Perception and Emotion in Virtual Reality:

The Role of the Body and the Contribution of Presence

Doctoral thesis presented to the Faculty of Human Sciences

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Abstract

This thesis reports four studies in the context of virtual reality (VR), feelings of presence, emotion, and perception. Previous research established the existence of cross-dimensional perceptual interrelations such as the interconnection between experienced motion and subjective time. This is thought to result from a common perceptual system. However, the specifics of this system are a matter of ongoing research. An important binding factor between perceptual dimensions is the bodily self, which was described as a reference for perception. In Study I, manipulations of the size of a virtual self-representation were shown to affect the spatial judgment of objects. In Study II, the degree of self-motion in an immersive virtual environment (IVE) influenced the subjective perception of time, corroborating previous findings about the common perceptual system. Besides the virtual self-representation, there is another important variable in VR experiments: Presence is described as the feeling of being in a mediated environment. Presence was not associated with improved performance in the spatial and temporal judgments of Studies I and II. However, in Study III, presence in a gaming activity was linked to improved mood after an experimental stress-induction. This especially applied to VR gaming, where impressions about the subjective realism of the IVE might have been crucial for mood repair. As outlined in Study IV, it is important to distinguish between presence as an attentional allocation to the mediated world and as an individual judgment about its realism. Taken together, the results from all studies corroborate the idea of the self as a fundamental perceptual reference, confirm results about the psychological connection between space and time, emphasize the benefits of VR gaming in improving mood, and elucidate the role of perceived realism in assessing presence in IVEs.

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List of the Manuscripts of this Thesis

The following manuscripts, on which this thesis is based, are provided in the appendix.

Manuscript I:
Weber, S., Mast, F. W., & Weibel, D. (2019). Body size illusions influence perceived size of objects: a validation of previous research in virtual reality. *Virtual Reality*, 1-13. https://doi.org/10.1007/s10055-019-00402-z

Manuscript II:
Weber, S., Weibel, D., & Mast, F. W. (2020a). How self-motion in virtual reality affects the subjective perception of time. *Timing & Time Perception*, 1-18. https://doi.org/10.1163/22134468-20191152

Manuscript III:
Weber, S., Mast, F. W., Weibel, D. (2020, forthcoming). Presence and Mood Repair – Experiencing Presence in a Virtual Reality Game Improves Mood after a Negative Mood Induction. *International Journal of Gaming and Computer-Mediated Simulations.* Copyright IGI Global, reprint with permission.

Manuscript IV:
Weber, S., Weibel, D., & Mast, F. W. (2020b). *How to Get There When You Are There Already? Defining Presence in Virtual Reality and the Importance of Perceived Realism.* Manuscript in preparation.

1. Introduction and Overview

Albert Einstein established that space and time are interconnected and that the perception of both is depending on the motion of the observer (Einstein, 1905). Whereas physics is relevant at velocities close to the speed of light, psychology is concerned with the connection of space and time in everyday perception. In this thesis, I will show that different domains of perception, such as time and space, are closely interrelated and that they depend on the own body as a system of reference. The body does not just act as a spatial cue for the perception of external space, our self and its ascribed properties fundamentally change our cognitions about the world. My work is based on experiments involving virtual reality (VR) technology. Thus, I will also explain why VR is a promising tool for conducting experiments involving time and space perception and discuss the shortcomings of current measurements of presence – the feeling of being in a mediated world such as an immersive virtual environment (IVE; cf. Steuer, 1992). Presence not only affects how our attention is captured by the VR system, but also how compelling and visually appealing the system appears to users. Presence also plays an important role in the regulation of emotions in IVEs and supports recovery from negative mood states.

In the first study of this thesis, I conducted an experiment with virtual body representations of the self (i.e. avatars). In an IVE, Participants slipped into a human avatar that was manipulated to be either unnaturally tall or short, or of normal size. The premise of the experiment was to investigate whether the size of one's own body – surely one of the most visible properties of the self – would change the way objects presented to the participants in the IVE would be perceived in terms of size. The experiment also varied the method by which a feeling of ownership over the avatar was created and whether the body was enabled to act as a visual reference or not.

In the second study of this thesis, another property of the self, self-motion, was the object of investigation. In this experiment, participants experienced a virtual car ride at different speeds and for different durations. Here, I studied the influence of self-motion velocity on the subjective perception of time. As in the first study, presence was included as a covariate because it could influence the way the IVE is experienced by participants.

In addition to the inclusion of presence in the two described works, presence was also the central construct in the third and fourth manuscript of this thesis: In an empirical study, presence was expected to enhance mood repair after an episode of stress. After a stress induction, participants played a computer game with or without using a head-mounted display (HMD) or watched a video recording of someone else playing the game. I was interested in how immersion and individually experienced presence would influence the overall state of mood. This study was originally based on the experiment of my Master's thesis and involved additional recruitments of participants, a new experimental structure as well as a substantially different statistical approach for data analysis.

Lastly, in an opinion article, which is the fourth work of this thesis, I summarized my observations of using presence as a covariate in experiments. The main goal of this article was to show how presence in an IVE is different from presence in other media and how important it is to include judgments about the perceived realism of the virtual world in presence questionnaires.

My thesis is an addition to the existing work on the perception of time, space, and emotion and demonstrates how strongly our own body and our self-motion are interconnected with the perceptual evaluation of the world. Furthermore, my work provides an example for an effective yet resource-efficient use of VR for conducting empirical research – especially in the domain of temporal, spatial and emotional perception and cognition. In the following, I will describe the four manuscripts in this thesis in larger depth and connect them with existing empirical work and theoretical concepts in the literature.

2. Space and Time Perception and the Influence of the Body

2.1 Theoretical Background

In experimental exercises during my Bachelor's studies, I contributed to an experiment about time-space synesthesia. This form of synesthesia is characterized by strong spatial associations of time concepts in the mind and is estimated to appear in as much as a fifth of the population (Mann, Korzenko, Carriere, & Dixon, 2009; Sagiv, Simner, Collins, Butterworth, & Ward, 2006; first described by Galton, 1880). A typical spatial association is imagining the months of the year in a circle (Mann et al., 2009). But not only synesthetes associate time with space, there are many time-space metaphors in common language: "a long day", "time flows", or "move a meeting forward" (Boroditsky, 2000; Lakoff & Johnson, 1980). These associations are found among different cultures (Alverson, 1994). Apart from language, we also use spatial aids like calendars and clocks to visualize time.

Empirical studies demonstrated that these two forms of perception are indeed connected: In early work by Benussi (1913), the time interval between three successively illuminated stimuli affected the perceived physical distance of the stimuli. This was called the *Tau effect* (Helson, 1930). In subsequent studies, the effect was replicated (Geldreich, 1934; Lechelt & Borcher, 1977), extended to tactile (Helson & King, 1931) and auditory stimuli (Scholz, 1924), and shown to be invertible (Cohen, Hansel, & Sylvester, 1953; Collyer, 1977). The latter was termed the *Kappa effect* (physical distance affects subjective duration; Cohen et al., 1953). Even though alternative explanations for these effects were suggested (i.e. imputation of uniform motion to discontinuous displays; Jones & Huang, 1982), more recent research has confirmed that space and time perception are intertwined. In a series of experiments by Casasanto and Boroditsky (2008), the length of lines presented on a computer screen affected their subjective presentation duration. Further studies showed that subjective time is represented on a (spatial) mental time line (e.g. Conson, Cinque, Barbarulo, & Trojano, 2008; Ishihara, Keller, Rossetti, & Prinz, 2008; an overview is provided by Bonato, Zorzi, & Umiltà, 2012) and that the processing of time is at least partially connected to activity in brain areas otherwise associated with space perception (e.g. Bueti, Bahrami, & Walsh, 2008; Oliveri et al., 2009).

Not only are space and time perception connected, but also many other associations between different domains of perception have been discovered (e.g. Marks, 1987; Marks, Szczesiul, &

Ohlott, 1986; Ward, Huckstep, & Tsakanikos, 2006). Particularly, there seems to be a common system of magnitude, whereby subjective judgments about the magnitude of such domains as time, numerosity, size, and luminance of stimuli as well as the perception of digits are all interrelated (e.g. Xuan Zhang, He, & Chen, 2007; for an overview see Cantlon, Platt, & Brannon, 2009). This led to the formulation of A Theory of Magnitude (ATOM) by Walsh (2003). The theory assumes that there is a common system for magnitude processing which is acquired in early development stages by learning the associations of perceptual dimensions while planning and performing actions (Bueti & Walsh, 2009). Semantic pairs like "more and less", "far and near", "big and small", and "fast and slow" are thought to depend on a general sense of magnitude (Bueti & Walsh, 2009). However, challenges to the model have been proposed, including findings that showed that different domains of perception are not symmetrically related. In the experiments by Casasanto and Boroditsky (2008), for example, only the length of the line affected its perceived duration and the actual presentation time did not affect the perceived length of the line. One possibility to reconcile these findings with the suggested cross-dimensional interferences in perception is to assume that our sense of space is the dominant perceptual system, which affects all other sensory domains. Bonato et al. (2012, p. 2267) have argued that "space might be the common metric for representing abstract, non-spatial entities, such as time". The idea is supported by cortical networks that share activation in spatial tasks and basic sensorimotor transformations (Bueti, Walsh, Frith, & Rees, 2008).

An important spatial cue in perception is the *bodily self*. The brain needs to constantly adjust its interpretation of sensory input to the current position of the eyes, the head, and the body. Thus, it is not surprising that our judgments about the size of objects and distances depend on our perceived eye height, which in turn is determined by visual cues but also proprioceptive and vestibular information (Leyrer, Linkenauger, Bülthoff, & Mohler, 2015). Similarly, perceived distance is affected by the orientation of the body (Harris & Mander, 2014) or by the gravitational force acting on the body (Clement, Loureiro, Sousa, & Zandvliet, 2016). Moreover, it was shown that the perception of audio frequencies is connected to the body’s orientation and the egocentric definition of "up" and "down" (higher frequencies were associated with the perceptual upright in a visual decision task; Carnevale & Harris, 2013). Perceived body size was also shown to affect tactile perception (cf. D'Amour, Pritchett, & Harris, 2015; de Vignemont, Ehrsson, & Haggard, 2005). In the *Weber Illusion*, the perceived size of a felt object depends on the body part on which the object is held against, depending on its density of tactile receptors (Longo & Haggard, 2011; Weber, 1834). Taken together, there is strong empirical evidence for a coupling of sensory information and body representation. Sensory signals are processed with reference to the body's shape, proportion, and movement (Harris et al., 2015). Consequently, Harris et al. (2015, p. 4) describe the body as a "universal reference system of the brain". Other authors refer to the body as "the fundamental ruler" (van der Hoort & Ehrsson, 2016, p. 1) or the "system of axes of coordinates" (translated from French: "système d’axes de coordonnées"; Poincaré, 1952, p. 100). The importance of the body in cognition has also been recognized in philosophy and psychological research under the term *embodied cognition*. Embodied cognition entails that cognition is fundamentally affected by the body (overviews are provided by Shapiro, 2019, and Wilson & Foglia, 2011). Serving as a reference system, the body presumably provides connections between different perceptual domains and is a possible source for the proposed common spatial metric of perception. Spatial concepts might be primarily learned through the interaction of the self with the world, which means that the body shapes and defines our concept of space (cf. Smith & Gasser, 2005; Thelen, 1995).

The body does, however, not only affect basic perception: In VR studies, identity cues of virtual body representations were shown to affect behavior and cognition (an overview is provided by Ratan, Beyea, Li, & Graciano, 2019). This means that participants' behavior and attitudes adapt to their avatar's characteristics, a phenomenon that was termed *Proteus effect* (Yee & Bailenson, 2007). To illustrate the concept, virtual body height was found to be positively connected to a more aggressive negotiation style (Yee & Bailenson, 2007; Yee, Bailenson, & Ducheneaut, 2009) and performance in a competitive online game (Yee, Bailenson, & Ducheneaut, 2009).

The Proteus effect demonstrates how behavior, thoughts, and beliefs are shaped by involuntary cognitive associations between the observed body representations in VR and their ascribed characteristics. As such, the Proteus effect is a primary example of embodied cognition and the close relationship between the body and the perception of the world. It is, however, still debated whether the Proteus effect primarily results from self-perception or schema activation (Ratan et al., 2019). It has been argued that closeness to the avatar (in terms of physical distance as well as similarity and identification) enhances the Proteus effect and that this demonstrates an interplay between self-perception and schema activation (Ratan & Dawson, 2016; Ratan & Sah, 2015). However, so far there is not much empirical evidence for this claim.

To address this concern and to investigate how the body affects our perception of space and time, two experimental studies were conducted, which serve as Manuscripts I and II of this thesis. Specifically, the study described in Manuscript I tested the assumption that changing the size of a virtual self-representation influences the perception of space. In the study described in Manuscript II, self-motion in VR was the determinant in question for space and time perception. Here, more specifically, the relation of space and time perception was investigated. In the remaining sections of Chapter 2, I describe the starting points, empirical implementations, and findings of the two experiments and explain the implications for research and everyday life.

2.2 Body Size and the Perception of Objects

In a series of experiments by Björn van der Hoort and colleagues, propositions of embodied cognition and the Proteus effect were empirically tested (van der Hoort, Guterstam, & Ehrsson, 2011; van der Hoort & Ehrsson, 2014; 2016). To find out whether the overall size of the "fundamental ruler" (van der Hoort & Ehrsson, 2016, p. 1) changes the perception of the size of objects, dolls in various sizes were used. A stereoscopic set of cameras captured the lower part of the doll, essentially creating a first-person view of the doll’s body. This footage was transmitted in real-time to an HMD, to give a participant the impression of looking down one's own body. To create a strong illusionary association between the self and the artificial body, both the participant and the doll were synchronously touched by a rod. Synchronous stroking is a commonly used method for inducing *body ownership* – the feeling that the touched artificial body is one’s own (cf. de Vignemont, 2011; the term was originally derived from research on the rubber-hand illusion, see Botvinick & Cohen, 1998, and Tsakiris & Haggard, 2005). Inducing ownership of a full body is also referred to as the full-body-illusion (Petkova & Ehrsson, 2008). The full-body-illusion is the consequence of the brain's attempt to reconcile the spatial and temporal correlations of visual and somatic signals (Petkova & Ehrsson, 2008).

The results of all three experiments showed that the perceived size of objects was influenced by the size of one's body. Object sizes were overestimated when embodying a small body but underestimated when embodying a large body. Such an effect of regressing one’s judgments towards midsize magnitudes is referred to as *contraction bias* in research on perception (Poulton, 1989). The contraction bias itself is not a surprising finding but van der Hoort et al. (2011) showed that the size of this bias was depending on the ownership condition: Synchronous as compared to asynchronous touch led to an increased contraction bias. This was coined the *own-body-size effect*. The effect was replicated in two successive studies (van der Hoort & Ehrsson, 2014; 2016), where it could furthermore be demonstrated that the effect is not an effect of mere visual comparison (the artificial body was occluded during the visual judgment of the objects' sizes).

There were no other direct replications of the effect. In VR, a study showed that varying the size of a participant's virtual hand led to a contraction bias when judging the size of balls presented next to the participant's hand on a table (Linkenauger, Leyrer, Bülthoff, & Mohler, 2013). The experiment included a control condition where the size of the hand of an avatar standing on the opposite side of the table was manipulated. Interestingly, there was no contraction bias in this control condition. Unfortunately, the experiment did not include subjective measures of ownership, meaning that it is not clear whether this was an effect of ownership or mere perspective. Another study used full-body tracking to create mappings of body movements onto an avatar (Banakou, Groten, & Slater, 2013). This created a full-body-illusion of being small compared to another avatar that was placed in the room. The mappings could be synchronous or asynchronous, thus offering an alternative manipulation of ownership. In this study, objects were generally overestimated compared to a control condition without a visible body, suggesting that the feeling of being small led to an overestimation of objects. When the mappings of the participants' movements were asynchronous, no such difference could be observed, suggesting that ownership is responsible for the effect. However, it is unclear how the advantage of having a body in an IVE could have contributed to these findings (cf. Ries, Interrante, Kaeding, & Anderson, 2008; Mohler, Creem-Regehr, Thompson, & Bülthoff, 2010). Both VR studies show important deviations from the original paradigm and do either not systematically vary the size of the whole body or do not maintain the same perspective in all conditions. Thus, it is still unclear whether the own-body-size effect as reported by van der Hoort et al. (2011) also applies to a VR setting, using virtual avatars instead of real-life dolls.

In essence, there are two important shortcomings of the own-body-size effect: 1) that the effect was never replicated outside the original lab using the same paradigm and 2) that the effect was never convincingly demonstrated in VR. It is important to test whether the effect also applies to VR not only to strengthen the evidence that the body acts as a fundamental ruler in perception, but also because it is vital to obtain the same results in VR as in setups using real-life props such as dolls. VR is a promising tool for conducting research that is economical, easy to adapt, ecologically valid, and allows a strict control of environmental variables (cf. Bohil, Alicea, & Biocca, 2011; Parsons, Gaggioli, & Riva, 2017; see also Chapter 3.1 of this thesis). VR is also used in practical applications such as training for pilots and surgeons (Colt, Crawford, & Galbraith, 2001; Khalifa, Bogorad, Gibson, Peifer, & Nussbaum, 2006). As such, it is important to know the effects of manipulating the body in VR on the perception of virtual objects and scenes. In order to design realistic IVEs that trigger the desired training effects on perception and motoric performance, one needs to know if and how VR differs from reality.

In my first study (Weber, Mast, & Weibel, 2019; Manuscript I in the appendix), my colleagues and I tackled these issues by implementing the paradigm used by van der Hoort et al. (2011) in a VR setting. We used virtual bodies instead of dolls and the IVE consisted of the laboratory room that was reconstructed in VR to give the impression that one is at the same physical space. In this IVE, participants embodied either very small, medium-sized, or extremely tall avatars. The participants judged the size of box-shaped objects in the virtual laboratory room. As expected, we could observe a contraction bias: underestimation of object sizes in the large avatar and overestimation in the small avatar. However, importantly, the magnitude of the contraction effect did not vary between synchronous and asynchronous touch conditions. Thus, we could not replicate the own-body-size effect, even though questionnaires showed that the manipulation of ownership had worked. We decided to implement a second experiment, where we did not only vary the synchronicity of touch, but also the perspective of the participant, having either the usual first-person perspective (1PP) of the avatar or shifting the avatar to the right to obtain a third-person perspective (3PP). This combined manipulation of touch sensations and perspective was intended to enhance the differences between the ownership conditions, as studies have shown that a 3PP is a powerful tool for disrupting ownership sensations (Maselli & Slater, 2014; Petkova, Björnsdotter, Gentile, Jonsson, & Ehrsson, 2011). The results from the questionnaires confirmed that the difference between the ownership conditions increased. As in the first experiment, the experienced presence in the IVE was increased in the high ownership condition compared to the low ownership condition, suggesting that the feeling of high body ownership and presence were related. Nevertheless, the manipulation of ownership did not lead to a differential effect on size judgments (own-body-size effect). Finally, to rule out the possibility of using the avatar as a size cue for judging the objects, we conducted a third experiment similar to that of van der Hoort & Ehrsson (2014; 2016), where we removed the virtual body during size judgments. Also, in this third experiment, we could demonstrate a contraction bias, but not the proposed own-body-size effect of van der Hoort et al. (2011) and van der Hoort & Ehrsson (2014; 2016).

In an exploratory follow-up experiment, I also implemented a full-body tracking using the Xbox Kinect sensor (Microsoft Corporation, Redmond, United States). Participants were standing upright in a virtual market square controlling a virtual body with their own movements. The body was either extremely tall (as tall as the surrounding buildings) or extremely small (same size as a drink can shown on the floor; see Figure 1). Again, the size of box-shaped objects had to be judged. A contraction bias could be observed, but there was again no impact of an ownership manipulation (synchronous or asynchronous mappings of body movements; see Figure 2). Possibly, however, the perspective cue in this experiment was too strong and obscured any ownership effects.

Taken together, even though the virtual body apparently interfered with the participants' perception of space (a contraction bias was obtained in all experiments), I could not confirm the proposition that ownership would enhance the impact of the ascribed characteristics of the body on visual perception. These findings are discussed in Section 2.4.

Figure 1. Small body condition (left) and large body condition (right) in the pilot experiment. Please note that, in the IVE, the virtual body would be facing forward

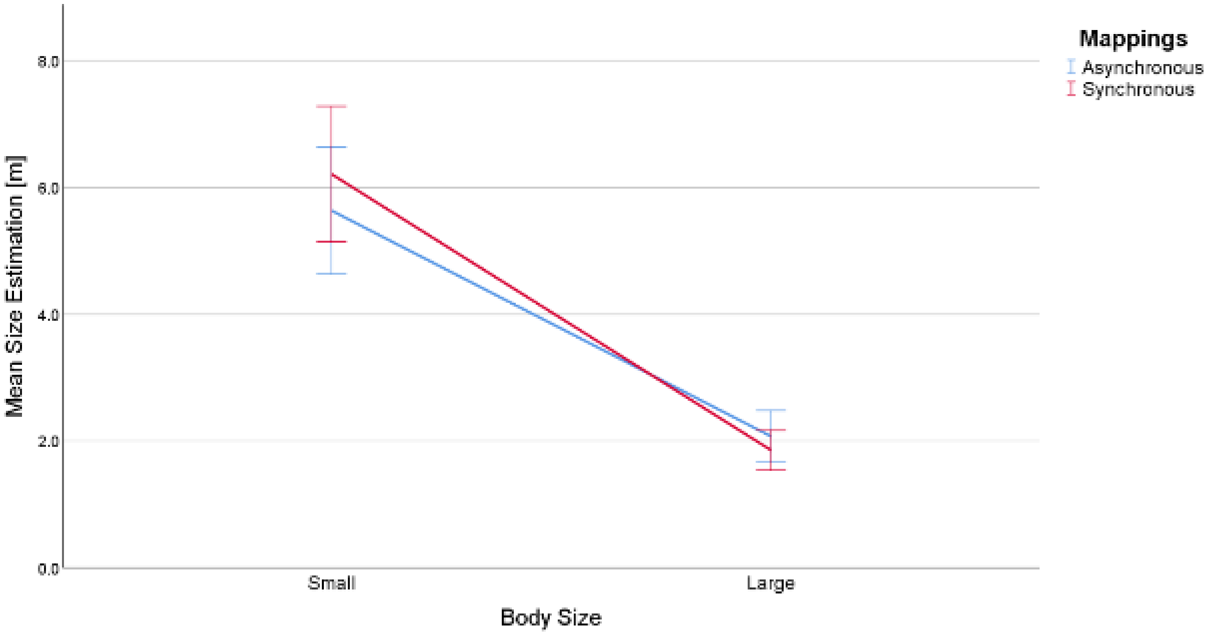

Figure 2. Size estimation as a function of body size (*F*(1, 54) = 34.35, *p* < .001) and synchronicity of mappings (*F*(1, 54) = 0.01, *p* = .921)

2.3 Self-Motion and Time Perception

In my next study, I extended the research on the own body in the sense of self-motion influencing space and time perception. Surprisingly, even though findings about the interrelatedness of space and time are numerous and both concepts are regarded as fundamentally intertwined in modern concepts of physics (see Sections 1 and 2.1), there is only scarce empirical evidence of a psychological influence of spatial self-displacement on time perception. Fast motion of simple geometrical stimuli was found to be linked to an increased subjective perception of their duration (Bonnet, 1965; Brown, 1995). The effect was approximately linear and could be replicated several times using different experimental designs (Au, Ono, & Watanabe, 2012; Bruno, Ayhan, & Johnston, 2012; Gorea, & Kim, 2015; Tomassini, Gori, Burr, Sandini, & Morrone, 2011).

However, only few studies extended the effect to the observer's own motion, changing the displacement of the entire visual field. In studies using a rotating device to induce passive self-motion, the rate of tapping on a button increased in trials with accelerated rotation (Binetti, Siegler, Bueti, & Doricchi, 2010; Capelli, Deborne, & Israël, 2007). Participants were instructed to press the button in a regular interval. In a similar study, accelerated rotation was associated with a temporally accelerated tone sequence (Binetti, Siegler, Bueti, & Doricchi, 2013). In these experiments, self-motion velocity was confounded with the rate of acceleration because of physical constraints (to achieve a certain speed, the participant needs to be accelerated, resulting either in different average or top speeds). Importantly, the participants were blindfolded during the task. Thus, the found effects do not indicate an effect of the visually perceived motion of surroundings. Instead, vestibular perception supposedly elicited the effect (cf. Capelli et al., 2007). However, unlike the visual perceptual system, the vestibular system of humans is arguably only able to detect changes in velocity, not constant speed (cf. Goldberg & Fernandez, 1984).

Apart from studies using blind rotation, there were two studies using self-motion during car rides. In a study by Brehmer (1970), participants were seated in a car driving on a highway. They had to produce time intervals that were a multiple the length of a previously experienced reference duration (*magnitude production paradigm*). The produced durations were longer in a higher speed condition. In a study by van Rijn (2014), participants were shown movie clips of virtual cars moving along a virtual road with varying velocities on a computer screen. Durations had to be judged to be either shorter or longer than a previously experienced reference duration, and the proportion of "longer" responses increased with increasing speed, independent from the actual duration (*magnitude comparison paradigm*). Both studies using car motion had disadvantages. In Brehmer's (1970) study, there was little control over the changing surroundings of the car and the conditions were possibly confounded with the amount of distraction associated with the car's speed on the highway. Additionally, the magnitude production paradigm is problematic because it has been argued that giving accurate perceptual estimations on a ratio scale is very difficult (Narens, 1996; see also Ellermeier & Faulhammer, 2000, and Zimmer, 2005). Similarly, the magnitude comparison paradigm used in van Rijn's study (2014) provides only an indirect measure of subjective time and the used time intervals were in a very small range of 2500 ms +/- 200 ms. It has been argued in the literature that effects of subjective time are heavily influenced by the measurement paradigm, often revealing conflicting results between different measures (Matthews, & Meck, 2014). Furthermore, it has been discussed whether the use of a reproduction paradigm provides a direct and intuitive measure for assessing subjective time (Zakay, 1990). In a reproduction paradigm, a previously experienced target duration is reproduced by the participant, usually by pressing a button (Grondin, 2008; Zakay, 1990).

Rammsayer and Verner (2014) have argued that a reproduction paradigm shows less intersubject variability than production paradigms and provides a more direct measure of subjective time. Reproduction could potentially lead to different results than studies using production paradigms. Therefore, my colleagues and I applied measures of reproduction to study the effect of visually perceived self-motion on time and distance perception (Weber, Weibel, & Mast, 2020a; Manuscript II in the appendix). In the experiment, participants wore an HMD. The IVE consisted of a straight virtual road leading through a city environment. Participants were passively driven along the road for different durations and varying speeds. The use of VR allowed for the application of constant virtual self-motion without the need for acceleration. Additionally, through the use of VR, we could effectively emulate a realistic car drive and still maintain a high control over the surroundings. As a consequence, the amount of attention required by the task was the same in each condition. Controlling for attention is very important because time perception is very context-dependent (Matthews & Meck, 2014). For example, a few studies have shown that fast stimulus motion is not necessarily associated with longer subjective presentation time (Darlow, Dylman, Gheorghiu, & Matthews, 2013; Nyman, Karlsson, & Antfolk, 2017). These differences can be explained by characteristics of the task and the stimuli that were used (the amount of required attention, how attention is allocated, but also the complexity of the stimuli and whether memory is involved; see Eagleman, 2008, for an overview). In our experiment, the use of VR allowed for highly standardized conditions, only varying in trial duration, self-motion velocity and traveled distance. Additionally, with the use of a prospective timing paradigm (participants know in advance that they will have to judge the duration), the level of memory involved in the timing task is lower than in a retrospective paradigm (participants are unexpectedly asked to judge the duration after the task; cf. Block, 1974; Block & Zakay, 1997).

The results of the experiment showed that a higher speed of the car was associated with longer subjective time as indicated by longer reproductions. However, the effect showed important deviations from linearity, suggesting that the effect of speed shrinks in the highest speed conditions. Moreover, whereas time intervals and the velocity of the condition were consistently underestimated by the participants, the traveled distance was overestimated. This suggests that the different domains of perception were not consistent with each other (having a lower velocity and requiring less time should result in traveling a lower distance). Another finding concerned experienced presence during the task, measured using questionnaires. Even though higher presence is usually associated with improved performance in perceptual tasks in IVEs (e.g. reduced underestimation of space; see Renner, Velichkovsky, & Helmert, 2013) and presence boosts task performance in skills training (Azar, 1996; Regian, Shebilske, & Monk, 1992), we could not find any relation between the accuracy of time judgments and reported presence, nor an effect of presence on self-reported confidence in the timing task. Thus, the interdependence between perceived space and time in the IVE was not affected by presence, although presence is usually associated with attentional allocation to the IVE (see Sections 3.1 and 3.3). The results of this study are further discussed in the next section.

2.4 Discussion

In two studies (Weber et al., 2019 and Weber, Weibel, & Mast, 2020a), together with my colleagues, I studied the influence of the body on time and space judgments. The observer – to use Einstein's term – was either manipulated in terms of its overall size or the speed of self-motion. I was able to demonstrate that both aspects of the observer interfered with the basic perception of objects' size, the subjective experience of time, and perceived distance. In the first study (Weber et al., 2019), the overall size of a virtual body influenced the perception of objects' size in an IVE, which corroborates previous findings (Banakou et al., 2013; Linkenauger et al., 2013; van der Hoort et al., 2011). The results also hint at a possible common perceptual system, combining spatial self-perception of the body with the relative size of external objects. There is cognitive influence from the characteristics of the body on perception in the sense of a Proteus effect. This influence is possibly able to affect behavior in certain situations (e.g. choosing a smaller object with a small avatar because the object appears bigger). Because hiding the body during the judgment phase did not result in changes in size judgments, it seems likely that schema activation contributed to the Proteus effect. The role of self-perception, however, remains unclear. We could not confirm the claim that closeness to the avatar enhanced the Proteus effect and, thus, that the Proteus effect would rely on self-perception in combination with schema activation (cf. Ratan & Dawson, 2016).

Our results also challenge previous conceptions that the subjective ownership toward the avatar would interfere with the extent of the contraction bias (van der Hoort et al., 2011; van der Hoort & Ehrsson, 2014; 2016). We were not able to replicate the own-body-size effect. The implication of these findings is that perception is depending on the body as a reference system, but the effect is not self-referential, meaning that the body needs not be thought of as one's own body, as suggested by the lack of influence of ownership. Even bodies not touched synchronously and lying in a 3PP evoked the contraction bias, despite them showing markedly reduced ratings of ownership. Thereby, our results show that manipulating the perspective in VR is a promising tool for disrupting self-reported ownership. However, future VR embodiment studies will have to pay attention to the disownership conditions as they may not result in the same effect as in conventional embodiment studies. In this regard, it would be interesting to test the bounding factors of how far off from a 1PP and how dissimilar to ourselves an avatar can be, while still influencing our perception. Another possible future experiment could replace the bodies in our experiment with non-body-like objects to decide whether the body is especially relevant for perception or if any object presented to the near-personal space affects the perception of objects in far-external space.

A main conclusion from our experiment is that the full-body-illusion in VR potentially works differently than in classical experiments. It may be that perception in VR is effectively different from perception in real life and sensory signals are not processed in the same way. At least, research since the early days of VR has consistently shown that space is being perceived as compressed in IVEs (cf. Renner et al., 2013). This effect was initially explained in terms of technical properties of the HMDs such as a reduced field-of-view and an increased weight, but could not be fully eliminated when using devices that were enhanced accordingly (e.g. Kelly, Cherep, & Siegel, 2017; Willemsen, Colton, Creem-Regehr, & Thompson, 2004). Possibly, virtual objects do not simply inherit the properties of their real-life counterparts and are judged differently in VR. However, there are many possible alternative explanations including that even very low ownership towards the avatar in our study could have still led to a strong perceptual influence on perceived objects' size. The virtual body could still have acted as a self-referential cue, even when presented in a 3PP and it is also possible that the body served as a visual reference drawn from memory (cf. van der Hoort & Ehrsson, 2016). Present experimental setups (Weber et al., 2019; van der Hoort et al., 2011) are not able to rule out these alternative explanations and, thus, future studies using other paradigms will be needed.

The results from the second study (Weber, Weibel, & Mast, 2020a) showed that conditions with higher velocity led to longer subjective time judgments, demonstrating an effect of spatio-visual cues on time perception and confirming previous experiments with moving stimuli (e.g. Brown, 1995; Tomassini et al., 2011). There was a monotonic increase in judged time with each increase in velocity, but we could not replicate the linear trend reported by Brown (1995). Possibly, in more complex situations like driving in a car, subjective time is no longer linearly associated with motion. In the driving simulation experiment by van Rijn (2014), for example, the effect of speed also decreased in very high-velocity conditions.

The findings can be explained by time perception theories. The *Internal clock model* (Treisman, 1963; cf. Grondin, 2010) postulates that nerve impulses are generated in regular intervals and the onset of a stimulus activates an accumulator that keeps track of the elicited pulses. In terms of this model, fast self-motion could lead to more impulses by speeding up the impulse generation process (cf. Brown, 2008). Alternative models postulating a *State-dependent-network* offer similar effect mechanisms. These models assume that time intervals are judged using changes in neural activation patterns (cf. Eagleman, 2008; Grondin, 2010). Higher speed and, thus, an increased change of visual input could lead to stronger changes in activation patterns. There are also newer models which assume that the visual input is directly linked to the rate of change in activation patterns (*Perceptually-driven-network*; Roseboom, Fountas, Nikiforou, Bhowmik, Shanahan, & Seth, 2019). All explanations have in common that time is heavily influenced by the perception of space. Indeed, a series of experiments by Casasanto & Boroditsky (2008) has shown that the subjective duration of a stimulus depends on its spatial properties. Interestingly, the opposite effect might not exist or be weaker: In the same study, the duration did not affect the perception of spatial properties. The authors noted that there are also numerous spatial concepts to express time in language, but not many temporal metaphors for expressing spatial concepts (with notable exceptions such as a place being "a one-hour drive" away). Consequently, it has been proposed that intermodal perceptual relations are not as consistent and as symmetric as the ATOM theory suggests (Walsh, 2003). ATOM assumes a common magnitude system that is acquired or strengthened through experience from actions (e.g. catching a ball or jumping in a pool). It suggests that higher magnitudes in one perceptual domain are connected to higher magnitudes in other domains and vice versa. However, because studies have challenged this proposition (Cai & Connell, 2015; Casasanto & Boroditsky, 2008; Riemer, Shine, & Wolbers, 2018), alternative models have been suggested that allow for asymmetrical intermodal relations. The *Asymmetry hypothesis* assumes that one domain can predominantly influence another domain, depending on the situation (Loeffler, Cañal-Bruland, Schroeger, Tolentino-Castro, & Raab, 2018). For example, studies have demonstrated that the processing of auditory information shows enhanced sensitivity to temporal information but lower sensitivity to spatial information, whereas the reverse is true for visual information processing (O'Connor & Hermelin, 1972; Recanzone, 2009; see Loeffler et al., 2018). Possibly, people rely on the modality with the highest informational value and, often, this modality is vision (cf. Loeffler et al., 2018). If asked to judge an abstract modality such as time, people strongly rely on concrete visual-spatial cues because they offer the highest informational value. A Bayesian framework for a common magnitude system has recently been proposed (Martin, Wiener, & van Wassenhove, 2017). In this framework, the differing dimensional weights are conceptualized with multiple perceptual priors.

My results support the view that cross-modal perceptual relations are not necessarily symmetrical. Over all conditions, time intervals were slightly underestimated and driving speed was also underestimated. According to physics, lower speed and less time result in less covered distance. However, the participants in our experiment overestimated distances. Thus, participants' responses were not consistent with physics. This means that the cross-dimensional relations in our experiment were not caused by a strictly symmetrical system of magnitude but rather showing asymmetrical cross-modal interrelations. The visual system might have influenced the judgments of distance, speed, and time differently, according to the relative importance of visual cues. In terms of a Bayesian model, this would mean that different priors were set to the sensory inputs. For example, distance is related more closely to spatial perception and is highly relevant in everyday life. When humans still relied on their own body as the main mode of transportation, it was essential to know what distance had been covered and how much was still ahead. Overestimation of distances could have protected early humans from undertaking dangerous paths of migration. In contrast, underestimating fast motion could serve the purpose of reducing motion sickness. Thus, the body and its visually experienced motion might be the common metric for evaluating the relative importance of different domains in the overall perception of time and space.

Another result of our study was that the self-reported feelings of presence were not associated with ratings of confidence and accuracy in time judgments. Therefore, similar to the first study, the subjective connectedness to the virtual world did not affect the actual perception of the IVE.

Possibly, there is also an influence of the direction and the acceleration of motion (cf. Grassi & Pavan, 2012; Matthews, 2011). However, in two pilot experiments, where I extended the IVE to include either accelerated motion (see Figure 3) or additional cars moving toward or away from the moving observer (see Figure 4), I could not find such an influence of either of both.

Taken together, the work reported in this chapter showed that time and space are interdependent and that the body serves as an important visuo-spatial reference to our perception of time and space. However, previous models supposing that these cross-modal interrelations are symmetrical and caused by a common system of magnitude need to be revised. Possibly, the visual system, in most cases, offers the highest informational value for our perception of space and time, and serves as the dominant system for time-space-judgments. Since every sensation is fundamentally perceived – and thus, affected – by the body, the real or virtual body might act as the underlying fundamental reference point for the integration of each individual sensation into a coherent state of perception.

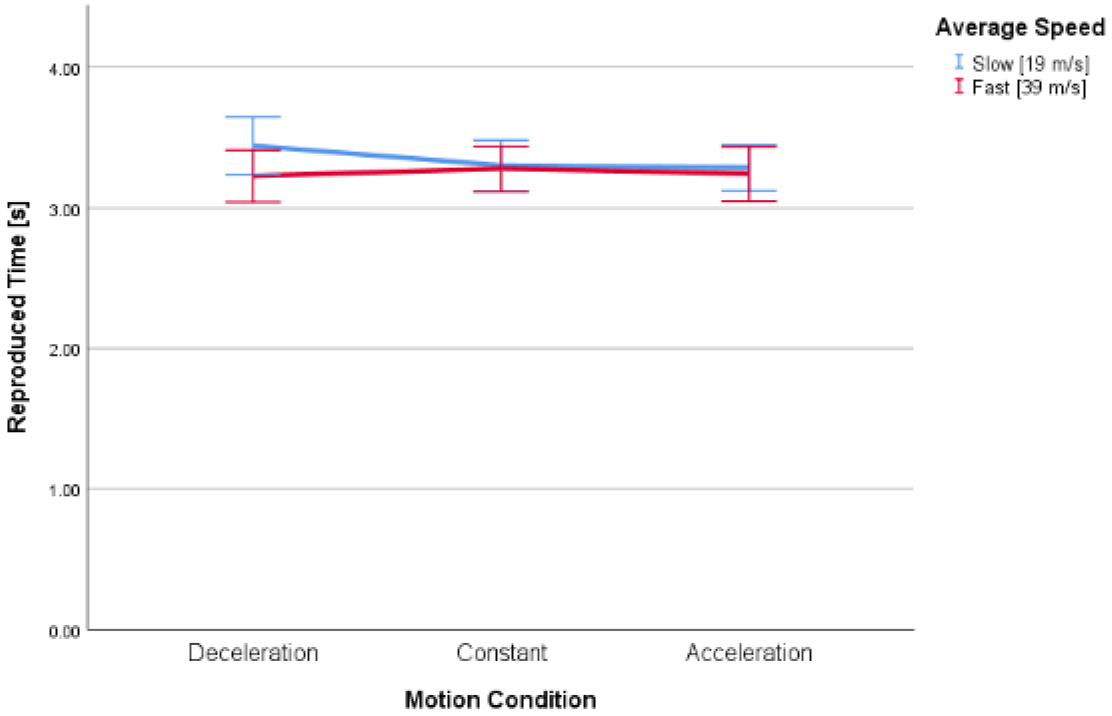

Figure 3. Reproduced time as a function of accelerated or constant motion ($F(2, 50) = 0.40$, $p = .673$) and average speed ($F(1, 25) = 2.66$, $p = .115$)

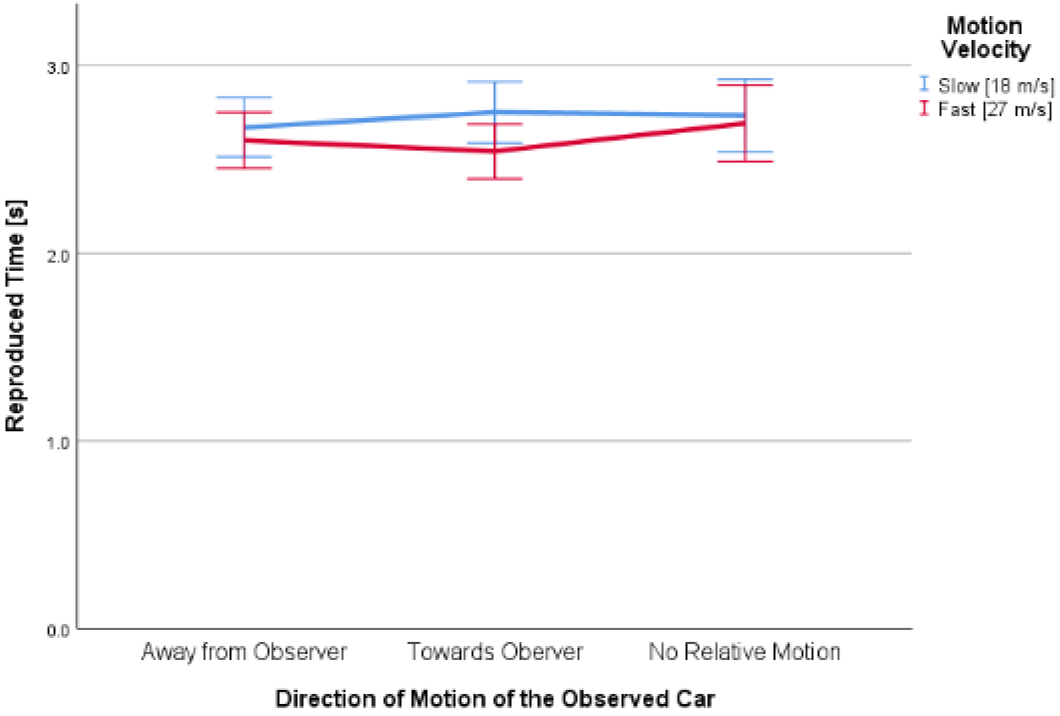

Figure 4. Reproduced time as a function of motion direction (*F*(2, 62) = 0.98, *p* = .381) and motion velocity (*F*(1, 31) = 0.04, *p* = .847)

3. Virtual Reality, Mood, and the Experience of Presence

3.1 Theoretical Background

Coincidentally, at the beginning of my doctoral studies, the first set of modern commercial VR HMDs was released (*Oculus Rift* and *HTC Vive*). These were not the first commercially available VR devices but marked a new beginning. During my studies, I gave several seminar guest speeches about the history of VR, where I stressed the fact that VR is a surprisingly old concept. One of the first depictions of a hypothetical VR device was that of the holographical glasses in the novel *Pygmalion's Spectacles* by Stanley G. Weinbaum (2015; originally published in 1930). The glasses allowed the user to experience very realistic fictional events. The concept of experiencing something as real even though it is not gathered popularity in literary works in the 1950ies with novels and short stories from Ray Bradbury (*The Veldt*; 1972; originally published in 1950), Damon Knight (*Hell's Pavement*; 1955), and Isaac Asimov (e.g. *Dreaming Is a Private Thing*; 1955). In the 1960ies, first VR devices were proposed and developed by pioneer Morton Heilig (*Telesphere Mask* and *Sensorama*; cf. Mazuryk & Gervautz, 1996) and Ivan Sutherland advanced theoretical conceptions of VR in his publication *Ultimate Display* (1965). In the 1980ies, military and civil research led to the first HMDs such as the *Virtual Environment Display System* (VIVED; 1984; cf. Schroeder, 1993) and the Eyephone (VPL Research Inc., 1988; cf. Mazuryk & Gervautz, 1996). Even though the popularity of VR started to rise in the early 1990ies and VR was now used as a tool for academic research (e.g. foundation of the *Presence* journal in 1992), commercial VR devices such as the *Virtual Boy* (Nintendo; 1995) did not lead to much success (Boyer, 2009). Only beginning in the 2010s, new initiatives were started to develop advanced and yet affordable VR displays, an example being the crowdfunding campaign by *Oculus VR* in 2012 (cf. Gleasure & Feller, 2015).

The new technology became a promising tool for research. Whereas early research was mainly concerned with creating collaborative IVEs and enhancing presence in VR (Joslin, Di Giacomo, & Magnenat-Thalmann, 2004; Skarbez, Brooks, & Whitton, 2017), nowadays VR is used in various contexts such as therapy and surgical training (cf. Bohil et al., 2011; Khalifa et al., 2006). In the therapy of phobic disorders, for example, VR allows for controlled structured desensitization of patients and has been shown to be an effective addition or replacement of traditional fear therapy (Fernández-Álvarez et al., 2019; North & North, 2016). There is also a number of advantages of using VR technology in research. It has been argued that VR offers the possibility to create realistic experiences with high external validity and, at the same time, a high degree of experimental control (Bohil et al., 2011; Parsons et al., 2017). Thus, VR is ideal for complex research designs that would otherwise not be feasible in the laboratory. VR also creates opportunities to manipulate variables such as the size of the body or constant self-motion (see Weber et al., 2019; Weber, Weibel, & Mast, 2020a). Variables that are impossible or nearly impossible to manipulate in a real experimental setting.

An important covariate in VR experiments is presence. The term presence is originally derived from *telepresence*, the experience of being present at another, distant, location (Akin, Minsky, Thiel, & Kurtzman, 1983; cf. McMahan, 2003). In the VR literature, presence is usually defined as having a feeling of *being there* in a mediated environment (Steuer, 1992). Lombard and Ditton (1997) instead emphasize the illusion of non-mediation and Waterworth and Waterworth (2001) refer to it as a form of perceptual processing. There are many conceptualizations of presence and it has been applied to various contexts such as watching movies and reading books (examples include: *absorption*; Baños et al., 1999; *arrival*; Kim & Biocca, 1997; *engagement*; Brockmyer et al., 2009; *narrative immersion* (Ryan, 2003); and *transportation*; Green & Brock, 2000). Furthermore, *immersion* is sometimes used interchangeably with presence (Murray, 1997). Slater (e.g. 1999; 2009) consistently referred to immersion as an objective characteristic of a VR system, whereas Witmer & Singer (1998) defined immersion as a psychological state influenced by individual judgments. Studies have demonstrated that immersion (or presence) is affected by personality traits (Weibel, Wissmath, & Mast, 2010; Weibel, Wissmath, & Stricker, 2011). Following a proposal by Lombard and colleagues (2000), immersion is, thus, divided into *perceptual* and *psychological* immersion. In newer literature, (system) immersion is consistently used in the sense of an objective characteristic of the system, whereas presence has replaced the term psychological immersion and reflects an individual appraisal of the system and a subjective feeling of being immersed (i.e. an *immersive response*; Cummings & Bailenson, 2015; Hein, Mai, & Hußmann, 2018; Wu, Gomes, Fernandes, & Wang, 2018).

There are also many competing questionnaires, each focusing on other aspects of the presence experience (for an overview see van Baren & IJsselsteijn, 2004). Furthermore, some studies have attempted to measure presence objectively by means of psychophysical methods (cf. Skarbez et al., 2017; see Section 3.3). Lombard and colleagues (2000), however, claim that self-reports are the most effective method for measuring presence. In all empirical studies included in this doctoral thesis, besides other measures of presence, I used the Pictorial Presence Self-Assessment Manikin questionnaire by Weibel, Schmutz, Pahud, and Wissmath (Presence SAM; 2015). This questionnaire is intended to measure presence intuitively and non-verbally using pictograms representing different extents of being involved and physically present in the medium (graphical representations were inspired by the Self-Assessment Manikin to measure emotion; Lang, 1980). This represents another approach for measuring the subjective impression of presence.

Immersion in the sense of presence has been used to improve spatial perception (Steinicke et al., 2009) as well as to recover from stress and improve mood (Reinecke, Klatt, & Krämer, 2011; Rieger, Frischlich, Wulf, Bente, & Kneer, 2015). In Manuscript III of this thesis, I studied the influence of objective immersion on mood improvement and differentiated it from the influence of individual presence. Furthermore, in Manuscript IV, I reviewed current definitions and measurements of presence and devised a distinction between presence as being there and presence as the perceived realism of a system and argued how this could improve the theoretical understanding of presence and lead to better operationalizations of presence in questionnaires. In the next sections, the theoretical framework, findings, and implications of these two manuscripts are described.

3.2 Mood Enhancement Through the Experience of Presence in Gaming

Immersive experiences are thought to lead to better mood and improved recovery from work-related stress. Reinecke (2009b) referred to the recovery concept from organizational psychology as introduced by Sonnentag and Zijlstra (2006). Therefore, recovery is defined as a renewal of depleted physical and psychological resources after phases of stress and strain. Four aspects of successful recovery were identified by Sonnentag and Fritz (2007): psychological detachment, relaxation, mastery, and control. Reinecke (2009a; b) has argued that immersive experiences are connected to psychological detachment because they stop negative cognitions and prevent episodes of rumination. Feelings of immersion could also contribute to the other aspects of recovery (cf. Klimmt & Hartmann, 2006; please note that “immersion” was often used interchangeably with “presence” in this particular field of research).

Indeed, studies using computer games as an intervention have shown that immersive experiences go along with increased recovery from work-related stress and mood repair. Reinecke and colleagues (2011) showed that involvement was associated with the subjective experience of recovery and recovery itself was connected to higher levels of enjoyment. Involvement is part of the presence experience as defined by Witmer and Singer (1998). Involvement was also related to interactivity – a loosely defined term described by the authors as active participation of the player and control over the game's progress (see Smuts, 2009, for an overview of the definition of interactivity). As such, interactivity shares similarities with (system) immersion. Interactivity – a digital game compared to a mindfulness app condition – was also connected to increased daily recovery experiences in a more recent study (Collins, Cox, Wilcock, & Sethu-Jones, 2019). Additionally, interactivity was shown to be positively associated with mood repair (Rieger et al.; 2015). Furthermore, two studies by Bowman and Tamborini (2012; 2015) have shown that task demand of a computer game is linked to mood repair. The authors stated that their definition of task demand is similar to interactivity. Improving mood is a more immediate effect of gaming and is thought to result from the desire to avert negative mood while at the same time maximizing positive mood by selecting appropriate media (cf. *Mood management*; Bryant & Zillmann, 1984; Zillman, 2000). The goal is to achieve an optimal state of mood (Bowman & Tamborini, 2012). This can be achieved by either reducing negative emotions or by increasing positive emotions in the sense of building up positive resources as a means of coping with new situations (cf. *Conservation of resources theory*; Hobfoll, 1989).

Interactivity and task demand are conceptually related to immersion since immersion is also thought to depend on possible interactions with the system (McMahan, 2003). However, there are no studies that specifically manipulated immersion, nor any study that investigated the role of individually experienced presence in computer games. Therefore, my colleagues and I studied both immersion and presence in the context of computer games (Weber, Mast, & Weibel, 2020; see Manuscript III in the appendix). Immersion was manipulated by means of a computer game varying in the degree of expected immersion between conditions. The low immersion condition involved watching someone else play the game, the medium immersion condition involved playing the game on the desktop computer, and the high immersion condition involved playing the game in VR. Thus, we were the first to implement a VR condition to study the effect of mood repair in computer games. This is important because VR is increasing in popularity and is used as a tool for gaming by millions of players (ReportLinker, 2019) and the illusion of presence is especially relevant for experiencing VR (cf. Steuer, 1992). A few studies have indicated that presence might indeed be beneficial for reducing stress (e.g. de Kort, Meijnders, Sponselee, & IJsselsteijn, 2006; Valtchanov & Ellard, 2010). However, these studies involved a relaxation task in a VR nature setting that was specifically designed to improve mood and the distinct contributions of system immersion and individual presence were not explored. Therefore, we also measured presence with the Presence SAM questionnaire and connected it to mood changes after the low, medium, or high immersion gaming activity.

Our results showed that both active gaming conditions improved positive emotions, whereas the low immersion video condition did not lead to changes in positive emotions. All conditions were able to decrease negative emotions. Using a moderation analysis, we could show that – in addition to the immersion of the condition – self-reported presence was associated with increased positive emotions in the VR condition. In a mediation analysis, we could furthermore show that presence improved positive emotions indirectly through enhancing the enjoyment of the activity – again in addition to the effect of immersion. These findings were interpreted as confirming previous results and extending the beneficial effect of immersive experiences in games on mood to instances of presence and the use of VR gaming. Further discussion of the results is provided in Section 3.4.

3.3 Defining Presence with Being There and Perceived Realism

Presence is sometimes used as a quality measurement for IVEs. Game developers aim to increase the immersion (i.e. the potential for eliciting presence) of their environments to enhance their favorability and to bind players to the game. A strain of research attempted to enhance presence in an IVE by using a *transitional environment*. Such an environment typically consists of a virtual replica of the room in which the experiment takes place. Participants are supposed to familiarize themselves with the properties of the VR display, explore the qualities of the virtually replicated surroundings and strengthen the feeling of being in the virtual world. Afterward, they set foot in a new IVE by walking through the door or a portal in the wall of the transitional environment. In an arbitrary task in this new environment, they should experience improved feelings of presence and show better performances in terms of judging distances and sizes of the virtual world compared to when directly entering the targeted IVE. This proposition was empirically supported in a series of experiments (Steinicke et al., 2009; Steinicke, Bruder, Hinrichs, Steed, & Gerlach, 2009). In a pilot study, I replicated this procedure by using a virtual replica of the laboratory room and a consecutive simple searching task in a large closed space (a Japanese dojo; see Figure 5) that could be accessed through the door of the laboratory room. In reference to a study by Slater, Steed, McCarthy, and Marinelli (1998), I referred to the transitional environment as the *ante room*. There were conditions with and without haptic exploration of the ante room and a control condition without a transitional environment. The results indicated that the ante room improved presence in the following task but there was no additional effect of haptic exploration (see Figure 6).

Figure 5. The virtual environment used for the searching task (right panel). The small upper panel on the left shows the ante room, the small lower panel on the left shows the real laboratory room

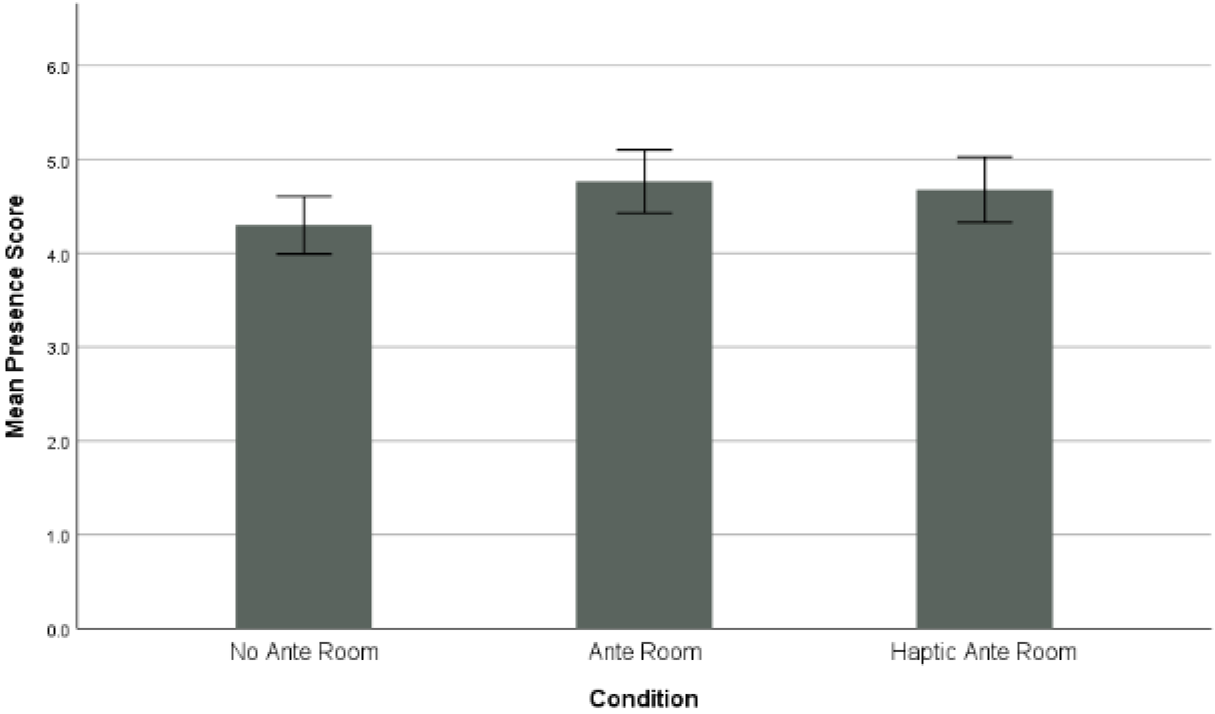

Figure 6. Main effect of the condition on presence scores in the searching task environment as indicated by the Presence Questionnaire (Witmer & Singer, 1998; *F*(2, 42) = 3.39, *p* = .043). Note: the subjective rating of cyber sickness on a scale from 0 to 20 was included as a covariate because a few participants reported strong symptoms of cyber sickness (not shown in the figure)

Even though achieving a high level of presence is a key desire for VR research and presence is probably assessed in a majority of VR experiments, there is still much confusion about the term. One source of confusion is that, in colloquial speech, presence is often referred to as immersion. The origin of the term *immersion* is the idea to dissolve in a virtual world like a fluid poured into a pool and be surrounded by the water (cf. Murray, 1997). However, as I have discussed in Section 3.1, immersion is also used more specifically to refer to the characteristics of the IVE and its abilities to evoke immersive experiences. Presence, on the other hand, is derived from *telepresence* and was predominantly used to refer to the individual immersive experiences in VR (see Section 3.1).

Another source of confusion is that there is much disagreement over the best way to assess presence. Some authors suggested that physiological and behavioral methods would be a valuable addition to self-reports. However, no consensus about the correct measure was reached and there are open questions about the validity of the proposed methods. As an example, responses to threatening stimuli were surmised to indicate the level of presence (Sheridan, 1992). Another example are postural responses to experiences of virtual motion as proposed in a study by Freeman, Avons, Meddis, Pearson, and IJsselsteijn (2000). However, this study found no significant relationship between self-reported presence and postural responses.

One problem in measuring presence with physiological and behavioral proxy variables is that these variables typically rely on the allocation of attention to the virtual world. In an opinion article (Weber, Weibel, & Mast, 2020b; Manuscript IV in the appendix), together with my colleagues, I argued that most common definitions of presence are linked to attention and that *being there* is predominantly used to describe presence. However, we think that this focus on being there is problematic, especially with the advanced VR devices of today: If one wears an HMD that blocks external visual and auditory signals and a significant part of the visual field is occupied by the virtual world, one effectively *is there*. Therefore, by definition, presence should be very high and there would be not much of a difference between different IVEs. This is clearly not the case since a simple IVE involving a poorly designed world (e.g. simple geometrical figures in empty space) is usually experienced quite differently than a carefully designed, realistic IVE that involves a coherent story, authentic characters and provides opportunities for exploring and challenging oneself (e.g. *Lone Echo* from the *Ready at Dawn* studio, a highly appraised VR game). Thus, we propose that perceived realism is the second pillar of the presence concept besides the feeling of being there. Together these aspects constitute the presence experience. Perceived realism is defined in our manuscript as an individual judgment about the degree of realism of the IVE, whereby realism encompasses the technical fidelity of the system (e.g. resolution, tracking quality), the perceptual quality of the IVE (e.g. shades, textures), and the coherence of the story (e.g. is it plausible, are there inconsistencies?). Thus, it is a comprehensive judgment involving different aspects and is very much depending on individual predispositions like one's *immersive tendency* (Jerome & Witmer, 2002), the situational *suspension-of-disbelief* (Schaper, 1978), and personal preferences. Even though realism was part of previous conceptualizations (e.g. Alexander, Brunyé, Sidman, & Weil, 2005; Baños et al., 2000; Stoffregen, Bardy, Smart, & Pagulayan, 2003), it received little attention in the most influential theories of presence and is often regarded merely as a beneficial factor for the feeling of being there (e.g. Lombard & Ditton, 1997). Additionally, questionnaires often do not properly distinguish between attentional aspects and realism judgments and include questions that are confusing for the user (cf. Weber, Weibel, & Mast, 2020b). Therefore, deriving a new concept of presence that differentiates between attentional allocation (being there) and judgments about the plausibility of the IVE (perceived realism) could help develop better operationalizations of presence in questionnaires. Further conclusions are provided in the next section.

3.4 Discussion

Presence was an important variable in all manuscripts included in this thesis. In the study on spatial perception of virtual objects, the level of presence varied between the ownership and disownership conditions (Weber et al., 2019; Manuscript I). This suggests that experiencing the illusion of virtual body ownership improves the sensation of feeling present in an IVE. This is a finding also reported in other studies (Lok, Naik, Whitton, & Brooks, 2003; Waltemate, Gall, Roth, Botsch, & Latoschik, 2018). However, along with ownership, the level of presence was not associated with different size judgments of objects. Thus, presence in our study was not associated with better performance in a perceptual task. Interestingly, in another study (Weber, Weibel, & Mast, 2020a; Manuscript II), we found that presence was also not associated with better performance in time judgments. Thus, surprisingly, I could not find any relation between presence and the perception of space and time in IVEs. This conflicts with other studies which showed that presence improves distance perception (e.g. Ahmed, Cohen, Binder, & Fennema, 2010; Ries, Interrante, Anderson, & Lindquist, 2006). Possibly, the contribution of presence depends on context: In the study assessing subjective time, we argued that time intervals may not have been perceived as being based on the virtual world per se and that time was judged independently from the feeling of being present. In the study assessing object sizes, the body might have been the dominant perceptual reference, overshadowing a possible contribution of presence. However, as these are only speculations, more research is needed for assessing bounding factors for the contribution of presence on sensory perception.

In contrast to these results, presence was an important intervening variable in feelings of mood (Weber, Mast, & Weibel, 2020; Manuscript III). We could show that presence leads to more enjoyment of a gaming activity and this in turn enhances positive emotions. Presence was especially important in the VR condition, showing an additional effect to immersion. Possibly, when being surrounded by an IVE (by using an HMD), having a feeling of presence is more important than in situations where there is a gap between the user and the screen (desktop and video conditions). To develop this thought further, the perceptual qualities of the IVE may have been more relevant in the VR condition since one already experiences the feeling of being there. Being present in an environment that subjectively looks realistic and convincing may be a strong boost for the individual immersive experience and lead to improved positive emotions. Building up positive emotions is a way of creating additional resources for coping with future events. However, one limitation of our study was that negative emotions did not decrease further with higher immersion or presence. This contrasts with other studies (Chen & Raney, 2009; Rieger et al., 2015) and may show that the choice of the game and the way of measuring mood is crucial for determining the intervention potential of computer games. Along with previous work, our results suggest that active gaming is an effective coping strategy for reducing negative thoughts, building up resources and recovering from stress and strain. As such, it could be used as a clinical tool in stress therapy. In contrast, our results show that watching others play may not be as effective as active gaming, possibly because of a lack of competition and control.

Presence may affect how VR experiments are perceived and how they affect behavior, although the work shown here has demonstrated instances where presence did not influence perception in VR. It is vital to create and establish valid and reliable measures of presence. We have shown a distinction of presence into being there and perceived realism that could improve the understanding of presence in VR and lead to better operationalizations of presence. According to the medium used (e.g. VR or desktop), either being there or perceived realism should be the focus of measurement in order to separate media effects resulting from attentional allocation and the subjective judgment of realism. It is conceivable, for example, that the subjective realism of an immersive IVE is especially important for sensory perception. Thus, further research should investigate the individual contributions of being there and perceived realism on various media effects.

Taken together, our results strongly suggest that VR is a valuable research tool and can be used to design experiments that are either not feasible or have significant disadvantages in a traditional setting. This is reflected in the use of unaccelerated motion and the use of unnaturally tall or short self-representations as well as the control over environmental variables such as attentional demand and visual surroundings. However, our results also hint at possible caveats in transferring findings from traditional experiments into VR settings. This may apply to certain situations, namely when using virtual self-representations in perception studies. It will be an interesting task in the future to pinpoint the specific conditions which are responsible for this discrepancy.

4. General Conclusion

The studies presented in this doctoral thesis demonstrated an interrelation between time and space and indicated that the body serves as a spatial reference system for the perception of both. The results from my experiments implicate that the own self and its characteristics in terms of overall size and self-displacement offer high informational value for spatial perception. Einstein wrote that "in the case of words such as "place" or "space," whose relation with psychological experience is less direct, there exists a far-reaching uncertainty of interpretation" (foreword in Jammer, 1954, p. xii). Because we might rely on a common psychological system of space in order to make perceptual judgments, the self and its characteristics serve not only as a spatial cue but as a fundamental reference to all our perception and reduce our uncertainty about space. The own self is defining our relationship with the world similar to the frame of a painting encompassing the work of art. Since the body and its sensory organs are the gateways to every possible sensation, it seems plausible that the entirety of our perception is processed according to its relevance to our body. As such, perceiving high levels of self-displacement as longer in duration might, for example, serve the purpose of preparing action in life-threatening situations such as car accidents. Another idea is that the sizes of objects are judged in reference to our body and, thus, according to their potential hazard. As previously suggested, the mappings of different perceptual domains show asymmetrical properties and, based on context or informational value, different weights can be placed on the sensory input systems. Presence on the other hand, might determine the extent to which a virtual world is attended and enjoyed, but might not be as important for our perception in IVEs as previously thought.

Furthermore, the results of this thesis show that presence supports the emotional processing of negative mood states, but no benefit of experiencing presence in judging the size of objects or estimating intervals of time could be demonstrated. Additionally, the results showed that watching others play might not be a viable strategy for mood regulation.

There is a wide range of practical implications of these findings. My work shows important caveats in using VR for perceptual training or telesurgery. The failure of demonstrating the own-body-size effect in VR indicates that caution is advised when transferring the findings of traditional studies into VR settings. At least, users seem to engage in flexible relationships with virtual self-representations. This also affects VR treatments of body disorders such as anorexia nervosa or muscle dysmorphia, where distortions of virtual bodies are used to change self-referential cognition. My results indicate that avatars need not be in close physical space in order to affect basic perceptual judgments. Furthermore, interventions to reduce racial bias by embodying users in unfamiliar bodies need to be evaluated in terms of transferability to the external world. Similarly, my results show that caution is needed when planning interventions for reducing the subjective duration of unpleasant experiences. For example, VR racing games might not be suitable for reducing the subjective duration of dental operations because fast motion of virtual surroundings leads to a lengthened impression of time. This has also implications for real-life driving, as one might underestimate time when driving with high speeds and, hence, also underestimate one's fatigue.

Another conclusion drawn from the results in this thesis is that – despite showing deviances from laboratory studies in terms of the own-body-size effect – VR itself is a promising tool for investigating variables that remain otherwise impossible to study. Users are able to form ownership feelings towards unnaturally tall and short avatars. Additionally, non-accelerated motion was well tolerated by participants. My findings also indicate possible uses of virtual replicas of laboratory rooms to design perceptual experiments and to provide gradual transitions to VR experiences. Lastly, my results offer insights into possible future approaches to protect against willfully induced perceptual illusions in VR that could become more common once VR will be widely used by the general public. I suspect that manipulations of one's virtual self-representation could be used in the future to affect our perceptual judgment of the virtual world. I advise researchers to continue investigating the relationship between the body and perception in order to deepen our understanding and take measures against willful manipulation. As the ancient Greek philosopher Democritus said:

"We know nothing accurately in reality, but [only] as it changes according to the bodily condition, and the constitution of those things that flow upon [the body] and impinge upon it" (Freeman, 1948, p. 142).

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Appendix

The following pages contain the four manuscripts referenced in this thesis. In case of published work, the last version before publication is provided.

Manuscript I:

Weber, S., Mast, F. W., & Weibel, D. (2019). Body size illusions influence perceived size of objects: a validation of previous research in virtual reality. *Virtual Reality*, 1-13. https://doi.org/10.1007/s10055-019-00402-z

Body Size Illusions Influence Perceived Size of Objects: A Validation of Previous Research in Virtual Reality

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Abstract

Previous research indicates that the size of the own body affects the judgment of objects' size, depending on the amount of subjective ownership towards the body (Van der Hoort, Guterstam, & Ehrsson, 2011). We are the first to transfer this own-body-size effect into a virtual environment. In a series of three experiments, participants (*N* = 68) had to embody small, medium, and large avatars and judge the size of objects. Body ownership was manipulated using synchronous and asynchronous touch. We also included a new paradigm with an additional change of perspective to induce stronger ownership (Experiment 2). Additionally, we assessed whether the visibility of the body during the judgment phase influenced the results (Experiment 3). In all three experiments, we found an overestimation in a small and an underestimation in a large body compared to a medium body. However, size estimation did not depend on the degree of ownership despite clear differences in self-reported ownership. Our results show that a virtual reality scenario does not require a visuotactile manipulation of ownership in order to evoke the own-body-size effect. Our validation of the effect in a virtual setting may be helpful for the design of clinical applications.

Keywords: own-body-size effect, ownership, virtual reality, size perception, embodiment, avatars

1. Introduction

The size of our body serves as a reference frame to the perception of our world (Harris et al., 2015; Proffitt & Linkenauger, 2013). The influence of the body on mental processes is generally referred to as *embodied cognition* (Wilson, 2002). In popular culture the impact of shrinking humans to the size of insects has been considered numerous times (e.g. in the movie *Honey, I Shrunk the Kids* and its sequels; Cox, & Johnston, 1999). The question whether such a transformation of the physical size of the own body would affect the perception of the environment was investigated in a series of pioneering experiments by Van der Hoort and colleagues (Van der Hoort, Guterstam, & Ehrsson, 2011; Van der Hoort & Ehrsson, 2014; 2016). Using an arrangement of cameras capturing artificial bodies and projecting the video feed onto participant's goggles, the participants had the feeling of being inside the body of dolls of various sizes (i.e. they had a feeling of body ownership; cf. De Vignemont, 2011). The sensation of ownership resulted in an altered estimation of object sizes. In the present study, we provide a first-time replication of these experiments in a virtual reality (VR) setup. In a series of three experiments, we recreated the original procedures and transferred them into a virtual environment. We formulated hypotheses based on the original findings and aimed at reproducing the results. In the following, we will discuss the original experiments in more detail and point out how a VR adaptation extends the knowledge about embodiment and body ownership in virtual environments.

In the original experiments, having ownership of bodies with different sizes changed the perception of box-shaped objects: In comparison to ownership of a normal-sized body, ownership of a small body resulted in an overestimation of the size of objects and, conversely, ownership of a large body resulted in an underestimation (Van der Hoort et al., 2011). This tendency of the perceptual system to regress towards the middle is referred to as *contraction bias* (Poulton, 1989). The contraction bias suggests a tendency to overestimate small and underestimate large magnitudes when there is a possibility to compare both to an intermediate reference magnitude. In the experimental setup, cameras captured the body of a doll lying on a mattress from a first person perspective (1PP) and transmitted the video feed to a participant wearing a head-mounted display (HMD). Using this setup, the participant had the view of the doll as it was his or her own body, except for the size of the body, which varied between 30 cm and 400 cm. Van der Hoort et al. (2011) used synchronous and asynchronous stroking of the participant's body and the doll's body in order to manipulate the level of experienced ownership (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). When applying this manipulation in combination with doll bodies of different sizes, the magnitude of the contraction bias was more pronounced in the synchronous condition (Van der Hoort et al., 2011). This was referred to as the *own-body-size effect*.

Van der Hoort et al. (2011) point out that the own-body-size effect is of great value in the context of tele-robotics and VR. They provide the following example of the benefit of simulated bodies: "a surgeon could experience a full-body illusion of "being" a microrobot performing surgery inside the patient's body". This type of setting could be implemented in VR. However, although Van der Hoort and colleagues explicitly point out that their findings are important for VR, they themselves did not use this technology. Therefore, it is a crucial question whether the own-body-size effect also applies to an immersive virtual environment (IVE). Does object perception in VR follow the same mechanisms as in real life? Previous studies suggested that perception in VR indeed differs from perception in real life. One example is the underestimation of room size and distances in VR (cf. Loomis & Knapp, 2003; Renner, Velichkovsky, &

Helmert, 2013). Additionally, the quality of current HMDs does not match the abilities of the human perceptual system (e.g. image resolution, frame rate, etc.). This limits the extent to which we can transfer results about human perception into VR. Moreover, there is also a reduced quality of depth cues, concerning for example shadows, textures, and occlusion of objects. Thus, it is not clear whether it is possible to replicate the own-body-size effect in a virtual setting and if the same rules for ownership and perception apply. To address these questions, we investigated the own-body-size effect in an IVE. We used the same paradigm as Van der Hoort and colleagues but with avatars instead of dolls and virtual objects instead of real objects. Our main goal was to assess the impact of an ownership manipulation on the own-body-size effect in an IVE.

There is still scarce knowledge about the use of VR technology and its influence on body ownership with the only exception being two studies. One study demonstrated an effect of the size of one's virtual hands on the perceived size of objects (Linkenauger, Leyrer, Bülthoff, & Mohler, 2013). A contraction bias for objects was observed only when one's own hands were altered but not the hands of an avatar on the other side of the table. However, there was no assessment of ownership of the two perspective conditions. In the second VR study, Banakou, Groten, and Slater (2013) used mappings of body movements to embody participants into a virtual child or small adult body. They observed a general overestimation of the size of box-shaped objects for both bodies compared to a baseline condition where participants made judgments from the same perspective but without a visible body. There was no such difference during asynchronous mappings of the participant's movements. However, it was not the size but the implied age of the body that was supposed to be responsible for the size estimation bias. Furthermore, it is unclear in what way the advantage of having a body in the IVE could have contributed to these findings (cf. Ries, Interrante, Kaeding, & Anderson, 2008; Mohler, Creem-Regehr, Thompson, & Bülthoff, 2010).

Although these studies demonstrate an effect of body size on judgments of object size, in both cases the setup was significantly modified when compared to the original studies by Van Hoort and colleagues. In the original paradigm, the size of the whole body affected size judgments in the far extra-personal space. Body size varied systematically from very small to very large bodies and each condition was implemented with the same perspective. It is still unclear whether this original paradigm can be transferred successfully to an IVE. As mentioned above, the authors already discussed the importance for such a transfer in terms of tele-robotics. Besides that, a successful replication would confirm embodiment theory in an IVE by establishing a proposed mechanism in which the body acts as a reference frame for perception. This could also help to explain the so-called Proteus effects (Yee & Bailenson, 2007), according to which a transformed self-representation in an IVE influences the user's behavior (e.g. his or her confidence in a negotiation task). As such, a successful replication would have implications for the design of virtual environments such as determining optimal body size transformations (cf. IJsselsteijn, de Kort, & Haans, 2006). It can also help to clarify whether future studies on embodiment can be transferred into IVEs. In embodiment research, IVEs have a number of benefits, including the possibility of flexibly altering one's own body and inducing ownership of exotic external bodies (e.g. animals). If basic external perception is influenced by virtual bodies, they can also have strong impacts on the perception of the own body. This has implications for the development of treatments for body image distortions such as *anorexia nervosa*. VR is already being used as a tool for investigating and treating eating disorders (Ferrer-García, & Gutiérrez-Maldonado, 2012). Future applications could involve body transformations to restore a healthy body image. Other potential areas of interest for body transformations are the treatment of phantom limb pain (Murray et al., 2007), body integrity identity disorder (First, 2005), virtual training methods for motor tasks in the context of surgery or sports (Gurusamy, Aggarwal, Palanivelu, & Davidson, 2008), and self-identification in computer games (Klevjer, 2012).

To assess the own-body size effect in an IVE, we conducted three experiments, which we designed as close as possible to the original paradigm of Van der Hoort and colleagues. Thus, we created a virtual version of our laboratory room and placed avatars on a virtual mattress. The size of the avatar bodies varied in size from 30 cm to 350 cm. All participants experienced three different sized avatars during the experiments: a small, a medium, and a large avatar. The participants were lying on an identical mattress in the real room and experienced the virtual room via an HMD. The potential magnitude of ownership feelings toward the avatar was manipulated using synchronous and asynchronous visuotactile stimulation that was applied to the real and virtual body. In the asynchronous condition of the second and third experiment, also the view was changed to a third person perspective (3PP) to further disrupt ownership feelings. In all three experiments, box-shaped objects were then presented in the far extra-personal space and participants had to judge their size. Whereas the avatar body was still visible in the first and second experiments during this judgment phase, in the third experiment we removed the body to assess whether the body acted as a visual reference cue.

In line with the findings of Van der Hoort and colleagues, we postulated the following hypotheses:

Hypothesis 1: The subjectively experienced amount of ownership is higher in the synchronous condition compared to the asynchronous condition.

Hypothesis 2: The size of objects during ownership of a small body is overestimated and the size of objects during ownership of a large body is underestimated with respect to the medium sized body (contraction bias).

Hypothesis 3: The contraction effect in the size estimation task is stronger in the synchronous condition compared to the asynchronous condition (own-body-size effect).

A successful manipulation of ownership is important for replicating the own-body-size effect (Hypothesis 1). Support for Hypothesis 2 would indicate that there is an effect of the size of the virtual body on the estimation of object size. However, in order to fully replicate the own-body-size effect, there should only be a contraction bias if there is a sufficient amount of ownership. Assuming that the manipulation of ownership is successful, the contraction bias is expected in the synchronous condition only (Hypothesis 3).

2. General Method

2.1 Participants

Overall, 68 healthy adult participants were recruited (53 females and 15 males, age: *M* = 22.3 years, *SD* = 3.8 years). The numbers for each experiment were as follows: Experiment 1: 22 (18 females, 4 males, *M* = 22.6 years, *SD* = 4.6 years); Experiment 2: 26 (20 females, 6 males, *M* = 22.5 years, *SD* = 3.6 years); Experiment 3: 20 (15 females, 5 males, *M* = 21.7 years, *SD* = 3.1 years). All participants had normal or corrected to normal vision.

Participants received credit points as an exchange for their participation. All participants provided written informed consent to take part in this study and were treated in accordance with the protocol approved by the Ethical Committee of the Faculty of Human Sciences of the University of Bern and with the Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants were debriefed after the experiment.

2.2 Design and Material

2.2.1 Design. There were a total of six conditions that every participant had to undergo in a within-subjects design. This resulted from a 3-by-2 design with three different bodies (*small*, *medium,* and *large*; see Figure 1) and two visuotactile stimulation conditions (*synchronous* and *asynchronous touch*). Conditions were presented in a random order. The dependent variables were ratings of presence and ownership and size judgments of the objects.

2.2.2 Virtual room and equipment. The experiment took place in a laboratory room with the dimensions 635 cm (length), 501 cm (width), and 277 cm (height). We created a virtual replica of the room with the exact same configuration and the exact same dimensions, including all tables, chairs, cabinets and doors (see Figure 2). In a corner of the room lay a mattress, which was also replicated in the IVE. Participants wore an Oculus Development Kit 2 HMD (Oculus VR, LLC., Irvine, United States) that was connected to a laptop computer (Intel i7 processor, 16 GB RAM and NVidia GeForce GTX 970M graphics card). The computer was also replicated and shown in the IVE. Its size was always scaled in accordance with the respective virtual body. The reason for this was that participants had to use the trackpad of the computer for making size judgments. Therefore, their sense of touch had to match their visual input in order not to disrupt the illusion. We used neutral looking avatars that were matched for gender (WorldViz LLC., Santa Barbara, United States). Due to limitations of the room's available space, the size of the *large avatar* was set to 350 cm instead of 400 cm as in the study by Van der Hoort et al. (2011). However, as in the study of Van der Hoort et al., the size of the *small avatar* was 30 cm and the size of the *medium sized avatar* was 180 cm. The participants were set to the same position in the room as the respective avatar. Real and virtual bodies were also both aligned perpendicular to the short wall of the room. Because the size of the avatar also affected the eye height, the virtual mattress was elevated or lowered to adjust for the difference. For the size estimation task, three white box-shaped objects were used. Their edge lengths were 10 cm, 20 cm, and 40 cm, in all conditions. They were presented in a random order in front of the participants at a fixed distance of approximately 450 cm from the position of the participants' eyes. A few other objects such as tables and chairs were also visible and served as familiar size cues (identical in the real and the virtual room). Other potential size cues, such as binocular disparity and eye convergence, were also implemented in the virtual room and remained constant across all conditions. However, due to technical limitations, it is currently not possible to alter the accommodation of the pupil in an HMD. Therefore, accommodation cues in the IVE did not conform to the real world but remained constant in all conditions. The HMD was set to allow only rotational but not translational movement to prevent participants from changing the perspective. The field of view (FOV) was set to 90 degrees.

2.2.3 Measurements: To assess the subjective ownership of the participants, we developed a small questionnaire that is composed of seven statements used by Van der Hoort et al. (2011) and Piryankova et al. (2014). An example item is “during the experiment, there were times when I felt as if the avatar's body was my body”. Answers were given on a Likert scale ranging from *fully disagree* (1) to *fully agree* (7). Similar questionnaires were used in previous studies about ownership (e.g. Dobricki, & de la Rosa, 2013; Normand, Giannopoulos, Spanlang, & Slater, 2011). Furthermore, the internal structure of these questionnaires has been assessed in psychometric studies (Longo & Haggard, 2012; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008). In our study, the internal consistency of the ownership questionnaire was good (Cronbach's Alpha = 0.81). The questionnaire can be found in the Appendix. All questions were presented in German.

Furthermore, we assessed levels of presence using the Pictorial Presence SAM questionnaire (Weibel, Schmutz, Pahud, & Wissmath, 2015), which consists of five pictograms each depicting different levels of presence. For each sequence, one of the pictograms that best fits the participants' subjective experience has to be chosen. The answer is then transformed into a number from one to five.

The third dependent measure was the subjective rating of the objects' size. Participants gave their judgments by choosing a numeric value from a list. The list contained values from 5 to 60 cm in steps of 5 cm.

2.3 Procedure

At the beginning of the experiment, the use of the HMD and the purpose of the virtual room were explained to the participants. They were then asked to lie down on the mattress and put on the HMD. There was a short phase in which the participants could familiarize themselves with the virtual room.

Next, the visuotactile stimulation was administered. This procedure differed between Experiment 1 and Experiments 2 and 3. It is described in the respective sections below.

After the stimulation phase, the three test objects were successively presented to the participants who had to judge their size by indicating the edge length via direct numerical assessment (chosen from a list of possible values; see Measurements section above). Judgments were made using the trackpad of the nearby laptop computer. Participants did not need to remove the HMD in order to give their judgments. This part of the experiment differed between Experiments 1 and 2 (the virtual body was still visible) and Experiment 3 (the virtual body was invisible). At the end of a trial, they were asked to remove the HMD and complete the ownership and presence questionnaires on the computer. The whole procedure was repeated for each of the six conditions. An overview of the differences between the three experiments can be found in Table 1.

3. Experiment 1

3.1 Method

The general structure of the experiment is described above in the Procedure section. For the visuotactile stimulation, we used a rod to touch participants 20 times each on the lower left leg, the right thigh, and the stomach. This took about one and a half minute. There was also a virtual rod that touched the virtual body on the same spots. Each virtual touch was started by a button press. This allowed the examiner to apply touches either synchronously or asynchronously to the participant and the virtual body. For the asynchronous touch in Experiment 1, the examiner randomly delayed either the press of the button or the touch of the rod on the real body by approximately 1 s. The size of the rod remained constant in respect to the size of the virtual body.

3.2 Results

3.2.1 Ownership and presence. To test whether the visuotactile stimulation had worked as intended, we analyzed questionnaire data from the ownership and presence questionnaires. An overview of descriptive statistics can be found in Table 2. A two-way repeated measures analysis of variance (ANOVA) with *stimulation* and *body size* as factors indicated that ownership was higher in the *synchronous* condition compared to the *asynchronous* condition (main effect of stimulation), $F(1, 18) = 14.70$, $p = .001$, $\eta_p^2 = 0.45$. This was not true, however, for control questions, $F(1, 18) = 0.07$, $p = .796$, $\eta_p^2 = 0.00$, indicating that the effect of stimulation was limited to questions about ownership and that there was not a general tendency to agree to the statements. In both analyses, the interaction and the main effect of body size were not significant (all $p > .05$). Results for presence ratings were similar: There was only a main effect of stimulation, $F(1, 18) = 6.39$, $p = .021$, $\eta_p^2 = 0.26$. All other effects were not significant (all $p > .05$). These results indicate that the manipulation of ownership was successful (Hypothesis 1): synchronous stimulation evoked higher levels of subjective ownership and presence. Additionally, ownership and presence did not depend on the size of the body.

In addition to the ownership and presence questionnaires, we also asked participants about their impression of the room's size and their judgments about their perceived age in all three avatar bodies. There was a linear effect of body size concerning the questions "I felt younger than I actually am" ($F(1, 18) = 22.07$, $p < .001$, $\eta_p^2 = 0.55$) and "I felt older than I actually am" ($F(1, 18) = 9.76$, $p = .006$, $\eta_p^2 = 0.35$), suggesting that participants felt younger in the small body and older in the large body. Similarly, there were linear effects of body size on the perceived size of the room: in the small body, the room appeared bigger than in the large body, $F(1, 18) = 40.82$, $p < .001$, $\eta_p^2 = 0.69$, and in the large body, the room appeared smaller than in the small body, $F(1, 18) = 23.92$, $p < .001$, $\eta_p^2 = 0.57$.

3.2.2 Size judgments. To test Hypotheses 2 and 3, we computed a two-way repeated measures ANOVA with *body size* and *stimulation* as factors and the difference between real size and estimated size of the test objects as dependent measure. According to Hypothesis 2, we expected a main effect of body size, whereas Hypothesis 3 required a significant interaction between body size and stimulation. We found a significant main effect of body size, $F(1.35, 24.29) = 11.41$, $p = .001$, $\eta_p^2 = 0.39$ (degrees of freedom were adjusted using Greenhouse-Geisser correction). There was a linear trend ($p = .002$) for body size, suggesting that there was an overestimation of size in the *small* body and an underestimation of size in the *large* body compared to judgments in the *medium* body (Figure 3). Therefore, Hypothesis 2 is supported by our data: There was a contraction bias. However, there was no interaction between body size and stimulation, $F(2, 36) = 1.07$, $p = .355$, $\eta_p^2 = 0.06$, and the main effect of stimulation was also not significant, $F(1, 18) = 1.05$, $p = .318$, $\eta_p^2 = 0.06$, see Figure 3. Thus, Hypothesis 3 (own-body-size effect) received no empirical support.

3.3 Discussion

We could successfully manipulate ownership according to the results in the questionnaires. We observed an effect of body size on the judgment of objects' size. Thus, we were able to reproduce the contraction bias. Nevertheless, we could not fully support the own-body-size effect as reported by Van Der Hoort and colleagues: there was no interaction between body size and stimulation. Two possible explanations need to be considered: 1) ownership *is not* crucial for the contraction bias and the mere presence of a virtual body at or near the location of the participant's real body accounts for the bias (explanation 1); or 2) ownership *is* crucial for the contraction bias (i.e. there is an own-body-size effect) but there was sufficiently high ownership in both the synchronous and asynchronous conditions in Experiment 1 so that the contraction bias was present in both conditions (explanation 2).

Explanation 1 would contradict results by Van Der Hoort et al. (2011), Van Der Hoort & Ehrsson (2014; 2016), Linkenauger et al. (2013), and Banakou et al. (2013). Furthermore, explanation 2 receives support from previous research findings: it has been shown that the mere perspective of looking at a body from a 1PP in an IVE leads to strong experiences of ownership. For example, Normand et al. (2011) reported that in the asynchronous condition, administered in the 1PP, a considerable amount of participants (between 23% and 32%) reported high scores in the ownership questionnaire. The role of perspective was also emphasized in various other studies (e.g. Kokkinara, Kilteni, Blom, & Slater, 2016; Maselli & Slater, 2013; Petkova, Khoshnevis, & Ehrsson, 2011b; Slater, Spanlang, Sanchez-Vives, & Blanke, 2010). It was noted that 1PP "dominates visuotactile synchrony in its contribution towards body ownership illusions" (Kilteni, Normand, Sanchez-Vives, & Slater, 2012). Hence, asynchronous visuotactile stimulation might not have been able to sufficiently disrupt ownership in Experiment 1. Even though we have found a difference of experienced ownership between the synchronous and asynchronous conditions, there were still considerably high levels of ownership present in the asynchronous condition as indicated by the descriptive statistics of Experiment 1 (see Table 2). It is therefore plausible that the contraction bias occurred in both the synchronous and asynchronous condition. We therefore administered a second experiment, where we used a different visuotactile stimulation aimed at disrupting ownership in the asynchronous condition more strongly than in Experiment 1.

4. Experiment 2

4.1 Method

We used the same design and procedure as in Experiment 1 except for the ownership manipulation. In addition to the visuotactile stimulation, we now changed the perspective of the participants. Therefore, the intention of Experiment 2 was to create an even stronger difference between conditions in terms of ownership. In the synchronous condition, participants were touched synchronously and had a 1PP view of the virtual body, the same as in Experiment 1. In the asynchronous condition, however, participants had a 3PP view of the body (see right side of Figure 1). The virtual body was moved to the left by about one time the width of the respective avatar's body. Additionally, the participants could only see the touches being applied to the virtual body but they could not feel them on their real body. The reasoning for the absence of tactile stimulation was that real touches being applied to seemingly empty virtual space could create confusion in the participants. Additionally, the touches could be associated with the avatar body by the participants, even if they were asynchronous.

4.2 Results

4.2.1 Ownership and presence. Again, we tested whether the modified stimulation procedure (additional perspective change) had worked as intended. Descriptive statistics are shown in Table 3. There were significant main effects of stimulation in two-way repeated measures ANOVAs for ownership, $F(1, 23) = 117.26$, $p < .001$, $\eta_p^2 = 0.84$, and presence, $F(1, 23) = 30.06$, $p < .001$, $\eta_p^2 = 0.57$. In both analyses, no significant interactions and main effects of body size could be observed. Additionally, we found no significant effects for control questions (all $p > .05$). These results again indicate a successful induction of ownership in the synchronous condition (Hypothesis 1). Furthermore, the effect sizes of the main effects of stimulation for ownership and presence were both higher than in Experiment 1, suggesting an even stronger effect of stimulation. The marginal mean of the ownership ratings in the asynchronous conditions (2.36) was now considerably below the middle of the scale (4; see Table 3).

Again, we asked participants about their impression of the room's size and their own perceived age. We found a linear effect of body size for the questions "I felt younger than I actually am" ($F(1, 23) = 29.66$, $p < .001$, $\eta_p^2 = 0.56$) and "I felt older than I actually am" ($F(1, 23) = 10.23$, $p = .004$, $\eta_p^2 = 0.31$), suggesting that participants felt younger in the small body and older in the large body. Similarly, in the small body, the room appeared bigger than in the large body, $F(1, 23) = 41.13$, $p < .001$, $\eta_p^2 = 0.64$, and in the large body, the room appeared smaller than in the small body, $F(1, 23) = 45.35$, $p < .001$, $\eta_p^2 = 0.66$.

4.2.2 Size judgments. As in Experiment 1, we tested Hypotheses 2 and 3 using a two-way repeated measures ANOVA. In line with Hypothesis 2, we found a main effect of body size on size judgments, $F(1.56, 35.96) = 21.03$, $p < .001$, $\eta_p^2 = 0.48$ (degrees of freedom were adjusted using Greenhouse-Geisser correction; Figure 4). As in Experiment 1, there was a linear trend ($p < .001$), suggesting that there was an overestimation in the *small* body and an underestimation in the *large* body compared to the *medium* body (contraction bias, Hypothesis 2). However, the interaction did not turn out significant, $F(2, 46) = 0.92$, $p = .405$, $\eta_p^2 = 0.04$. Additionally, we found no main effect of stimulation, $F(1, 23) = 0.53$, $p = .474$, $\eta_p^2 = 0.02$. See Figure 4 for details. Therefore, as in Experiment 1, we could not support Hypothesis 3 (own-body-size effect).

4.3 Discussion

Again, we could show a contraction bias in size judgments. However, the bias was not stronger in the synchronous condition compared to the asynchronous condition. Therefore, the additional manipulation of perspective did not lead to a stronger own-body-size effect. Altering the perspective of the virtual body has already been used in previous studies (e.g. Petkova, Björnsdotter, Gentile, Jonsson, & Ehrsson, 2011a). These studies demonstrated considerable levels of ownership in conditions with a 1PP (Petkova et al., 2011a; b; Maselli & Slater, 2014). We observed lower ownership ratings in the asynchronous 3PP condition in Experiment 2 than in the asynchronous 1PP condition of Experiment 1 and there was also a clear difference between 1PP and 3PP in Experiment 2. Thus, the change in perspective in Experiment 2 successfully improved the impact of the ownership manipulation. Nevertheless, there was no effect of ownership on size judgments.

It is still possible that the contraction bias we found in our study reflects an effect of visual comparison rather than ownership. This explanation was already addressed and ruled out for the original paradigm in the follow-up studies by Van der Hoort and Ehrsson (2014; 2016). To rule out this possibility in our experiments, we administered a third experiment.

5. Experiment 3

5.1 Method

In Experiment 3 we tested whether the removal of the body as a visual reference cue during size judgments would negatively affect the contraction bias. The same design and procedure as in Experiment 2 was used except that, after the stimulation phase, the virtual avatar body was removed and the judgments of the test objects had to be made without the possibility of using the body as a visual reference. Therefore, results of Experiment 3 can be attributed more closely to the previous manipulation of ownership by ruling out a visual comparison effect during the judgment phase.

5.2 Results

5.2.1 Ownership and presence. Descriptive statistics are shown in Table 4. Again, there was a significant main effect of stimulation for ownership, $F(1, 19) = 39.98$, $p < .001$, $\eta_p^2 = 0.68$. Ownership was higher in the synchronous condition. There was also a main effect of body size for ownership, $F(1.95, 37.11) = 4.63$, $p = .017$, $\eta_p^2 = 0.20$ (degrees of freedom were adjusted using Greenhouse-Geisser correction). Ownership was significantly higher in the *normal* body compared to the *large* body ($p = .014$, Tukey adjusted post-hoc tests). There was no significant main effect of stimulation for presence, $F(1, 19) = 1.39$, $p = .253$, $\eta_p^2 = 0.07$. In contrast to Experiments 1 and 2, there was an additional significant main effect of stimulation for control questions, $F(1, 19) = 9.08$, $p = .007$, $\eta_p^2 = 0.32$, meaning that statements not related to ownership received more support in the synchronous condition. All other effects were not significant (all $p > .05$). These results conflict with the expectations of Hypothesis 1. The fact that there was also a difference between stimulation conditions in the control questions could be due to a response bias. Additionally, there was no effect on presence ratings.

As in the previous experiments, we asked participants about their impression of the room's size and their own perceived age. We observed the same effects as in Experiments 1 and 2 except that participants did not feel significantly older in the large body. There was a linear effect of body size for the question "I felt younger than I actually am" ($F(1, 19) = 7.31$, $p = .014$, $\eta_p^2 = 0.28$) but not for the question "I felt older than I actually am" ($F(1, 19) = 3.75$, $p = .068$, $\eta_p^2 = 0.17$), suggesting that participants felt younger in the small body but not significantly older in the large body. Additionally, in the small body, the room appeared bigger than in the large body, $F(1, 19) = 47.47$, $p < .001$, $\eta_p^2 = 0.71$, and in the large body, the room appeared smaller than in the small body, $F(1, 19) = 61.10$, $p < .001$, $\eta_p^2 = 0.76$, similar to Experiments 1 and 2.

5.2.2 Size judgments. As in Experiments 1 and 2, we used a two-way repeated measures ANOVA. Again, there was a significant main effect of body size, $F(2, 38) = 6.09$, $p = .005$, $\eta_p^2 = 0.24$ (Figure 5). The linear trend ($p = .002$) showed that there was a contraction bias (overestimation of size in the *small* body and underestimation of size in the *large* body compared to the *medium* body). Therefore, Hypothesis 2 could be supported using nonvisible bodies in the judgment phase. However, as before, Hypothesis 3 (own-body-size effect) received no support: There was no interaction between body size and stimulation, $F(2, 38) = 1.06$, $p = .358$, $\eta_p^2 = 0.05$, and there was no main effect of stimulation, $F(1, 19) = 2.10$, $p = .164$, $\eta_p^2 = 0.10$ (Figure 5).

5.3 Discussion

To conclude a full validation study of the own-body-size effect, we administered a condition where there was no visible body during the judgment phase. Again, we could show that there was a contraction bias. Since the body could not act as a visual reference during the judgment of the objects, it is probable that cognitive aspects associated with the body led to the contraction bias. These aspects include ownership but also priming of the previously presented body. A direct visual comparison can be ruled out as an explanation for the results since no body was visible during the judgment phase. However, it is still possible that participants made a mental visual comparison between the objects and their memory of the body. There was no instruction to imagine a visual body. Nevertheless, we are unable to rule out this explanation completely and further research could clarify the role of mental comparisons (e.g. by changing the instructions of the task or asking participants about their strategies).

As in Experiment 1 and 2, we could not show that the contraction bias depended on the stimulation condition. Again, there was a significant difference in the amount of experienced ownership as indicated by the questionnaire data. However, surprisingly, although we used the same visuotactile stimulation procedure as in Experiment 2, the difference of ownership between conditions was descriptively not as pronounced as in Experiments 1 and 2. A possible explanation is that we only assessed ownership at the end of each trial, thereby including both the ownership induction and the size judgment phase in the subjective ownership rating. Participants, in hindsight, might have experienced the judgment phase as having lower ownership because there was no body visible during the latter part of the experiment. This could have lowered the overall ownership ratings. Nevertheless, we expected a difference between stimulation conditions. Another point to consider is that there was a higher agreement with control questions in the synchronous condition. Analyses of the control questions showed that both received more agreement in the synchronous condition: Participants had a stronger impression of having two bodies at the same time and a higher agreement with the statement that the avatar began to visually resemble their own body. A possible explanation is that the removal of the avatar after the ownership induction interfered with participants' interpretation of the control questions. Potentially, seeing the virtual world alternatingly with and without a virtual body could have led to an impression of having two bodies at the same time when the virtual body was present and synchronous. Similarly, the body could have appeared visually similar to the own body because of the striking difference between having a body and having no body in the virtual world. Nevertheless, ownership questions received more support in the synchronous condition, indicating that there was still an ownership difference.

6. General Discussion

In our study we were able to demonstrate the own-body-size effect in an IVE setting. We remained as close as possible to the original setup (Van der Hoort et al., 2011). In Experiment 1 we used a well-established method of manipulating ownership by applying either synchronous or asynchronous touches to virtual bodies. In Experiment 2 we applied either synchronous or no touches and manipulated the perspective of the virtual body. We used an approach that was inspired by the results of previous VR studies showing that manipulating the perspective in VR can be more effective than visuotactile stimulation (e.g. Maselli & Slater, 2013; Petkova et al., 2011a; b; Slater et al., 2010). In Experiment 3 we ruled out that visual comparison of the virtual body and the test objects affected the own-body-size effect.

In all three experiments, we found a significant contraction bias. However, the visuotactile ownership manipulation had no effect. The supposedly stronger manipulation of ownership in Experiment 2 did not impact this finding. In addition, the contraction bias was observed in Experiment 3 when using invisible bodies in the judgment phase. In sum, we could successfully demonstrate the contraction bias in an IVE. Our results support previous findings that suggest an effect of the size of one’s own body on the perception of objects (Banakou et al., 2013; Linkenauger et al., 2013; Van der Hoort et al., 2011). In all of our experiments, a larger body led to an underestimation of object size and a smaller body led to an overestimation. However, using an IVE, we could not show an influence of the amount of ownership on the strength of the contraction bias. It is possible that other mechanisms hinder the comparability of the findings from the virtual and the real world, respectively. For example, as mentioned above, distances are systematically underestimated in an IVE (Renner et al., 2013). There were two studies that already used an IVE to investigate effects of virtual bodies on object size judgments and they could demonstrate that the size of the body affects judgments (Banakou et al., 2013; Linkenauger et al., 2013). However, these studies did either not accurately manipulate or measure ownership sensations towards the virtual bodies or they did not demonstrate a contraction bias but rather a general overestimation of objects for ownership of small bodies. Results from these studies did therefore not elucidate how the strength of body ownership is associated with the contraction bias in an IVE. The IVE in our experiments elicited a contraction bias and therefore affected perception in the same way it was affected in the real world. However, the feeling of ownership towards virtual bodies was, although present, not as decisive for the perception of the virtual world as expected. This is in contrast to the original proposition of the effect by Van der Hoort and colleagues.

Another explanation for the lacking influence of ownership is that, in VR, only a little amount of ownership is needed to induce the contraction bias. We tried to rule out this explanation in Experiment 2. We observed larger differences between the stimulation conditions in self-reported ownership than in Experiment 1 and ownership was low in the asynchronous condition. Therefore, we could confirm that altering the perspective of the body is a promising approach for manipulating ownership in an IVE. However, this manipulation did not affect the size judgments. Even a lower amount of ownership was able to produce the contraction bias. Possibly, an IVE itself is already convincing the user that she or he is connected to the avatar. Users could automatically inherit properties from their virtual manifestations due to the visually compelling character of the environment, regardless of the amount of ownership reported in questionnaires. This explanation could pose problems for inducing disownership in future VR embodiment studies since conditions with low ownership could entail the same behavioral consequences as high ownership conditions. Yet another conceivable explanation for our results is priming. In all three experiments, priming of the concepts smallness and largeness in the ownership phase of the respective conditions could have influenced the size judgments. However, this is unlikely the case because we would expect that priming of smallness would lead to smaller judgments of objects and vice versa.

Overall, our results show that caution needs to be taken when transferring embodiment studies into VR setups. Visual perception does not necessarily involve exactly the same processes in an IVE as in a real environment. It is conceivable that an ownership sensation of a virtual body has different properties when compared to an ownership sensation of a physically present body-like object. Furthermore, the own-body-size effect could be more fragile than previously thought and depend on the characteristics of the ownership manipulation.

One limitation of our study is that we only used self-reports of ownership and no physiological measures (e.g. skin conductance response to a threat). Even though self-reports have been used throughout ownership research, physiological measures could still provide a more sensitive assessment of ownership and reveal aspects that cannot be captured with self-reports. However, there are only few studies that specifically address differences between both forms of measurement and they either reported similar effects for both forms of measurement (e.g. Palomo et al., 2017) or even a stronger effect for subjective measurements (Rohde, Di Luca, & Ernst, 2011).

To summarize our findings, we showed that the size of the body serves as a reference frame for the perception of object size. A visual comparison between the body and the object is not responsible for the effect. Furthermore, we could increase the impact of an ownership manipulation on perceived ownership by additionally manipulating the perspective. In future studies this procedure could be further improved by altering the perspective to a larger degree, so that the virtual body is outside of the near-personal space of the participant in order to induce an ownership disrupting condition. Additionally, in future studies, other means of manipulating ownership in an IVE such as real-time movements of avatars could be considered.

6.1 Conclusions

We demonstrated that high levels of ownership need not be a crucial factor for evoking a contraction bias in a VR setting. This means that caution is advised when assessing behavioral consequences of body ownership in VR, especially regarding perception. Ownership feelings need not reflect the entire relationship a user forms to his or her virtual self-representation. Our results have implications for potential VR therapies for body disorders such as anorexia nervosa or muscle dysmorphia. For example, Keizer, van Elburg, Helms, & Dijkerman (2016) could show that it is possible to decrease overestimation of body size in anorexia nervosa patients by manipulating the virtual body. Furthermore, in the context of social phobias, the illusion of having a large body could be used in the sense of the Proteus effect (Yee & Bailenson, 2007) to enhance self-confidence. Regarding body ownership, it has been shown that experiencing ownership of avatars is able to modulate pain thresholds (Martini, Perez-Marcos, & Sanchez-

Vives, 2014) and to reduce racial bias (Maister, Sebanz, Knoblich, & Tsakiris, 2013). The results from our study demonstrate the importance of the perspective in eliciting such ownership feelings. We can also draw conclusions about VR content development: demonstrably, very large or very small virtual body representations are suitable for evoking strong ownership feelings. Humans seem to have an astonishingly high tolerance for accepting exotic or impossible bodies as their own frame of reference. This enlarges possibilities for game designers to engage users in widely different avatars and opens up the possibility to use microrobots in surgery, as van der Hoort and colleagues (2011) point out. Our results indicate that it is feasible to experience ownership of a small artificial body. However, the contraction bias needs to be taken into consideration when performing complex spatio-visual tasks such as surgery.

Compliance with Ethical Standards

Conflict of Interest: The authors declare that they have no conflict of interest.

Participants were treated according to the Code of Ethics of the World Medical Association (Declaration of Helsinki) and informed consent was obtained

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Table 1.

Overview of the experiments.

Experiment	Ownership manipulation	Size Judgments
Experiment 1	Synchronous vs. asynchronous touch (both in 1PP)	Body visible
Experiment 2	Synchronous touch in 1PP vs. asynchronous touch in 3PP	Body visible
Experiment 3	Synchronous touch in 1PP vs. asynchronous touch in 3PP	Body not visible

Table 2.

Descriptive statistics for ownership, control, and presence questions in Experiment 1.

Scale	Synchronous condition	Asynchronous condition
Ownership	4.48	3.61
Control Questions	3.11	3.06
Presence	3.50	3.17

Notes: Displayed are the marginal means for the synchronous and asynchronous stimulation conditions. *N* = 57 for all questions

Table 3.

Descriptive statistics for ownership, control, and presence questions in Experiment 2.

Scale	Synchronous condition	Asynchronous condition
Ownership	4.44	2.36
Control Questions	2.36	2.14
Presence	3.53	2.89

Notes: Displayed are the marginal means for the synchronous and asynchronous stimulation conditions. *N* = 72 for all questions

Table 4.

Descriptive statistics for ownership, control, and presence questions in Experiment 3.

Scale or Question	Synchronous condition	Asynchronous condition
Ownership	4.11	2.98
Control Questions	2.27	1.98
Presence	3.52	3.45

Notes: Displayed are the marginal means for the synchronous and asynchronous stimulation conditions. *N* = 60 for all questions

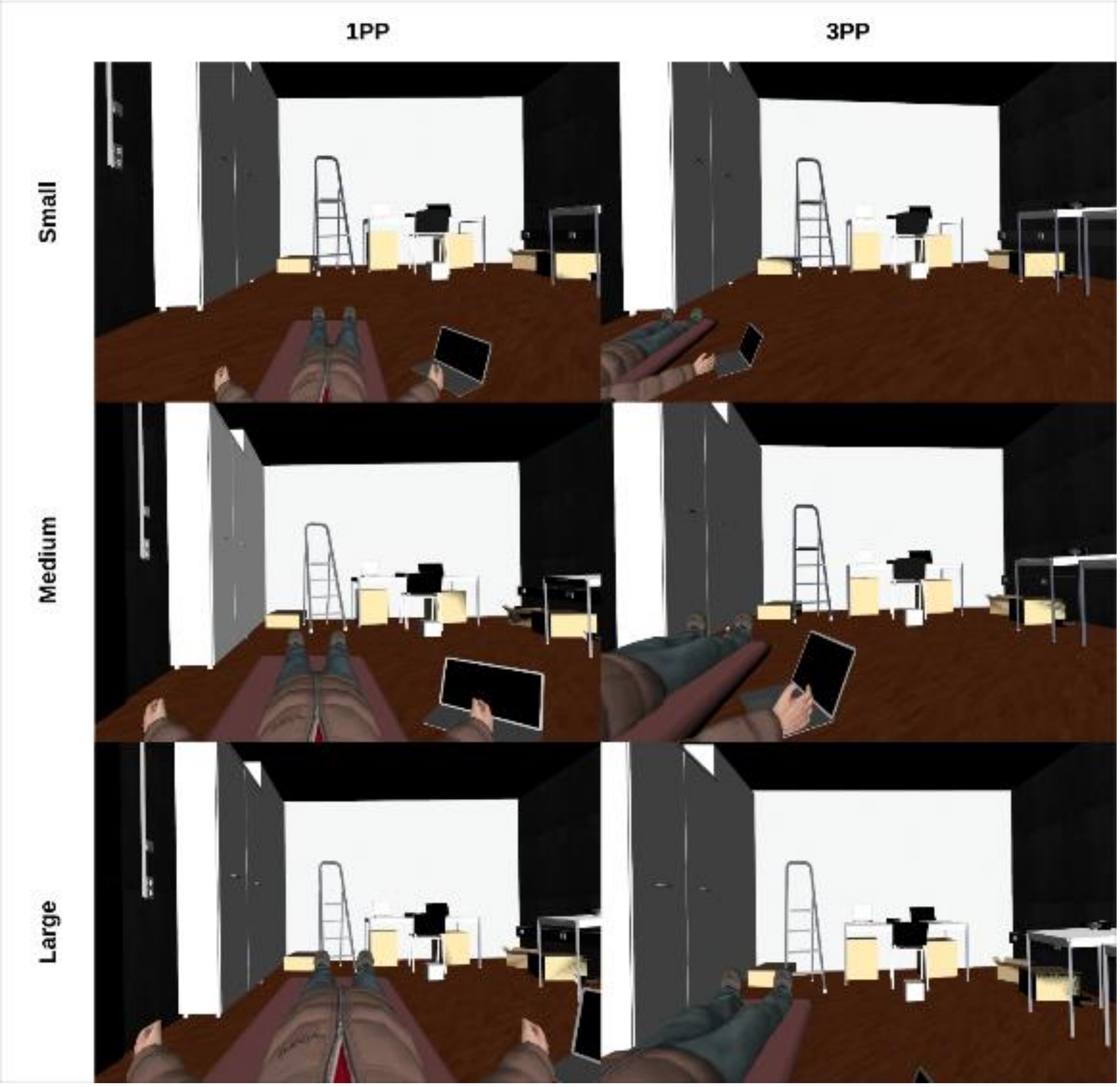

Fig. 1 Left side: the three body size conditions in the first-person perspective (used in all experiments). Right side: the three body size conditions in the third-person perspective (used in the asynchronous conditions in Experiments 2 and 3). Note that the bodies are shown from slightly above the participants' actual viewpoint in VR in order to compensate for the loss of stereoscopic information and to make size differences more visible. In the experiment proper, the bodies appear from an egocentric perspective

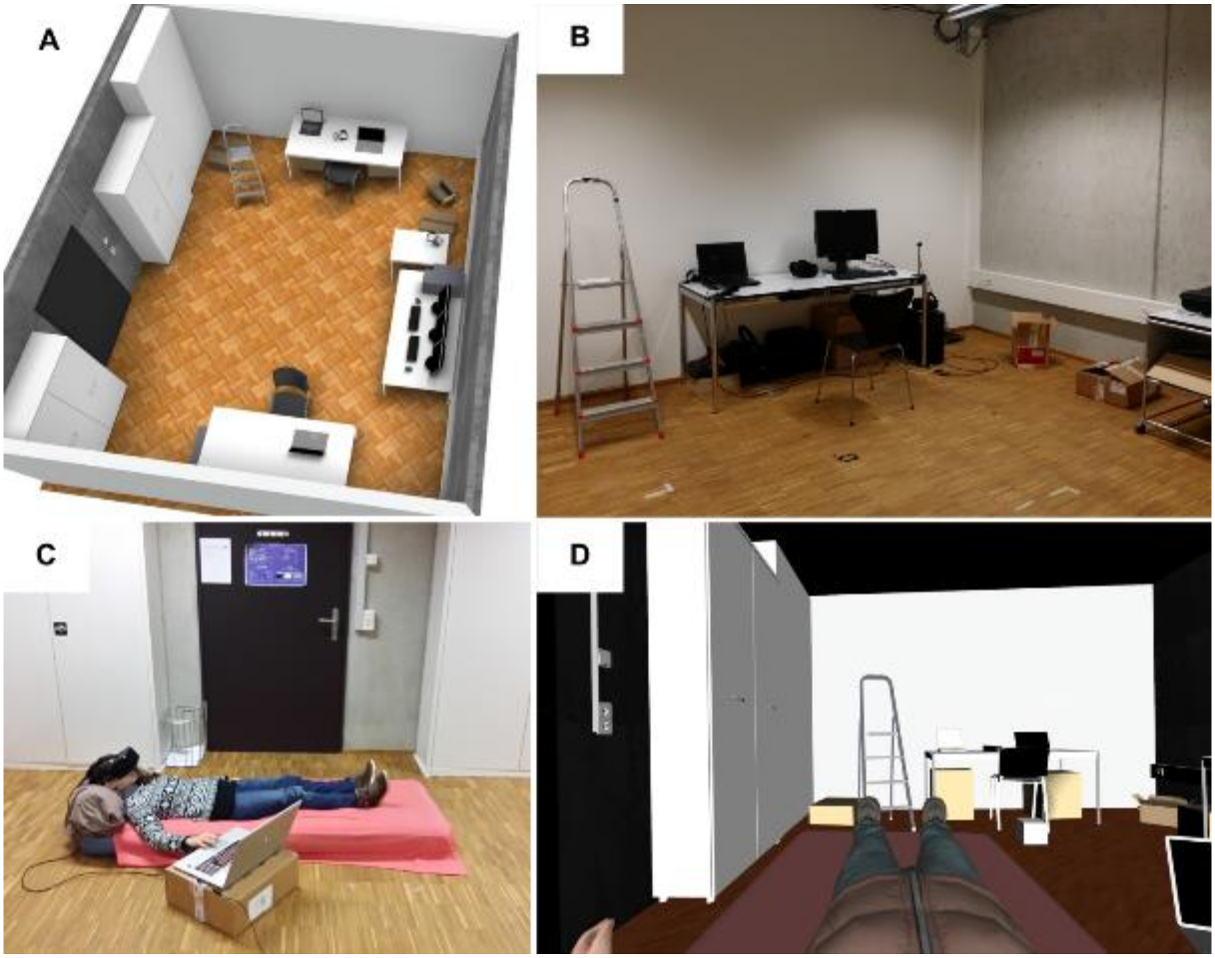

Fig. 2 a) Virtual replica of the laboratory room. b) Real laboratory room. c) A participant is lying on the mattress making size judgments. d) View of the participants during size judgments in Experiment 1 (shown is the large body condition). In Experiment 2 the view in the asynchronous condition was shifted to the right of the body and in Experiment 3 the body was not visible during judgments. The white box on the right of the avatar had to be judged

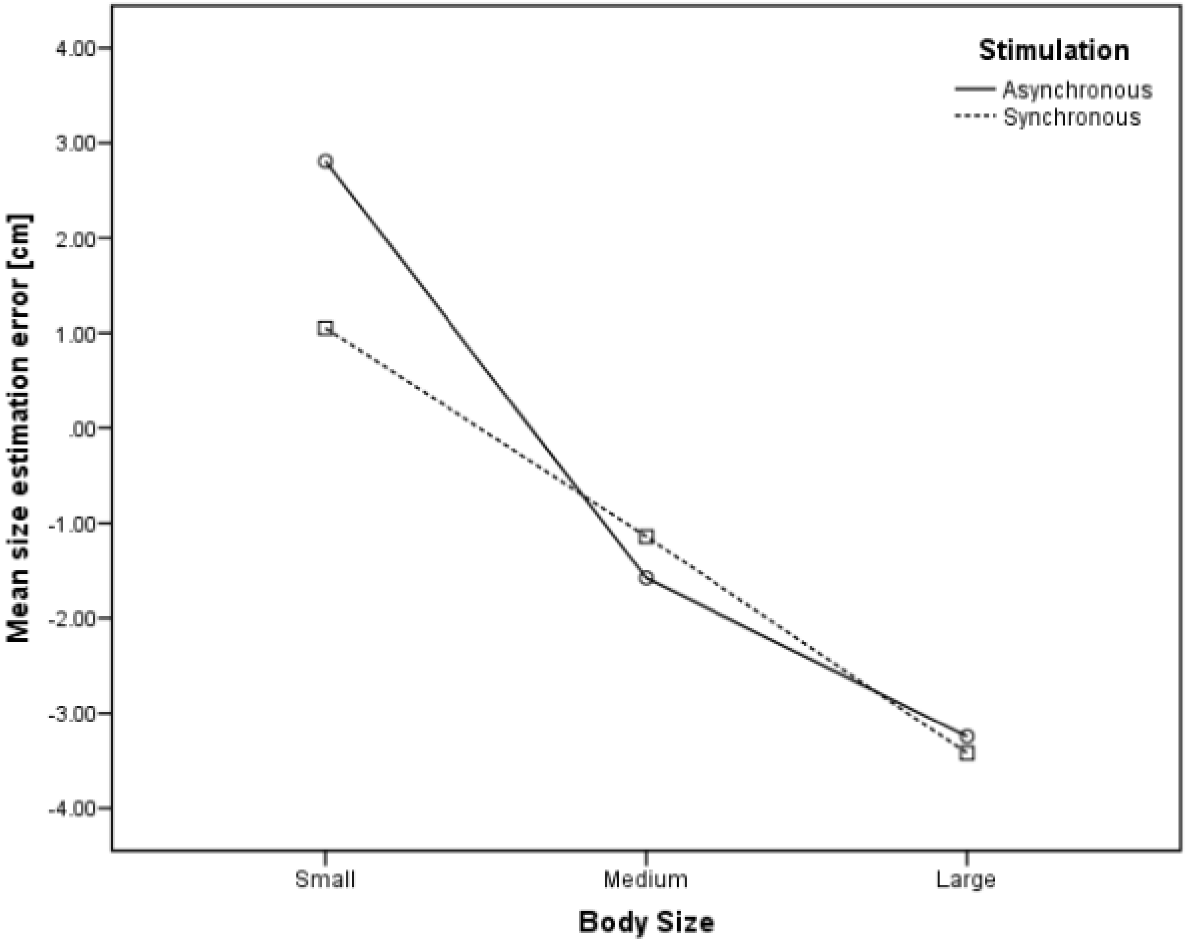

Fig. 3 Results of the two-way repeated measures ANOVA with the difference between real and estimated size of the test objects as dependent measure (Experiment 1)

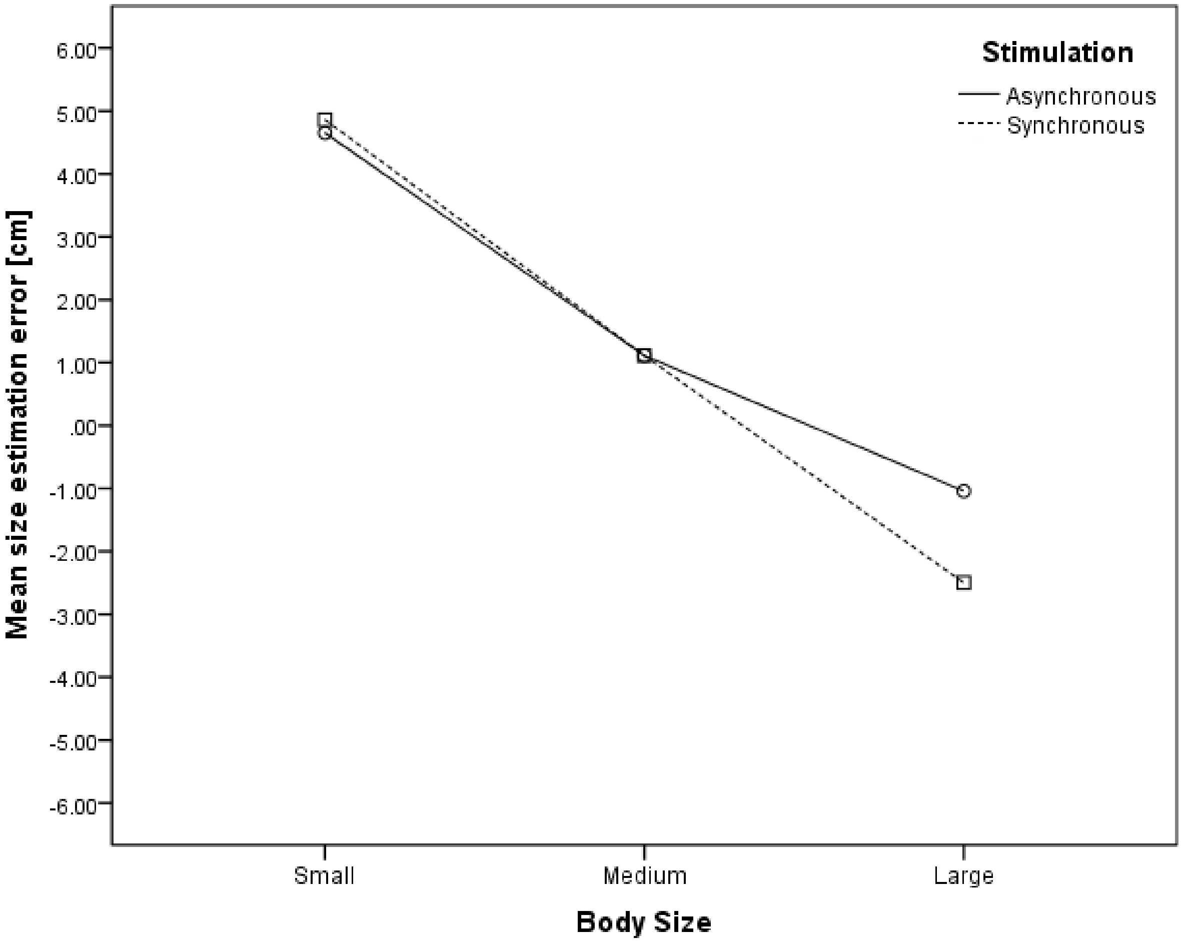

Fig. 4 Results of the two-way repeated measures ANOVA with the difference between real and estimated size of the test objects as dependent measure (Experiment 2)

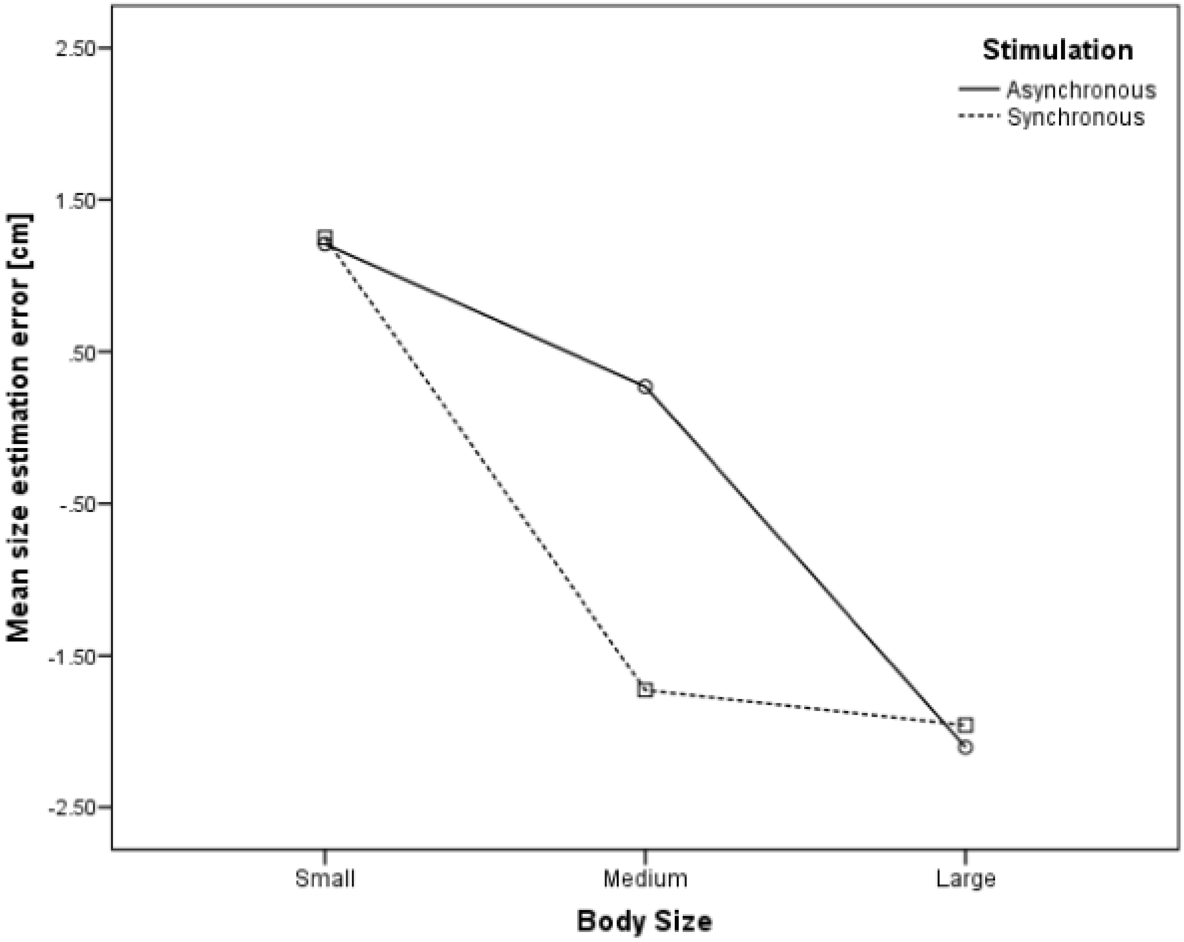

Fig. 5 Results of the two-way repeated measures ANOVA with the difference between real and estimated size of the test objects as dependent measure (Experiment 3)

Appendix

Ownership questionnaire

Questions

During the experiment, there were times when …

… I felt as if the avatar's body was my body (ownership).

… I had the feeling that I was looking at myself (ownership).

… it seemed as though the touch I felt was caused by the object touching the avatar (ownership).

… I had the feeling that I was lying in the same location as the avatar (location).

… I felt I could move the avatar, if I wanted to (agency).

… I felt as if I had two bodies (control question).

… the avatar began to resemble my own body in terms of shape, skin tone, or some other visual feature (control question).

Answer scale

Fully disagree ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 Fully agree

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How Self-Motion in Virtual Reality Affects the Subjective Perception of Time

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Abstract

The velocity of moving stimuli has been linked to their experienced duration. This effect was extended to instances of self-motion, where one's own movement affects the subjective length of time. However, the experimental evidence of this extension is scarce and the effect of self-motion has not been investigated using a reproduction paradigm. Therefore, we designed a virtual reality scenario that controls for attention and eliminates the confounding of velocity and acceleration. The scenario consisted of a virtual road on which participants (*n* = 26) moved along in a car for six different durations and with six different velocities. We measured the subjective duration of the movement with reproduction and direct numerical estimation. We also assessed levels of presence in the virtual world. Our results show that faster velocity was connected to longer subjective time for both forms of measurement. However, the effect showed deviations from linearity. Presence was not associated with subjective time and did not improve performance in the task. We interpreted the effect of velocity as corroborating previous work using stimulus motion, which showed the same positive association between velocity of movement and subjective time. The absence of an effect of presence was explained in terms of a lacking dependency of time on characteristics of the virtual environment. We suggest applying our findings to the design of virtual experiences intended for inducing time loss.

Keywords: time perception, self-motion, presence, virtual reality

1. Introduction

The dominant view in time perception research presumes the existence of an internal clock (cf. Grondin, 2010). A prominent example is the pacemaker-counter model, according to which subjective time is influenced by some form of pacemaker that tracks time by generating impulses in regular intervals (Gibbon, 1977; Gibbon et al., 1984; Rammsayer & Ulrich, 2001; Treisman, 1963). The state-dependent-network is yet another model which has received support in the domains of motor control and visual perception (Eagleman, 2008; Grondin, 2010; Karmarkar & Buonomano, 2007). According to this model, time perception is an intrinsic process that is based on time-dependent changes in the state of neural activity. There is experimental support for either model of time perception (cf. Grondin, 2010; Ivry & Schlerf, 2008).

Irrespective of the mechanism, our subjective time apparently is not only depending on temporal information but also on unrelated sensory input: for example, the overall magnitude of stimuli such as size, luminosity, or motion velocity has been shown to affect the subjective estimation of presentation time (Matthews et al., 2011; Rammsayer & Verner, 2014; Xuan et al., 2007). Brown (1995) reported a linear relationship between the velocity of moving stimuli and the subjective length of the duration of their appearance. Higher velocities led to longer subjective estimates of presentation times, independent of the actual presentation time, which varied from 6 to 18 s. This positive association between stimulus motion velocity and perceived duration was subsequently reproduced in several other studies (Gorea, & Kim, 2015; Kaneko, & Murakami, 2009; Tomassini et al., 2011). Based on similar findings, Walsh (2003, 2015) proposed the ATOM model (A Theory Of Magnitude). The ATOM model postulates a general mechanism for detecting magnitudes across sensory modalities. Specifically, the model assumes strong intercorrelations between space, time, and numerosity judgments.

Surprisingly, only few studies looked at an effect of velocity of one's *own body motion* on the subjective experience of time. In this study, we suggest a new way to study this effect of self-motion. We used immersive VR technology to achieve high control over stimulus variables while maintaining external validity. We aimed to explore whether velocity of self-motion affects the judgment of time in a prospective time judgment task. Self-motion was induced by vection in a car-driving task. Participants wore a head-mounted display (HMD) and moved along a virtual road leading through a city environment as co-drivers in a car. The velocity of the movement as well as its duration were systematically varied. Participants had to express the subjective duration of their movement explicitly by numerical estimation and implicitly by reproduction of the target duration. Subjective time in immersive virtual environments (IVEs) has applied potential in activities where timing is important.

1.1 Motion and Perception of Time

If motion is actively generated by participants, it is no longer possible to differentiate between the effect of self-motion and the motor efforts that require attentional resources. According to internal clock models, tasks with higher attentional demand lead to shorter subjective time because there are fewer resources available to keep track of timing pulses (cf. Brown, 2008). Studies that engaged participants in stationary physical exercise (either on a treadmill or on an ergometer) found an underestimation of time compared to control conditions without exercise (Kroger-Costa et al., 2013; Vercruyssen et al., 1989). However, in these studies the (active) self-motion is confounded with the exercise: Similar to a dual-task paradigm, attentional resources are captured by the exercising task and are thus not fully available for the timing task. It is our goal to overcome this limitation and to ensure that the above-mentioned results are indeed the result of self-motion. Therefore, participants in our study experienced *passive* self-motion.

Only few studies used passive self-motion to investigate the effect of motion velocity on time perception. Participants were moved on rotating devices in the dark and had to produce time intervals by regularly tapping a button while being moved (Binetti et al., 2010; Capelli et al., 2007). Tapping rate was higher in accelerated motion trials. These studies indicated that with increasing acceleration the subjective time estimation seems to shorten (i.e. there is an underestimation of time in fast acceleration). This seems to contradict the effects of visually induced motion via stimuli, where increased motion velocity led to an overestimation of time. It is possible that faster passive acceleration required more attentional resources than slower acceleration or no motion (Capelli et al., 2007). Ramped up movements could be more demanding for participants and require more attention to sensory input during self-motion. Therefore, it is possible that ramped up movements capture attentional resources and, thus, lead to shorter produced time intervals. In these experiments, participants were blindfolded, which means that any effect of motion can only be attributed to vestibular perception. Additionally, the vestibular system can only detect changes in velocity, and this limits the possibilities of investigating self-motion at constant velocity. Furthermore, the mean velocity of motion was confounded with the length of the acceleration and deceleration phase. While there is certainly an interest in studying real passive movement, the duration needed for accelerating or decelerating cannot be discerned from the effect of constant velocity when only short real passive displacements are applied.

In Brehmer’s study (1970), participants were co-drivers in a car on the highway. While looking forward through the front window, they had to produce intervals that were multiples of the length of previously introduced time intervals (*magnitude production* paradigm). For example, if they were introduced to a 10 s interval before entering the car and then, while moving on the highway, the experimenter asked for an interval of twice the length of the standard interval, they had to produce a 20 s interval. When the car was going faster (i.e. driving 100 kph instead of 50 kph), they produced longer intervals. Although attention was effectively held constant and trials were long enough to limit the influence of acceleration and deceleration phases, there are still problems associated with the magnitude production paradigm. It has been argued that humans are not capable of making accurate quantitative judgments on a ratio scale, as it is necessary in magnitude production (cf. Narens, 1996). Investigations by Ellermeier and Faulhammer (2000) and Zimmer (2005) showed that this objection was corroborated and they concluded that participants are unable to produce accurate quantities.

Van Rijn (2014) showed participants a video of a virtual car moving on a road. The video was either sped up or slowed down to create trials with differing motion velocity. The reference velocity was 100 kph and there were additional trials with 50, 75, 125, and 150 kph. A *magnitude comparison* paradigm was chosen for judging time. Participants were first introduced to a standard duration and, later, had to compare each trial to this standard duration. The intended differences between the standard duration and the trial durations were in the range of -0.2 to +0.2 seconds. The result was that an overestimation of time was present in the higher velocity conditions, whereas an underestimation could be observed in lower velocities. This positive effect of velocity resembles the effect of stimulus motion on subjective time. The study had a high validity and effectively controlled for effects of attention and acceleration. One limitation of the experiment is, however, that only time differences within the subsecond range were presented. Interestingly, Brown (1995) also found an overestimation for faster motion and for moving stimuli. In this case, however, vection induced from the moving surroundings of the car was responsible for the effect.

Taken together, there were mixed results about the effect of self-motion velocity on time perception. Some studies contradict the results of stimulus motion and found that fast passive self-motion led to an underestimation of time, while others support the results of stimulus motion and found an overestimation. This discrepancy can be explained with differences in study design: If attention was held constant, faster motion led to an overestimation of time (Brehmer, 1970; van Rijn, 2014). We propose that self-motion after controlling for attention will produce similar results as those found in studies using visual stimulus motion: faster motion leads to longer subjective time judgments. Furthermore, we propose that this relationship is linear. Therefore, we state the following two hypotheses:

Hypothesis 1: Higher target velocities are associated with longer subjective durations and lower target velocities are associated with shorter subjective durations.

Hypothesis 2: The effect of target velocity on subjective duration is linear.

An important limitation of previous research about the effect of self-motion on subjective time is that time perception was measured using different paradigms. None of these paradigms involved an explicit measure of time experience. Additionally, there was no study that applied a reproduction paradigm. Reproduction is one of the standard paradigms in time perception research (Grondin, 2010). Reproduction methods show less inter-subject variability and are less dependent on socially learned time units than other forms of measurements such as production of time and verbal reports, according to Rammsayer and Verner (2014). The same authors argue that time reproduction is the preferred method to investigate effects on prospective time perception since it represents a ‘natural’ form of measurement. Accordingly, we will include reproduction measures in our study.

A second addition of our study is the use of immersive VR technology. We propose that a VR paradigm will help to isolate the effect of self-motion velocity on time perception and enhance external validity: VR allows to control for effects of attention since neither motor effort nor ramp-up phases are required. Furthermore, it allows stricter control over the surroundings than real world scenarios (Loomis et al., 1999). At the same time, it imitates real life situations and provides high external validity. IVEs possess a range of additional depth cues and more realistic motion than 2D environments (Armbrüster et al., 2008).

Taken together, our study combines and extends the experiments by Brehmer (1970) and van Rijn (2014). It connects realistic car motion from a first person point of view with the possibilities of generating true constant velocity trials. We are the first to use a VR paradigm for assessing the effect of self-motion on subjective time. We are also the first to use reproduction for assessing subjective time in the context of self-motion. Finally, another addition of our experiment is the assessment of presence as described in the next section.

1.2 Presence and Perception of Time

Presence is the degree to which one feels immersed, or present, in a virtual world. It is often defined in the literature as the feeling of being physically present in a technically mediated environment (Steuer, 1992; Weibel et al., 2011; Wissmath et al., 2010). Presence has already been linked to time perception in games. Empirical studies found that a high level of presence was related to greater time loss (Hägni et al., 2007; Sanders & Cairns, 2010; Wood et al., 2007). In contrast, Nordin (2014) did not find a link between presence and time perception. Yet other findings suggest that presence could enhance distance perception in a virtual world (Interrante et al., 2006; Ries et al., 2008; Mohler et al., 2008). It is therefore possible that presence could also enhance time perception in VR. However, to our knowledge, there is no empirical study that addressed this idea. Considering the mixed results in gaming studies and the lack of knowledge about the relationship between presence and time perception, we wanted to include measures of presence in our study and look at possible beneficial effects of presence on time perception. Therefore, we are the first to combine the effect of self-motion velocity on time perception with measures of presence. Insights into this relationship allow us to assess how presence in a virtual world is connected to the perception of time and if presence can contribute to an improved perception in IVEs.

2. Method

2.1 Participants

We recruited 26 participants, of which ten were male (age: *M* = 21.3 years, SD = 2.1 years) and sixteen were female (age: *M* = 21.1 years, SD = 1.9 years). All participants had normal or corrected to normal vision. Four participants (15.4%) reported having prior experience with HMDs. Sixteen participants (62%) were in possession of a driving license.

Participants were students from the University of Bern and received course credit in exchange to their participation. They provided written informed consent about taking part prior to the experiment and were debriefed after the experiment. They were treated in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and the study was approved by the Ethics Committee of the Faculty of Human Sciences at the University of Bern.

2.2 Design and Material

The driving task consisted of six different temporal intervals (*2*, *3*, *4*, *5*, *6*, and *7* s) and five different velocities (*5*, *30*, *60*, *120*, and *240* kph) as well as a no motion condition (*0* kph). This resulted in 36 combinations of time and velocity, each of which was realized once, resulting in 36 trials per participant. The trials were presented in random order.

The dependent measures in the driving task were the time estimations (numerical estimation or reproduction, see procedure section for details), velocity, and distance estimations (both via visual analog scales). We also obtained presence and confidence ratings by using questionnaires. Confidence was assessed with a single item on an analog scale ("How confident are you about the correctness of your time judgments?"). For presence ratings the Pictorial Presence SAM (Weibel et al., 2015) and a questionnaire by Dinh et al. (1999) were used. The SAM consists of six sequences of five pictograms. The sequences represent different aspects of presence and the corresponding pictograms depict the intensity levels of presence. For each sequence, one of the pictograms that best fits the participants' subjective level of presence has to be chosen. The answer is then transformed into a number from one to five. The Dinh et al. questionnaire is comprised of ten questions that are accompanied by a Likert scale with five answer categories (*1* = poor, *5* = excellent). Additionally, participants have to indicate their subjective level of presence with a number from *1* to *100*, where *1* means having absolutely no presence at all and *100* means having as much presence as in the real world. The internal consistency of both presence scales was sufficiently high (Dinh et al. scale: Cronbach's Alpha = .82; SAM: Cronbach's Alpha = .74).

The virtual world was a long straight street, leading from a rural area into a city. There were no other cars in traffic and no human avatars on the sidewalk. The virtual model was provided by Esri Inc. (Redlands, United States) and used with permission. The experiment was run on the Vizard platform (WorldViz LLC., Santa Barbara, United States). The participants were seated on the co-driver's seat of a virtual car and they were facing forward. Apart from a steering wheel that was placed on the table next to the participants (Logitech G27, Logitech international S.A., Apples, Switzerland), no other props were used to emulate the virtual world in the laboratory room. Next to them was an avatar that appeared to drive the car. The participants themselves did not have a visible virtual body. During driving, sound effects of the inside of a car on the highway were played. The sounds were not matched to velocity and were the same in all conditions. Remarks of participants in pilot trials of the experiment indicated that this was not experienced as disturbing for the feeling of presence. Participants wore an Oculus Rift HMD (Oculus VR, LLC., Irvine, United States) and provided inputs by means of an Oculus Remote controller.

2.3 Procedure

After a short explanation of the task and the handling of the controller, participants put on the HMD and familiarized themselves with the virtual car interior. When they were ready, the experimenter started the task. Participants could from now on start a trial by pushing a button. In each trial, the car moved along the road with a certain velocity and duration. When the time limit was reached, the HMD screen turned black and the interior car sound effect ceased playing. Immediately afterwards participants reproduced the target duration by pressing a dedicated button on the controller once for beginning the reproduction interval and once for stopping it. There was a short auditory feedback whenever the button was pressed. The participants were instructed to reproduce the duration from the beginning of the car motion until the fade out of the screen. After the reproduction, participants were presented with a series of input screens, where they had to give an estimate of the duration, velocity and traveled distance of the car ride. The numerical time estimation had to be given by choosing a value from a list with a range of 1 to 9 s in intervals of 0.5 s. Participants were advised to rely on their feeling of time. The other estimates were given on visual analog scales reaching from 0 to 300 kph (velocity), and 0 to 600 m (distance). Throughout the reproduction and judgment phase, the background remained black and only input screens were visible. After finishing the estimates, the participants found themselves back in the car at the same starting position as before. They were now able to start the next trial. After half of the trials, participants were given the chance for a short break. At the end of the last trial, they had to give a self-evaluation of their performance in the time reproduction task (see design and material section above). Hereby the visual analog scale ranged from *0% confidence* to *100% confidence*. At the end of the task, participants were asked to fill out two presence questionnaires on the computer.

3. Results

Descriptive statistics of the dependent variables are depicted in Table 1. Overall, target durations were underestimated with numerical estimation and reproduction as dependent measure. Both measures were positively correlated, $r(930) = .58$, $p < .001$. We observed a response bias resembling the Vierordt's law (Woodrow, 1951): Shorter durations were overestimated and longer durations were underestimated in comparison to the overall subjective mean estimation error (see Fig. 1). Overall, target velocities were underestimated, only the 5 and 30 km/h target velocities were slightly overestimated (see Fig. 2). Distances were generally overestimated, except for the three longest distances, which were underestimated (see Fig. 3). Time judgments were positively associated with velocity judgments (numerical estimation: $r(930) = .26$, $p < .001$; reproduction: $r(930) = .14$, $p < .001$) as well as with distance judgments (numerical estimation: $r(930) = .33$, $p < .001$; reproduction: $r(930) = .25$, $p < .001$). Adjustments using Bonferroni's method and bootstrapping (1000 samples) were performed in order to obtain values of significance. Furthermore, we obtained similar levels of presence as in previous studies (Dinh et al., 1999; Hendrix & Barfield, 1996a; 1996b; Weibel et al., 2015; Wissmath et al., 2010).

To obtain measures of subjective time relative to elapsed time, we calculated the ratio of estimated or reproduced duration divided by the target duration, for each trial. We refer to this measure as *subjective duration*. A resulting value of one means that the target time was judged accurately, a value above one that time was overestimated, and a value below one that time was underestimated. We found a positive relationship between target velocity and subjective duration for numerical estimation ($r_\tau = .14$, $p < .001$; Fig. 4) and reproduction ($r_\tau = .08$, $p = .001$; Fig. 5). This was in accordance with Hypothesis 1: higher target velocities were associated with longer subjective time. To assess the linearity of the effect of velocity (Hypothesis 2), we implemented a linear contrast analysis that was adjusted for the unequal spacing of target velocities. The linear contrast was significant for both numerical estimation ($F = 51.24$, $p < .001$) and reproduction ($F = 31.41$, $p < .001$), supporting Hypothesis 2.

In addition to measures of association, we calculated a multilevel model with *target velocity* as a factor and *target duration* as a linear predictor to adjust for both the factorial structure and the nested layering of the data (cf. Goldstein, 2011; Raudenbush & Bryk, 2002). We included *participants* as a second-level variable and used it to specify a random intercept and a random coefficient for the factor *target velocity*. The dependent variable was the *subjective duration* in terms of *numerical estimation* and *reproduction*. The analysis was performed with the *mixed* function from the *afex* package in *R*, using maximum likelihood estimation (Singmann et al., 2015). We observed a significant main effect of target velocity on numerical estimation, $\chi^2(5) = 23.10$, $p < .001$, and reproduction, $\chi^2(5) = 16.20$, $p = .006$. Faster velocity conditions elicited longer subjective time ratings than slow velocity conditions. This was, again, in accordance with Hypothesis 1. There was also a negative effect of target duration on numerical estimation, $b = -0.022$, SE = 0.003, $p < 0.001$, and reproduction, $b = -0.036$, SE = 0.004, $p < 0.001$. In both cases, there was no significant interaction between target duration and velocity (both $p > .05$). To again test for the linearity of the effect of target velocity, a model comparison between the above model where velocity was entered as a factorial variable and an additional model where it was entered as a continuous variable was initiated. The model with the continuous variable did not improve model fit (numerical estimation: $\chi^2(26) = 10.08$, $p = .998$; reproduction: $\chi^2(26) = 34.63$, $p = .120$). Thus, the linearity assumption received no support in the multilevel analysis. This conflicts with Hypothesis 2.

Taken together, the results were in accordance with Hypothesis 1 and partly in support of Hypothesis 2. There was a linear relationship between target velocity and subjective time in the association measures. Additionally, there was a positive but non-linear relationship between target velocity and subjective time in the multilevel analysis, which adjusted for the nested factorial structure of the data. Figures 4 and 5 show that the fitted curves decline in the two highest velocity conditions, indicating possible deviations from linearity.

To test our assumptions about presence, we analyzed the associations between presence ratings and time judgments. Adjustments using Bonferroni's method and bootstrapping (1000 samples) were performed in order to obtain values of significance. There was no correlation between presence and mean subjective time in numerical estimation (Dinh et al. scale: $r(24) = -.22, p = .541$; SAM: $r(24) = -.04, p = 1$) and reproduction (Dinh et al. scale: $r(24) = .12, p = 1$; SAM: $r(24) = -.03, p = 1$). This means that the individual level of presence was associated with neither overestimation nor underestimation of time compared to the overall mean estimation of the sample. To test if presence was connected to performance in time judgments, we needed to calculate the accuracy of time judgments. Accuracy was defined as the absolute difference between target duration and numerical estimation or reproduction. Presence was not associated with accuracy in numerical estimation (Dinh et al. scale: $r(24) = .09, p = 1$; SAM: $r(24) = -.13, p = 1$) and reproduction (Dinh et al. scale: $r(24) = .12, p = 1$; SAM: $r(24) = .15, p = .919$). Presence ratings were also not associated with accuracy in velocity and distance judgments (all $p > .05$). Interestingly, presence ratings were also not associated with confidence ratings (Dinh et al. scale: $r(24) = .09, p = .657$; SAM: $r(24) = .27, p = .184$). Furthermore, confidence ratings did not show associations with accuracy of time judgments (numerical estimation: $r(24) = -.17, p = .420$; reproduction, $r(24) = -.02, p = .930$). The maximally observed power for these analyses was

0.31. The results did not support our proposition: higher levels of presence did not lead to better performance in the time judgment task.

4. Discussion

In this experiment, we tested whether the velocity of one's own body motion influenced the perception of time. The results showed longer time judgments in conditions with high velocities compared to conditions with low velocities. This confirms the effect of self-motion on time judgment as reported by Brehmer (1970) and van Rijn (2014). The subjective duration of self-motion trials increased with each increase in velocity. However, contrary to our expectations, this increase is not linear. A linear effect of velocity was reported in studies using stimulus motion (Brown, 1995; Tomassini, et al., 2011). The multilevel analysis suggests deviations from a linear effect of velocity. Especially the effects of the two high velocity conditions (120 and 240 kph) were not as pronounced as expected. This is in line with the study by van Rijn (2014), in which the fast self-motion condition was weaker compared to what would be expected from a linear prediction. The data by Brehmer (1970) were not suitable for testing a linear effect of velocity. At this point, we have no explanation why self-motion does not elicit the same linear effect as stimulus motion and whether linearity is always absent in the effect of self-motion. Future studies using self-motion paradigms are needed to provide answers to these questions. Apart from the linearity assumption, we were able to demonstrate a monotonic positive relationship between self-motion velocity and subjective time, thereby confirming previous work. Not only the observation of fast moving stimuli leads to longer time judgments but also the overall motion of the surroundings from a first-person perspective. These results are in accordance with the assumption that subjective time can be affected by sensory input.

Specifically, the faster the virtual surroundings changed, the longer was the subjective impression of time. This could be explained by an internal clock model in which the timekeeper mechanism is accelerated by sensory input. A state-dependent-network model could also serve as an explanation. Fast changes in visual input correspond to large changes in activation patterns, which in turn lead to a lengthening of subjective time. Roseboom et al. (2019) proposed yet another mechanism according to which subjective time is explained in terms of changes in perceptual content. In this model, no internal clock or activation pattern is necessary. Instead, changes in visual content directly lead to temporal information that can be used to provide a subjective duration judgment. In our experiment, this would imply that the speed of a trial was effectively equal to the rate of change in visual content, which could be detected by the visual system and transformed into a behavioral response.

It has been argued in the literature (e.g. Casasanto & Boroditsky, 2008; Lambrechts et al., 2013, Riemer et al., 2018) that there is an asymmetric relationship between time and space judgments: space perception strongly influences time perception but not necessarily vice versa. In our experiment, there was an overall underestimation of time and velocity but an overall overestimation of distance. Thus, the judgments of the participants seemingly conflicted with physics (if time is shorter and velocity is lower, then also distance is by necessity shorter). Nonetheless, there was a significant positive relationship between time and distance judgments, suggesting that time judgments could indeed be influenced by distance judgments. With our experimental setup, it is not possible to assess the direction of causality and to decide whether space perception influenced time perception more strongly than vice versa. Interestingly, however, the supposed violation of physical laws seems to be based on the fact that there was also a positive correlation between time and velocity judgments. This suggests that – contrary to physics – higher velocity judgments were connected to longer time judgments. Therefore, the suggested coupling of magnitudes in our experiment was not consistent with real life, which challenges the assumptions of the ATOM model.

We used an IVE to control the attentional demand between moving and non-moving conditions and maintain a high level of external validity. Furthermore, we could implement motion without any motor effort or ramp-up phase. Additionally, we extended previous findings to explicit measures of time and time reproduction. Both measures were influenced in the same way by velocity of self-motion as shown earlier by magnitude production (Brehmer, 1970) and magnitude comparison (van Rijn, 2014). Thus, self-motion velocity does indeed affect our subjective impression of time. Our experiment is the first demonstration in which a VR setup was used to induce self-motion in a time perception task and we could therefore demonstrate that the effect is also applicable to immersive virtual worlds and thus computer games.

Furthermore, we proposed that the presence level could affect performance in the time judgment task. However, this proposition was not supported: presence was not associated with performance in the time judgment task and no relation between presence and confidence ratings was observed. We also did not observe a general decline in the magnitude of time judgments with increasing levels of presence. Since aggregated data were used to assess these relationships, statistical power was low due to the small number of data points in the aggregated variables (n = 26, i.e. number of participants). Thus, we can only rule out a strong effect of presence on performance in our data. Previous findings reported a beneficial effect of presence on spatial perception (cf. Interrante et al., 2006; Ries et al., 2008; Mohler et al., 2008). However, there could be no such effect or a smaller effect for temporal perception. The flow of time is potentially the same in the real world and IVEs whereas there are substantial differences in the configuration of space (resolution, extent of details, field of view, etc.). Thus, the level of presence did not play a significant role in the prospective judgment of time intervals in an IVE. Nevertheless, it is also possible that the connection between presence and the judgment of visual characteristics (i.e. distances) is simply *stronger* than the connection between presence and the judgment of temporal characteristics. Another possibility is that presence plays a minor role for the judgment of short intervals and only affects subjective time on a larger scale.

There is one limitation to consider in our experiment: the amount of visual information of a trial is confounded with its target duration and velocity. For example, in long and fast trials, participants saw more aspects of the virtual world than in short and slow trials (i.e. buildings and street crossings). This limitation also applies to previous studies of self-motion. To distinguish between the amount and velocity of visual information in future studies, we suggest inducing basic optic flow in VR environments. For example, dot clouds could be used to hold the amount of unique visual information constant while manipulating the velocity of the dots. We implemented an immersive environment in our study in order to remain close to real life driving situations.

Results from this study have clinical and practical implications. For example, insights into the relationship between motion and subjective time could support the design of serious games intended for reducing the subjective duration of unpleasant experiences such as dental operations or prolonged periods of waiting. For instance, our results show that, surprisingly, fast-paced racing games could be less efficient in inducing time loss. Additionally, our results show that the design of windows on long-distance flights or train rides could affect the subjective duration of the journey: subjective time is affected by motion of the surroundings. Conceivably, virtual displays could be used to affect the subjective time experience. Another application is the subjective perception of speed in real-life driving. We showed that fast driving resulted in an overestimation of time. Potentially, drivers are tempted to exceed the speed limit in zones with an already high limit, in order to compensate for the subjective longer duration (cf. van Rijn, 2014).

To sum up, our findings show that increased velocity of self-motion induced by vection, leads to an overestimation of short time intervals. This was true for both measurements, reproduction and direct numerical estimation. The amount of presence experienced in the virtual world did not influence the magnitude of time judgments or the accuracy of time judgments. Unlike the perception of space, the flow of time depends less on the characteristics of the virtual world, and thus, there was no effect of presence on time perception in VR.

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Tables

Table 1.

Descriptive statistics of the dependent variables

Variable	Minimum	Maximum	*M*	SD
Numerical estimation of time	-6000 ms	4000 ms	-794 ms	1414 ms
Reproduction of time	-6756 ms	4494 ms	-812 ms	1204 ms
Estimation of velocity	-215 kph	180 kph	-21 kph	52 kph
Estimation of distance	-400 m	367 m	33 m	78 m
Self-confidence rating	10.45%	86.93%	53.64%	18.97%
Presence SAM	2.83	4.50	3.53	0.44
Presence Dinh et al. subjective	20%	95%	51.15%	21.86%
Presence Dinh et al. scale	1.70	4.00	2.84	0.57

Note: For all estimation variables, differences between the actual value and the estimated value are displayed.

Figures

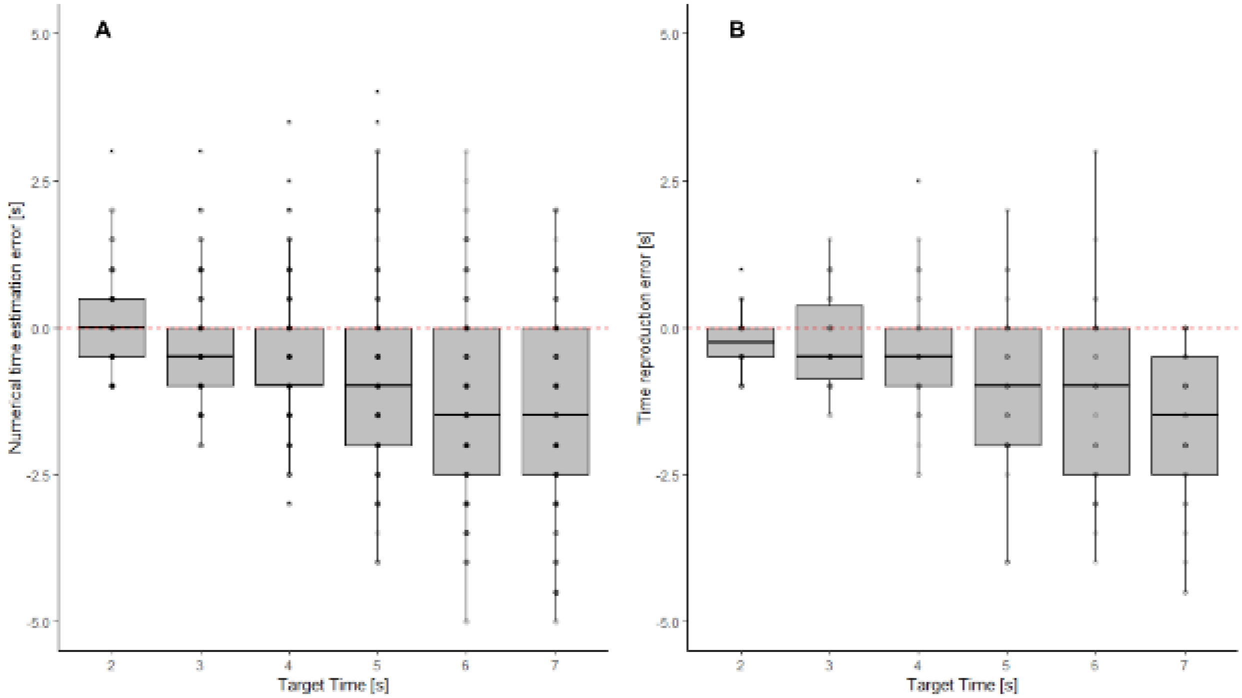

Figure 1. Panel a) shows the numerical time estimation error and panel b) the time reproduction error as a function of target time. Both measures are defined as the difference between target time and estimated time. Red dotted lines indicate veridical judgments

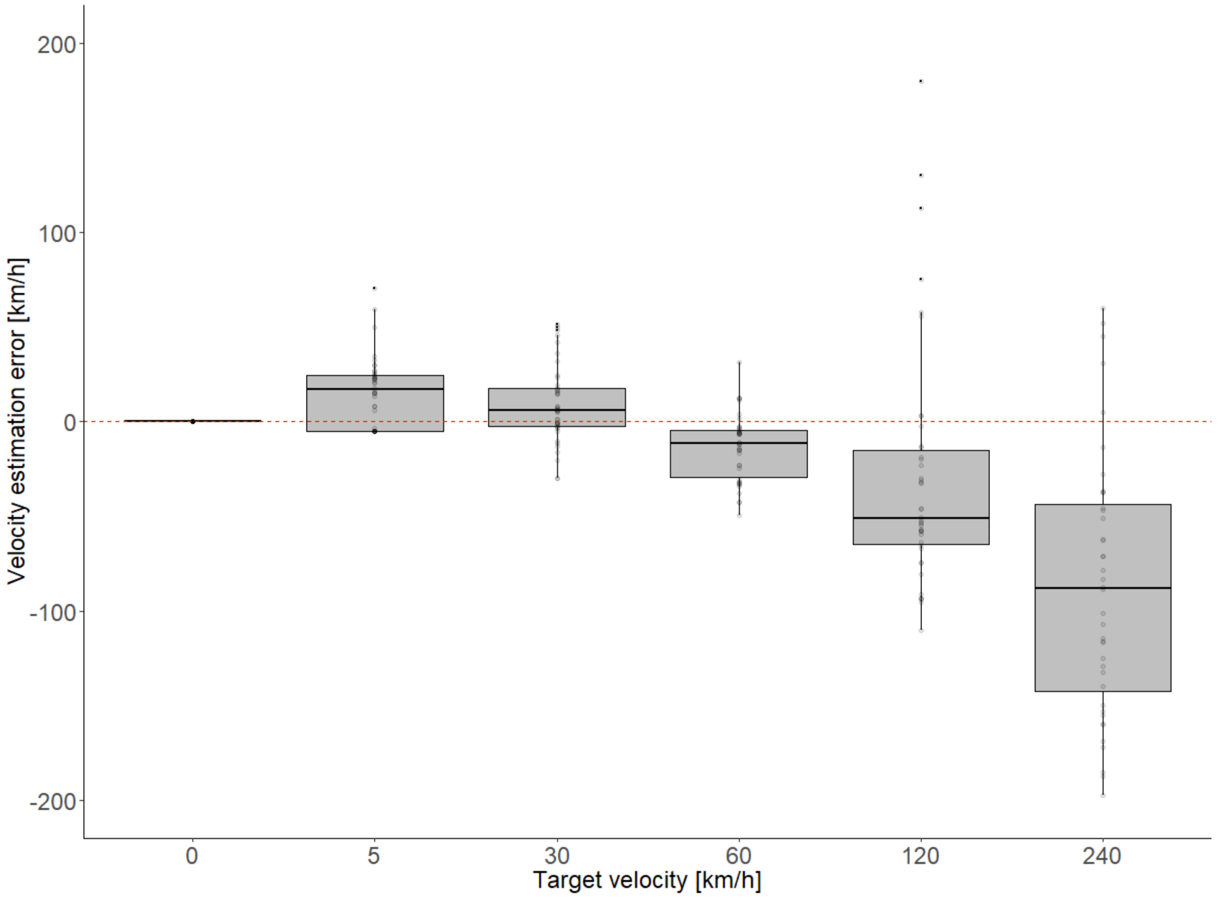

Figure 2. Velocity estimation error as a function of target velocity. Velocity estimation error is defined as the difference between target velocity and estimated velocity. The red dotted horizontal line indicates veridicality

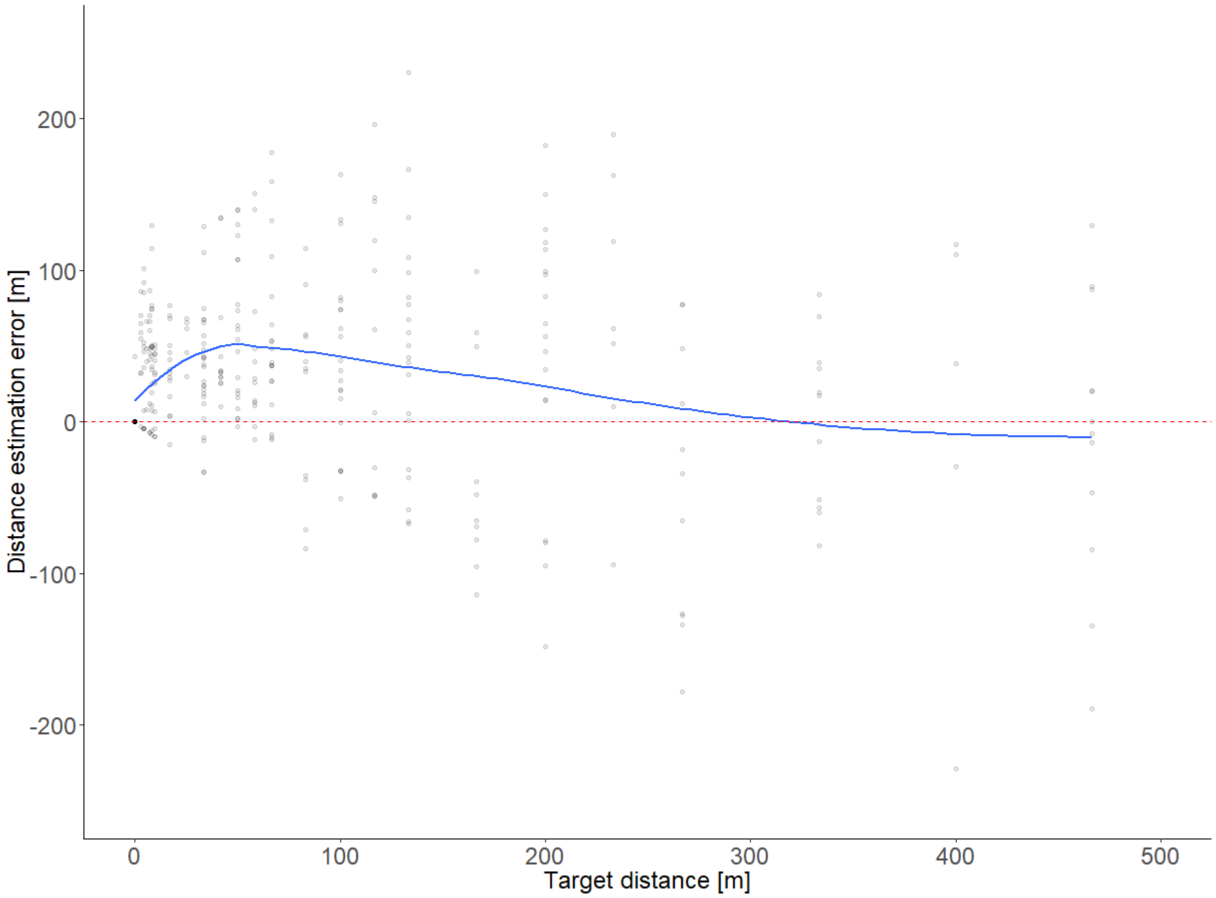

Figure 3. Distance estimation error as a function of target distance. Distance estimation error is defined as the difference between target distance and estimated distance. The target distances result from all possible combinations of target times and target velocities. Distances are therefore pictured as a continuous variable. The red dotted horizontal line indicates veridicality. The blue line expresses the relationship between the variables as a loess curve

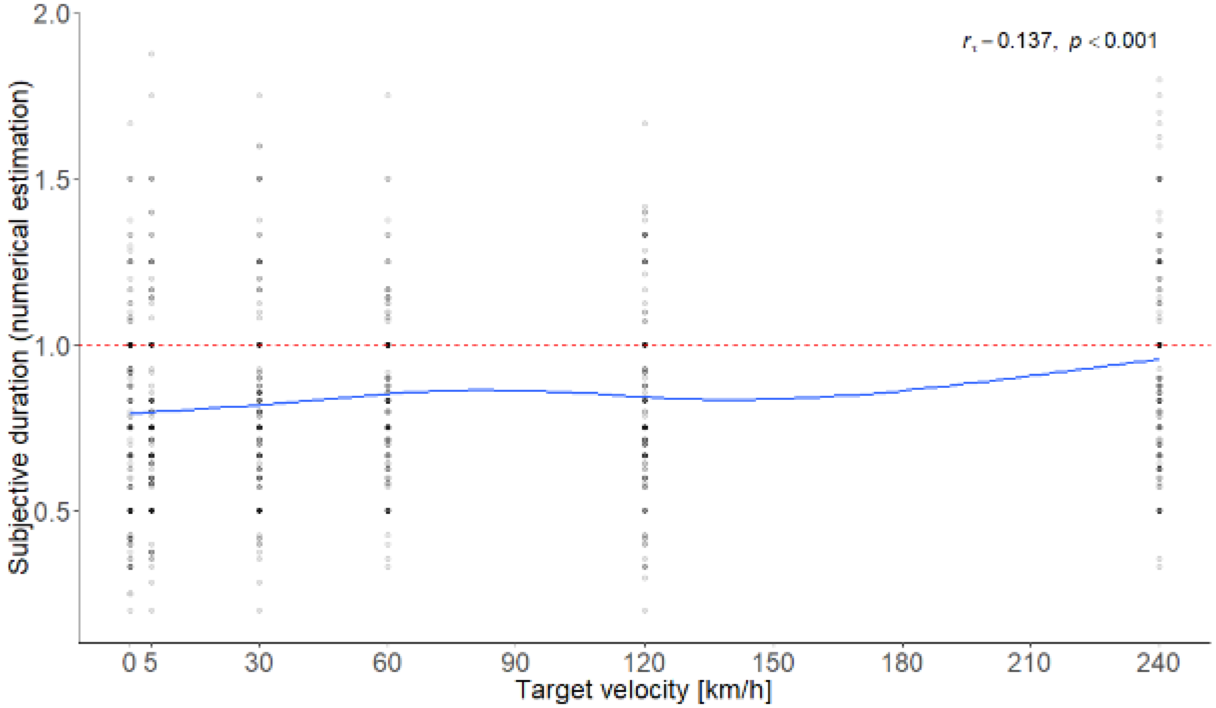

Figure 4. Relationship between target velocity and subjective duration for numerical estimation. Subjective duration is calculated by dividing the estimated value by target time. Therefore, values above one indicate overestimation and values below one indicate underestimation. The dotted red line indicates veridical judgment. The blue line expresses the relationship between the variables as a loess curve

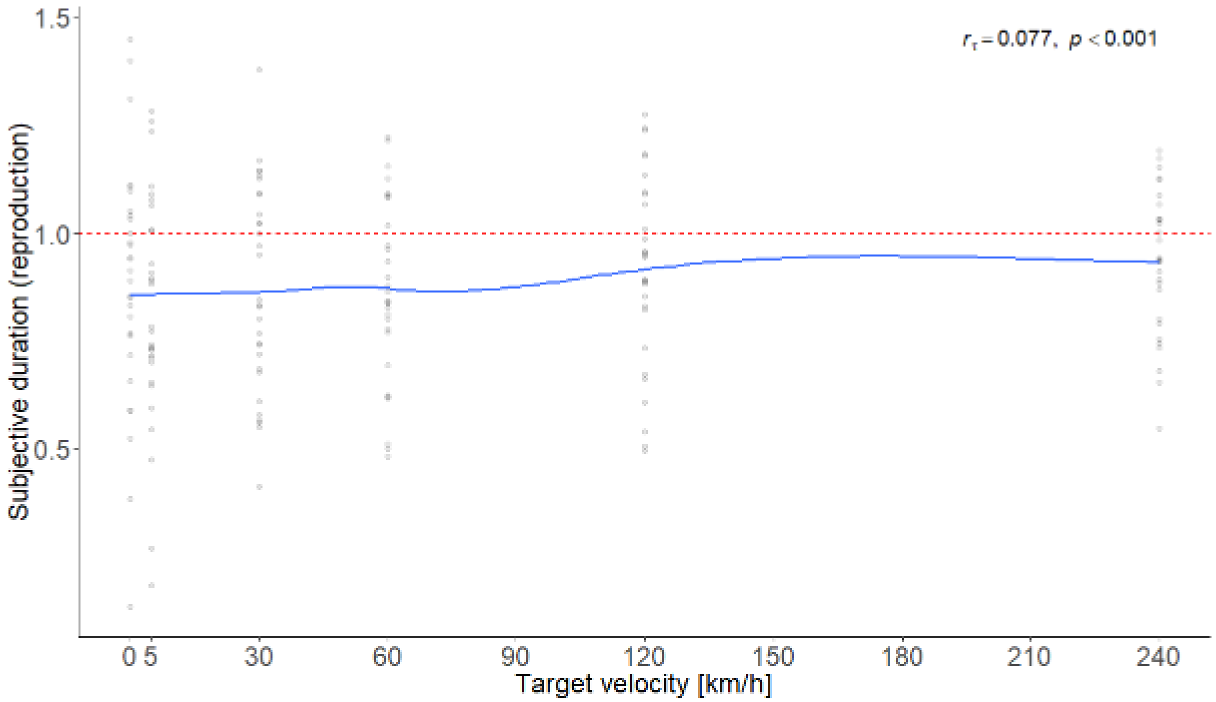

Figure 5. Relationship between target velocity and subjective duration for reproduction. Subjective duration is calculated by dividing the estimated value by target time. Therefore, values above one indicate overestimation and values below one indicate underestimation. The dotted red line indicates veridical judgment. The blue line expresses the relationship between the variables as a loess curve

Manuscript III:

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Presence and Mood Repair – Experiencing Presence in a Gaming Activity Improves Mood after a Negative Mood Induction

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Abstract

Previous research suggests that the sense of being immersed in computer games is beneficial for recovering from episodes of stress and leads to improved mood states. So far, however, no study linked explicit measures of presence – the individual experience of immersion – to mood enhancement. In our experiment, we varied the degree of immersion in a gaming activity and measured individual levels of presence and enjoyment in order to connect them to measures of mood repair after a stress-induction. The participants (N = 77) either played a game in virtual reality (VR; high immersion condition), in a desktop setting (medium immersion condition), or they watched a recording of the game (low immersion condition). Positive emotions were enhanced in the high and medium, but not in the low immersion condition. Individual presence was a significant predictor in the VR condition only. Furthermore, presence and mood repair were positively associated with enjoyment. An explanatory mediation analysis showed that enjoyment mediated the effect of presence on mood repair in positive emotions. These findings demonstrate positive effects of presence experiences in gaming for the improvement of mood. Experiencing strong presence in a VR game seems especially helpful for enhancing mood and building up positive emotional resources.

Keywords: presence, immersion, virtual reality, mood repair, recovery, computer games, enjoyment

1. Introduction

In recent years, research about media use – especially *gaming* – has shifted its focus towards the investigation of positive effects (cf. Reinecke & Eden, 2016). A case in point is mood improvement. A number of authors suggest that interactive elements and high immersiveness of a computer game positively affect mood and may help to recover from work-related stress and strain (Bowman & Tamborini, 2012; 2015; Reinecke, Klatt, & Krämer, 2011; Rieger, Frischlich, Wulf, Bente, & Kneer, 2015). Interactivity and immersion are closely linked to *presence* – the feeling of *being there* in a mediated environment (Steuer, 1992; Witmer & Singer, 1998; Wissmath, Weibel, Schmutz, & Mast, 2011). Presence is often used synonymously with immersion (cf. McMahan, 2003). However, unlike interactivity and immersion, presence is a clearly defined term and is widely used in virtual reality (VR) and gaming research (cf. McMahan, 2003). As mentioned, it is believed that immersing oneself in the world of a computer game can have a positive effect on one's mood. Surprisingly, however, the role of presence has not yet been investigated in the context of mood repair and gaming. The present study aims to close this gap.

Presence has been described as mediated contents being experienced as real and one’s self-awareness being immersed into another world (Draper, Kaber, & Usher, 1998). According to Lombard and Ditton (1997), presence is a perceptual illusion of non-mediation. Following a proposition by Slater and Wilbur (1997), the term presence is separated from immersion in more recent literature (Cummings & Bailenson, 2015; Hein, Mai, & Hußmann, 2018; Wu, Gomes, Fernandes, & Wang, 2018). Immersion is based on technical properties of the system and is objectively quantifiable. Presence, however, is the individual psychological response to the properties of the system (Norman, 2010; Wirth et al., 2007; Witmer & Singer, 1998). Empirical findings show that presence is indeed modulated by individual expectations and personality traits (Bucolo, 2004; Weibel, Wissmath, & Mast, 2010; 2011a; 2011b). We will follow this distinction henceforth in this article by examining the influence of immersion (the characteristic of a computer game) as well as presence (the individual experience of immersion).

According to Reinecke (2009a; 2009b), the immersive experience (i.e. presence) is a key factor that accounts for the recovery experience of computer games. *Recovery* is a concept from organizational psychology and describes the renewal of depleted physical and psychological resources after phases of stress and strain (Sonnentag & Fritz, 2007; Sonnentag & Zijlstra, 2006). Sonnentag and Fritz (2007) proposed four central aspects of successful recovery: *Psychological detachment* (mental disengagement from work-related stress), *relaxation* (deactivation of arousal and increased positive affect), *mastery* (building up new internal resources through challenging experiences and learning opportunities), and *control* (increased self-efficacy and feelings of competence through experiencing personal control). The results of Reinecke (2009a; 2009b) suggest that presence goes along with psychological detachment, which contributes to the recovery experience of gaming activity. Additionally, entertaining media are an ideal way to stop negative cognitions and preventing episodes of rumination by letting their users immerse in the mediated environment. This is in line with Tamborini and Skalski (2006) who suggest that playing computer games requires the full attention of the player and strongly binds cognitive capacities to the screen, what in turn leads to a highly immersive experience. Games also often require taking over new roles (Bessière, Seay, & Kiesler, 2007) and experiencing fictional worlds (Yee, 2006). They provide opportunities to control the progress of events or characters (Klimmt & Hartmann, 2006) and to experience feelings of autonomy, challenge, and competition (Klimmt & Hartmann, 2006; Ryan, Rigby, & Przybylski, 2006). Thus, computer games contribute to all four aspects of successful recovery and are likely to enhance mood and support recovery form stress and strain (Collins & Cox, 2014; Reinecke, 2009a; 2009b; Reinecke et al., 2011).

Empirical investigations into the role of computer games in recovery are provided by three correlational online studies. In two studies by Reinecke (2009a; 2009b), levels of work-related fatigue and exposure to daily hassles were positively related to the use of games for recovery. Thus, participants who associated playing games with recovery played more extensively after stressful events. In addition, Collins and Cox (2014) found a relation between the amount of gaming activity and recovery from work-related stress.

In experimental studies, *interactivity* was manipulated by comparing active gaming with watching gameplay recordings and videos. There is no consensus about the definition of interactivity (cf. Smuts, 2009), but the respective authors focused on “active participation of the player” and having “control over the progress” of the game (Collins, Cox, Wilcock, & Sethu-Jones, 2019; Reinecke et al., 2011). As such, interactivity shares strong similarities with the immersion of games. In these experiments, interactivity has been shown to play a crucial role in recovery. Recovery in turn was shown to affect other measures such as cognitive performance (Reinecke et al., 2011) and enjoyment (Reinecke et al., 2011; Tamborini, Bowman, Eden, Grizzard, & Organ, 2010; Tamborini et al., 2011). In the study by Reinecke and colleagues (2011), a repetitive and tedious working task was used to induce a need for recovery. Participants were then assigned to one of four conditions that varied in interactivity (video game, recording of a video game, an animated video clip, and a control condition). The degree of interactivity of the condition positively affected the *involvement* in the game. Involvement was measured with the involvement subscale of the presence-questionnaire by Witmer and Singer (1998). Therefore, involvement is part of the presence experience as defined by Witmer and Singer. Involvement was positively associated with recovery, which in turn was positively associated with enjoyment. In a recent study, Collins et al. (2019) found that only a digital game condition could improve recovery as opposed to a mindfulness app and a non-media condition. Tamborini et al. (2010; 2011) showed that recovery through gaming was positively associated with enjoyment. Recovery in these studies was operationalized with need satisfaction (cf. Reinecke et al., 2011). Taken together, previous research on recovery from work-related stress has demonstrated that interactivity, and thus also likely immersion, supports recovery and that feelings of presence and enjoyment could serve as important individual enhancing factors for successful recovery. However, the different contributions of a game's immersion and the individual presence experience have not been worked out so far.

Instead of recovery from work-related stress, yet other studies used *mood repair* as a measure of the immediate effect of gaming on current mood. This approach is mainly inspired by mood management theory (Zillmann, 2000). Mood management assumes that individuals seek to avert negative mood and maximize positive mood by selecting appropriate media (Bryant & Zillmann, 1984; Knobloch & Zillmann, 2002; Mastro, Eastin, & Tamborini, 2002). Thus, mood repair is defined as the change in positive and negative mood after an intervention to regain an "optimal" state of mood (Bowman & Tamborini, 2012, p. 1339). In two studies by Bowman and Tamborini (2012; 2015), the task demand of a computer game was manipulated in order to influence mood repair (task demand is similar to the concept of interactivity, according to the authors). The results of both studies showed a curvilinear effect of task demand on mood repair, meaning that a medium level of task demand was evoking the strongest mood repair (Bowman & Tamborini, 2012; 2015). In a study by Rieger et al. (2015), high interactivity (i.e. gaming compared to watching a recording of the game and a control condition) was positively associated with mood repair. Positive emotions generally increased across conditions, whereas negative emotions only decreased in the highly interactive condition. The same result was previously obtained in a study by Chen and Raney (2009).

Even though immersive experiences were postulated to affect mood and recovery and related concepts such as involvement, interactivity, or task demand were empirically investigated, there is a lack of studies that differentiate between immersion and presence. Particularly, there is a lack of studies that specifically link subjective immersion in the sense of *presence* (being there in a mediated environment; Steuer, 1992) with mood repair or recovery after playing video games. Presence is of great importance in virtual reality (VR) research as a VR display completely surrounds the user with another world as opposed to a desktop display that provides a discontinuity between the screen and the user in front of the screen (Slater & Wilbur, 1997) According to Steuer (1992), presence is the underlying concept of VR. Thus, it is important to include VR conditions in the study of stress recovery and mood repair in order to understand the impact of presence. However, surprisingly, no study so far has manipulated presence with a VR gaming condition.

A few studies have assessed presence in the context of relaxation tasks in a nature setting specifically designed to induce stress recovery or *restoration* (e.g. de Kort, Meijnders, Sponselee, & IJsselsteijn, 2006; Sponselee, de Kort, & Meijnders, 2004). Restoration was defined as renewing resources, enhancing the ability to focus one's attention, reducing stress, and promoting positive affect (cf. de Kort et al., 2006). These studies show a beneficial effect of presence on reducing stress and enhancing mood. It would be of high interest to study presence also in the context of computer games as it is of high interest in the gaming community and has been shown to be one of the driving factors for playing computer games (Yee, Ducheneaut, & Nelson, 2012). Jennett et al. (2008, p. 644) even describe it as being “key to a good gaming experience”. As Reinecke (2009a; 2009b) pointed out, immersive experiences in games (i.e. presence) are also crucial for the recovery experience. However, empirical findings for this claim are sparse and none of the reported studies explicitly measured presence. Thus, in our experiment, we used an explicit measure of presence and linked it to mood repair following a phase of computer gaming. To induce increased variability in presence and to look at differences between the immersion of conditions, we manipulated the mode of presentation of the gaming activity, including a VR condition. We are the first to include a VR condition in the context of gaming and mood improvement. Again, the available literature is mainly based on research on VR therapy and stress reduction in relaxing virtual environments (VEs). Although, results of these studies show a clear effect of presence in VEs on stress reduction and mood enhancement, it is not clear whether computer games would elicit the same effect (e.g. Annerstedt et al., 2013; Freeman, Lessiter, Keogh, Bond, & Chapman, 2004; Liszio, Graf, & Masuch, 2018; Valtchanov & Ellard, 2010; Villani & Riva, 2012; Villani, Riva, & Riva, 2007; Villani, Luchetta, Preziosa, & Riva, 2009; for an overview see Villani, Cipresso, Gaggioli, & Riva, 2016).

Thus, the aims of the present study were 1) to link presence with mood repair following a gaming experience, 2) to differentiate between the effect of individual experienced presence and the effect of immersion as a property of the system, and 3) to add a VR gaming condition. For this purpose, 77 participants underwent a stress-induction to create a need for mood repair. Afterwards, they were assigned to one of three immersion conditions in which they either played a computer game in VR using a Head-mounted display (HMD), played the same game on a desktop computer, or – in a control condition – watched a recording of the same game. To assess mood repair after the respective experience, we assessed mood ratings before gaming (after the stress-induction, respectively) and after gaming and compared both measures. The individual level of presence was assessed with a questionnaire. We also included a measure of enjoyment since enjoyment was shown to be related to recovery or need satisfaction and involvement (Reinecke et al., 2011; Tamborini et al., 2010; 2011). Additionally, Wirth et al. (2007) proposed that presence acts as a booster of media effects such as enjoyment. Thus, we explored relationships between enjoyment, individual presence and mood repair.

In accordance with the literature review above, we stated the following hypotheses:

(1) The higher the immersion of the gaming activity, the stronger the effect of mood repair.
(2) The higher the level of individual presence, the stronger the effect of mood repair.
(3) Enjoyment is positively related to (a) mood repair and (b) presence.

Insights into these issues could help us to better understand the potential of computer games as a means for mood repair and the role of presence.

2. Method

2.1 Participants

77 participants (24 male and 53 female) took part in the experiment. We excluded five participants because they guessed the hypotheses (see section 2.5 for details). The average age was 23.1 years (*SD* = 5.7 years). Participants received either course credit or a little token of appreciation (chocolate bar) for their participation and were debriefed after the experiment. The study was approved by the ethics committee of the Human Sciences Faculty of the University of Bern and participants were treated according to the declaration of Helsinki (World Medical Association, 1991).

2.2 Design

We used a mix of group comparisons and correlational analyses. On the one hand, we used groups to investigate influences on mood ratings in terms of immersion. On the other hand, we investigated the relationship between mood ratings and individual presence scores of participants across conditions. Participants were randomly assigned to one of three groups: *VR*, *desktop*, and *video* condition. The conditions varied in the level of immersion, with the *VR* condition having the highest immersion and the *video* condition having the lowest immersion. Using a meta-analysis, Cummings and Bailenson (2015) demonstrated that the level of immersive quality of a system leads to higher experienced presence, which especially applies to the level of user tracking and the use of stereoscopic visuals. Thus, the *VR* condition should evoke the highest presence levels. Additionally, two studies have shown that actively playing a game evoked more presence than watching a pre-recorded playing session (Kätsyri, Hari, Ravaja, & Nummenmaa, 2013; Wong, Rigby, & Brumby, 2017). Nevertheless, watching pre-recorded video games can still lead to feelings of presence (Collins et al., 2019; Wong et al., 2017), which means that all conditions should lead to at least some degree of presence and that the average level of presence should vary between conditions.

The *VR* and *desktop* conditions involved playing the game *Star Conflict*, with (*n* = 31) and without the addition of an HMD (*n* = 29). The *video* condition required participants to watch a recording of the same game (*n* = 17). See section 2.3 below for more information. We obtained different subsample sizes because the *video* condition was later added as a control condition. However, unequal group size is not a requirement for simple group comparisons (i.e. non-factorial designs; cf. Miliken & Johnson, 1984). The possible loss of statistical power implies a conservative testing of the hypotheses. For correlational analyses, we weighted data points according to the size of the group (cf. Meinck & Rodriguez, 2013) or included the condition as a factorial variable.

The measured variables were feelings of *presence* while playing, ratings of momentary mood (*positive* and *negative*), and *enjoyment*. Before being randomly assigned to a condition, participants had to undergo a stress-induction procedure. Differences between mood ratings before and after the procedure served as a check whether the stress-induction worked as expected. In order to assess *mood repair*, differences in positive and negative mood ratings between after the gaming activity and after the stress-induction were computed. Mood repair was defined as a change of mood ratings in the desired direction (positive values indicating an increase in positive mood and a decrease in negative mood). A summary of the experimental design is shown in Figure 1.

2.3 Material

2.3.1 Stimulus material. We used the game *Star Conflict* (Star Gem Inc., 2015; Figure 2). Star Conflict is a “fast-paced, third person space shooter, allowing players to sit at the helm of a starship and take part in high-octane skirmishes for control of ancient alien artefacts” (Star Conflict Wiki, 2015). The game involves elements of strategy and action. Five subjects that were tested in a pilot test prior to the actual experiment described the game as non-violent and fun to play. Whereas the original game is a multiplayer online game, in this study only the initial tutorials of the game were used, where participants learned to control the ship and how to take over an enemy base. We chose the game because full technical support for playing in VR was given and it was freely available. Furthermore, the game is described as highly immersive by players in online forums (Oculus VR, 2015). Additionally, the genre of the game is suitable for detecting effects on mood enhancement: Collins and Cox (2014) showed that first person shooters and action games were most highly correlated with recovery experiences, whereas the recovery potential of sports games turned out to be lower.

For the desktop and the video condition, we used a commonly available gaming notebook with a 15.6-inch LED screen (resolution: 1920 x 1080 pixels). In the VR condition, participants played with the Oculus Rift DK 2 (Oculus VR, 2014). Both active playing groups used an Xbox 360 controller (Microsoft Corporation, 2005) as input device.

2.3.2 Stress-induction. Two stress-induction procedures suggested by Bauer, Pripfl, Lamm, Prainsack and Taylor (2003) and McLaughlin, Lefaivre and Cummings (2009) were combined. The resulting procedure comprised an anagram task and a number series task, each consisting of five items. Participants had to find solutions within a given time period of ten minutes. All items were unsolvable or almost unsolvable, except for one item in each task, which was included for plausibility. Participants were motivated to perform well by putting a chocolate bar in front of them. They were informed that they would receive the bar depending on the score in the test. They were told that most participants usually achieved the required score (cf. Henna, Zilberman, Gentil, & Gorenstein, 2008). After returning the response sheet, participants were told that they did not score high enough for receiving the chocolate bar.

2.4 Measurement Instruments

2.4.1 Mood repair**.** Momentary mood was assessed using the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). Mood repair was then computed as the difference between the post-game mood ratings and the pre-game mood ratings (t3 – t2). We refer to decreases in negative mood as *mood repair in negative emotions* and to increases in positive mood as *mood repair in positive emotions*. The PANAS is one of the most used measures to assess current mood and emotions (Watson & Vaidya, 2003). Previous studies suggest that it is a useful measure to assess sudden changes in mood (e.g. Russell & Newton, 2008). Participants in our study gave ratings on an analog scale (measured in cm with a range of 0 to 13 cm) for ten positive and ten negative adjectives (e.g. *alert* or *determined* as positive and *upset* and *ashamed* as negative adjectives). In our study, the reliability of the scales was Cronbach's $\alpha = .86$ for positive and Cronbach's $\alpha = .84$ for negative emotions.

2.4.2 Presence. Feelings of presence were obtained by the Pictorial Presence SAM questionnaire (Weibel, Schmutz, Pahud, & Wissmath, 2015). The SAM questionnaire – which was inspired by the widely used Self-Assessment Manikin to measure emotion (Lang, 1980) – was recently developed to assess presence intuitively and unambiguously. It has been shown to be a valid and sensitive measure for assessing spatial presence (Weibel et al., 2015). For six items representing the sensation of presence, participants choose one of five graphical representations that best matches their sensations. In the present study, the SAM questionnaire showed a sufficient reliability with Cronbach's $\alpha = .67$.

2.4.3 Enjoyment. In line with various other studies (Green, Brock, & Kaufman, 2004; Knobloch & Zillmann, 2002; Weibel et al., 2011; Weibel, Wissmath, & Stricker, 2011c) we measured enjoyment with one single item: "On a scale from one to ten, how much fun have you had?" (1 = *no fun at all*; 10 = *a lot of fun*).

2.5 Procedure

In order to assure the feasibility of the procedure, participants were told that the study served the purpose to relate their ability to solve a rule-based cognitive task with their ratings of presence in a gaming task. Furthermore, they were told that the ratings of current emotions would serve as a control variable.

The procedure of the experiment is summarized in Figure 1. First, participants filled out the PANAS. Then they were introduced to the anagram and the number series task. They had ten minutes to complete the tasks. After explaining the results of the test, participants filled out the PANAS again in order to test whether the stress-induction was successful. Next, participants were randomly assigned to one of the three experimental conditions. First, the handling of the controller was explained. Furthermore, in the *VR* condition, they were instructed on how to use the HMD and were told to immediately report any feelings of nausea. Participants were asked to freely play the game or watch the recording. The duration of this phase was 30 minutes in each condition. Afterwards, participants filled out the PANAS a third time in order to test whether playing the computer game led to mood repair. Finally, participants filled out the presence scale and answered the enjoyment question, followed by a demographic questionnaire. We carefully interviewed each participant after the experiment to make sure we did not include participants who guessed the hypotheses. Only five participants reported that they drew a link between the gaming task and the mood questionnaires and were therefore excluded. Upon completion of the experiment, the participants were debriefed.

3. Results

3.1 Strategy of Analyses

We used two different approaches to test our hypotheses: In an experimental approach, we compared the three experimental conditions in terms of positive and negative mood repair, presence, and enjoyment, using one-way analyses of variance (ANOVAs) or Kruskal-Wallis tests. In a correlational approach, we calculated measures of association between individual levels of presence, enjoyment, and mood repair. Group-size-weighted bivariate correlations with Pearson coefficients were used. Additionally, we calculated a moderated regression model to differentiate the effect of individual presence on mood repair from the group-level effect of presence. This is important because of the hierarchical structure of the data: Individual presence and mood repair are nested in the three conditions and, thus, the overall level of presence and mood repair could vary between groups (contextual effect). Therefore, analyzing the effect of presence only on the individual level would potentially result in a *Simpson's paradox* (cf. Ameringer, Serlin, & Ward, 2009). We also report an exploratory mediated regression model to test whether enjoyment serves as a mediator variable between presence and mood repair. Since mood repair in positive and negative emotions were both left skewed, we performed a log-transformation with an added constant on both variables. This way we obtained normally distributed residuals for the correlational analyses.

3.2 Descriptive Statistics

A summary of descriptive statistics for the whole sample is presented in Table 1. All but six participants had never used an HMD before. Additionally, the average time participants spend playing computer games in a week was 66 minutes (SD = 164 minutes).

3.3 Manipulation Checks

To examine the stress-induction procedure, we analyzed differences in the PANAS ratings before and after the stress-induction (t2 – t1). As expected, the mean value for positive emotions after the stress-induction ($M = 6.41$, $SD = 2.37$) was lower than the baseline mean value assessed before the stress-induction ($M = 7.42$, $SD = 1.85$). This indicates that the stress-induction for positive emotions was successful, $t(76) = -6.81$, $p < .001$, $d = -0.78$. Similarly, ratings for negative emotions were higher after the stress-induction ($M = 2.70$, $SD = 2.08$) than before the stress-induction ($M = 1.57$, $SD = 1.33$), $z = 2652$, $p < .001$, $d = 0.67$ (a Wilcoxon signed-rank test was used because residuals were not normally distributed).

A one-way Kruskal-Wallis test was used to assess differences in presence scores between conditions for the SAM questionnaire because residuals were not normally distributed. This served as a check whether the manipulation of designated immersion worked as intended. The test revealed a significant effect, $\chi^2(2) = 19.0$, $p < .001$, $\varepsilon^2 = 0.25$. Post hoc comparisons (Dwass-Steel-Critchlow-Fligner) showed that presence scores were lower in the *video* condition compared to the *desktop* and *VR* conditions (both $p < .01$). Descriptively, there was a linear trend, which suggests that the higher the intended immersion of the condition, the more presence was reported by participants. This is in accordance with our expectations. Presence scores for each condition are shown in Figure 3.

A one-way ANOVA revealed also a significant difference between conditions in enjoyment, $F(2, 74) = 12.2$, $p < .001$, $\eta_p^2 = 0.25$. Post-hoc comparisons (Tukey) indicated that the *video* condition involved lower enjoyment compared to the other conditions (both $p < .001$). Enjoyment scores for each condition are shown in Figure 4.

3.4 Testing the Hypotheses

Hypothesis 1. The higher the immersion of the gaming activity, the stronger the effect of mood repair.

We looked at mood ratings to test the first hypothesis. Overall, there was a change in emotional ratings from before gaming to afterwards across conditions for positive, $t(76) = 3.82$, $p < .001$, $d = 0.44$, and negative emotions, $t(76) = -6.90$, $p < .001$, $d = -0.79$ (see table 1 for descriptive statistics). This means that overall, a significant effect of mood repair in positive and negative emotions could be observed. In line with the first hypothesis, the strength of mood repair depends on immersion: There was a significant difference in the change of positive emotions between conditions, $F(2, 74) = 5.18$, $p = .008$, $\eta_p^2 = 0.12$ (see figure 5). A planned contrast revealed that the *video* condition differed from the other conditions, p = .002. Successful mood repair in positive emotions could only be observed in conditions involving active gaming (see descriptive statistics in figure 5: There was a decrease in positive emotions for the *video* condition). There was, however, no differential effect for mood repair in negative emotions between conditions, $F(2, 74) = 0.21$, $p = .811$, $\eta_p^2 = 0.01$ (see figure 5). This means that the strength of mood repair was affected by the condition only in positive emotions, which partially supports the first hypothesis.

Hypothesis 2. The higher the level of individual presence, the stronger the effect of mood repair.

Weighted bivariate correlations were computed using the *weights* package in *R* (Pasek, 2018; R Core Team, 2019). The results show that individual presence is related to mood repair in positive emotions but not in negative emotions (see Table 2 for an overview). This means that a higher individual presence rating was associated with stronger mood repair in positive emotions. This partially supports our second hypothesis stating that individual presence levels enhance mood repair.

To control for a potential Simpson's paradox, we calculated moderated regression models with presence as a linear predictor and immersion as a factorial predictor. The dependent variables were mood repair in positive and negative emotions. The results for positive emotions are shown in Table 3. The model for negative emotions yielded no significant prediction of mood repair ($R^2 = .08$, $F(5, 70) = 1.14$, $p = 0.346$). A simple slope analysis revealed that presence predicted mood repair in positive emotions only in the VR condition ($b_{VR} = 0.15$, $p = 0.002$; other slopes both $p > 0.05$; see Figure 6). Therefore, the positive effect of individual presence on mood repair in positive emotions was limited to the VR condition.

Hypothesis 3. Enjoyment is positively related to (a) mood repair and (b) presence.

Enjoyment was positively associated with mood repair in positive emotions but not negative emotions (see Table 2). Enjoyment was also positively associated with presence. Thus, hypothesis 3a was partially and hypothesis 3b fully supported.

To further investigate the relationship between the variables presence, enjoyment and mood repair in positive emotions, we tested an explorative mediation model using the *jAMM* module in *jamovi* (Gallucci, 2019; The jamovi project, 2019). We tested whether enjoyment mediates the relationship between individual presence and mood repair in positive emotions. To again control for possible contextual effects, the immersion of the condition was entered as an additional explanatory variable (all possible moderation effects of immersion were non-significant and were therefore not included in the final model). An overview is provided in Figure 7. The results show that the relationship between presence and mood repair in positive emotions is mediated by enjoyment. The unstandardized regression coefficients between presence and enjoyment and between enjoyment and mood repair in positive emotions were statistically significant. The indirect effect was tested using bootstrapping procedures (1000 samples) as proposed by Hayes (2017). The unstandardized indirect effect of presence on mood repair in positive emotions was significant, $B = .29$, $SE = .14$, 95% $CI = .07, .62$. There was, however, no total and no direct effect of presence on mood repair in positive emotions (both $p > .05$). These results are consistent with indirect-only mediation (Zhao, Lynch, & Chen, 2010). The indirect effects of the immersion conditions on mood repair in positive emotions were not significant (both $p > .05$).

4. Discussion

We investigated whether immersive gaming conditions led to improved mood repair after a stress-induction and whether the individual level of presence was associated with better mood repair. High immersion was operationalized with a VR gaming condition, medium immersion with a desktop gaming condition, and low immersion with a passive video condition. Supporting our expectation, the level of presence varied between the conditions, with the *VR* condition evoking the highest levels and the *video* condition evoking significantly lower levels than the two active gaming conditions. The active gaming conditions were also evoking higher levels of enjoyment and stronger mood repair in positive emotions. This supports the idea that immersion in video games improves the overall state of mood after episodes of stress. However, whereas negative emotions generally decreased after the gaming activity, the immersion of the condition and the individual level of presence did not affect mood repair in negative emotions. Furthermore, using a moderation analysis, we could show that the individual level of presence was a significant predictor for mood repair in positive emotions, after controlling for immersion. However, presence only led to significantly improved mood repair in the VR condition. Finally, using an exploratory mediation analysis, we showed that only the individual level of presence led to improved mood repair in positive emotions by evoking higher levels of enjoyment (indirect-only mediation). Immersion was also associated with higher enjoyment but showed no indirect effect on mood repair.

The main result of our study is that individual presence levels are favorable for attaining an overall improved mood state. This provides empirical support for the claim that presence experiences in gaming enhance well-being and mood (Collins & Cox, 2014; Reinecke, 2009a; 2009b; Reinecke et al., 2011). Previous research has linked effects of mood enhancement to the extent of experienced presence in relaxing VR environments (e.g. Freeman et al., 2004; Villani et al., 2007; Villani et al., 2009). Our results suggest that presence contributes to mood repair not only in immersive environments designed to be relaxing, but also in games. We could show that presence was associated with mood repair in positive emotions. There seemed to be a weak association with mood repair in negative emotions, but this finding did not reach statistical significance. After controlling for immersion, we could demonstrate that individual presence affects mood repair in positive emotions independent of the differences between the conditions. However, this effect was limited to the *VR* condition. In the *desktop* condition, there was a small but non-significant effect, and in the *video* condition, the effect was negative but also non-significant. A possible explanation for these results is that presence plays a more important role in an immersive virtual world. This means that gaming itself is crucial for improved mood and that presence only enhances mood in VR gaming. Potentially, presence is only beneficial for mood repair if it is relevant for the respective medium: A simple yet non-immersive game can still evoke strong enjoyment in players, whereas a game like Star Conflict relies on immersive gameplay features to involve the user in the game narrative, which then leads to enjoyment. The immersive elements are even more important if the world is supposed to appear convincingly realistic as in a VR condition. A floor effect in the *video* condition could serve as an alternative explanation: the *video* condition was not able to lead to large enough presence and enjoyment scores to improve mood. Indeed, there were no high presence scores for the *video* condition (the highest score was 3.80). Additionally, very high scores (> 4.5) were mainly observed in the *VR* condition. Thus, it is possible that presence scores were not high enough in the *desktop* condition to evoke an individually increasing effect on mood repair, whereas the *VR* condition provided participants with the opportunity to experience large increased presence scores, leading to highly improved mood. There are also other possible explanations and additional studies using VR gaming are needed to confirm our results.

Apart from the effect of presence on mood repair, our results also confirm previous findings: A gaming activity led to an overall improved mood state after a stress-induction (cf. Collins & Cox, 2014; Reinecke 2009a; 2009b). The size for this effect was small to medium in positive emotions (0.44) and large in negative emotions (-0.79; Cohen, 1988). As in previous studies, active gaming led to an overall improved mood state compared to watching a video (Chen & Raney, 2009; Collins et al., 2019; Reinecke et al., 2011; Rieger et al., 2015). Thus, positive mood only increased in the gaming conditions. There was no difference between the VR and the desktop condition, which means that VR as a medium might not be overall better at improving mood than desktop gaming, despite offering a higher potential for strong presence experiences. It is possible that the interactivity of active playing led to already strong mood repair in the gaming conditions and that the VR condition was simply not offering an additional benefit in our study. After all, Star Conflict is described as fun to play in online forums (Oculus VR, 2015). This assumption could be tested in future studies by comparing VR and desktop conditions using games with different potentials for mood improvement.

In contrast to the active gaming conditions, positive mood showed a small decrease in the video condition. Generally, this is in line with our expectations but could indicate that watching a pre-recorded gaming session does not provide a boost in positive emotions. This is an important finding because watching others playing games on YouTube, Twitch.tv, or at e-sports tournaments is increasingly popular among gamers (Gandolfi, 2016; Smith, Obrist, & Wright, 2013). Studies suggested that watching such videos involves experiences of presence (Collins et al., 2019; Wong et al., 2017). In a previous study by Chen and Raney (2009), the increase in positive mood was higher in an interactive condition but was also positive in a non-interactive condition and a control condition. Rieger et al. (2015) found a similar increase of positive emotions in all interactivity conditions. In contrast to positive emotions, negative emotions in our experiment decreased in each condition to about the same amount, indicating no advantage of active gaming and VR technology. Interestingly, previous studies (Chen & Raney, 2009; Rieger et al., 2015) found that negative emotions did not decrease in a non-interactive condition but only in an interactive condition. Thus, the *video* condition in our experiment showed a surprising decrease in negative emotions but also a decrease in positive emotions. A reason for this could be the different choice of games. Star Conflict probably involves more action and strategy than games used in previous studies, which could enhance the potential for increasing positive emotions. Another reason could lie in different measurements of mood repair: Rieger et al. (2015), for example, operationalized positive and negative mood with measures for happy and depressed mood. In contrast, the PANAS questionnaire, which was used in our study, is targeted at more general mood states, including items such as *attentive* and *nervous*. However, the *video* condition in our experiment evoked also less presence and enjoyment scores than the active gaming conditions. This is in line with anecdotal reports of participants. It is plausible, therefore, that the low overall enjoyment of the video led to the unimproved positive mood. Additionally, there was arguably a lack of competition in the *video* condition. According to Reinecke (2009a; 2009b), successful recovery demands for a task structure that enables competence and mastery experiences. The same could be true for mood repair. As for negative mood, it is possible that negative emotions decreased naturally over time. We cannot separate the effect of time from the overall effect of the gaming activity since there was no non-medium control condition. Thus, further studies should investigate the specific advantage of watching others play by contrasting it with a non-medium control condition.

Another important point is that we found no meaningful associations involving mood repair in negative emotions. Interestingly, the two measures of mood repair showed no substantial correlation. Negative emotions could, therefore, activate other processes than positive emotions. It is possible that gaming is especially helpful for restoring positive affect but not as effective as previously thought in reducing negative affect. Interestingly, recent findings from organizational psychology provide evidence that recovery from work-related stress goes beyond the replenishing of depleted resources and involves preemptively building up resources to increase coping capabilities and to avoid future loss of resources (Conservation of Resources Theory; Hobfoll, 1989; cf. Reinecke & Eden, 2016). Thus, preemptively building up a positive mood state by increasing positive emotions could be more functionally relevant for gamers and more easily achievable than eliminating negative emotions. It is worth noting, however, that previous studies did find a beneficial effect of gaming for negative emotions. Context (i.e. the type of game and the method for inducing a negative mood state) could play an important role. This discrepancy should be addressed in further research by specifically comparing the effects of positive and negative mood repair and by varying the type of computer game and other variables such as the length of media exposure.

Lastly, we showed that enjoyment mediated the effect of presence on mood repair in positive emotions. This supports our expectation that presence is beneficial for mood repair because it leads to a higher enjoyment of a game. Wirth et al. (2007) suppose that increased presence in entertaining media leads to increased enjoyment of the media's content. Accordingly, Teng (2010) proposes that immersion in games is pleasurable and satisfies the user’s need. In accordance with this assumption, Weibel and Wissmath (2011) were able to show for various computer games that presence has a positive influence on enjoyment. Reinecke and coworkers (2011) noted that enjoyment could be an important amplifier for the recovery effect. Enjoyment was also related to involvement in their study. Our results support these conclusions. Presence was highly correlated with enjoyment and higher enjoyment led to increased mood repair in positive emotions. However, our results should be considered exploratory and further studies are needed to confirm this relationship.

Our results clearly demonstrate positive effects of gaming. However, it is important to note that this might not always be the case and that there could also be negative effects. Bowman and Tamborini (2012; 2015), for example, showed that high task demand – as opposed to medium demand – led to less mood repair. We did not measure task demand, but it is likely that task demand was medium and not high in our study: the control of the ship in Star Conflict is comparatively complex, but participants only played a beginner's tutorial. Consequentially, all participants managed to complete the tutorial successfully. However, if the demand of a game is too high, effects of mood repair could be severely impaired (Bowman & Tamborini, 2012; 2015). Furthermore, a recent experience sampling study found that more than half of the studied media occurrences (including gaming) showed at least some degree of conflict with other goals and responsibilities (Reinecke & Hofmann, 2016). This goal conflict as well as the evaluation of one’s own media use as a form of procrastination can result in feelings of guilt that reduce enjoyment and impair situational well-being (Reinecke, Hartmann, & Eden, 2014; Reinecke & Hofmann, 2016). Reinecke and Eden (2016) propose that prolonged media exposure may turn media use from a resource-providing into a resource-consuming activity. Thus, prolonged gaming could lead to impaired mood, even when short-term effects are positive. Successful media-induced recovery and mood repair seem to depend on the right dosage.

In conclusion, our results show that gaming improves mood. Furthermore, the individual level of presence enhances the effect of mood repair in VR and presence is also strongly related to media enjoyment. Our results show that the presence experience in a game affects mood repair beyond the effect of the game's immersion and that only presence might influence positive emotions by evoking higher enjoyment. The individual level of presence is especially important for VR games as they may potentially offer greater opportunities for experiencing high levels of presence. Presence experiences effectively enhance mood states and build up resources. This has implications for the VR gaming industry as well as health research. The positive effect of presence in VR could be used for the treatment of stress and negative affect. In addition to relaxing environments, games offer challenges and competition and are a form of treatment that can draw from thousands of readily available experiences. Additionally, immersive experiences in games are beneficial for mood repair and show that the immersion of a game combine with the individual's reaction towards the game to promote psychological well-being and recovery from stress and negative mood states.

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Table 1.

Descriptive statistics for variables across all conditions.

Variable	*min*	*max*	*M*	*SD*
Enjoyment	1	10	5.70	2.75
Pictorial Presence SAM	1.00	5.00	3.40	0.85
Mood repair in positive emotions	-2.21	7.46	0.80	1.84
Mood repair in negative emotions	-1.18	9.10	1.27	1.61

Notes: *N* = 76 for Pictorial Presence SAM and 77 for all other variables.

Table 2.

Bivariate weighted correlations between variables (across conditions).

	1	2	3	4
1. Mood repair in positive emotions	-			
2. Mood repair in negative emotions	.20	-		
3. Pictorial Presence SAM	.34**	.14	-	
4. Enjoyment	.52***	.12	.51***	-

Notes: * $p < .05$, ** $p < .01$, *** $p < .001$ (one-tailed). All p-values were adjusted using the Bonferroni method. Mood repair in positive and negative emotions was log-transformed to obtain normally distributed residuals. $N = 76$ for Pictorial Presence SAM and 77 for all other variables.

Table 3.

Mood repair in positive emotions predicted by presence (focal predictor) and immersion (moderator).

Predictor	*b*	SE	95% CI	
Intercept	0.33	0.07	0.19	0.46
Presence	-0.06	0.07	-0.20	0.08
Desktop condition	0.25	0.08	0.10	0.40
VR condition	0.18	0.08	0.03	0.34
Presence x desktop condition	0.11	0.08	-0.06	0.27
Presence x VR condition	0.21	0.08	0.04	0.38

Notes: $R^2 = 0.27$, $F(5, 70) = 5.18$, $p < .001$. The video condition was used as the reference group (dummy coding). Presence was centered. Mood repair in positive emotions was log-transformed in order to obtain normally distributed residuals.

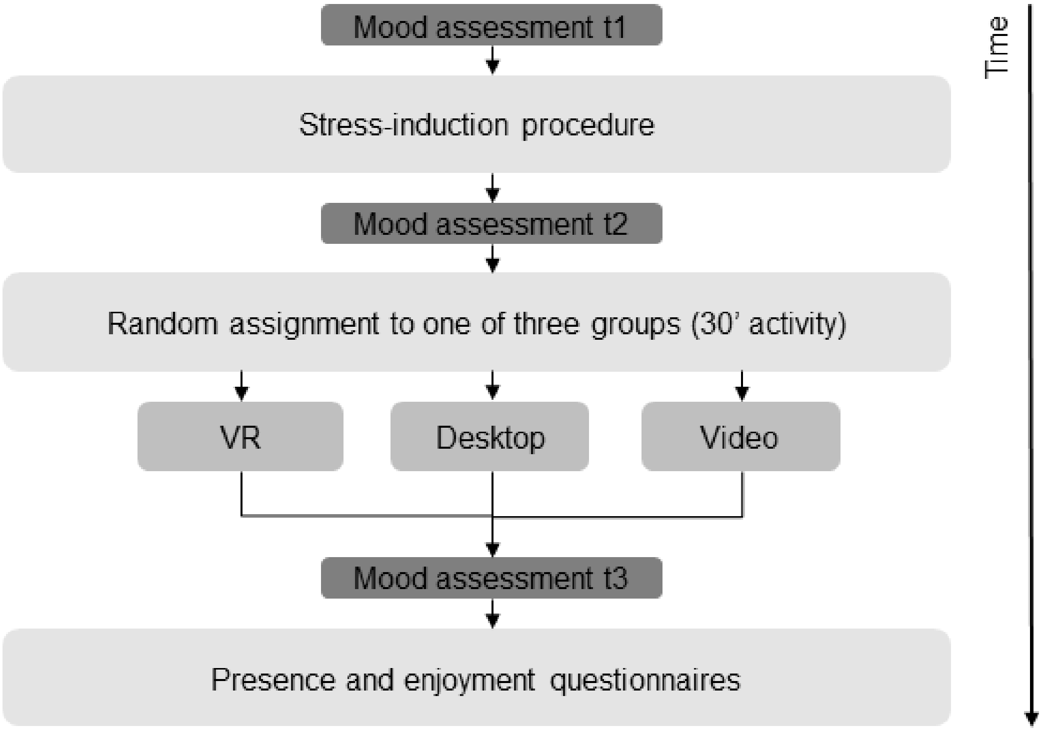

Figure 1. Graphical representation of the procedure

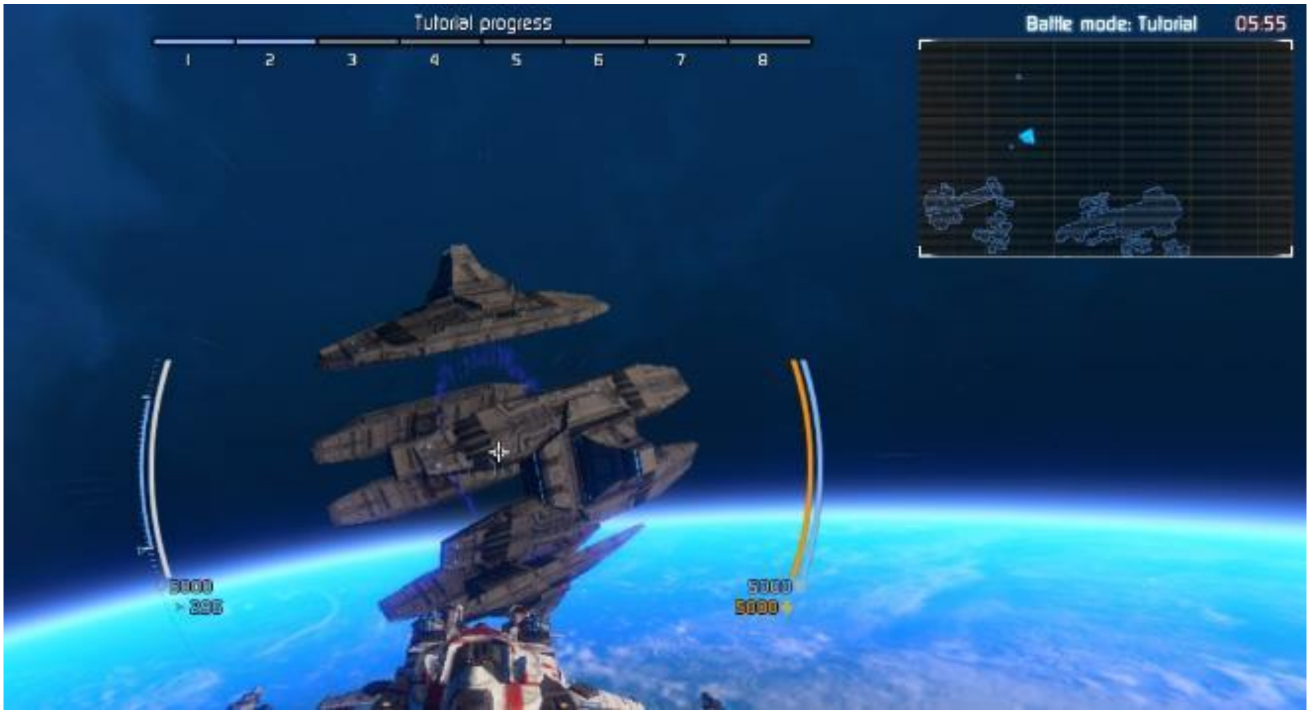

Figure 2. Screenshot from Star Conflict

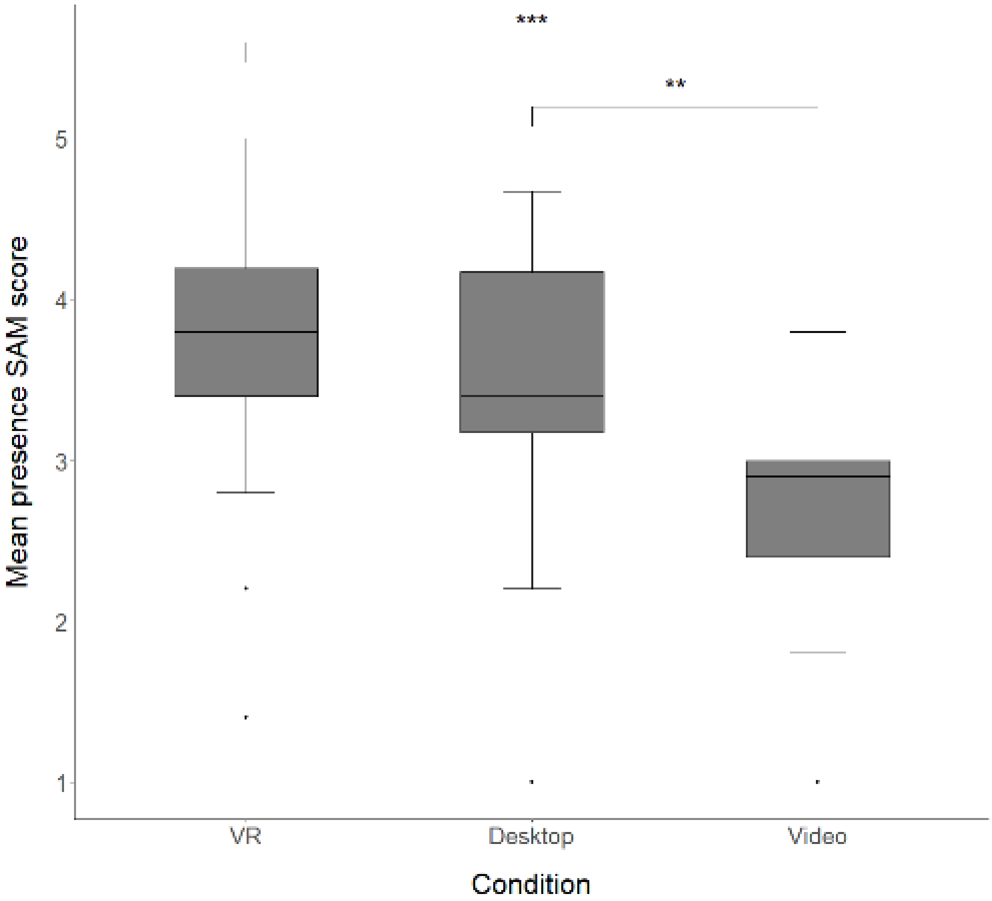

Figure 3. Mean presence SAM scores for each condition. Error bars represent standard errors.

Significance codes: ** *p* < .01, *** *p* < .001

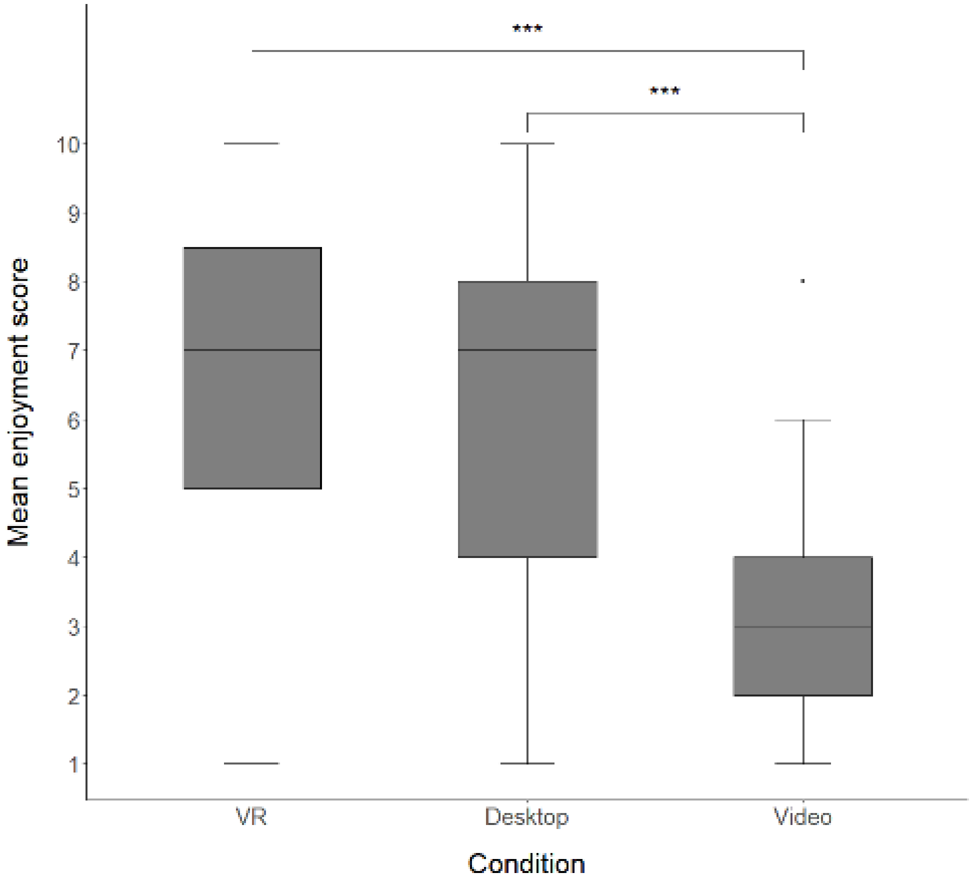

Figure 4. Mean enjoyment scores for each condition. Error bars represent standard errors.

Significance codes: ** *p* < .01, *** *p* < .001

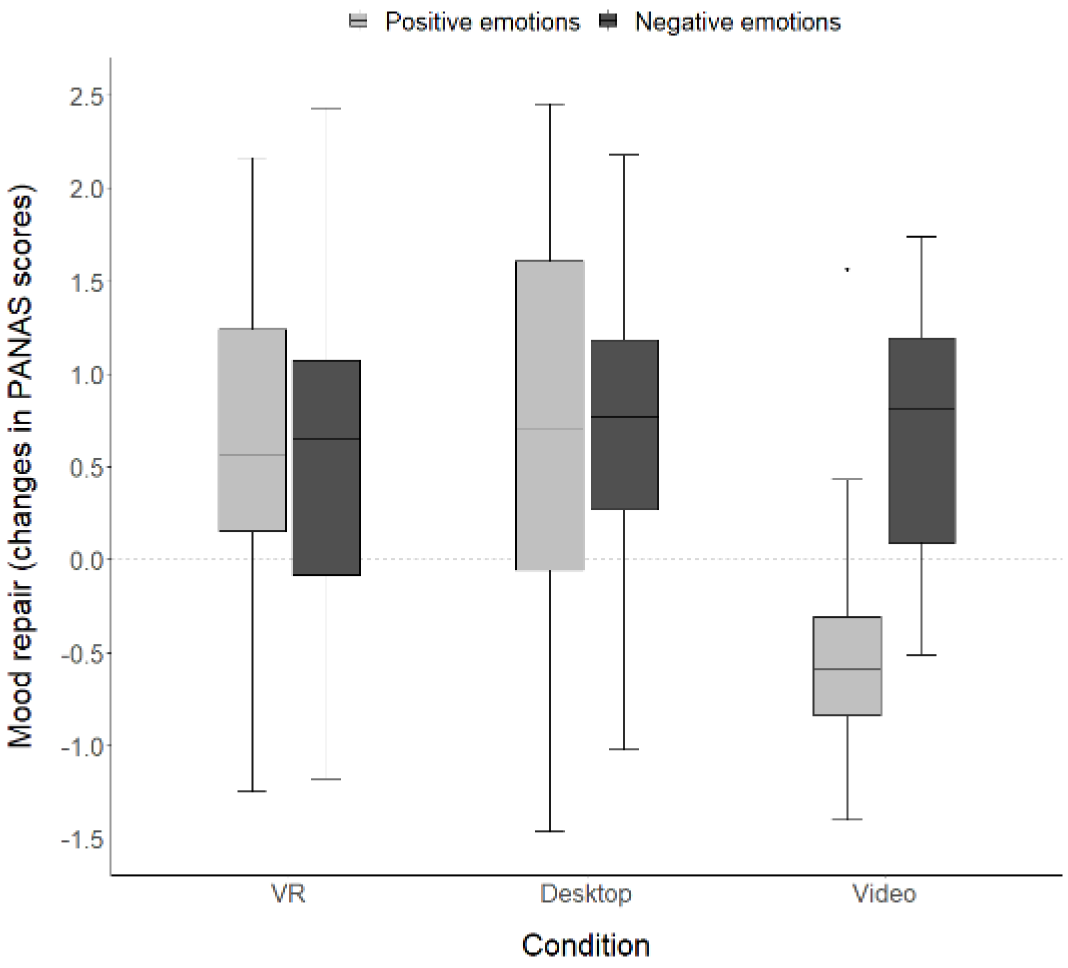

Figure 5. Mood repair in positive and negative emotions in each condition. In terms of positive emotions, stronger mood repair was found for the two gaming conditions compared to the video condition. Note that decreases in negative emotions (i.e. change in the desired direction) are shown as positive values to facilitate interpretation. Error bars represent standard errors

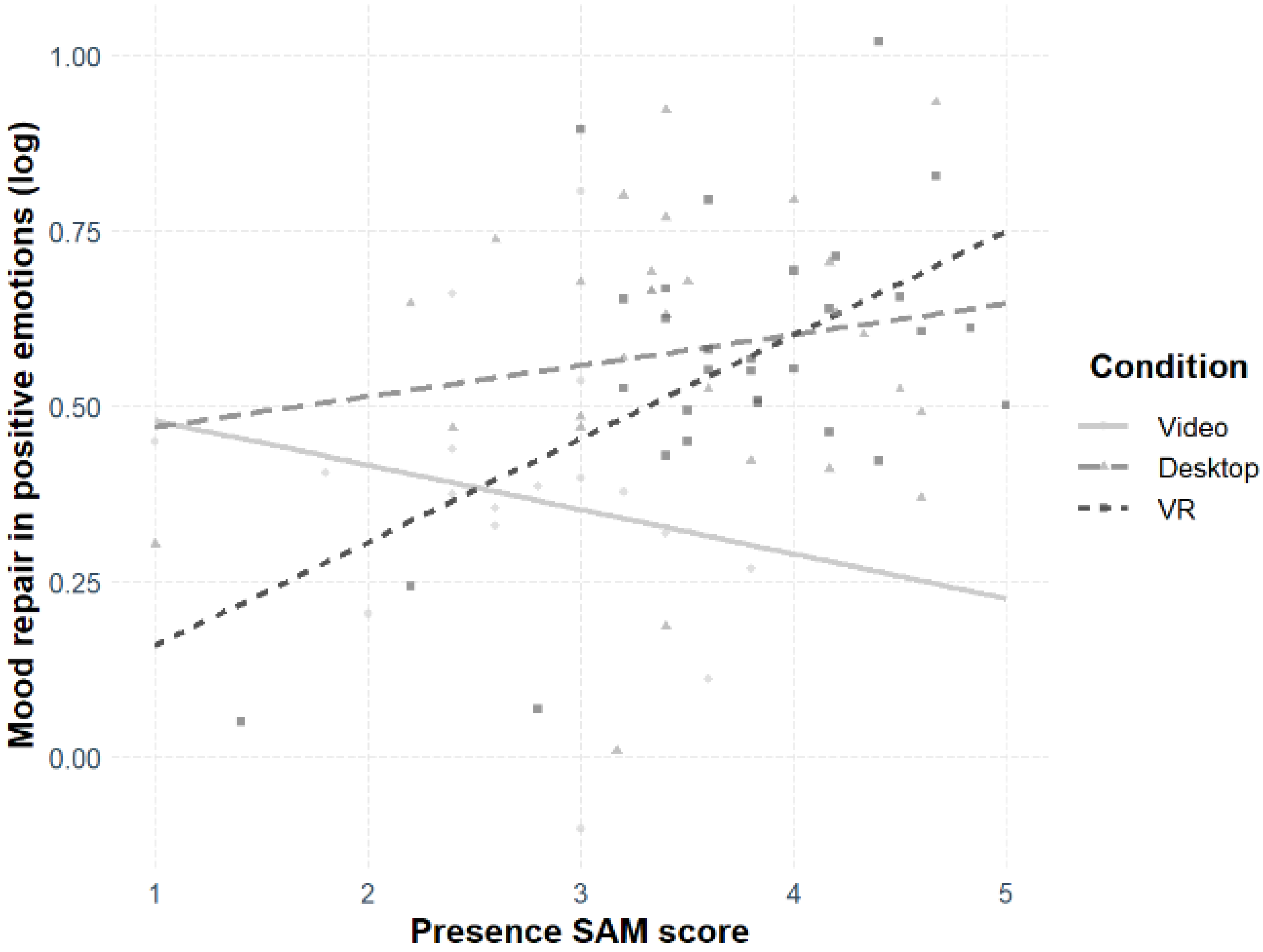

Figure 6. Simple slope analysis for the effect of presence on mood repair in positive emotions.

Only the simple slope in the VR condition was significant (*p* = .002)

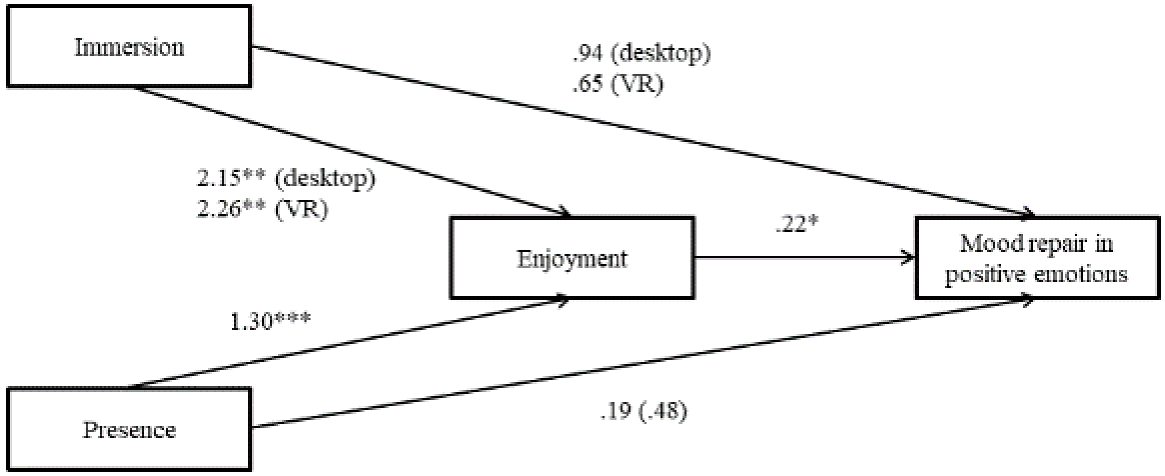

Figure 7. Unstandardized regression coefficients for the relationship between presence and mood repair in positive emotions as mediated by enjoyment. Immersion was entered as an explanatory variable to control for contextual effects. This categorical independent variable is shown with only one rectangle, but its effects are estimated using contrast variables (dummy coding with the video condition as reference category). Presence was centered. Covariances among independent variables are estimated but not shown. The total effect between presence and mood repair is in parentheses. Bias-corrected bootstrapping (1000 samples) was used to obtain p-values. *p < .05, **p < 0.01, ***p < 0.001

Manuscript IV:

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How to Get There When You Are There Already? Defining Presence in Virtual Reality and the Importance of Perceived Realism

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1 Introduction

Opticians do not only measure visual acuity but also the visual field, stereoscopic vision, and color vision. In the same vein, presence researchers should not only measure attentional allocation to the virtual environment (VE) but also the *perceived realism* of the VE. Perceived realism is a perceptual and cognitive evaluation of the virtual world. When in VR, a user will typically compare the look of virtual objects to real world objects and judge the level of congruence. Similarly, a story and its characters are also evaluated in terms of consistency and plausibility. With widespread use of immersive VR technology, it has become an easy task to absorb users in a VE and thus judgments about the realism of the VE become more important. Interestingly, perceived realism is not part of the most widely used presence definitions or is blended in with the term *being there*, respectively. Being there is strongly associated with attentional allocation and dominates current presence definitions. Mental absorption and perceived realism are both important aspects of presence and need to be combined in order to obtain an adequate assessment of presence in VR. Thus, theories and measures of presence need to be extended and establish perceived realism as an important domain besides being there.

2 Presence in VR: Being There and Perceived Realism as Two Crucial Dimensions

Presence is defined as the sense of being in a computer-mediated environment (Draper et al., 1998; Steuer, 1992) or being in a computer-generated world such as in VR (Sheridan, 1992; Slater & Wilbur, 1997). Presence is a shortened term for *telepresence* and was first introduced by Minsky (1980). According to Steuer (1992), presence is the extent to which one’s attention is allocated to the mediated environment rather than to the immediate physical environment. Thus, commonly, the expression *being there* was used to describe presence (Sheridan, 1992; Steuer, 1992; Witmer & Singer, 1998; see Skarbez et al., 2017). Lombard and Ditton (1997) use the term *illusion of non-mediation*. This illusion occurs when a person does no longer perceive the mediated environment as being displayed by a media device. A similar concept was proposed by Wirth et al. (2007), according to which presence occurs when attention is allocated to the mediated environment being the user’s primary egocentric frame of reference (PERF). Slater

(2003, 2009) conceives presence as the result of a *Place Illusion* (PI) and a *Plausibility Illusion* (Psi). The PI is the result of sensorimotor contingencies (actions in the VE correspond naturally with perception). It relies on technical preconditions. PI also refers to a “sense of being there” (Slater, 2009, p. 3551). In contrast, Psi is based on story-based interactivity and the credibility of characters.

To our knowledge, three studies were carried out to gather insights into the dimensionality of presence (Lessiter et al., 2001; Schubert et al., 2001; Witmer et al., 2005). Factor analyses yielded either an involvement or an engagement factor (Skarbez et al., 2017, p. 24). Both terms are connected to attention and the sensation of being there. The sensation of being there depends on the amount of attentional resources allocated to the virtual world rather than to internal thoughts or other non-visible external sources. If one feels present at a certain place, it means that one's thoughts are concerned with this place rather than another place or the medium itself. Thus, in line with Wirth et al. (2007), the mediated world constitutes the primary frame of reference. The prevalence of attention is also reflected in numerous concepts such as *involvement* ("focusing one’s energy and attention on a coherent set of stimuli"; Witmer & Singer, 1998, p. 227), *engagement* or *engrossment* ("the amount of time, effort and attention required from the gamer increases for more immersive experiences"; Brown & Cairns, 2004, p. 1299), *perceptual immersion* ("blocking as many of the senses as possible to the outside world and making it possible for the user to perceive only the artificial world"; McMahan, 2003, p. 77), or *absorption* ("the ability to get lost in the task at hand"; Baños et al., 1999, p. 144). We argue that this shift of attentional focus is the main concept that underlies the sense of being there. Accordingly, we define *being there* in this article as the allocation of attentional resources to the mediated world and the sensation of perceptually being surrounded by the VE.

Thus, presence is commonly associated with increased attention towards the VE and decreased attention towards external factors and the medium itself. However, presence in this sense could also be achieved by other activities requiring our attention such as focusing on the street while driving a car – clearly not a task where one would use the term presence. In this article, we focus on presence in VEs. VEs create a virtual world that is supposed to be realistic, credible, and believable. Absorbing the user is easily achieved by blocking external auditory and visual sensory input by means of head-mounted displays (HMDs). However, having a sense of being there does not necessarily imply a high level of perceived realism and, thus, a high level of presence. For example, a non-realistic world filled with simple geometrical shapes can elicit the feeling of being there, simply because this is the only environment providing sensory stimulation. Even though the attentional focus is directed to the VE in this case, one does arguably not perceive it as highly realistic or believable. Therefore, perceived realism is the important dimension that is needed for a more complete understanding of presence. Perceived realism is not a mere function of the technical properties of the VR system but rather results from the interaction between individual expectations and the properties of the VE such as tracking quality and visual appearance of objects. Users typically compare the look of virtual objects to real world objects and judge the level of congruence. This results in a judgment about the credibility of the VE. Narrative elements and characters are also evaluated in terms of consistency and plausibility (cf. *suspension-of-disbelief*). Judgments about credibility and plausibility are likely to depend on individual differences between users (cf. *immersive tendency*). Empirical findings support this idea, as they show that presence is modulated by individual expectations, personal relevance, and personality traits (Bucolo, 2004; Weibel et al., 2010; 2011a, 2011b, 2011c).

Perceived realism shares similarities with Slater's concept of Psi (2003; 2009). Psi is the extent to which one experiences the illusion of something happening as "really happening" (Slater, 2009, p. 3553). Psi occurs if there is a correlation between the user's actions and corresponding events in the VE. In contrast to Psi, perceived realism is a conscious judgment, not just a perceptual illusion. We do not regard it as a rapid and automatic response but rather as a conclusive judgment about the credibility and realness of the VE. Another difference is that users also take into account the visual quality of the VE. In Slater's (2009) terminology this would be referred to as PI – the illusion of being there. PI is binary (one is there or not) and modality-specific (users can have full visual PI even when there is no auditory PI, or vice versa). However, in accordance with other presence theories, we define being there as an allocation of attentional resources. Therefore, users can allocate continuous amounts of attention to the VE and this is usually strongly correlated across perceptual modalities.

Apart from Slater (2009), perceived realism was not an essential part of influential theories of presence. Although realism is often mentioned, it is usually only regarded as a beneficial factor for feeling absorbed. Unfortunately, perceived realism and attention are often mistakenly blended into the term being there. Lombard and Ditton (1997), for example, assume that an illusion of non-mediation is more likely to occur when perceived realism is high. The low priority of perceived realism can partly be attributed to the fact that the presence literature is largely based on research with early versions of HMDs with narrow field-of-views or non-VR media such as videos and desktop games. Presence in modern VR is different from presence experienced when exposed to traditional media. The user has no longer to close the gap between the physical place surrounding the computer screen and the environment that is displayed on the screen (cf. Slater & Wilbur, 1997). In three factor analyses mentioned above, either realness (Schubert et al., 2001), naturalness (Lessiter et al., 2001), or sensory fidelity (Witmer et al., 2005) were part of the final factorial structure. This underlines the need to consider the perceived realism when conceptualizing presence. In many presence theories, some form of realism is mentioned but usually not addressed in detail (e.g. Lombard & Ditton, 1997, and Witmer & Singer, 1998). Realism is, however, part of separate conceptions such as *fidelity* (Alexander et al., 2005), *reality judgment* (Baños et al., 2000), *stimulus fidelity* (Stoffregen et al., 2003), *coherence* (Skarbez et al., 2017), and *perceived realism* (Busselle & Bilandzic, 2008). We think that these concepts complement the sense of being there and they need to be incorporated into a comprehensive definition of presence in VR. For this purpose, we suggest the term *perceived realism* and define it as the individual judgment about the degree of realism of the VE.

There is no presence concept that explicitly distinguishes between being there as a form of attentional allocation and perceived realism. We claim that the focus on being there without separating attentional allocation and perceived realism is problematic for VR because the meaning of being there within VR is highly ambiguous. Unlike television, users are already *there* if equipped with a modern HMD: The entire visual field is taken in by the display, headphones are drowning external noise, and haptic devices emulate the sense of touch (cf. McMahan, 2003). Since VR devices effectively surround users with the virtual world, presence as the sense of being there is almost inevitably very high, even if VEs are poorly designed. There is almost no way of *not* being there. There is no need of getting somewhere if one is already there. This conceptual flaw manifests itself in questionnaires that are not properly adapted to modern VR and hinder a clear operationalization of presence, because they include confusing questions. For example, it is not clear how participants are supposed to respond to an item like "how much did the visual/auditory aspects of the environment involve you?" from the Presence Questionnaire (PQ; Witmer et al., 2005). In VR, there is no sensory information from the world other than the visual and auditory inputs. Yet other widely used questionnaires fail to differentiate between VR and other media experiences. The item "somehow I felt that the virtual world surrounded me" from the Igroup Presence Questionnaire (ITQ; Schubert et al., 2001) is another example. Being surrounded by the virtual world is literally inevitable. The Slater-Usoh-Steed Presence Questionnaire (SUS; Usoh et al., 2000; cf. Hein et al., 2018) uses the item, "during the time of the experience, which was strongest on the whole, your sense of being in the office space, or of being elsewhere?" For all items of this kind, it is difficult to give a conclusive answer because one is fully surrounded by the VE and *elsewhere*. In fact, many participants in VR studies report difficulties when filling out presence questionnaires. They often wonder whether they are expected to answer, “I totally agree” because a VE perceptually surrounded them or whether they are supposed to answer, “I totally disagree” because the VE was not realistic and they were at any moment in time aware of the office space surrounding them despite not seeing it. The ambiguity of questionnaire items instills different response strategies in presence questionnaires, which is highly undesirable for research. As Weibel et al. (2011c) claim, “almost every empirical study on presence includes subjective data in terms of questionnaires” (p. 866). Since this also applies to the studies conducted in VR, this is highly problematic. Presence – measured by questionnaire – is for example often used as a covariate in VR experiments, yet it is not clear whether the existing questionnaires in fact measure what is intended: Is it the allocated attention to the VE that is expected to affect the output variable or is it the judgment about the realism of the VE? Depending on the research context, it could be one of the dimensions or both. The interpretation of items could be markedly improved by separating between items measuring the sense of being there as an attentional focus on the one hand, and items measuring the perceived realism of the VE on the other hand. This would allow for a clearer operationalization of presence. Not including a separate measure for the perceived realism neglects important aspects of the virtual world and leads to a reduced range of possible responses and ambiguities in questionnaires.

Presence in VR positively affects various output measures such as task performance and therapy outcome (e.g. Ragan et al., 2010; Riva et al., 2015). Thus, evoking presence is essential for VR development as well as for research. It is not surprising that presence has been identified as a design ideal for synthetic environments (e.g. Draper et al., 1998). Being there is undoubtedly an essential part of the presence experience. It is especially important for traditional media such as desktop games and movies where one's senses are not completely surrounded by the medium and one has to actively focus on the medium. In some cases, the feeling of being there might even be the main source of presence. In VR, however, where one quite literally enters an alternative physical reality, not much is needed to create a strong sense of being there and, thus, credible and convincing VEs play a much more important role in achieving strong feelings of presence. Thus, presence in VR is more than just being absorbed by a medium; it is depending on believable and credible virtual surroundings that constitute a completely different virtual world. In our view, the feeling of presence occurs if a mediated environment (1) captures and maintains our attention and (2) is perceived as realistic. Therefore, we suggest dividing presence into the two dimensions *being there* and *perceived realism*. This is illustrated in Figure 1. In essence, being there reflects the academic view on presence, whereas perceived realism is crucial for VR developers as they typically focus on the physical realism of a VE like wide field-of-views, low-latency tracking, and high graphical quality but also on creating a plausible and compelling story (e.g. Abrash, 2014: Bracken & Skalski, 2009; McGloin et al., 2013). The suggested two-dimensional concept of presence thus also combines the developers' and researchers' understanding of presence.

3 Discussion

Past research on presence either neglected perceived realism or did not separate perceived realism from being there. This resulted not only in contradictory definitions of presence but also in numerous confusing questionnaire items. Unlike other media, VR creates highly absorbing experiences and evoking a sense of being there is easily achieved by blocking external sensory input. Creating credible and realistic VEs is also important for achieving strong feelings of presence in VR. Enhancing the perceived realism of VEs is also a main focus of VR development. Yet, it is often neglected in theoretical conceptions or blended in with being there as a form of attentional allocation. Including questions about the perceived realism of a VE and separating them from questions asking about attentional allocation could reduce the confusion in presence questionnaires: Dividing presence into two dimensions will provide a clearer operationalization, which will make effects of presence on other measures better interpretable. This distinction closes the gap between developers' main concerns about presence (perceived realism) and the researchers' focus on presence (being there).

Attention is not enough: the virtual world needs to be believable, authentic, and visually appealing. This is especially true for professional VR applications that rely on maximal comparability to the real world, such as training environments for surgeons, firefighters, or pilots. A clearer separation of being there and perceived realism makes presence more generalizable across media and especially more applicable to VR. Medium-specific questionnaires could be developed. In terms of VR, questionnaires should focus on the perceived realism of the VE. This way, game designers could obtain subjective quality measures of their VEs. Researchers could use more detailed presence measures that separate being there and perceived realism. This will lead to stronger and clearer relationships between presence and output variables like enjoyment, therapy outcome, or learning.

4 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

5 Author Contributions

SW, DW, and FM contributed to the conception of the manuscript; SW wrote the first draft of the manuscript. All authors contributed to manuscript revision, read and approved the submitted version.

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7 Figure

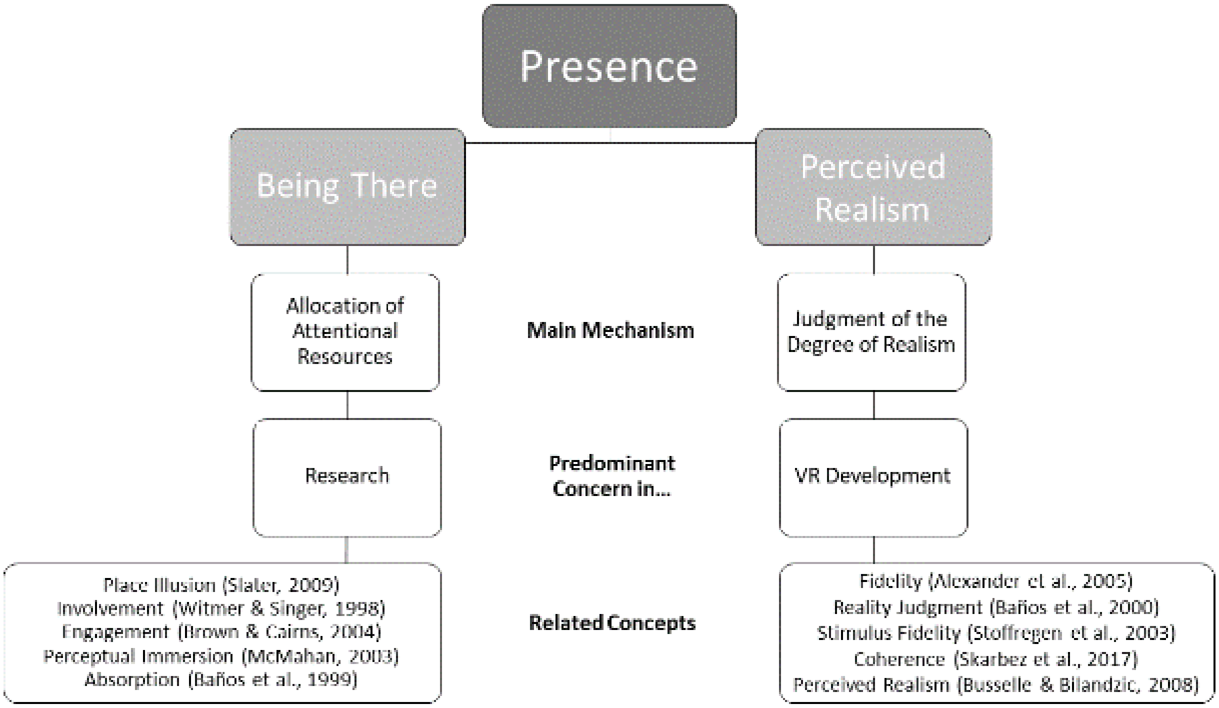

Figure 1. Being there and perceived realism as dimensions of presence