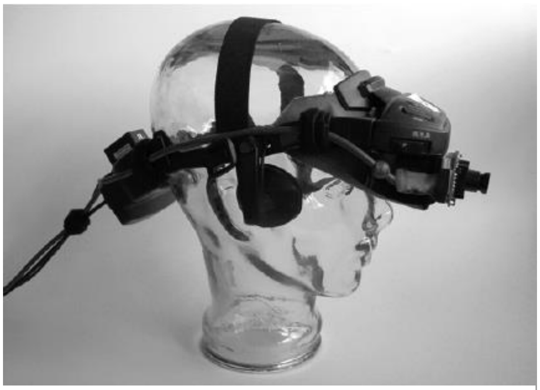

Figure 1: an example of an HMD (Lovell, 2007)

A *head-mounted display (HMD)* is a device that can be worn on the head, as the name implies (see Figure 1). It is commonly called Virtual Reality glasses. It has two screens right in front of the eyes on which two slightly different angles of video are shown to achieve stereopsis (binocular vision). The apparatus has motion trackers, which makes sure that any head movements translate to what is seen of the environment. Most HMD's make use of remotes, so that the user of the device can interact with their environment through pointing and clicking. A virtual environment like a videogame displayed on a television screen may lead to a high level of involvement, but the immersive characteristics are lost if the user is not enveloped by the virtual environment. Exclusion of external input makes the use of a head-mounted display essential for immersion as stimuli from reality must be excluded as much as possible (Witmer, 1998).

Despite the popularity of the use of a HMD, this thesis will also discuss the CAVE system. CAVE stands for *Cave Automated Virtual Environment* and is a projection-based VR system that results in a room-sized immersive three dimensional environment (see Figure 2 and 3). Because there is no head-mount necessary, the CAVE system can be used by multiple people at once. CAVE was developed specifically with engineering purposes in mind (Visbox Inc., 2016).

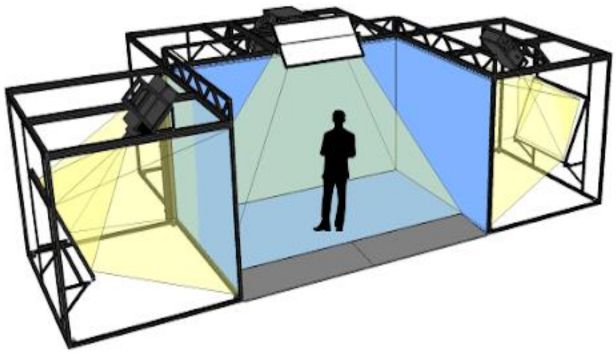

Figure 2: CAVE schematic model (ViscubeTM C4-4K)

Figure 3: CAVE example image (Kolodynski, 2018)

Immersion involves the technical capability of a system to generate a convincing enough environment for a test subject to interact within virtual reality. It is the technical component to VR that makes presence possible. Parameters of immersion are the field of view, the quality of rendering in each sensory modality and how many sensory modalities are being simulated as well as the realism of the images that are being displayed (Slater & Wilbur, 1995). Frame rate and latency are important features for immersion. Latency refers to the time it takes for the result of the actions of the test subject to take place. Here it is important that the results of actions to take place at a predictable and natural speed. Another important factor for immersion is proprioception, proprioception in VR refers to a situation when for instance a user suddenly tilts or turns their head, what they see should change in real-time and in a predictable manner. Slater (2003) describes presence as the phenomenon that arises from the interaction between the human sensory and motor systems and the immersive system. More sophisticated VR simulations with therefore higher immersion result in increased presence (Baños et al., 2004).

1.3 Terminology

For readability I will use the words *(test) subject, participant* and *user* interchangeable, all refer to the singular natural person that is in a hypothetical or actual experiment that has to do with presence. Sometimes this natural person will be simply referred to as 'the person in the VE'. Especially when there is a head-mounted display, or CAVE concerned or even an exoskeleton to simulate haptics, *user* will be used more frequently.

1.4 Method

I have answered my research question through thorough literature research on the subject of presence in virtual reality. I started out with three papers, distributed to me by my thesis supervisor prof. dr. Stefan van der Stigchel. These papers are Bulu (2012), Sanchez-Vives & Slater (2005) and Witmer & Singer (1998).

I have searched for sources in two primary ways; search engine Google Scholar and through the sources of papers that I have previously found. Through Google scholar I initiated my search with search terms 'virtual reality presence' and 'presence in VR'. Later in the process I also used 'presence questionnaire' to fill out the segment on questionnaires. I have read a lot of papers because they were quoted as being significant for the field of presence research in other papers that I was reading. I have found all papers in February and March of 2020.

I have read 41 papers on this subject. However, some I chose to disregard and not include in my thesis because - especially with the older research - a lot of papers mention virtual reality while they are actually using a clever form of three-dimensional video. For the purpose of this thesis I only wish to include research that used a high-presence set up which means that I only include research that makes use of a HMD or CAVE system to view the virtual environment.

I decided to only include factors that influence presence if at least three credible sources have all concluded that the factor is of importance. By comparing the findings of different experiments I aimed to ensure that all factors mentioned in this thesis can provide actual knowledge of the subject.

Chapter 2: What influences presence?

As the previous subsections on what presence is and how VR can be useful, this section will detail the factors that influence presence, as to further our understanding of presence. For this purpose it is important to understand what influences people to feel presence so we can infer what influences the level of presence in VR.

2.1 Outline

To make the following section as clear as possible, I divided the factors that influence presence into three categories; Realism factors, External factors and Meaning factors. Many different authors have made different categorisations, but none that I found myself completely agreeing with. I realise that there is a lot of interplay between different factors, as many factors influence other factors from other categories. Therefore this categorisation is far from perfect, however I think that the set of all factors that influence presence are so tightly interwoven with many other factors that no perfect categorisation can be made. What follows is my categorisation, which as a primary goal has to give clarity on such an extensive field of study.

Realism factors, which are often related to the strength of the system that is creating the VE, contain a lot of hardware and immersion related factors for that reason.

- Congruency
- Control
- Haptics
- Locomotion
- Body movement
- Sound

External factors, these are the factors that have to do with the environment where the participant's body is located whilst the participant is "in" the virtual environment.

- Exclusivity of presence
- Errors
- Interface and HUD awareness
- Internal world
- Simulator sickness

Meaning factors, these are the factors that have to do with how the person in a VE feels about the environment.

- Emotion
- Involvement
- Immersive personality
- Human interaction

2.2 Factors that influence presence

1. Realism factors

The more realistic the virtual environment seems, the more sense of reality the users attribute to it, which has positive implications for presence (Magnenat-Thalmann et al., 2005). Many of the following factors are also involved with immersion, as the technical capabilities of the system dictate in part how realistic the environment can be.

Congruency

The first factor that must be noted when discussing the realism of a VE is the visual congruency of the virtual environment to a real world environment. Congruency is determined by multiple subfactors, starting with *environmental richness,* which was first raised as a factor with a positive influence on presence by Sheridan (1992). The degree of environmental richness is determined by the amount of detail and information that a virtual environment holds. Sheridan (1992) theorizes that when there is a lot of information for the senses to process, this leads to a stronger sense of presence. As already postulated in the field of VR by Witmer and Singer, (1998) vision is the sense that is used the most in daily life and as a result is of the largest influence on presence in a VE. It is therefore unsurprising that research shows that more accurate visual input through the use of motion-parallax and stereoscopics further enhances presence (Zeltzer, 1992).

Spatial fidelity is the combination of motion-parallax, stereoscopics, additional depth cues, display update rate and field of view. High spatial fidelity is the result of hardware prowess and it is highly important for presence because it indicates how the user looks at the VE. When the way people look around in the VE is achieved in a natural way, presence is heightened (Bystrom, Barfield & Hendrix, 1999). Motion parallax refers to elements of headtracking. When a person in a VE makes a sudden head movement it is necessary for maintaining high presence that the environment moves realistically and fast enough with said movement. This quickly updating, highly detailed virtual environment requires strong hardware to keep up with these fast updating visuals, which ties in with the importance of display update rate. Usually a wide enough field of view and realistic depth cues can be achieved with the use of an HMD, so the technical capabilities of the field of VR have progressed enough to lend itself to high spatial fidelity.

But it is not only the visual stream of input that is important for presence, as research by Held & Durlach (1992) confirms Sheridan's (1992) findings by showing that *multimodal presentation* is important for the congruency of a VE with reality. As in real life our sensory modalities constantly need to work together, coherent stimulation of multiple senses simultaneously should heighten presence in VR. For example, when a person sees a ball bounce in a VE, the person would expect to hear a ball-related sound on each impact. One could therefore understand that the *consistency of this multimodal information* is also very important. It also works in reverse: when a person sees a ball bounce in a VE, the person would not expect for example the sound of a car horn on each impact. This dissonant, unrelated sound could have a negative effect on presence.

This effect is substantiated by the concept of consistency of information, which dictates that if the stimuli in the VE are consistent with what the subject is used to from the real world, this has a positive impact on presence (Held & Durlach, 1992). Another thing that the subject would be used to is the continuity of stimulus, for example the bouncing ball would be expected to keep bouncing and not to disappear suddenly. This continuity of stimuli is referred to as scene realism by Witmer and Singer (1998).

Shortly summarized, for increased presence everything that is experienced in the VE should be continuous and congruent with real world stimuli and, when possible, multiple senses should be stimulated in unison.

Control

Held and Durlach (1992) distinguished multiple different factors that all concern the amount of control a user can exert over the VE. For clarity, all control-related subfactors are discussed in this umbrella factor called 'Control'. First is the *degree* of control as introduced by Sheridan (1992), who stated that the more control a person in a VE has over their task, the more present that person will feel. Second is the *immediacy* of control as introduced by Held & Durlach (1992) and discussed at length as well by McGreevy (1992) which relates to the technical capabilities of the system that is used to generate the virtual environment. Witmer and Singer (1994) refer to the same phenomenon when they mention *control responsiveness*. The immediacy of control refers to how long it takes for the effects of an interaction with the VE to show their results. If this time is realistic, this leads to a higher sense of presence. On the flipside, if the effects are too slow due to noticeable lag, or unnaturally fast due to no built-in natural lag, this will have negative influence on the person's presence.

Besides controlling the environment, Sheridan (1992) also found that the ability of the participant to move themselves around in the VE to be of tantamount importance for presence. Zeltzer (1990) combined the editorial power of modifying the VE with the control the user has over their own movement and called it user interaction. User interaction was shown to have a strong impact on the amount of presence that is experienced. All research on the subject of control in VR suggests that a combination of strong hard- and software and intelligent pre-programmed time delay for reactions is of high importance for presence in VR.

Haptics and kinesthetics

To be able to control any virtual environment, one needs some sort of apparatus to connect the user to the VE. In many cases this apparatus is an HMD combined with simple remote controls in each hand. However, researchers already expected early on that more natural ways to interact with the VE might lead to better VR research and therefore higher presence. Salisbury & Srinivasan (1997) first stipulated the impact of haptic feedback to enhance experiences in VR. This subject was extensively studied later on by Laycock & Day (2003) in different VR applications. Haptic feedback includes both tactile and force feedback. Force feedback links a person to the computer by applying forces on the person through the use of actuators (such as an electric motor). Tactile feedback is linked to the receptors in the skin of a person and it is experienced with heat, vibrations and pressure as well as with textures of surfaces. Research conducted by Insko et al., (2001) revealed that haptic devices effect task performance positively.

Experiments have shown that force feedback exerted on the user of the VE has positive influence on the user's ability to complete their tasks within the VE (Laycock & Day, 2003). According to these researchers the key to true immersion (and with it higher presence) through haptics lies within allowing the user to feel the force feedback when colliding with virtual objects on any part of their body. To achieve this level of immersive force feedback the haptic device must envelop at least parts of the body of the user. Such a device is called an exoskeleton. By surrounding an arm, for example, force feedback can be applied on the whole limb instead of mere points. Using these devices that are grounded on the body of the participant can greatly increase the realism of the virtual experience and therefore heighten presence. Haptic devices could be a way to get the sensations of being in a VE closer to how reality feels to a person. As these devices could facilitate more realistic interaction with the environment and more natural movement.

Locomotion

How a person moves around in the VE is of great importance, as unnatural ways of moving around (e.g. point-and-click to teleport) are theorized to strongly decrease presence (Held & Durlach, 1992). Slater, Usoh and Steed (1995) conducted a research based on the naturalness of locomotion in VR where they had participants walking in place while wearing an HMD and a neural net that detected when the participants were walking. The idea here is that the physical sensation of walking in place, combined with the visual input of the environment moving around you as if you are walking through it leads to better immersion and presence. Their research showed that whenever the hardware and software came together and the simulated walking worked, people preferred this to pointing and clicking as a navigation technique and leads to stronger presence. As described by Witmer & Singer

(1998) objects need to move at the relative speed that one perceives they are moving in for the environment to be more immersive. When this does not work correctly, presence is lower. Results from Slater, Usoh & Steed's experiment confirmed this idea (1995). Whenever there were errors and the movement and visuals did not cohere, the presence was weakened. So naturalness of locomotion has a strong impact on presence, but because the technical prowess of the system that generates the environment is so important, further technical development was needed.
Research shows that the technical side of the field has progressed quite a lot when it comes to moving platforms and omnidirectional treadmills to achieve more natural locomotion in VR. Moving platforms could aid in perceiving the sensations that one would experience in reality, such as moving at high speed or moving over rough terrain, which could heighten presence. Motion platforms have great applications in flight training, a well-known example being flight simulators, which are used in pilot training as well as in VRET for a fear of flying and have proven to be highly immersive which indicated presence could be high in them as well (Stevens & Kincaid, 2015).

Body movement
Similar to ease of locomotion, ease of natural body movement in general is important for high presence. There is a positive feedback loop in how presence leads to more body movement, and more (successful, natural) body movement leads to higher presence (Slater and Steed, 2000). This relation between presence and natural body movement is illustrated by research by Slater & Steed(2000), where they had their participants play a game of chess. Results show that highly present participants moved naturally around other pieces to touch their piece, while participants with lower reported presence moved through other objects to get to their piece in a way that would not be possible in reality. This research reveals that behaving in the VE as if it were real, made it feel more real.

Sound
Besides the importance of realistic visuals, realistic sounds are theorized to be as important or even more important than realistic visuals for immersion and high presence (Magnenat-Thalmann et al., 2005). 3D spatial audio is important here as research shows that binaural sound recordings are necessary to achieve truly realistic surround sound to simulate an environment through hearing (Allen & Berkeley, 1979). The right amount of realistic sound can transport a person to a virtual environment. Combining realistic visuals with realistic audio has a very positive impact on presence.

2. External factors

As the previous factors show, realism plays a large role in presence. However, there are many factors that do not concern realism of the VE but are still of importance for achieving high presence. The following subsection of factors is concerned with matters that impact presence that come from outside of the VE.

Exclusive presence
Slater et al. (1994) stress the importance of high presence in the virtual environment being balanced out by low presence in the location where the subject's body is located. Low presence in the real world is essential for high presence in the virtual location. HMD's exclude all visual input from the real world, which is one of the reasons why HMD's are so popular in research. Slater & Wilbur (1995) note how important it is that as much real world stimuli as possible are excluded from the experience. Another example of how real world stimuli can be distracting is the added weight of a haptic device, as this is force feedback coming from the real world, it could negatively impact presence (Slater & Steed, 2000). Slater and Wilbur (1995) theorize that despite the fact that all

actions and sensations in the VE are mediated by the system that generates the VE, in order for the person in the VE to feel high presence everything must feel as if it is unmediated.

Errors (Real world)
When stimuli from the real world are not excluded sufficiently this brings up distracting factors. (Slater & Steed, 2000). For example, a door is opened that should not have been opened during an experiment and a draft wafts into the lab. Feeling this draft might distract the test subject that is in a VE and this distraction would decrease their presence. If a phone rings down the hallway and the test subject can faintly hear it, this auditive distraction would decrease presence. A distraction from the real world that is quite common in VR research occurs when the participant moves around the lab and a cable coming from the HMD wraps around their legs. All these different forms of real life distraction seem obvious but should not be left out when analysing presence.

Errors (Glitches)
Another way a test subject might be reminded of reality is when technological errors occur. For example, a small glitch occurs in the VE when one looks at a more complex scene or a framerate stutter occurs when one moves from one virtual room to another area. All these little technical mistakes and errors that could occur during training or experiments in VE could lower the experienced presence of the person in the VE. Slater and Steed (2000) confirm the importance of good soft- and hardware as the results showed that technical errors caused test subjects to 'break' their presence. Therefore, besides the fact that the hardware and software that is used to generate the VE must be strong enough to do so, it is also necessary that the quality it delivers is continuous as errors in the system can lead to breaks in presence which can lead to lower presence overall.

Interface and Heads-up Display awareness
Witmer & Singer (1998) describe various distraction factors in their paper, many of which have to do with the previously mentioned exclusivity of presence. They incorporate the concept of interface awareness, which is mostly a problem within teleoperation, as a teleoperator would be looking at an interface to discern what to do (Held & Durlach, 1992). As VR has progressed a lot since then, interface awareness is usually not a problem for presence in VR. However, when it comes to games and training in a VE, the user might have a Heads-up Display (HUD) in their visual field, which shows for example the different tools that the user has at their disposal. The negative effects of high interface awareness on presence could be similar to the effects high awareness of such a HUD would have. More research on this subject is necessary, but the theory so far is that the more distracting or interfering in the tasks the HUD or interface is, the worse this is for the experienced presence (Witmer & Singer, 1992; Schuemie, 2001).

Internal world
A much more abstract source of distraction can be found in the internal world, as sometimes thoughts and daydreams can distract a person from the virtual environment. A simple example for this can be the sudden anxiety that comes with the thought: "Did I leave the stove on?". There is no clear solution to how to circumvent this distraction factor, but it might explain some between-subjects differences (Slater & Steed, 2000).

Simulator sickness
Another problem with VR that can differ strongly between different participants is introduced by Witmer and Singer, (1994) namely the fact that when test subject experience so-called 'Simulator sickness' their presence is negatively impacted. When subjects start to feel nauseous due to the interaction between movement in the VE and no movement in real life, this leads to them feeling present within the virtual environment. Smoother, more predictable and controlled movement

within the VE can help with dispelling any simulator sickness and therefore heighten the sense of presence. The research of Witmer et al. (1996) revealed that when participants experience strong simulator sickness their presence is sharply decreased. A negative feedback loop can exist here, as high presence may cause the participant to not notice their simulator sickness and therefore remain at a high level of presence. The use of an omnidirectional treadmill could help dissipate this problem by having the participant actually move in real life as well (Buoguila, Ishii & Sato 2000).

3. Meaning factors

The last factor group that must be discussed is that of the meaning generating factors. Because realism and external distractions have now been discussed, the last category of factors that need to be discussed is the one concerning the meaningfulness of the content of the VR experience.

Emotion
Riva et al. (2007) have conducted research into the effectiveness of VR as an emotion induction medium as well as seeing whether the amount of emotion that is induced or experienced within the VE influences the level of presence that is experienced. Their results suggest that VR is indeed an effective mood inducer which makes it a promising platform for clinical psychology. Diemer et al. (2015) confirm that VR is a robust medium for inducing emotions, especially negative emotions like anxiety. The test setup Riva et al. (2007) used is one of three parks: a relaxing park, an anxious park and a neutral park. All test-subjects experienced all three parks and results showed that presence was significantly higher in the relaxing and anxiety park when compared to the neutral park. The researchers conclude that the emotional content of the two parks had a positive influence on the rate at which presence was experienced.

Involvement
Strong focus on anything leads to involvement with that which is focussed on, although involvement does not always indicate presence, e.g. one can feel high involvement when reading a book but not present in the location where the story take place. A poignant example of involvement leading to immersion is how hyper realistic dreams can lead to a person feeling as if the dream is real. Presence research has shown that high involvement with the task at hand in a VE can lead to an increased sense of presence (Witmer & Singer, 1998).

Immersive personality
Many researches (Sanchez-Vives & Slater, 2005; Bulu, 2012) show that it matters for the amount of presence a person experiences whether that person has an “immersive personality”. An immersive personality refers to some people who are naturally more predisposed to feel immersed in any medium, from stories to virtual environments. Some people will need a much more realistic virtual environment to be able to feel presence, while others are able to immerse themselves in a book and feel strong presence in a very low-level, low-immersion set up. When doing research into presence, personal differences between subjects should be taken into account.

Human interaction
Schuemie et al., (2001) conducted a research into human interaction in a multi-participant VE. Their results show that the participant’s presence was positively impacted by more human interaction in the VE. More recorded interaction lead to higher presence for all people involved in the interaction, and higher presence usually leads to people seeking out more interaction within the VE. The interplay between more presence leading to more interaction and vice versa creates a positive feedback loop.

Chapter 3: How is presence measured?

As written by Sanchez-Vives and Slater (2005): “The measurement of presence is an important challenge in presence research.” This thesis aims to aid that challenge by outlining many different measuring techniques, their strengths and shortcomings. As mentioned in the dissertation of De Barros (2014): “A general methodology for accurately measuring presence is still unknown”. My goal is that this thesis can be a stepping stone in the process that will eventually lead to a robust methodology in measuring presence.

3.1 Outline
Measuring techniques for presence can be divided in three groups, as initially divided by Insko et al. (2003). To keep this overview as coherent and clear as possible, this chapter will adhere to the following subdivision of the techniques:

- Subjective
- Behavioural
- Physiological

3.2 The measuring techniques

1. Subjective

‘The user is asked about his level of presence’ (Slater, 1999).

Direct subjective presence assessment/Questionnaires
A common approach for measuring presence is direct subjective presence assessment, which means that researchers would have their test subjects answer a questionnaire directly after their experiment. Sheridan (1992) postulates that presence is subjective or a mental manifestation and therefore not easily measured with objective physiological measurement techniques. However, as Sanchez-Vives and Slater (2005) put it: “Questionnaire-based methods have shown to be unstable, in that prior information can change the results.”. This quote refers to the fact that previous knowledge of presence and knowledge about the experiment that the participant takes part in could lead to the participant giving different answers than they would have without previous knowledge

Freeman (1999) postulates that the many researches into presence that depend on questionnaires are faulty. Problems arise for instance when the terms used in the questions that are asked are not completely familiar to the test subjects. Another problem with this post-test direct subjective assessment is that anything that transpired between the test and the questionnaire, or shortly before the test, could influence the way the subject is feeling, which could influence how the questionnaire is answered, despite the fact that these difference might be unrelated to the experiment. Another problem that Freeman (1999) introduces regarding direct subjective assessment is the fact that the assessment being done post-test introduces a host of issues that have to do with inaccurate recall and other memory problems.

Despite all these shortcomings there are many different presence questionnaires that have been put to good use, here follow the three most influential research questionnaires.

<u>Presence Questionnaire & Immersive Tendencies Questionnaire (PQ & ITQ) Witmer and Singer (1992)</u>
As mentioned in the ‘immersive personality’ factor, individual differences between test subjects and their character might influence the rate at which the subjects experience presence. This relation between the character of a person and their ability to immerse themselves in a virtual environment

is measured with two different questionnaires: the Presence questionnaire (PQ) and the Immersive Tendencies Questionnaire (ITQ) (Witmer and Singer, 1992).

University College London Questionnaire (Slater et al., 1995; Usoh et al., 1999)
The UCL questionnaire combines seven questions based on reported presence with three questions on behavioural presence and three questions that measure the ease of locomotion. This diverse approach makes it a well-rounded questionnaire.

Igroup Presence Questionnaire (Schubert et al., 1999)
The IPQ is a compounded questionnaire, based on multiple other presence questionnaire, among which those of Witmer and Singer (1992) and Slater, Usoh and Steed (1994). It is based on eight factors from the previous questionnaires, five of which are concerned with immersion. This questionnaire is largely focussed on how the technicalities of the VE influence the participant's presence.

Comparing Questionnaires
Usoh et al. (2000) conducted experiments with the PQ and the UCL where two groups performed the same task; one in VR and one in reality. Both groups were asked to fill out both questionnaires in random order and eventually the outcomes were so similar that there was no significant difference in presence between reality and virtual. Reality measurements being undistinguishable from virtual measurements forms a problem for measuring presence solely through questionnaires. However, questionnaires can be used to validate or support objective measures and are therefore greatly useful.

Continuous presence assessment
IJsselsteijn et al. (1997, 1998) developed a continuous way of measuring presence, as a response to displeasure with the post-test nature of presence questionnaires (Freeman et al, 1999). They call it continuous presence assessment and it requires the test subject to operate a handheld slider while being presented with the stimulus in VE. The test subjects are then instructed to slide the slider up when their presence is increased and down when it is decreased. The fragile claim here is that the haptic slider is so easy to operate that it does not distract from being immersed and present in the virtual environment. The fact that data can be generated consistently throughout the experiment is a strong point for this technique. A big shortcoming however, is the fact that the participant's hands are occupied, which means that the participant cannot properly interact with their environment, which is of such importance for presence that this method seems unusable.

Breaks in presence / Presence counter
Slater and Steed (2004) introduce a new technique that gathers information during the participant's experience in the virtual environment, rather than after it. This technique relies on the hypothesis that people in a VE sometimes experience a break in presence, which means that the person realises for a short moment that they are actually not in the VE. When a break in presence occurs from the virtual to the real, the participant can report this. These breaks of presence are counted. The other way around however, when the participant transitions from real world presence to presence in the VE, they cannot report this because reporting it would immediately re-break their presence. The thought here is that while experiencing high presence in the VE, the participants will not think about having to report the breaks in their presence. But the moment they break their presence and are back to feeling presence in reality, they would remember their assignment and be able to report their break. So this technique does not measure what strengthens presence but rather what breaks it. Their results imply a positive relationship between body movement and presence, which confirms previous findings from Slater et al. (1998).

2. Behavioural

Presence is measured based on the behaviour of the subject while using the system (Sheridan, 1996).

Natural behaviour

Another approach to measuring presence is to look at the behaviour of the test subject. If the subject reacts to their virtual surroundings as if the VE is real life, this is a clear sign of high presence (Slater, 2003). Measuring presence through natural behaviour is related to the factor on body movement, as previous research has shown that when people move their body in a natural way in the VE, this has positive influence on their presence. Consequently, when a user moves their body in a natural way this correlates to the user feeling high presence, in combination with natural body movement leading to higher presence this creates a positive feedback loop.

Interaction with environment

Another way to use the naturalness of behaviour in VR to measure the amount of presence is to see how test subjects interact with their environment. This is a technique that builds on the naturalness of body movement factor. Research of Slater & Steed (2000) shows that the people that interacted with their environment in the VE as if it were real life, i.e. by moving around objects and not moving through them, reported higher presence. The researchers observed how much and in what manner the participant moves around in and interacts with the VE, which was compared to the way the participants filled out a presence questionnaire. Interaction with the environment could be used to approximate the level of presence a person in a VE is feeling.

Reflexes

An interesting aspect of behaviour is involuntary action, such as socially conditioned behaviours or reflex responses. Sheridan (1996) experimented with socially conditioned behaviours such as involuntarily offering up your hand when someone motions to shake it in VR. Sheridan (1996) as well as Held & Durlach (1992) conducted experiments on reflex responses. For example, having people automatically catch objects that are thrown at them in VR, or testing startle responses to sudden, shocking stimuli. Results of Held & Durlach's research show that there is a level of presence necessary for the participants to react reflexively to these different stimuli in the VE.

Conflicting information

Another way to test behaviour in VE was studied by Prothero et al. (1995) and Slater et al.(1995). Both researches used conflicting information between the VE and real world to see where the participants felt most present. Slater et al.(1995) showed a radio to subjects in real life before having them put on a HMD and seeing a virtual radio in the same location as the real. Then the researchers moved the real radio and asked the participant to point at it. A high self-reported level of presence correlated with pointing to the virtual radio. This is a clear way to show how contradictory information with the visual in the VE and the audio from reality can make a highly present individual behave differently from a less present individual.

Behaviour in real life after VR

While observing behaviour in the VE gives a lot of information, measuring presence through behaviour can also be done retroactively. This way of measuring presence through behaviour can be achieved by observing how well skills practised or learned in VR transfer to the real world. Previous research by Witmer and Singer (1994) has shown that skills learned in a VE can be useful in real life, as the researchers simulated battlefields to train soldiers in war-fighting tasks. The outcomes of this experiment suggested that VE's can be effective as a training medium when the VE adequately represents the real world situation. The aim of their research was to determine the level of realism that was needed for the test subjects to feel present as higher presence leads to higher performance.

Their results show strong indication for a correlation between presence and performance. Research by Welch (1997) reached the same conclusion.

Witmer et al. (1996) conducted an experiment on VR as a learning medium, in which three groups learn the layout of a building; one in VR, one in real life and one with only a map and verbal directions. Results show that the real life group did best, followed closely by the VR group. The research also shows that the participants in the VR group experienced presence in the VE and that their level of presence loosely correlates with how well each individual performed. Witmer et al. predict that as VR hard- and software becomes more powerful and less prone to errors higher presence and performance should be seen. Therefore, the skill retention after VR training could be used to measure presence in the VR training retrospectively.

After affects
Another way that behaviour after VR can change is through the exhibition of after effects (Barfield & Weghorst 1993). A form of after effect is the result a VRET session can have on experienced anxiety. Research by Krijn et al., confirms the hypothesis that presence is necessary to generate anxiety. The researchers also found that the therapy was effective, which means that the participants had sufficient levels of presence in the VRET (Krijn et al., 2004). The degree in which anxiety is lessened over time after the VRET program has concluded was used to retroactively determine whether the person in the VRET was present.

Human interaction in multi-user VE's
Slater, Sadagic and Usoh (2000) found a positive relationship between a person's sense of presence and their sense of co-presence, which is the sense of being with other people. The experiment consisted of a small group of people solving riddles in a VE together. The amount of interaction and the naturalness of interaction between multiple people in a shared VE was used to approximate the amount of presence that each person is experiencing. When compared to these same participant's answers to a presence questionnaire, the amount of human interaction and leadership people showed seemed to correlate with their level of presence. Schuemie et al. (2001) conducted a research into the interactivity of VE's and found that when people experienced co-presence in a VE with other people, this had a strong positive impact on the experienced presence of a person.

3. Physiological

Physiological properties of the body of the test subject as measured and can be related to the level of presence of the subject (Meehan et al., 2002).

Heartrate elevation
Research by Meehan et al. (2002) has shown that heartrate can be used quite well to measure presence, as it is consistent and sensitive to any anxiety inducing input and much more sensitive than other physiological measures in the same research. Meehan et al. compared the heartrate elevation over time to self-reported (subjective) measures and results correlated very well. This correlation implies that as a way of measuring presence, heartrate elevation can be used to generate data for statistical analysis. A drawback of using a test subjects heartrate as a measure for presence is the fact that a person can get used to stressful input quite quickly, which means that over multiple repetitions of the same experiment using the same stressor input, the heartrate elevation decreases strongly. Due to the fact that participants get used to the heartrate elevating stimuli, the experiment outcomes cannot be replicated with the same subjects.

Skin conductance & temperature

Skin conductance and skin temperature fluctuation were tested in the same previously mentioned research by Meehan et al. (2002). Skin conductance works as a measurement technique because the skin of the palm of the hand becomes more conductive when a person is stressed, ergo a higher skin conductance level correlates to higher stress levels. A positive correlation was found between skin conductance and presence, as the results from the skin conductance test were compared to the results of a presence questionnaire as answered by the subjects post-test (Meehan et al., 2000). Skin temperature changes very slowly in response to stimuli, which makes it useful as a measurement technique only whenever exposure to a stimulus lasts longer than two minutes. This measurement technique is based on blood circulation towards extremities slowing down when the person is stressed, which means that higher stress levels correlate to lower temperature. Similar as the skin conductance test, the skin temperature measurements were compared to the results of a presence questionnaire and the results correlate. These experiments showed however that both skin temperature change and skin conductance change happened too slowly to measure up against the more robust measurement that is heartrate fluctuation (Meehan, 2001).

Wiederhold et al.(1998) found a positive relation between higher skin conductance and a higher presence set up in their experiment which involved the fear of flying and an airplane simulator. The high presence set up was distinguished as such based on receiving higher presence ratings on the used questionnaire compared to other setups. This result was confirmed by Schuemie et al., (2001) whose research showed that other physiological behaviours such as sweating and losing balance were correlated with heightened presence, as their comparison with the results of a presence questionnaire revealed.

Anxiety generated

Krijn et al. (2004) conducted an experiment that used Virtual Reality graded Exposure Therapy in which multiple people with acrophobia (fear of heights) received exposure therapy either in VR or in vivo. Results indicated that 6 months after therapy, the decrease in anxiety from both groups was similar. The research made use of two different experiment set up's, one which was deemed as high presence set up and one deemed as the low-presence setup. There was a small difference measured in how well the results kept up over time between these set up's, with the results from the high presence set up staying stronger. The researchers concluded that some level of presence is necessary to generate any anxiety but that the difference in how much presence was experienced between the set ups that were used did not matter.

I want to theorize however that it is not the case that the presence difference between these set ups had no impact. Because ten out of the 35 patients that were tested did not generate anxiety in the VE and therefore did not finish the experiment. However, seven of these ten patients that did not feel enough presence were using the low-presence set up and only three of the ten failed to feel present enough in the high presence set up. I find it too over-simplified to conclude that the level of presence had no impact on how well the treatment took hold, when 70% of the people that dropped out of the research because no anxiety was generated in the VE were subjected to the low presence set up. It seems to me as if the level of presence in each set up did matter and caused some participants to not meet the needed threshold amount of presence to generate anxiety.

Price & Anderson (2007) conducted a research into acrophobia using virtual reality as well in which a simple form of exposure therapy that failed to elicit any true desensitisation of fear was used. However, the results showed that presence was definitely necessary to generate anxiety which corroborates findings of Krijn et al. (2004).

Analysis

Factors

There are 16 factors that influence presence discussed in this thesis. I do not hold any illusions about being able to determine which factors are most important, as I would argue that more experiments must be conducted to compare different factors before anyone can make such a value judgement. I argue that all three groups of factors must be accounted for to achieve high presence, this is to say that high realism must be a goal for any VE a researcher would want to build, and the VE must be meaningful to the subjects in some amount. As high realism and meaningfulness are necessary to be able to generate a VE in which high presence is possible. Lastly, researchers must work to exclude as much external stimuli as possible. The strength of our hardware has previously limited how realistic of an environment can be generated. I am pleased to say that realistic VE generation is no longer hampered by technological issues, therefore I recommend that researchers make good use of this modern technology and where possible use a wireless HMD and a quiet location. For meaning generation I would recommend researchers to think hard on what they are trying to achieve and generate an involving environment for their intended purposes.

Measurement techniques

To distinguish between different measurement techniques and to conclude on what works best when it comes to measuring presence, I want to use the factors for a good measure of presence that Meehan et al. (2002) introduced. The first factors for a good measure is that the technique is reliable, in that any produced results can be reproduced. Secondly the technique must be *valid*, which means that the presence measure that is used must be comparable in results to an already well-established subjective measurements technique. Lastly the measure should be objective, to rule out as many between-subject differences as possible, which rules out all subjective measures such as the presence questionnaires. I agree with this exclusion of questionnaires as a single measure, because while I think that the questionnaires have been of unmatched value, but they should not be used as a standalone measure due to their subjective nature. I think, however, that questionnaires do offer an excellent way to calibrate other measures. As a way to ensure the objectivity and specificity of a measurement, I think it would be useful to utilize both a presence questionnaire and a behavioural or physiological measure.

I regard heartrate measurement as a good physiological measure. When this physiological measure is used in conjunction with a presence questionnaire, researchers should be able to generate results for experiments that are concerned with stimuli that influence heartrate. If the heartrate of the participant would elevate when a same situation presented itself in real life then this physiological measure is a good measure. If one would not have an elevated heartrate in real life then this combination of a questionnaire and heart rate elevation measurement is not a good measure for the experience in VR.

For experiments that do not base their research on fear-related topics, I think a behavioural approach in conjunction with a presence questionnaire would work best. To measure the presence of a test subject in a regular virtual area heartrate elevation should not be the discerning factor, as there is no reason for the subject's heartrate to spike in a regular situation. The fact that different researches involve different physiological behaviours to be measured explains why different measures must be used for anxiety related research, when compared to research that does not involve elevating the subject's heartrate.

Recommendations

To summarize the analysis and form a recommendation based on my findings, I recommend the following measurement technique for different researches.

For research concerning anxiety and phobias I recommend the use of heart rate elevation measurements as a physiological measurement combined with a presence questionnaire, as explained in the previous section 'Analysis'.

For research that is not related to stimuli that would raise the participant's heartrate, I recommend the combined use of a presence questionnaire and the behavioural measurement technique of tracking the naturalness of behaviour within the VE and the amount of interaction they have with their environment. As seen in Chapter 2, many factors that positively influence presence have to do with the amount of control one can exert over their environment as well as how realistic their interaction and movement in the VE can be. At this point in 2020, I reckon that with the widespread use of HMD's combined with ergonomic controllers we have reached a point where the hard- and software used are strong enough to generate realistic VE's and through the use of the controllers the VE's allow for sufficiently realistic interaction with the VE as well. Consequently, in a realistic VE, merely observing how the person in the VE behaves can tell a lot about how much presence they are experiencing.

Lastly, for training purposes I recommend a questionnaire combined with measuring the amount of interaction with the environment and the behaviour in the VE as well. However, I would also recommend to track the trainee's progress in the skill that they have trained in VE for an extended period of time after the VE training has concluded.

Discussion

In this thesis over forty papers on presence in virtual reality are discussed. This is a large amount, but nevertheless I fear it is far from enough to generate a truly all-encompassing analysis of presence in VR. For future research I would recommend searching for more sources concerning physiological measurements of presence as I think many modern experiments will want to make use of them. However, as it was my aim to give an overview of the field of presence in VR, I do not regret the fact that I did not focus on the most recent developments. I think knowledge of the foundations of the field is very important as we must understand where we come from before we can decide in which way to move on. In my introduction I mentioned the fact that different authors have already tried to give an overview of presence. However, these papers give an overview of at most ten different researches and are usually working from some agenda as many of these authors use their opinionated overview to promote their own measuring technique. I believe this thesis has provided the field of presence research with a thorough overview of previous research and potentially even a valuable resource for future research.

The categorisation I made for both factors and measurements is mostly to promote legibility of the thesis. Many different factors are intrinsically linked in ways that transcend these categories, and the same goes for the measurement techniques. However, for the purpose of this thesis some categorisation was necessary and I think this is a good way to look at the different factors and measurement techniques.

In my Recommendations section I recommend future researchers of presence to measure presence in their experiment through a combination of subjective and objective techniques. However, many of the factors that I have discussed in Chapter 2 have been measured through the use of presence questionnaires alone. Due to the fact that I have substantiated each factor by consulting at least three credible sources, all with similar findings, I reckon I have only included factors that truly influence presence. Regarding the fact that many factors were initially discovered years, or even decades ago, the researchers had no other options besides using presence questionnaires. With the fact that I have used many sources to build each factor, I consider it highly likely that the factors I have outlined do in fact influence presence.

Because nowadays we have more options when it comes to behavioural and physiological measurement techniques for presence, I recommend that future researchers use more than only questionnaires. I do not however wish to insinuate that because we now have more opportunities, these previous researches hold no truth. However, like I mention in the analysis of the factors, I think more research needs to be done on the factors that influence presence, using modern tools and techniques, to investigate whether these factors are of real influence on presence.

Future uses of VR for which high presence is necessary

Housing crisis / working remotely

The housing crisis forms a problem for the established urbanised way of life most western countries have at this point, as more and more urban areas are saturated and too expensive to house all the people that wish to live there. The housing crisis problem will only be getting worse as our population grows steadily, because of this I foresee great opportunities in VR meetings and VR office spaces, so people can interact with their co-workers on a daily basis without having to live in the most expensive areas in the world. As the hard- and software used in VR becomes more affordable, more people will get used to communicating through virtual spaces.

Virtual Reality Exposure therapy

Krijn et al.(2004) have shown that while HMD virtual reality treatment is much cheaper than the golden standard of in vivo exposure therapy, its results are similar. The lower price point of VRET, combined with the fact that it works means that in the future as VR equipment becomes more accessible to the population, more people could receive high quality therapy without it forming an economic burden. Virtual Reality could be used for patients with various forms of anxiety, phobias and stress disorders. The patient could be put in a virtual environment that simulates a situation in which their anxiety would spike and the patient could practise more constructive behaviour in the safety of a virtual environment (Sanchez-Vives & Slater, 2005). But the possibilities stretch even further, as for more serious posttraumatic stress disorders in for example veterans of war, or abuse victims these patients could undergo continuous exposure therapy by themselves. As VR sets can cost as little as 500$, patients could slowly expose themselves to their triggers at their own pace, from the comforts of their own home.

Training purposes

Laycock & Day (2003) describe how minimal invasive surgery such as laparoscopy has become increasingly popular over time due to the fast recovery of patients and the little damage laparoscopies do to healthy tissue. Minimal invasive surgeries pose a larger challenge for doctors however, considering the limited visual input doctors receive during surgery as well as very different handling of instruments and limited hand-eye-coordination. Practising laparoscopies in virtual reality has been made possible by the laparoscopic impulse engine, which is a haptic device designed especially for doctors to train in virtual environments. The laparoscopic impulse engine is claimed to bring unprecedented levels of realism to surgical simulations. More of these devices could be designed and created to aid professionals and students in practising really any task imaginable. Tasks that were previously very difficult to practise could be approached from the VE.

This thesis has revealed what factors influence presence, how presence is currently measured and how I think presence should be measured in the future. Using this knowledge of presence in the VR applications for remote working, therapy and training purposes could help the field. The field of VR applications in daily life can give people a lot more freedom and can make different kinds of therapy and complex training more accessible. I think a future in which we use VR to the fullest in at least these applications looks attainable and promising.

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