



# The Influence of Avatar Embodiment on Time Perception - Towards VR for Time-Based Therapy

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Psycho-pathological conditions, such as depression or schizophrenia, are often accompanied by a distorted perception of time. People suffering from this conditions often report that the passage of time slows down considerably and that they are “*stuck in time.*” Virtual Reality (VR) could potentially help to diagnose and maybe treat such mental conditions. However, the conditions in which a VR simulation could correctly diagnose a time perception deviation are still unknown. In this paper, we present an experiment investigating the difference in time experience with and without a virtual body in VR, also known as avatar. The process of substituting a person’s body with a virtual body is called avatar embodiment. Numerous studies demonstrated interesting perceptual, emotional, behavioral, and psychological effects caused by avatar embodiment. However, the relations between time perception and avatar embodiment are still unclear. Whether or not the presence or absence of an avatar is already influencing time perception is still open to question. Therefore, we conducted a *between-subjects* design with and without avatar embodiment as well as a real condition (*avatar* vs. *no-avatar* vs. *real*). A group of 105 healthy subjects had to wait for seven and a half minutes in a room without any distractors (e.g., no window, magazine, people, decoration) or time indicators (e.g., clocks, sunlight). The virtual environment replicates the real physical environment. Participants were unaware that they will be asked to estimate their waiting time duration as well as describing their experience of the passage of time at a later stage. Our main finding shows that the presence of an avatar is leading to a significantly faster perceived passage of time. It seems to be promising to integrate avatar embodiment in future VR time-based therapy applications as they potentially could modulate a user’s perception of the passage of time. We also found no significant difference in time perception between the *real* and the VR conditions (*avatar*, *no-avatar*), but further research is needed to better understand this outcome.

**Keywords:** virtual reality, time perception, avatar embodiment, immersion, human computer interaction (HCI)

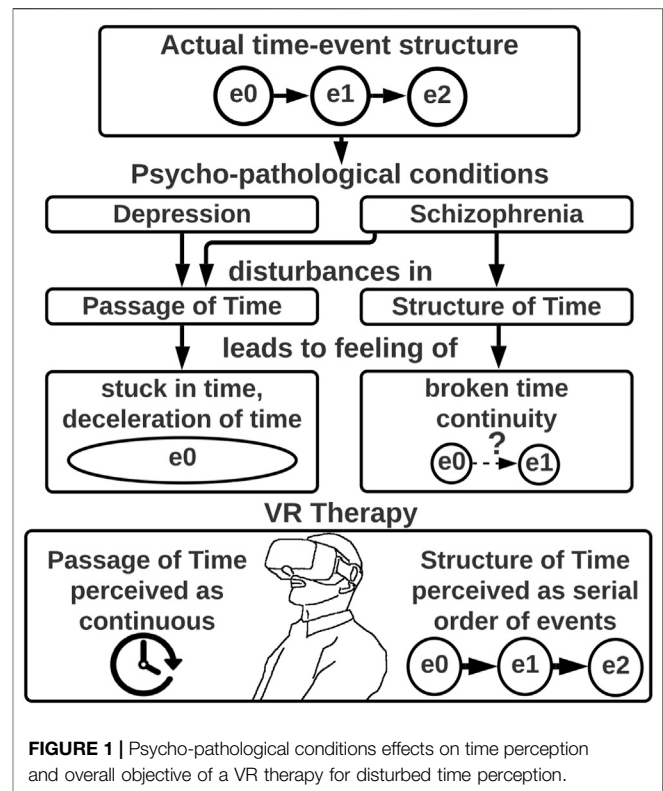
## 1 INTRODUCTION

Deviations of time perception can indicate important mental health problems. Psycho-pathological conditions, like depression or schizophrenia, are commonly associated with a disturbance of the sense of time, often described by the feeling of being “*stuck in time*” (Vogele and Kupke, 2007). People with schizophrenia have difficulties estimating time intervals (Vogele and Kupke, 2007) and a disturbance in the order of events (Giersch and Mishara, 2017). The succession of events and the relationships between events, aka *time event-structure*, which contributes to the sense of time continuity, is actually distorted for persons suffering from schizophrenia. Typically, information that occurs within windows of 20–50 ms is judged to be simultaneous, and such temporal simultaneity can help to group information together (Javitt and Freedman, 2015). Asynchrony helps us to distinguish successive events from one another, and to order them. However, patients with schizophrenia have difficulties in distinguishing sensory stimuli in time (Giersch and Mishara, 2017). Basic temporal structure is maintained by people with depression, but they report a slowing-down of the experienced passage of time (Vogele and Kupke, 2007; Fuchs, 2013). Persons affected by such disorders are severely handicapped, since the feeling of time contributes to our well-being (Meissner and Wittmann, 2011; Droit-Volet et al., 2013; Wittmann, 2013). Although these psycho-pathological conditions can be detected, the diagnoses and therapies targeting a distorted time perception are difficult to realize.

Virtual Reality (VR) therapy has been proven to be efficient in treating a variety of specific psychological disorders, e.g., specific anxieties or post-traumatic stress disorders (Wallach et al., 2009; Gonçalves et al., 2012; Lindner, 2020). Most approaches regarding people suffering from schizophrenia or depression do not focus on the disturbed perception of time (Freeman et al., 2017). Patients in group therapies prefer the possibility of anonymization through an avatar (Dilgul et al., 2021). Hence it seems worthwhile to investigate the applicability of VR for the development of diagnostic and therapeutic methods based on time perception as depicted in **Figure 1**.

However, such an envisioned usage of VR needs to first sanitize VR with respect to any potential impact on time perception per se and on healthy subjects. Prior work confirmed the existence of a perceived distance compression in VR (Grechkin et al., 2010). Since space and time are interdependent phenomena in human perception (Helson and King, 1931; Jones and Huang, 1982; Sarrazin et al., 2004), it is not unreasonable to hypothesize similar distortions to exist for the perceived time in VR, i.e., time compression or extension. It was also shown that the perception of time in VR can be influenced passively *via* the medium as a distraction (Schneider and Hood, 2007; Schneider et al., 2011) or actively by means of time influencers, or so-called *zeitgebers* (e.g., velocity of the course of the Sun) (Schatzschneider et al., 2016). “Zeitgebers are cues that help to locate oneself in time (of day) or to mark the passing of time, i.e., the speed of time” (Schatzschneider et al., 2016).

Substituting a person’s body with a virtual body significantly impacts the experience of perception in VR. Numerous studies



demonstrated interesting perceptual, emotional, behavioral and psychological effects caused by embodiment (Peña et al., 2009; Spanlang et al., 2014). In addition, VR therapeutic applications tend to develop environments using different forms of embodiment (Shahnewaz et al., 2016; Hamzeheinejad et al., 2019; Kern et al., 2019).

Achieving plausible and believable virtual embodiment requires specific technical skills and expensive infrastructure, usually requiring full-body tracking and possibly haptic feedback (Spanlang et al., 2014). The use of advanced VR systems used in avatar embodiment studies is neither conceivable nor recommended in a medical practice with medical personnel who are not trained in the operation of the required technology. Technical problems can quickly render a VR experience detrimental. This should be avoided at all costs, especially for patients suffering from psychosis. Low-cost VR consumer systems such as the Oculus Quest™ seem to ease the technical complexity and hence operation of VR systems. Such systems and their head and hand tracking lack sufficient full-body tracking for a faithful avatar embodiment. Alternative approaches based on inverse kinematics do not yet solve this problem, as they are often still prone to incorrect movement predictions, which can lead to undesirable biases in perceptual, emotional, behavioral and psychological effects. At the moment, there is no simple or cost-aware approach to faithful movement reproduction. The actual need to support avatar embodiment is an important question to answer for future time-based VR therapy tools to determine whether it is worth investing research and development time in (extended) embodiment.

Lugrin et al. (2019) measured the estimation and judgement of a short waiting time in VR with or without avatar embodiment, and with different approaches to replicate an existing room (i.e., using a 360°-panoramic picture or rendered 3D models). The results showed that waiting time in VR can be perceived differently than in reality. Only differences in the perceived time between a real waiting situation and a waiting situation in VR without an avatar could be determined. This first results suggests a possible relation between avatar embodiment and time perception. However, no measures such as embodiment or presence were taken in the course of this study and only 15 participants per condition were evaluated. Taking into account previous work and its identified limitations this paper reports on a study focusing on the influence of embodiment on time perception. The approach focuses on the specific manipulation of embodiment as an independent variable, the collection of a substantial sample size and the use of a sufficiently long duration during VR exposure.

The next sections will summarize our contributions and main findings before presenting the related work and our approach. The experiment carried out is then described in detail, while the last part will discuss the overall results and limitations before concluding with our future work.

## 2 CONTRIBUTIONS

We present a novel study investigating the influence of VR with and without embodiment on time perception of healthy people. We replicated and extended the experiment from Lugrin et al. (2019). We added additional measures related to presence and avatar embodiment and collected a larger sample. The experiment is reproducing a *waiting* task scenario, which is typical for time perception experiments (Osuna, 1985; Taylor, 1994; Zakay, 2014). However, we evaluated this task in a real and in a virtual condition. We let people wait in the real physical environment or, in VR inside a virtual environment replicating the real one. Our main finding is that the presence of an avatar in VR leads to a significantly faster perceived passage of time, whereby the participants felt the time going faster. Integrating avatar embodiment into future time-based VR therapy applications therefore seems promising, as it could potentially modulate the user's perception of the passage of time. There was no significant difference in terms of time perception between the *real* and the VR conditions (*avatar, no-avatar*). This result contradicts the previous findings of Lugrin et al. (2019) therefore future work is needed to examine potential underlying factors.

## 3 RELATED WORK

The definition of time is multifaceted and varies across many research areas, e.g., in physics, biology, philosophy and psychology. *Physical Time* and *Psychological Time* are two distinct concepts that are essential in understanding time perception. *Physical Time* is defined as a “non-spatial

continuum in which events occur in apparently irreversible succession from the past through the present to the future” (The free dictionary, 2020). The *Physical Time* could then be understood as the time given and measured using clocks in the real world and is considered to be objective. The *Psychological Time*, in contrast, is often described as being subjective: “It refers to temporal dimensions such as duration, pace and the order of perceived and internal events” (Zakay, 2014). This sense of time co-constitutes our subjectivity (Kant, 1990) which we can experience as “*stream of consciousness*”—a continuous whole that passes over time (James et al., 1890). In this paper, we refer to this as “*passage of time*.” Time also structures the serial order of events enabling us to differentiate memory contents (past) from actual sensory experiences (present) to prepare goal-directed actions (future). We refer to this as “*structure of time*.”

### 3.1 Time Estimation and Time Perception

In the area of psychological time research, many models have been developed that attempt to describe the underlying processes of time perception. One of the most prominent models today is the Attentional-Gate Model (AGM) (Zakay and Block, 1995; Block and Zakay, 1996; Zakay and Block, 1997). The AGM describes a so-called pacemaker, which emits pulses continuously and at a fixed rate. This rate varies depending on the arousal level of a person. The number of pulses within a time interval are counted by the cognitive counter. However, the cognitive counter only registers impulses when attention is focused on time. The total number of impulses is then passed on to the working memory, which compares it with values in the retrospective memory already known from the past for certain periods of time. Consequently, the AGM implies that the resources of attention must always be shared between the focus on time itself and other events. The AGM is mainly used due to its heuristic value to describe the subjectively perceived time (Jokic et al., 2018).

In the area of psychological time research two methods exist to estimate time subjectively. One can let people estimate a certain interval of time, either prospectively or retrospectively. When estimating time prospectively, the person knows in advance that after a task or activity the elapsed time should be estimated. According to the AGM, the accuracy of the assessment is then mainly dependent on the attention given to time itself (Zakay and Block, 1995; Block and Zakay, 1996; Zakay and Block, 1997). In contrast, when estimating time retrospectively, people do not know in advance that they will be asked to estimate time at a later stage. Therefore, the estimation depends strongly on the information stored in memory (Ornstein, 1969; Block and Reed, 1978; Block, 1982; Block and Zakay, 1996). Two of the best known models that attempt to explain retrospective time estimation are the contextual-change model (Block and Reed, 1978; Block, 1982) and the Ornstein's storage size hypothesis (Ornstein, 1969).

The contextual-change model states that the subjective passed time depends on the number of contextual changes stored in memory and the amount of information available at the moment of estimation (Block and Reed, 1978; Block, 1982). According to Ornstein (1969), the subjectively estimated time of a period of

time depends on how much memory storage space is used for the events occurring in that period. It is generally assumed that depending on whether time is estimated prospectively or retrospectively, different cognitive processes are involved (Hicks et al., 1976; Block, 1992; Zakay, 1993). Especially the influence of attention on time differs between the two types of estimation (Zakay, 1993). In waiting situations one often unintentionally focuses on the time itself and therefore a time duration estimation of the interval is always prospective (Zakay, 2015). In the case of a longer waiting period, it is likely that in addition to the prospective mechanisms, the retrospective memory components will also influence the time duration judgement (Jokic et al., 2018). In general, the sense of time can change considerably in waiting situations.

This is often due to the sensation of wasting time (Osuna, 1985) or the unknown waiting duration (Taylor, 1994). These feelings usually have a negative connotation and are related to the perception of a slow passing time (Sackett et al., 2010). In this case persons tend to overestimate the actual waiting time, usually referred to as boredom (Zakay, 2014). If distractors like magazines are not available, people not only get more bored, but they also focus more on time itself, which leads to the experience of an even more slowed waiting time (Zakay and Block, 1997).

### 3.2 Time Studies in Virtual Reality

VR can be defined as “an approach that uses displays, tracking, and other technologies to immerse the user in a virtual environment” (LaViola, 2017). Such a VE is “a synthetic, spatial (usually 3D) world seen from a first-person point of view. The view in a virtual environment is under the real-time control of the user” (LaViola, 2017). Immersive VR embeds users in a three-dimensional environment and can elicit a sense of presence in this particular constructed world (Steuer, 1992; Bryson, 2013; Lelyveld and Entertainment, 2015). Often the sense of presence is also defined (at least partially) as the feeling of “being there” (Witmer and Singer, 1998; Lelyveld and Entertainment, 2015). Some contributions modify or extend this concept (Sanchez-Vives and Slater, 2005; Slater, 2009). They refer to the previously defined “presence” as place illusion, the illusion of being in the place depicted by the VE. The reality of the events taking place there is then defined as plausibility illusion.

A study provided a proof-of-concept by showing the influence on cognitive functions and time judgments of virtual Sun movements (Schatzschneider et al., 2016). It has been suggested that time could be scaled to a reference time, e.g., by accelerating or decelerating the time of visible clocks or increasing or decreasing the duration of a virtual day (Schatzschneider et al., 2016). A framework exploring ways to intentionally manipulate the perception of time in VR using zeitgebers was presented Landeck et al. (2020). Time travel illusion and its effects on people was also investigated, showing to have an impact on regretting bad decisions (Friedman et al., 2014; Pizarro et al., 2015). In this case, the time travel illusion is based on repeating the same scenario several times. You see your older self and its actions. One then has the

possibility to manipulate the overall result based on the previously acquired knowledge. It was also shown, that fear does not affect time estimation in VR (Kitajima et al., 2020).

van der Ham et al. (2019) recently investigated the estimation of time duration by letting people watch video clips in VR and in the real world. They found no significant difference in the estimated time duration between VR and the real world. In addition, Bruder and Steinicke (2014) conducted a pilot study to investigate whether the time perception in the real world differs from that in VR. It was shown that VR including a walking task does not change the subjective time by itself. However, the surveyed ten persons only had to estimate time intervals between 2 and 5 s. They were also aware that they had to estimate time. In such prospective experimental designs, the experienced duration depends heavily on the amount of attention to time (Fleisig et al., 2009). If all attention resources are devoted to a task, factors such as boredom do not matter (Zakay, 2014). In other situations, such as a prolonged waiting situation, the results would probably be different. In such a situation, due to a lack of a task or distraction, attention would always be focused on the time itself and boredom could occur. Consequently, the results are not generally transferable. Lugin et al. (2019) investigated such a waiting situation in which they made people wait 7.5 min in a room without distractors or a task. The results showed that people rate the waiting time duration in VR without embodiment higher than when waiting in reality. The absence of a virtual body could produce a deviation in time perception possibly related to reduced plausibility of the virtual environment.

If the quality of the simulation shows inconsistencies, the interest of the participants in the environment may increase (Latoschik et al., 2019) and could lead to an expanded perception of time. It is unclear why there was no difference between the VR with embodiment and VR without embodiment conditions, which should also differ in terms of plausibility. The experiment is limited, however, especially in the collection of important measures and the size of the sample. Neither embodiment nor presence was examined and only 15 subjects per condition were surveyed. Landau et al. (2020) showed that young adults who were embodied in a virtual body of a child using 180° stereoscopic video significantly overestimated the duration of the VR experience compared with a control group embodied in a virtual body of their own age. Furthermore, after exposing participants to a VR experience, Bansal et al. (2019) observed a novel relationship between action and event speed that resulted in a recalibration of time perception in a psychophysical task.

### 3.3 Avatars and Embodiment

The term “avatar embodiment” describes the process of substituting a person’s body with a virtual body in VR (Spanlang et al., 2014). This requires motion capturing of a user’s body that is used to animate an avatar representing oneself and that can be visualized in first-person perspective *via* a Head-Mounted Display (HMD) providing synchronized visuomotor feedback to the user (Gall and Latoschik, 2018). Research has clearly confirmed that embodiment substantially

promotes immersion (Slater and Steed, 2000; Waltemate et al., 2018) and that typical psychophysical effects of embodied VEs (including presence, body ownership, emotional response, etc.) are emphasized by high immersion and photo-realistic and personalized avatars (Achenbach et al., 2017; Latoschik et al., 2017; Waltemate et al., 2018). Avatar embodiment can also create a so-called Proteus effect (changing the way a person acts, thinks or feels) (Peña et al., 2009), e.g., by acting like a child (Banakou et al., 2013). Embodied VEs provide a promising and safe way to manipulate the perceived time duration, and can provide an important tool for a better understanding of human cognition. While full-body embodiment allows more experimental control, it may also work as a distractor itself. If avatar embodiment functions as a distractor, this could in turn lead to an underestimation of time. To enhance the overall sense of embodiment, according to Kilteni et al. (2012) the influencing subcomponents (feeling of self-localization, sense of agency, sense of body ownership) have to be addressed. The feeling of self-localization is improved by matching movements and a first-person perspective in relation to the artificial body. The sense of agency is enhanced in VR when motion is mapped to the virtual body in real-time or almost real-time. This is done by tracking the participant's movements and transferring them to the movement of the virtual avatar. By using an inverse kinematics method (Yuan and Steed, 2010) only certain parts of the body have to be tracked. Several factors are known to increase the sense of body ownership, e.g., bottom-up factors like synchronous sensory information of the physical biological and the seen virtual avatar's body are strong promoters. This can be achieved by visuotactile (e.g., haptics) or visuoproprioceptive (e.g., matching movements of the virtual avatar) feedback (Gonzalez-Franco et al., 2010). In addition, late research also identified the positive effect of realism and similarity on body ownership as top-down factors using photo-realistic and personalized avatars (Achenbach et al., 2017; Latoschik et al., 2017; Waltemate et al., 2018).

The close connection between the sense of time and self-consciousness is underpinned by studies showing a linkage to the sense of the internal state of the body, so-called interoception (Meissner and Wittmann, 2011; Droit-Volet et al., 2013; Wittmann, 2013; Pollatos et al., 2014). The temporal organization of perception and action, ranging from the processing of milliseconds of duration up to daily rhythms and beyond, has been studied extensively (Buhusi and Meck, 2005; Wittmann, 2016). With increasing time intervals affective and interoceptive bodily states play an important role (Craig, 2009; Droit-Volet et al., 2013; Wittmann, 2013).

### 3.4 Summary

So far, many factors have been identified that affect perception of time in real life, especially in waiting scenarios. In contrast, there is little evidence on the influence of embodiment on time perception in VR. Since embodiment can significantly influence the VR experience, as well as the cost and time of development and systems needed (i.e., requiring full body tracking or not), it is important to further investigate its possible impact on time perception.

## 4 MATERIALS AND METHODS

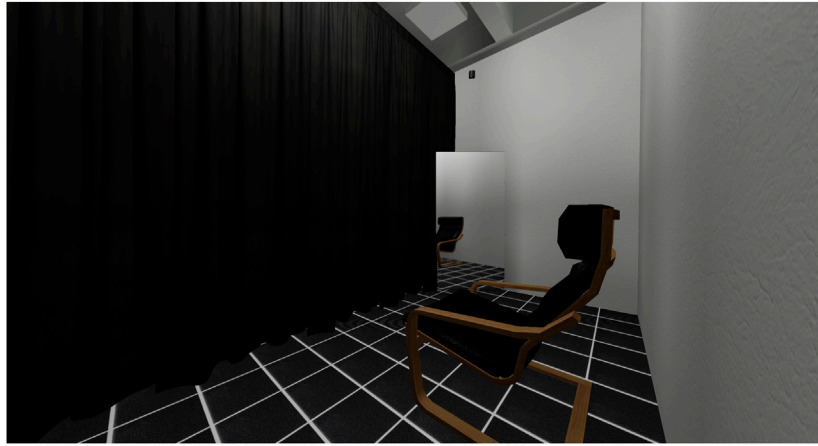
To use VR as a potential diagnosis and therapy tool for people with a distorted sense of time, we want to address the following question: "Does immersive VR with the absence of an avatar already provoke any time perception deviation, e.g., a compression or extension, for healthy users?" For this purpose, we explore the impact of the Illusion of Virtual Body Ownership (IVBO) by omission or inclusion of an avatar on time perception. Our design follows the approach of Lugin et al. (2019). We let people wait for 7.5 min in a room without any distractors or time indicators (**Figure 2**). We performed a *between-subjects* design with three conditions: 1) letting people wait in VR with an avatar (*avatar*) 2) letting people wait in VR without an avatar (*no-avatar*) 3) letting people wait in the real physical environment without the use of VR (*real*). We tackled prior limitations of Lugin et al. (2019) by collecting additional measures and a larger sample. We also added a virtual mirror in the scene allowing participants to see a reflection of their avatar (**Figure 3**). A virtual mirror allows participant to view the reflection of their virtual human body moving as they move. Synchronous mirror reflection tends to elicit a higher subjective sense of ownership over the avatar (Gonzalez-Franco et al., 2010; Spanlang et al., 2014). **Supplementary Video S1** shows both VR conditions.

It is important to understand that in the waiting situation where you wait for an unknown amount of time without any possible distractors or interaction, all conditions should elicit a slower perception of time (Osuna, 1985; Taylor, 1994), also referred to as boredom (Zakay, 2014).

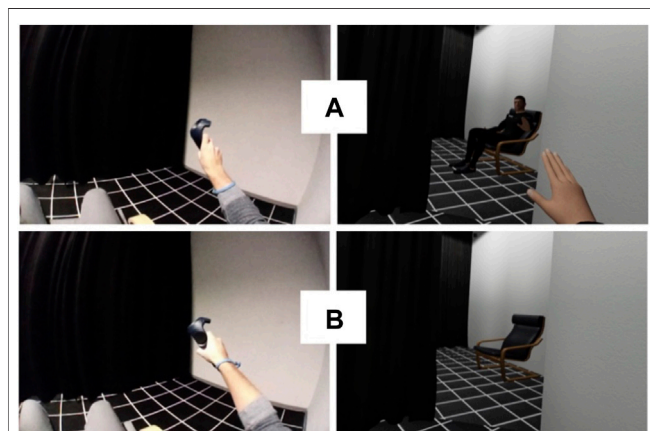
However, we believe the absence of a virtual body will strongly alter the time perception during the waiting phase. The lack of a virtual body should significantly decrease the illusion of plausibility and place (Slater and Steed, 2000), as well as increase boredom (Osuna, 1985; Taylor, 1994; Zakay, 2014) and could therefore be connected to more discomfort and negative emotions resulting in a longer perceived waiting time (Angrilli et al., 1997; Droit-Volet et al., 2004).

Slater and Steed (2000) showed a positive relationship between presence and avatar embodiment in an immersive VE. The lack of an avatar should reduce presence. A result also confirmed by Gall and Latoschik (2018), in which participants experienced breaks in presence when not receiving synchronized visuomotor feedback regarding their body movement. A lower presence is also associated to a lower enjoyment (Sylaiou et al., 2010), meaning that participant without avatar should have a higher feeling of boredom. In addition, the lack of virtual body will prevent participants to interact with the simulation. In the *avatar* condition, participants at least have the possibility to control their virtual body and see it move as they move.

Moreover, the lack of a virtual body should increase discomfort and even eeriness because it creates an unusual and unnatural situation. In particular, because there is a conflict between proprioceptive and visual feedback. The participants immersed in VR can feel their real body, but they cannot see it (Gall and Latoschik, 2018). Previous work (Schwind et al., 2017) revealed that realistic human hands with missing fingers have negative effects such as fear of amputation, limb loss or feeling of losing body control. It also has been shown that the



**FIGURE 2** | Picture of the virtual environment: It was taken from a third person view.



**FIGURE 3** | Participant looks in the virtual mirror (A) with avatar, (B) without avatar.

lack of a body makes correct estimations of space and distance/depth more difficult (Ries et al., 2008; Phillips et al., 2010)

The existence of a perceived distance compression in VR has already been verified in earlier work (Grechkin et al., 2010). Since time and space are considered to be interdependent phenomena in human perception, (Helson and King, 1931; Jones and Huang, 1982; Sarrazin et al., 2004), it is reasonable to assume that subjectively perceived time distortions could exist in VR. These could manifest themselves in the form of a subjectively perceived extension or compression of time. Therefore, we believe that the time perception in the *real* condition will differ from the VR conditions (*avatar*, *no-avatar*). On the one hand, it was already shown that VR as a medium can passively lead to an underestimation of time (Schneider and Hood, 2007; Schneider et al., 2011). On the other hand, in a waiting situation discomfort could become more apparent to the participants. Wearing a HMD can result in digital eye strain or symptoms related to its ergonomics, e.g., neck pain (Hirzle et al., 2021). This would result in negative emotions, which are related to the perception of

**TABLE 1** | Measures and dependent variables.

ID	Dependent variables
	Subjective
DV1	Demographic and VR previous experience questionnaire
DV2	Simulation sickness questionnaire (SSQ)
DV3	Waiting time estimation (STSS)
DV4	Awareness of body (STSS)
DV5	Awareness of space (STSS)
DV6	Thinking about time (STSS)
DV7	Time passing (STSS)
DV8	Boredom (STSS)
DV9	Igroup presence questionnaire (IPQ)
DV10	Virtual embodiment questionnaire (VEQ)

a slow passing time (Angrilli et al., 1997; Droit-Volet et al., 2004). People would also potentially focus more on time itself and tend to overestimate the waiting time (Zakay and Block, 1997). Time perception could additionally be influenced by other factors such as the field of view, the refresh rate of the HMD and simulation frequency or the colors and the resolution of the images shown on the display (Brown, 1995; Kanai et al., 2006; Thönes et al., 2018).

In the case of time experiments in the range of minutes, both a time duration estimation and an assessment of the passage of time are recorded (Jokic et al., 2018; Lugin et al., 2019), therefore we formulated the following hypotheses:

- (H1) The estimation of the waiting duration will be longer in the *no-avatar* condition compared to the *avatar* condition.
- (H2) The passage of time will be perceived slower in the *no-avatar* condition compared to the *avatar* condition.
- (H3) The estimation of the waiting duration as well as the passage of time in the *real* condition will differ from the VR conditions (*avatar*, *no-avatar*).

## 4.1 Measures

All collected dependent variables are displayed in **Table 1**.

#### 4.1.1 Simulator Sickness Questionnaire

Simulator sickness was assessed with the Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) before and after the experiment. It was used to check the quality of the VR simulation and to determine any negative effects that might have affected the results.

#### 4.1.2 Inventory on Subjective Time, Self, Space

We also used the Inventory on Subjective Time, Self and Space (STSS) (Pfeifer et al., 2016; Jokic et al., 2018). Jokic et al. (2018) used a time arrow covering a range from 0 to 30 min to let participants estimate the waiting time. However, we slightly modified this question to make it independent of a time frame provided by an arrow and to avoid a central tendency bias. The adapted question is now based on Tobin et al. (2010): “*Intuitively (without further thinking), how long do you think the waiting time lasted (in minutes and seconds)?*.” To measure the intensity of consciousness of the physical self and space, two non-verbal image scales were used, containing response categories from 0 to 6.

We used the same questions as Jokic et al. (2018): “*How intensively did you experience your body most of the time?*” and “*How intensively did you experience the surrounding space most of the time?*” Higher values imply a better consciousness of body and space.

In addition, three 100 mm-line visual analogue scales were presented to the participants, 1) “*How often did you think about time?*” (anchor points: not at all—extremely often), 2) “*How fast did time pass for you?*” (extremely slow—extremely fast), 3) “*How much boredom did you experience most of the time?*” (no boredom at all—extreme boredom)

#### 4.1.3 Virtual Embodiment Questionnaire

The VEQ (Roth and Latoschik, 2019, 2020) is used to assess embodiment and is a further development of the Alpha-IVBO (Roth et al., 2017) and the original IVBO. It consists of the subscales “Ownership,” “Agency” and “Change.” Participants had to answer the corresponding questions at the end of the experiment in the *avatar* and *no-avatar* conditions. Each subscale has four items that are rated on a seven-point Likert scale (1–7).

#### 4.1.4 Igroup Presence Questionnaire

Since presence and embodiment correlate with each other, we also assessed presence using the Igroup Presence Questionnaire (IPQ) (Schubert et al., 2001; Regenbrecht and Schubert, 2002; Schubert, 2003). after the waiting period. The IPQ consists of the subscales “General Presence,” “Spatial Presence,” “Involvement” and “Experienced Realism.” The items of the subscales are rated on a seven-point Likert scale (0–6). Due to the IPQ’s questions about the virtual environment (e.g., “Somehow I felt that the virtual world surrounded me.” or “I did not feel present in the virtual space.”), it was only collected for the *avatar* and *no-avatar* conditions and not for the *real* condition.

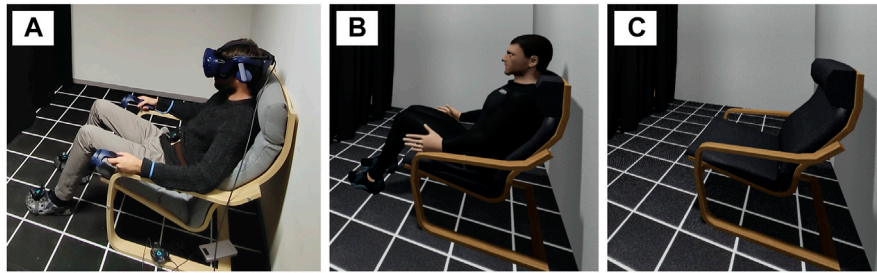
## 4.2 Design

We delimited the tracking area of our lab by curtains to create a real waiting room. There was only a carpet and a chair. This real

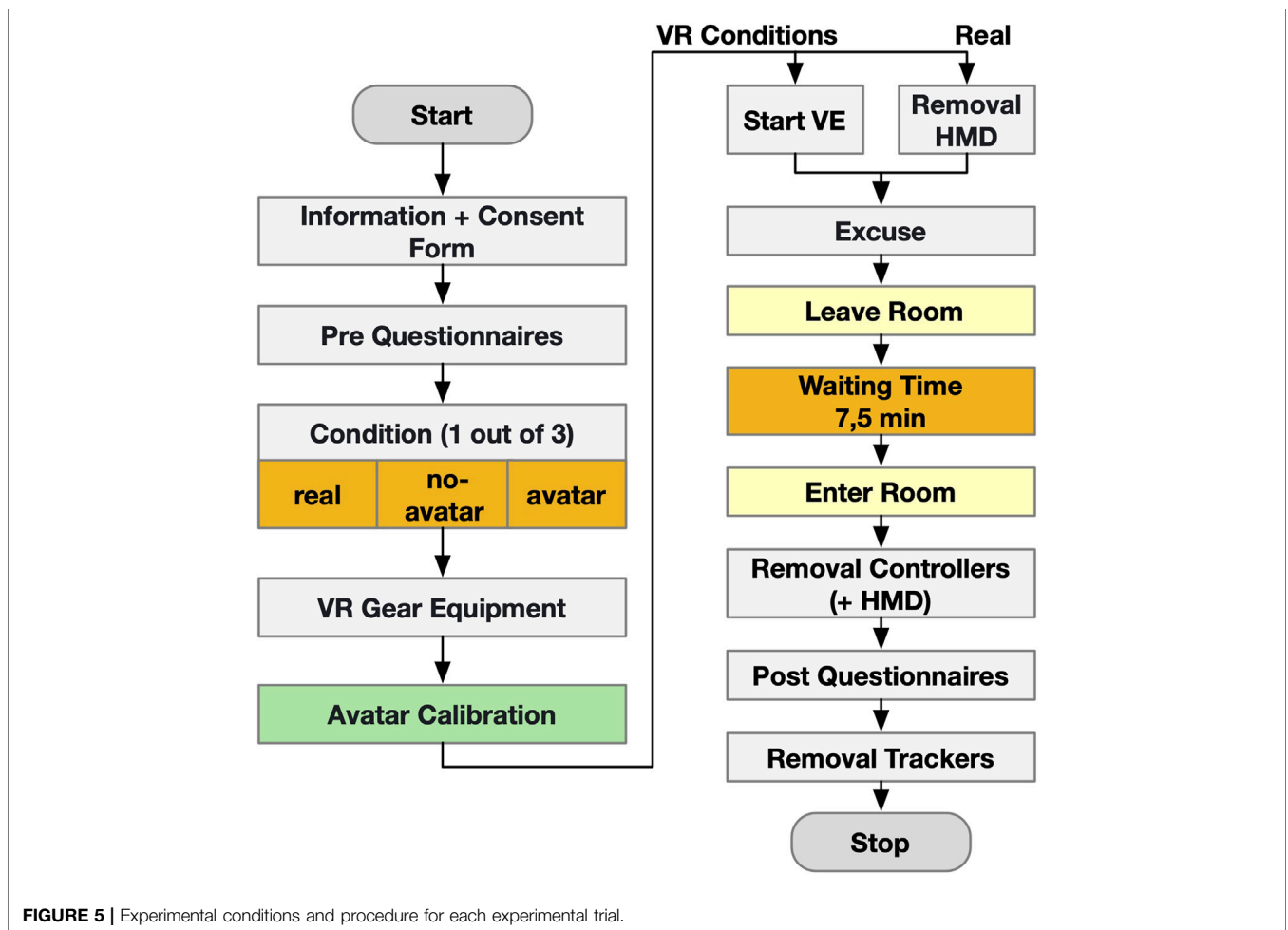
waiting room environment was remodeled using 3D models. Since we wanted to create visual-haptic coherence when using an avatar, participants had to be able to touch the chair. To adjust the 3D model, we tracked the position of the real chair and adjusted the model’s size to the real chair’s dimensions. The provided avatar was selected depending on the gender of the participant and its size was scaled accordingly. In general, the subjects received a relatively simple human avatar (**Figure 4**). To match the avatar’s position and movements with those of the participant, feet, hips, hands and head were tracked. Based on the positions of these, the positions of the remaining body parts were calculated using inverse kinematics. Neither an avatar nor the tracking devices were displayed in the *no-avatar* condition. During first tests, some participants reported that they sometimes closed their eyes. Since closing the eyes for a longer duration could influence the manipulation of embodiment, we used the VIVE Pro Eye to add another sanity check. The integrated eye tracker allows for a recording of the time frames during which the participants closed their eyes.

## 4.3 Procedure

Participants were recruited for a VR experiment. None of them were aware of the real goal of this experiment. **Figure 5** visualizes the structure of a 13-stage long experimental session. First, participants were welcomed by the experimenter and received a consent form. Once they signed it, they filled a demographic questionnaire and the SSQ. Pupil distance was measured and set on the headset. We ensured that no distractors such as cell phones or watches were available. For ensuring comparability between the conditions, the VR equipment was also attached in the *real* condition. Once all VR devices were attached, the participant was asked to stand still for the calibration of the avatar. After the calibration, the participants had to sit on the chair behind them. For the *avatar* and *no-avatar* conditions the corresponding VE was started. In the *real* condition the HMD was removed. Then the experimenter pretended that something was not working properly and needed the help of a colleague. While the colleague is called in, the participants should hold the controllers in their hands and remain seated on the chair. The experimenter left the room and waited 7.5 min in an adjacent room. The experimenter observed the subject through a camera to be able to stop the experiment if it appeared that the participant was suffering from any discomfort. After 7.5 min the experimenter came back and apologized for the inconvenience. First, the HMD and the controllers were removed from the test person. In the *avatar* and *no-avatar* conditions the participants then filled the modified STSS, the SSQ, the VEQ and the IPQ during the “Post Questionnaires” phase. In the *real* condition, they only filled in the modified STSS and SSQ, as most of the IPQ and VEQ questions cannot be answered adequately without having been in the VR before. To avoid revealing the end of the study, the trackers remained attached. After the questionnaires were completed, we removed the trackers. Finally, participants got the information about the real aim of the experiment and were asked about general feedback. On average, each experimental session lasted 25 min.



**FIGURE 4 |** (A) Participant waits with VR Headset, (B) *avatar* condition, (C) *no-avatar* condition.



**FIGURE 5 |** Experimental conditions and procedure for each experimental trial.

#### 4.4 Software and Hardware

The VE was developed using the Unreal Engine 4™. For the correct animation and calibration of the avatar IKinema Orion and the corresponding plugin for the Unreal Engine 4™ were used. The hardware setup consisted of a stationary PC (Intel Core i7-6700k 4.0 GHz CPU, 16 GB of RAM, Nvidia GeForce GTX 1080 Graphics card). On this machine, the application runs on average with 90 fps. The end-to-end latency was measured in two ways. Once by manually counting frames.

This was done using a high-speed camera that captured a 240 fps video of a 60 Hz screen, showing the movement of motion tracked controllers. We also measured the latency using a sine fitting approach (Stauffert et al., 2020). The latency was on average 48 or 42 ms depending on the method. These values are sufficient for a VR application (Carmack, 2013; Waltemate et al., 2015).

The participants were immersed in the VE using the HTC VIVE™ Pro. The corresponding HMD has a resolution of



**TABLE 2 |** Main results—STSS.

	Real		No-avatar		Avatar		$p$ -value	Effect size
	Mean	SD	Mean	SD	Mean	SD	$p \leq$	$\eta^2$
Waiting time estimation (STSS)	6.34	2.40	7.22	2.91	6.99	2.41	0.34	0.021
Awareness of body (STSS)	2.86	1.38	2.94	1.26	2.40	1.09	0.15	0.038
Awareness of space (STSS)	2.86	1.42	2.74	1.42	2.40	1.26	0.35	0.021
Thinking about time (STSS)	51.06	22.47	45.37	22.39	40.8	24.5	0.18	0.034
<b>Time passing (STSS)</b>	<b>47.37</b>	<b>14.10</b>	<b>45.57</b>	<b>15.75</b>	<b>55.17</b>	<b>17.11</b>	<b>0.028*</b>	<b>0.073</b>
Boredom (STSS)	46.97	25.71	42.86	23.15	46.71	26.99	0.75	0.006

Rows are bold if results are significant.

\* $p < 0.05$ .

1440x1600 pixels per eye, a 110° field of view, and a refresh rate of 90 Hz. The hand movements were recorded using the two HTC VIVE™ Pro wireless motion tracked controllers. HTC VIVE™ trackers were used to identify the position and movements of the hips and feet. One tracker was attached to a belt and two to the shoes. To track the exact position of the chair in the room, a tracker was mounted on it. The size of the tracking area was 2.35 m × 1.75 m × 3 m.

## 4.5 Participants

A total of 121 participants were recruited for the study. Sixteen participants had to be excluded due to technical issues or since they did not follow the protocol. The mean age of the remaining 105 people (73 females, 32 males) was 24.14 years ( $SD = 7.65$ ). 67 participants had prior experience with VR and 96 were native speakers. None of the subjects were visually impaired or had to be excluded because of simulator sickness or for closing their eyes too often.

## 4.6 Statistical Analysis

All STSS items as well as the IPQ ratings and VEQ ratings were analyzed on the interval measurement scale (Boone and Boone, 2012; Pfeifer et al., 2016; Jokic et al., 2018). When normality and variance equality were given, each STSS item was analyzed with a one-way Anova. Normality was verified by the Shapiro-Wilk test and variance homogeneity by the Levene's test. Since the Anova is quite robust to violations of normality (Glass et al., 1972; Lix et al., 1996; Blanca et al., 2017), especially with a large number of subjects ( $n = 105$ ), we performed an Anova, even though the assumption did not hold. In case variance equality could not be assumed, we performed a Welch Anova. The effect size is indicated by Eta squared  $\eta^2$ . The results of the STSS are shown in **Table 2**.

For each IPQ and VEQ item independent  $t$ -tests between groups were performed if normality and variance homogeneity held true. Normality was checked using the Shapiro-Wilk test and variance homogeneity applying the F-test. In case normality could not be assumed, a Mann-Whitney  $U$  test was used. If only the variance homogeneity assumption held not true, a Welch-Satterthwaite equation was applied. The effect size is indicated by Cohen's  $d$ . The results of the IPQ and the VEQ are shown in **Table 3**.

Additionally, three one-sample Wilcoxon signed rank tests were performed to analyze whether either of the three conditions deviates from the objectively measured 7.5 min.

## 4.7 Results

### 4.7.1 Inventory on Subjective Time, Self, Space

The outcome of the Levene's test indicate that variance homogeneity can be considered for all STSS items. Normality could not be assumed for any of the STSS items. The results show no significant difference between the estimated waiting time between the conditions (**Figure 6**). Of the three visual analogue scales of the STSS, only time passing showed a significant difference (**Figure 7**). In the *avatar* condition time was experienced to pass faster than in the *no-avatar* condition. Regarding the deviation from the objective time, there was no difference between the *avatar* condition ( $M = 6.99, SD = 2.41, Mdn = 5.67$ ) and the 7.5 min;  $Z = -0.80, p = .42$ . Neither did the *no-avatar* condition ( $M = 7.22, SD = 2.91, Mdn = 6.50$ ) significantly differ from 7.5 min;  $Z = -1.32, p = .19$ . However the *real* condition ( $M = 6.34, SD = 2.40, Mdn = 5.5$ ) did significantly differ from the 7.5 min;  $Z = -2.95, p \leq .01$ .

### 4.7.2 Igroup Presence Questionnaire

The IPQ was only analyzed for differences between the *avatar* and *no-avatar* conditions. The results of the F-tests show that variance homogeneity could be assumed for all IPQ subscales but "Experienced Realism." All but "General Presence" can be considered normally distributed. There was a significant difference in the IPQ "Spatial Presence" scores. The IPQ subscale "Involvement" scores did also significantly differ.

### 4.7.3 Virtual Embodiment Questionnaire

The VEQ was only analyzed for differences between the *avatar* and *no-avatar* conditions. With regard to the subscales of the VEQ, variance homogeneity can only be considered for "Ownership." The results of the Shapiro-Wilk tests show that normality can not be assumed for any of the subscales. The "Ownership," the "Agency" and the "Change" subscale scores were significantly higher in the *avatar* condition.

## 4.8 Discussion

We measured significantly higher IVBO values for the *avatar* condition compared to the *no-avatar* condition, thus confirming a successful manipulation check of our independent variable *embodiment*. The results also confirm our  $H2$  and reject our  $H1$ .

We expected the estimation of the waiting duration to be longer in the *no-avatar* condition compared to the *avatar* condition ( $H1$ ). In terms of presence, the values of the IPQ

**TABLE 3** | Main results—IPQ and VEQ.

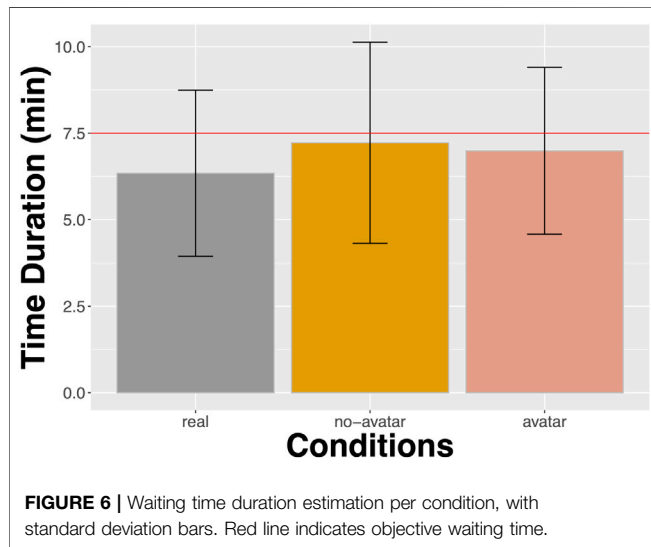
	No-avatar		Avatar		<i>p</i> -value	Cohen's
	Mean	SD	Mean	SD	<i>p</i> ≤	<i>D</i>
General presence (IPQ)	3.43	1.63	3.83	1.54	0.29	0.25
<b>Spatial presence (IPQ)</b>	<b>3.18</b>	<b>1.23</b>	<b>3.77</b>	<b>1.18</b>	<b>0.05*</b>	<b>0.48</b>
<b>Involvement (IPQ)</b>	<b>2.04</b>	<b>1.09</b>	<b>2.94</b>	<b>1.35</b>	<b>0.01**</b>	<b>0.74</b>
Experienced realism (IPQ)	2.86	0.78	2.74	1.25	0.61	0.12
<b>Ownership (VEQ)</b>	<b>2.58</b>	<b>1.55</b>	<b>4.13</b>	<b>1.46</b>	<b>0.001***</b>	<b>1.03</b>
<b>Agency (VEQ)</b>	<b>3.23</b>	<b>2.08</b>	<b>5.46</b>	<b>1.29</b>	<b>0.001***</b>	<b>1.29</b>
<b>Change (VEQ)</b>	<b>2.04</b>	<b>1.14</b>	<b>3.50</b>	<b>1.70</b>	<b>0.001***</b>	<b>1.01</b>

Rows are bold if results are significant.

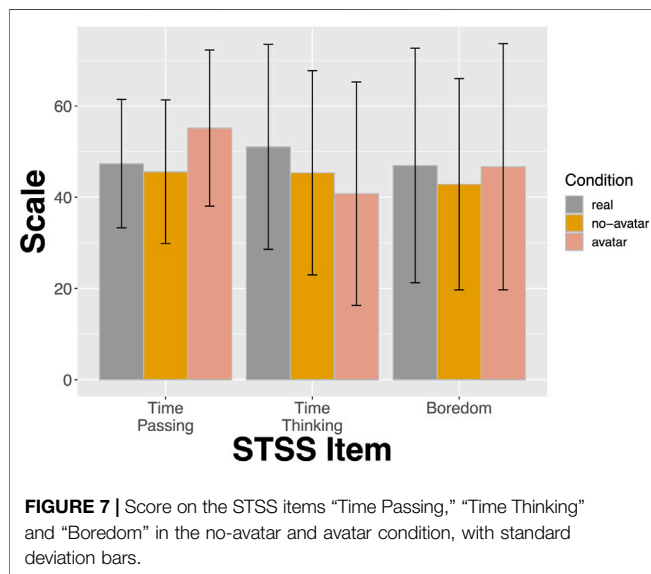
\**p* < 0.05.

\*\**p* < 0.01.

\*\*\**p* < 0.001.



**FIGURE 6** | Waiting time duration estimation per condition, with standard deviation bars. Red line indicates objective waiting time.



**FIGURE 7** | Score on the STSS items “Time Passing,” “Time Thinking” and “Boredom” in the no-avatar and avatar condition, with standard deviation bars.

subscales “Spatial Presence” and “Involvement” were significantly higher in the *avatar* condition than in the *no-avatar* condition. “General Presence” and “Experienced Realism” did not differ

significantly. Since a positive relationship between presence and body movement in an immersive VE was shown by Slater and Steed (2000), one could expect that all IPQ subscales would differentiate between the two groups. In addition to embodiment, we enhanced presence by matching visual and haptic feedback (Gall and Latoschik, 2018). This could have led to the fact that the “General Presence” subscale, which asks for the feeling of being present in the virtual world, did not differ significantly between the *avatar* and *no-avatar* condition. With regard to “Experienced Realism,” no differences between the conditions could probably be identified, as all participants were in the same VE. The significantly lower Spatial Presence and Involvement measured in the condition without an avatar seem to confirm that the illusion of place and plausibility (Sanchez-Vives and Slater, 2005; Slater, 2009) were not present. However, it seems that being able to interact with one’s avatar and see it in the mirror did not make the situation any less boring. This is supported by the STSS item boredom, which shows no significant difference between the conditions. Although presence and plausibility were lower in the *no-avatar* condition, no difference in time duration estimation was observed and *H1* was rejected.

Regarding our *H2*, we expected a difference in the passage of time. Participants in the *no-avatar* condition would perceive a slower passage of time compared to the *avatar* condition (*H2*). The STSS item asking “How fast did time pass for you?” did reveal a significant difference between the conditions. As mentioned before presence and plausibility differed between the conditions. Even though the avatar did not make the waiting situation any less boring, *H2* was confirmed. Although the people were able to move freely and received proprioceptive and haptic feedback, they did not see their own bodies. As a result, they may have become more focused on the position of their real body. The presence of the mirror might have intensified this effect, making the presence or absence of a virtual body inevitably noticeable. It could also be related to emotional discomfort, but we didn’t specifically access that kind of comfort. Our expectation that the *real* condition would differ from the *avatar* condition in terms of both time duration estimation and passage of time *H3* could not be confirmed and has to be rejected.

Considering the time duration estimations, the waiting time in the *real* condition did not significantly differ from the VR

conditions (*avatar*, *no-avatar*), but was on average more than 30 s shorter. It seems that VR as a medium itself did not act as a distractor. This is supported by the fact that there was no significant difference in terms of boredom between the conditions. The time was underestimated on average in all conditions, which is quite surprising. In particular, in the *real* condition, we expected duration estimations to be similar to Jokic et al. (2018) rather than Lugin et al. (2019) due to the sample size of the studies. On average, however, people in our study estimated the waiting duration about 2 min shorter than Jokic et al. (2018) and about 50 s longer than Lugin et al. (2019).

A possible explanation could be the nature of the waiting scenario. Similar to Lugin et al. (2019) a technical problem was simulated, which created a kind of “accidental” waiting scenario. According to Minsky (1974) a typical waiting situation could be seen as a “frame.” A “frame” can be defined as “a data-structure for representing a stereotyped situation” (Minsky, 1974). A frame representing information about a waiting scenario probably includes some sort of a room with a door, a window, some uncomfortable chairs across the walls and a table. You also are prepared to wait for a specific event you are aware of beforehand, e.g., waiting at the doctor.

Looking at the study done by Jokic et al. (2018) their design fits the waiting room “frame.” People were waiting in a stereotypical room for an experiment to start. However, the “accidental” waiting scenario was neither in a typical room nor was it a typical situation. People were sitting on a comfortable chair in an area delimited by black curtains and the experiment they signed up for already started. The deviation from a typical waiting room scenario was necessary in this case due to the use of VR and the calibration of the avatar. The difference between the subjects’ expectations of a typical waiting room and the actual waiting room may have increased their awareness. They then did not focus on time itself but on the current situation, resulting in an underestimation of the waiting time duration (Zakay and Block, 1997; Zakay, 2015).

Additionally the fact that people were sitting on a comfortable chair during the waiting time could lead to a rather relaxed situation. On the one hand the lowest subjectively estimated time in the *real* condition could then be due to the fact that for the other conditions the subjects were wearing a HMD which could have led to digital eye strain or HMD ergonomic related symptoms to be more apparent. In the *real* condition, on the other hand, they could rather lean back on the chair and sink into thoughts, which leads to an underestimation of time (Thönes and Wittmann, 2016). This would also explain why only the *real* condition did significantly differ from the objective 7.5 min.

However, the explanation could also be much simpler. Participants might embellished their time duration judgements to gloss over the delay at the start of the study for the benefit of the experimenter. When asked if the respective person had to wait too long, most participants answered that the delay was not a problem.

In terms of time passing, there was also no significant difference between the *real* and the VR conditions (*avatar*, *no-avatar*). However, there is a tendency that people in the *real* condition report a slower passage of time compared to the *avatar* condition. As mentioned before boredom did not significantly differ between the conditions. There was also no significant

difference regarding time thinking, but you can see a tendency that people in the *real* condition tend to focus more on time itself compared to the *avatar* condition. A potential connection between the passage of time and time thinking should therefore be observed more closely in future experiments.

In summary, embodiment between the *avatar* and the *no-avatar* condition was significantly different and our hypothesis *H2* that time is perceived slower in VR without an avatar could be confirmed. In contrast, time duration estimates of participants did not differ significantly between the *avatar* and *no-avatar* condition and our *H1* was rejected. Furthermore, the *real* condition did not differ from the VR conditions (*avatar*, *no-avatar*) in terms of estimating the duration or passage of time and *H3* was also rejected.

Why the *avatar* condition differs from the *no-avatar* condition with regard to the passage of time but not with regard to the time duration estimation could be due to the kind of manipulation. Our results show a significantly lower Spatial Presence and Involvement in the condition without an avatar thus seemingly confirming that the illusion of place and plausibility were not present. Wearden (2015) argues that time duration estimation and passage of time must be considered separately. While both seem to be influenced by similar factors (Jokic et al., 2018), previous studies also showed that time duration can be influenced without influencing time passage and vice versa (Wearden et al., 1998; Wearden, 2008). In particular, the lack of the two illusions could therefore be a factor that has only or at least a stronger influence on the time passage than on the time duration estimation.

With regard to the results identified by Lugin et al. (2019), we argue that the integration of a virtual mirror to strengthen any embodiment effects, renders a direct comparison between the experiments invalid. However, both experiments show similar effects of a time perception deviation for certain conditions. Our empirical results do not allow for the reasons to be explicitly pinpointed but they generate enough results for an informed speculation about the common reason. The conditions under which the time perception deviation was detected were also characterized by different aspects that seemed to have influenced the plausibility of the environment. The affected conditions did not include an avatar which becomes even more apparent as a break in plausibility in the our experiment with the additional mirror where participants did not see themselves in the *no-avatar* condition. This in turn could be associated with more discomfort and negative emotions, leading to a longer perceived waiting time (Angrilli et al., 1997; Droit-Volet et al., 2004). Lugin et al. (2019) did not identify the same deviation effect for the 360°-panoramic picture without avatar condition. It can potentially be explained by the low-realistic rendering (no real depth-cues besides head rotations, e.g., no stereo or motion parallax) which—in itself—maybe is of such a lower plausibility that the missing avatar does not really make a big difference anymore.

Even though there was no significant difference between the *real* condition and the VR conditions (*avatar*, *no-avatar*) in terms of the perception of time, there is still an interesting tendency. Although having an avatar in VR should be more closer to reality, the *real* condition was actually closer to the *no-avatar* condition than to the *avatar* condition in terms of the feeling of passage of time. Since the results are not consistent with Jokic et al. (2018)

and Lugin et al. (2019), more research is needed to better understand the underlying factors.

## 4.9 Limitations

Only healthy people participated and therefore our results are limited in terms of transferability to people with a disturbed sense of time. The sample also contained more women than men, which could have led to a bias. We only used a generic male and female avatar model in our studies. The passage of time could further be affected by the avatar appearance (Latoschik et al., 2016; Roth et al., 2016), e.g., providing a photo-realistic and personalized avatar (Waltemate et al., 2018). Such an avatar would not only lead to a higher avatar acceptance, but also result in an increased plausibility of the VR. This potentially leads to an even faster passage of time. To validate this assumption, a future study needs to provide personalized avatars and analyze their effects on the perceived passage of time. We also did not directly measure discomfort, which should be recorded in future experiments.

## 5 FUTURE WORK

Overall, we believe that our results represent a first step towards successful diagnosis and treatment of psycho-pathological conditions in VR based on the measurement and manipulation of time perception. Our future work is divided in four main research directions. The first step is to replicate our experiment with a clinical population.

We also would like to extend our experiment by including a variable *foreperiod* task with and without virtual body as first starting point to develop a diagnostic and treatment tool for individuals with schizophrenia. This variable *foreperiod* task consists in measuring reaction time when one waits for a red light to turn green. At a variable interval, a target is displayed on the screen and participants must confirm its appearance by pressing a response key quickly. With increasing interval duration, the reaction times to recognize the target become faster (Niemi and Näätänen, 1981). The acceleration of reaction times at longer intervals is referred to as the “variable foreperiod effect” and reflects the increasing expectation over time. This probability increasing with time is referred to as the “hazard function” and can be used to dynamically generate and update temporal predictions. Martin et al. (2017) showed that this predictive expectation appears to be disrupted in patients with schizophrenia. Our results could then play an important role in the choice of embodiment when replicating the variable foreperiod task in VR.

As an alternative, approaches in the direction of mindfulness could be explored. Mindfulness can be defined as “the awareness that emerges through paying attention on purpose, in the present moment, and nonjudgmentally to the unfolding of experience moment by moment” (Kabat-Zinn, 2003). It has been shown that mindfulness can be associated with time perception and a higher level of mindfulness can lead to a faster passage of time (Weiner et al., 2016). There are already quite a few therapeutic approaches in VR that rely on mindfulness meditation (Döllinger et al., 2021). People slowly drift down a computer-generated river in VR (Navarro-Haro et al., 2016; Gomez et al.,

2017; Navarro-Haro et al., 2019) or walk through a forest (Gromala et al., 2015). The use of an avatar in such scenarios could potentially lead to an even faster perceived passage of time and counteract the slowed perception of time reported by patients.

Our next main research direction is to investigate active manipulations of time influencers in VR, as performed by Schatzschneider et al. (2016). According to Brown (1995), faster speeds lengthened perceived time to a greater degree than slower speeds and intervals associated with more changes are perceived to be longer than intervals with fewer changes. By manipulating the velocity, frequency and amount of visual stimuli, such as the arm of a clock as an artificial *zeitgeber*, the manipulation could lead to a counterbalance to the feeling of time slowing down, potentially leading to improved patient well-being. We would like to extend the possibility to influence time perception with different avatar embodiment and disembodiment variation.

## 6 CONCLUSION

This article investigated the influence of avatar embodiment on time perception of healthy people in VR. Subjects had to wait seven and a half minutes 1) with an avatar in VR (*avatar*) 2) without an avatar in VR (*no-avatar*) 3) or in the real physical environment (*real*) in a room without distractors or time indicators. After the waiting period, participants were asked to estimate the waiting time duration and to describe their experience of the passage of time. Our main result indicates that an avatar leads to a faster perceived passage of time. There was also no significant difference in time perception between the *real* and the VR conditions (*avatar*, *no-avatar*), but additional work is needed to better understand the underlying factors.

Based on our results, an integration of avatar embodiment into future time-based VR therapy applications appears to be promising, as it could potentially moderate the user’s perception of the passage of time. Our future work will focus on replicating and extending our experiment with actual patients suffering from psycho-pathological conditions. To get one step closer to a concrete solution for a time-based VR therapy, a replication of the variable foreperiod task in VR or the use of a mindfulness meditation environment utilizing different forms of avatar embodiment such as *no-avatar*, *partial-avatar*, and *avatar*, could be a promising first starting point.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethikkommission des Institut Mensch-Computer-Medien (Universität Würzburg). The patients/participants

provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

FU, ML, J-LL, and MEL contributed to conception and design of the study. FU and ML developed the software and performed the statistical analyzes. FU wrote the first draft of the manuscript. J-LL and MEL were the project administrators and supervised the work. All authors contributed to manuscript revision, read, and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/frvir.2021.658509/full#supplementary-material>

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**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.

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