# Body and Time: Virtual Embodiment and its Effect on Time Perception

Fabian Unruh, David Vogel, Maximilian Landeck, Jean-Luc Lugrin, Marc Erich Latoschik

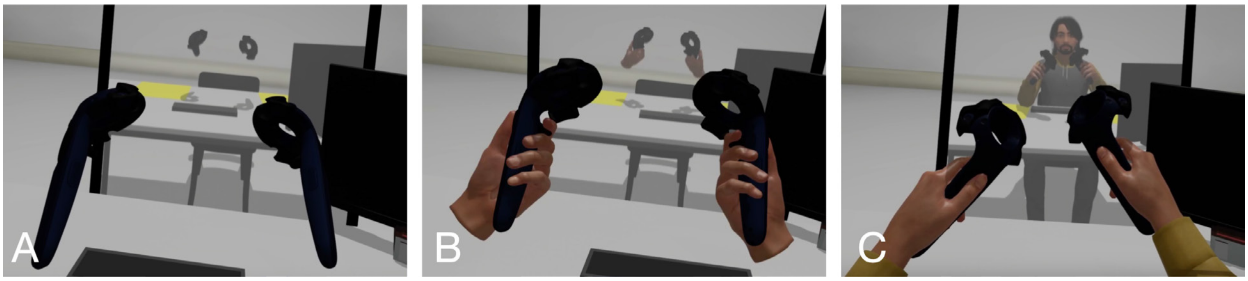


Fig. 1: The different degree of embodiment conditions. First-person perspective with a virtual mirror placed in front of the participant. A) *low* condition showing just the controllers, B) *medium* condition showing hands and controllers, C) *high* condition showing a full body avatar and controllers.

**Abstract**—This article explores the effect of one's body representation on time perception. Time Perception is modulated by a variety of factors including, e.g., the current situation or activity, it can display significant disturbances caused by psychological disorders, and it is influenced by emotional and interoceptive states, i.e., "the sense of the physiological condition of the body". We investigated this relation between one's own body and the perception of time in a novel Virtual Reality (VR) experiment explicitly fostering user activity. Forty-Eight participants randomly experienced different degrees of embodiment: i) without an avatar (*low*), ii) with hands (*medium*), and iii) with a high-quality avatar (*high*). Participants had to repeatedly activate a virtual lamp and estimate the duration of time intervals as well as judge the passage of time. Our results show a significant effect of embodiment on time perception: time passes slower in the *low* embodiment condition compared to the *medium* and *high* conditions. In contrast to prior work, the study provides missing evidence that this effect is independent of the level of activity of participants: In our task, users were prompted to repeatedly perform body actions, thereby ruling-out a potential influence of the level of activity. Importantly, duration judgements in both the millisecond and minute ranges seemed unaffected by variations in embodiment. Taken together, these results lead to a better understanding of the relationship between the body and time.

**Index Terms**—Time Perception, Virtual Reality, Virtual Embodiment, Avatar, Presence

## 1 Introduction

Time is a multi-layered phenomenon. It is not only an essential factor in many disciplines, such as physics or psychology, but also in everyday life. Depending on the person, the situation, and the activity, the subjective perception of time can change significantly. Earlier research has demonstrated that time perception can be affected on different ranges of duration (for review see Grondin [25]). In addition, the experience of the passage of time during a duration appears to be distinct from the ability to judge the length of that duration [30, 77]. In other words, we may experience five minutes as passing by quickly, and the next five minutes as passing by slowly, all the while knowing that both intervals lasted five minutes and were of identical duration.

Time often passes slowly while waiting or during boring situations, whereas when engaged in an interesting activity, such as, e.g., playing a video game, time may pass very quickly [69]. These effects could be explained by the attention to oneself and the resulting self-awareness. In a waiting situation, this is much more pronounced than in a more pleasant activity [82]. This idea is supported by studies that show that time perception can be influenced by emotional and interoceptive states [15, 43, 49]. The assumption is also supported by the fact that similar areas of the brain are activated both in the perception of time and in the perception of bodily signals [9, 10, 49]. The influence of affective and interoceptive body states also becomes stronger with increasing time intervals [9, 15, 81]. The body seems to function as an anchor point in space and time and one must first understand oneself as an entity in space before one can perceive time at all. This connection between body and time experience may be altered in mental illness [12, 19, 70, 71]. For example, in patients with schizophrenia, it can sometimes be expressed by a disconnectedness from their own body [12]. As a potential result, they often cannot place the chronological order of events correctly [21], and find it difficult to estimate time intervals [65, 72]. Such an impairment of time perception has strong negative effects on daily life, as the sense of time contributes to our well-being [15, 43, 71, 81]. To counteract the symptoms, body-directed interventions such as physical exercises and cognitive behavior therapy are used [24, 66]. Physical exercises in particular are highly related to one's own body. Physical activity is said to increase the level of neurotransmitters (e.g. endorphins or serotonin), improve muscle and cardiovascular function and improve one's body image [24].

Unfortunately, traditional experimental approaches as well as physical exercise and intervention methods are limited in terms of body-related manipulations. Here, VR technology is able to systematically and globally alter and control many aspects of a digital replication of the real surrounding and the sensations a person receives.

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This includes the users' bodily appearance, the so-called avatar. The substitution of one's own body by a virtual avatar of almost arbitrary appearance has various significant perceptual, emotional, behavioral, and psychological effects [47, 60]. It has also been shown that VR therapy is effectively used in the treatment of a number of specific psychological disorders, e.g., post-traumatic stress disorders and anxiety disorders [22, 40, 73].

Overall, VR technology opens-up promising approaches for experimental manipulations of embodiment-related factors in basic research. Similarly, it may also be useful for VR-based interventions for persons suffering from disorders related to distorted time perceptions targeting the close connection between body, self-consciousness and sense of time. However, such a proposed use of VR must first consider VR in terms of possible effects on the perception of time itself and on healthy individuals.

VR technology has progressed significantly. However, today's interactive VR exposures are still not capable to reproduce reality indistinguishable from the physical world around us, and it is questionable if that goal can be reached at all using non-intrusive approaches. Consequently, today's VR will still exhibit incongruencies on the sensory and perceptual layers, e.g., caused by the display technology, the rendering approaches, the timing and latency, or simply by missing cues for all of our senses. In addition, depending on the manipulation of embodiment in VR, different degrees of incongruencies are also created on the cognitive layer, all of this could potentially influence the perception of time [36].

First evidence show that time passes faster when waiting in VR with a virtual body than without a body, but no difference was found in comparison to real world waiting [68]. However, waiting is a very specific scenario when it comes to time perception [69] and in many VR applications users are more active and frequently interact with the environment (e.g. moving objects). Hence, it is important to understand whether and how different levels of embodiment distort time perception even in non-waiting scenarios including active participants, which–as a more general case–would also cover many more scenarios applicable for basic research.

The next sections summarize our contributions and key findings. We then highlight the related work and present our approach. The experiment conducted is described, while the final sections discuss the overall results and limitations before closing with our future work.

### 1.1 Contribution

We introduce a novel study investigating the impact of virtual embodiment in VR on time perception of healthy people in an interactive scenario. Participants experienced different degrees of embodiment in VR: i) no-avatar (*low*), ii) hands (*medium*) iii) and a high-quality avatar (*high*). The effects of each condition were enhanced by a virtual mirror during exposure. The task was to activate a virtual lamp several times with the help of the controller. The time delay between action and reaction (lamp on) was randomly set to 200ms, 400ms, and 800ms and occurred equally often. Participants then had to estimate the duration of time intervals for milliseconds and minutes ranges, and judge the passage of time. Our main finding is that the passage of time in an interactive scenario is perceived significantly slower in the *low* condition than in the *medium* and *high* conditions. In conjunction with previous findings in a waiting room scenario, this effect appears to be at least partially independent of the activity level. In addition, the assessment of duration for both time spans did not appear to be affected by the degree of embodiment. The manipulation of embodiment seems to specifically influence the passage of time and not time duration perception.

## 2 Related Work

Time is a complex construct and can be defined in different ways. To better understand the perception of time, one could distinguish between *Physical Time* and *Psychological Time*. The *Physical Time* would be the objective time expressed by clocks. The *Psychological Time* could be defined as being subjective. Time is then dependent on temporal dimensions such as duration, speed and the order in which internal events are perceived [86]. In this paper, we further distinguish between *Time Duration Judgement* and *Passage of Time*. We refer to the subjective estimate of the duration of a past time interval as *Time Duration Judgement* and how fast time subjectively passes by as *Passage of Time*.

### 2.1 Time Perception in Psychology

Various theories attempt to explain the fundamental mechanisms of time perception. One of the best known models is the Attentional-Gate Model (AGM) [4, 88, 89]. It involves a so-called pacemaker that continuously emits pulses at a fixed rate. Depending on the person's level of arousal, this rate may vary. The cognitive counter is responsible for counting the number of pulses within a certain time interval. To be able to register a pulse, attention must be paid to time itself. The information is then forwarded to the working memory and the total number of pulses is compared to known values of time periods from the past. Since there is only a certain amount of resources available, they have to be divided between the focus on time itself and other processes. A stronger focus on time leads to an overestimation of duration and a slower passage of time [18, 29].

In general, the subjective perception of a time interval can be assessed either prospectively or retrospectively. If the subjective time perception of a time interval is prospectively measured, it is known beforehand that the elapsed time is to be assessed afterwards. In the case of retrospective assessment, the relevance of time is only revealed after the specified time interval. Taking the AGM into account, this means that the subjective time perception is strongly influenced by the measurement method [85]. In addition, depending on the method, different cognitive processes are activated that further influence the subjective assessment [3, 26, 85].

In waiting situations, time often passes very slowly. This is due to the fact that time is unconsciously paid attention to. Therefore, a subjective assessment of such a time interval can always be classified as prospective [87]. The fact that time often passes more slowly in a waiting situation is reinforced by the fact that waiting is perceived as negative [53]. This is due to the uncertainty of the waiting time [64] and the feeling of wasting time [46]. Boredom also slows down the passage of time [89]. If people are bored, they have more resources available to focus on time itself and are typically less excited resulting in a lesser state of arousal [80].

But there are also situations in which time passes more quickly. Studies on video games show that players often lose the sense of time or time passes very quickly while playing [8]. Often one is then in a so-called "flow" state [11]. In this state, one does not focus on time itself but only on the current task [82] and the level of arousal tends to increase. A prerequisite for getting to this state is that the activity matches one's abilities [11, 82].

Although the AGM is used to explain time perception in the range of milliseconds to minutes, different mechanisms become more or less relevant depending on the time interval duration. An aspect of estimating time duration in the millisecond range is that time intervals between an intentionally directed action and its result in the sense of the success of the action are estimated to be significantly shorter than time intervals of the same length between events without an intentional action, e.g. between two observed events [44]. In the range of several minutes, even retrospective aspects could come into play in a prospective design, as the pure prospective mechanisms would not remain active throughout [29].

Besides the length of the time intervals and the estimation method, the content of an environment is also of importance. If an environment is more complex or changes more frequently, more elements need to be processed and less attention can be given to time itself. Therefore time intervals in more complex and rapidly changing environments are comparatively overestimated [50].

Furthermore, the body itself could play an essential role. By focusing on time itself, one also becomes more self-conscious [82]. Several studies already showed that the perception of time can change depending on emotional and interoceptive states [15, 43, 49]. Expecting pain [45], seeing aversive pictures [14], or watching frightening films [16] can result in an overestimation of time intervals.

These effects can also become stronger when one is actively paying attention to bodily responses [49] and with increasing time intervals [9, 15, 81]. Considering the AGM, bodily states could act as the pulses of the pacemaker [82].

### 2.2 Avatar Embodiment in VR

VR immerses the user in virtual environments using dedicated technologies [38] to establish a close loop between user actions captured by motion tracking and special input devices and the generation of adequate feedback mimicking real-world stimuli comparable to perceptions in the physical world. In many cases, this virtual environment (VE) consists of an artificially created three-dimensional world in which the user can control a first-person view in real time [38]. Being in an immersive virtual environment can create a sense of presence [6, 39, 62]. This feeling can be defined as "being there" [39, 79] or as the so-called place illusion [54, 58]. The place and the plausibility illusions are assumed to be orthogonal components contributing to the overall presence as one of the central qualities of VR [54, 58, 59].

Recent theories emphasize the importance of plausibility due to its assumed wider applicability to the enlarged scope of Mixed Reality exposures with different degrees of virtuality [36, 56, 57]. Coherent and congruent simulation of embodiment cues on the sensory and perception layer can create virtual body ownership, i.e., the feeling of owning and controlling a virtual body, still allowing manipulations on the cognitive layer, e.g. by giving a male person a female body or vice versa.

Avatar embodiment can be defined as the replacement of one's own body with a virtual one in VR [60]. To animate and move a virtual body, the real body must be tracked using motion capture hardware and software. For the visualization of the first-person perspective, a Head-Mounted Display (HMD) can provide the required synchronized visuomotor feedback [20]. The feeling of being embodied in VR is mainly influenced by the feeling of body ownership, the feeling of self-localization and the feeling of agency [32]. One factor that can contribute to a strong body ownership is the synchronous movement of the virtual avatar corresponding to the real body [23]. By integrating a mirror in a suitable place in the virtual environment, this behavior can be made apparent to the user [23, 60]. Another way to strengthen body ownership is to increase similarity and realism through the adoption of personalized and photo-realistic avatars [1, 35, 74]. To enhance the feeling of self-localization, a relative match between the movements and the first-person view to the virtual body is required [23].

Transferring one's own movements directly to the virtual body is also crucial for improving the feeling of agency. Depending on the avatar and the virtual environment, it is not always necessary to track the entire body. It is possible to use inverse kinematics to track some parts of the body and thus calculate the positions of the others [84]. Being embodied in VR can lead to a variety of psychophysical effects. These include emotional response, body ownership and presence [13, 60]. They can be reinforced by a high degree of immersion and personalized avatars [1, 35, 74]. Having a virtual body can also significantly change a person's behavior. The so-called Proteus Effect causes a person to adjust their behavior depending on the kind of virtual body they receive [83].

### 2.3 Time Perception in VR

Our perception of time is influenced by a lot of factors. Some of them are of natural origin like the sun. It was shown that speeding up or slowing down a virtual sun in VR can already influence duration judgements in the minute range [55]. To be able to investigate further factors more easily in the future, a framework for the investigation of so-called zeitgebers was developed [34]. Just like the sun, zeitgebers help to orientate oneself in time (of the day) or to grasp the speed of time [55].

Some studies also focus on investigating whether and how VR itself could have an impact on time perception. Potentially occurring negative symptoms regarding simulator sickness in VR can already have an influence on the perception of time [52]. The stronger the symptoms, the longer a time interval is estimated [52]. It was also shown that waiting in a virtual environment that was a replica of a real room resulted in a slower passage of time compared to waiting in the real room [28]. In terms of arousal, there was no difference between the conditions. However, the people waiting in VR were more bored, which may have caused time to pass more slowly.

Lugrin et al. [42] conducted a similar waiting study but additionally compared waiting with a body and without a body in VR. The results indicate that one is estimating the waiting duration longer in VR without a body compared to waiting in the real room. There was no difference between the conditions in terms of boredom and the passage of time. However, if we look at the estimated time duration in the real condition, it is untypical for waiting scenarios. Usually, waiting times are overestimated, but the participants in this study estimated the waiting time of 7.5 minutes to be only 5.5 minutes on average. Since there were only 15 participants per condition and important measures such as presence and embodiment were not obtained, it is difficult to draw firm conclusions. A study by Unruh et al. [68] replicated the approach from Lugrin et al. [42] and focused on collecting a larger sample and obtaining presence and embodiment data. The results show that time was passing faster in the avatar condition compared to the no avatar condition in VR. Both conditions did not differ from the real condition.

The already discussed studies investigated the perception of time in the minute range. In an interactive task to estimate millisecond time intervals, Suzuki et al. [63] showed that time durations are underestimated both in the presence and absence of an intentional action. Using VR, they had individuals either press a button themselves or play back a previously performed action recorded during a practice session. This shows that typical effects such as a shorter time duration estimation for an intentional action and its result also occur in VR. However, the results extend this insight by showing that an intentional action or agency is not necessarily required, but that this effect can also be explained by a causal link.

In a similar study, Zopf et al. [90] showed that movement congruence also has a significant influence on millisecond time estimates. If the movements were congruent, the time intervals were underestimated more than if there was incongruent feedback. They also investigated a possible impact of virtual embodiment on time perception by having people perform the task with a virtual hand or a virtual sphere but the results showed no significant difference between the conditions.

However, the results of Zopf et al. [90] are difficult to generalize to virtual body perception inside a headset-based virtual reality environment. Their study was performed using a tailored mixed-reality system displaying one floating virtual hand (with no skin texture) using a 3D screen on top of the participant's hand. The task consisted of pressing a button. For this, the participants placed their hand on a hand-rest and their index finger was positioned on a response button.

In their system, participants were still able to see their real body and environment. In a fully visually immersive system using a VR headset, the participant 's body is completely invisible and partially or fully replaced by a virtual body [61]. In addition, numerous studies demonstrated that virtual body embodiment with a VR headset is strongly impacting the feeling of owning a different body with many perceptual, psychological, emotional and behavioral effects [13, 60, 83] Virtual embodiment and presence often correlate. Unfortunately, virtual embodiment was only measured using two modified rating scale items adopted from the non-VR rubber hand illusion and a rating scale used to measure agency disruption in hypnosis in non-VR scenarios. Presence was also not measured at all, hence any correlation of their dependent variables in terms of embodiment remains largely speculative.

### 2.4 Summary

Previous research showed that there are many factors which influence the subjective perception of time. However, a person's body seems to play a central role in his/her time perception which should be studied in more detail. Similar brain regions are activated in both time perception and bodily signals [9, 10, 49] and many studies show an influence of emotional and interoceptive states on time perception [15, 43, 49].

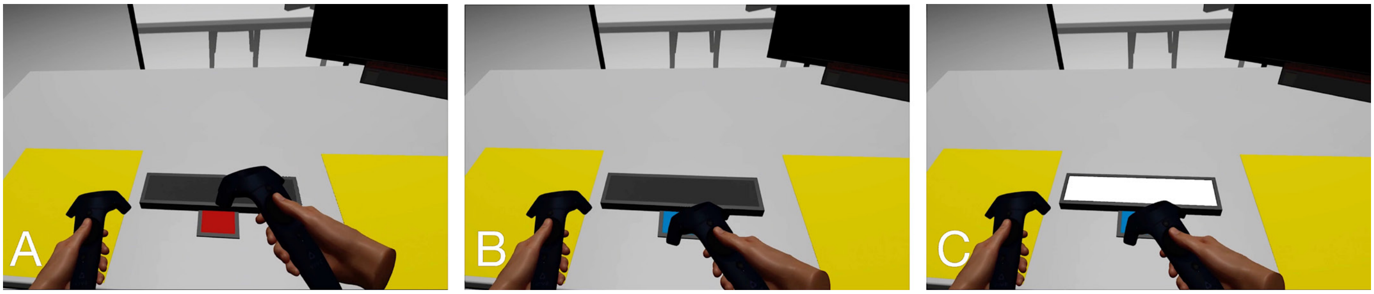


Fig. 2: Execution of the task in the *medium* condition. A) Participant moves his dominant hand towards the light switch. B) Light switch was pressed and the light switch changed color. C) The light switches on after the delay.

Here, manipulating one's own body representation is specifically possible using VR technology, if necessary low-level virtual embodiment cues are successfully generated.

In a study by Zopf et al. [90] to influence time perception in the millisecond range in an active scenario by manipulating virtual embodiment, no significant differences were found. However the study was limited in terms of immersion and the implementation of the virtual embodiment. Unruh et al. [68] countered many of these limitations by using an HMD, replicating a real environment in VR, giving subjects a human avatar and measuring virtual embodiment using a questionnaire tailored and validated specifically for virtual embodiment. Unlike Zopf et al [90], they did not investigate an active scenario, but simply had subjects wait in VR and showed that the manipulation of virtual embodiment impacts time perception in a waiting room scenario.

However, waiting room scenarios themselves are specific in terms of time perception [53, 87] and therefore the results are difficult to generalize. We hypothesize that a passive waiting room scenario without any explicit interaction with the environment does not sufficiently foster agency as an important sub-factor for virtual embodiment. The extent to which a stronger focus on agency could have an impact on time perception is therefore still unclear and needs to be clarified.

## 3 Methods

To better assess the validity of previous findings and the relevance of agency, we investigate the influence of the degree of embodiment on time perception in an interactive scenario. The scenario involves activating a virtual lamp and estimating the time interval until the lamp comes on. Taking into account previous work by Suzuki et al. [63] the delay was either 200ms, 400ms or 800ms. All delays occurred equally often and in random order. This task was chosen for its simplicity and avoidance of flow. It is important to avoid flow, as this would otherwise significantly influence the perception of time [82]. Flow could also prevent typical effects of the virtual body from occurring [41]. By using a photo-realistic avatar and integrating a mirror into VR, we increased embodiment as much as possible [23, 35, 60, 74].

We performed a *within-subjects* design with three different degrees of embodiment as conditions: i) no-avatar (*low*) ii) hands (*medium*) iii) high-quality avatar (*high*). To enable the task to be performed equally in all conditions, the controllers of the VR device were always visible and the light switch should be pressed with the controller in one's dominant hand. Consequently, in the *low* condition one still possessed some form of embodiment although no body was displayed. All conditions are shown in Fig. 1 and the task in Fig. 2. To avoid a sequence effect in time estimation, the participants were informed beforehand that they had to estimate time intervals during the study. They also completed a training run and the order of the conditions was counterbalanced. We formulated the following hypotheses:

**(H1)** The passage of time will be perceived slower the lower the degree of embodiment

**(H2)** Time duration judgements in the millisecond range will be shorter the lower the degree of embodiment.

**(H3)** Time duration judgements in the minute range will be shorter the lower the degree of embodiment.

### 3.1 Participants

A total of 55 participants took part in the study. 7 participants had to be excluded because they did not follow the protocol or there were technical difficulties. Of the remaining 48 participants (27 females, 21 males), 44 were native speakers and the average age was 23.2 years ($SD = 3.60$). 42 of the subjects were right-handed, 6 were left-handed, and no one was ambidextrous. Furthermore, 40 subjects had previous experience of wearing an HMD. Of these 40 participants, 6 had already participated in one VR study, 25 in 2-9 VR studies, and 4 had even participated in more than 10 VR studies.

### 3.2 Measures

#### 3.2.1 Virtual Reality Sickness Questionnaire (VRSQ)

Simulator sickness was assessed before and after the experiment using the Virtual Reality Sickness Questionnaire (VRSQ) [33]. It is a shortened version of the Simulator Sickness Questionnaire (SSQ) [31] specially adapted for use in VR. It contains the 2 subscales "Oculomotor" and "Disorientation" from which the "Total" score is calculated. The aim was to check whether the VR environment had negative effects on the participants and whether the results could be biased.

#### 3.2.2 Time Perception

To estimate the time between the light switch being pressed and the light coming on, a slider was displayed on a screen in VR after each iteration. One could then estimate the elapsed time between these two events on a scale from 0 to 1000 milliseconds. We refer to this as the "time interval estimation". Duration of time, passage of time and boredom were assessed with the same questions and scales previously used by Lugrin et al. [42] and Unruh et al. [68], a) "*Intuitively (without further thinking), how long do you think the waiting time lasted (in minutes and seconds)?*", b) "*How fast did time pass for you?*" (extremely slow - extremely fast), c) "*How much boredom did you experience most of the time?*" (no boredom at all - extreme boredom). Except for a slight adjustment of the duration question, the questions are originally from the Inventory on Subjective Time, Self and Space (STSS) [29, 48]. All three questions were part of the post questionnaires (see Fig. 5). Since the time spent in VR could vary between the conditions due to the task, the difference between the estimated time duration and the time actually spent in VR was calculated to get the "time duration estimation". The values are given in minutes and negative values indicate an underestimation. To calculate the differences in time interval estimates between conditions, the average of all estimated times was taken.

#### 3.2.3 Embodiment

To assess the embodiment in the *medium* and *high* conditions the Virtual Embodiment Questionnaire (VEQ) [51] was used. In the *medium* and *high* conditions we collected data for all three subscales "Ownership", "Agency" and "Change". In the *low* condition, we only assessed "Change" subscale. We chose to do this to avoid confusing the participants. All questions in the subscales "Ownership" and "Agency" refer to a virtual body that is not present in the *low* condition.


Fig. 3: Different avatars proposed to participants. In the top row all available male avatars can be seen: A) a European-inspired light-skinned avatar, B) an oriental-inspired light-skinned avatar C) and a dark-skinned avatar. In the bottom row all available female avatars can be seen: D) a European-inspired light-skinned avatar, E) an oriental-inspired light-skinned avatar F) and a dark-skinned avatar.

Since the “Agency" questions are not directly about owning a body but about controlling it, we defined an alternative subscale. We call it “ObjectAgency". It contains the same questions as the “Agency" subscale, with the word “body" replaced with the word “object". To determine the validity of the “ObjectAgency" subscale it was collected in all three conditions. This allowed us to compare the values of the “Agency" and the “ObjectAgency" subscales in the *medium* and *high* conditions. All four subscales contain four items that are rated on a seven-point Likert scale (1-7). The corresponding questions were part of the post questionnaires (see Fig. 5) and were asked after each condition.

Since a statistical comparison of the three conditions with regard to "ownership" is not possible, we collected an additional item to check the success of our manipulation:"I had the feeling of owning a virtual body". This item was also part of the post questionnaires (see Fig. 5) and was answered on a seven-point Likert scale (1-7).

#### 3.2.4 Igroup Presence Questionnaire (IPQ)

Due to the connection between embodiment and presence [74], the Igroup Presence Questionnaire (IPQ) was also assessed. The IPQ is composed of the four subscales “General Presence", “Spatial Presence", “Involvement" and “Experienced Realism". The items were rated on a Likert scale (0-6). The IPQ was part of the post questionnaires (see Fig. 5).

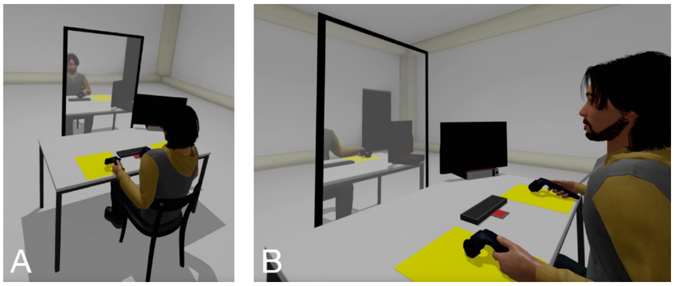


Fig. 4: Virtual Environment from A) a third-person perspective and B) a side perspective.

### 3.3 Design

The virtual environment consisted of a room with a table at its center. On it was a PC, a monitor and a flat lamp. In addition, two areas of the table were colored to define the resting position of the hands. In front of the table was a mirror and the subject sat on a chair (see Fig. 4). To enable visual haptic feedback, the table in the virtual room was also present in the real room. Both had identical dimensions and the virtual table was calibrated to match the position of the table in the real room. In general, the environment should appear as natural as possible. Consequently, the PC fan also emitted a constant light noise to increase VR immersion. Both when the light switch was pressed and when the lamp came on, a sound was heard to further reinforce the haptic and visual feedback of the respective actions with an auditory signal. Pressing the light switch also changed its color (see Fig. 2). After each switch-on of the lamp, the participants should return to their resting position to prevent them from leaving their hand over the light switch. In general they should use their dominant hand to press the light switch. The lamp always appeared in a different place, so that people did not perform the identical movement all the time and get bored.

Depending on the gender of the subject, the subject could choose one of three male or female avatars at the beginning of the experiment. Virtual embodiment should be strengthened by providing a selection of avatars to avoid rejection of the avatar and maximizing resemblance [2, 74]. A European-inspired light-skinned avatar, an oriental-inspired light-skinned avatar and a dark-skinned avatar were available (see Fig. 3). The avatars available for selection were the so-called metahumans from the Unreal Engine$^{TM}$ [67]. These are detailed and high-resolution avatar models that can be animated. The selected avatar was displayed in the *high* condition during the experiment. In the *medium* condition, only the hands of the selected avatar were displayed.

Using inverse kinematics, Eubanks et al. [17] suggest tracking the head, hands, and feet to enhance the sense of embodiment and sense of spatial presence. Since the experiment took place in a seated position and the feet are rarely visible during the task due to the table, only the positions of the controllers and the HMD were tracked. All other body part positions were calculated, where the participants' movements only affected the body parts above the waist.

Before the participants started the task, there was a short acclimatization phase to make them aware of their current embodiment.

To test the feeling of the different embodiment types and the experiment itself, a pilot study was conducted with five VR experts. These were characterized by the fact that they use embodied VR several times a week. All of them confirmed that the implementation was well done and that the experiment worked without issue.

### 3.4 Software and Hardware

The Unreal Engine 4™ was used to develop the virtual environment. The animations of the avatar were set with a custom script that was optimized for inverse kinematics in VR. It is based on a script developed for Metahumans provided by Unreal Engine 4™. The application was running on average with 90 fps on a high end desktop PC (Intel Core i9-10900k 5.30 GHz CPU, 64 GB of RAM, Nvidia GeForce GTX 3090 Graphics card).

End-to-end latency was measured manually by counting frames. For this purpose, a video was recorded with a 240fps camera that shows the movements of the motion tracked controllers on a screen. The latency was on average 32 ms which is sufficient for a typical VR application [7, 75].

To immerse the participants in the VE, the HTC VIVE™ Pro was used. The respective HMD has a field of view of 110°, a resolution of 1440*x*1600 pixels per eye and a refresh rate of 90Hz. Using the two HTC VIVE™ Pro wireless controllers, the participants' hand movements were tracked.

### 3.5 Procedure

Figure 5 illustrates the sequence of one experimental session. First, the participants were welcomed and asked to sit on the chair that was fixed on the floor. They were told to hand over their mobile phone and watch if they had any with them. They were given a consent form to sign and could clarify open questions with the experimenter. Afterwards, they filled out the demographic questionnaire and the first VRSQ on a laptop.

The experimenter helped the participants to put on the HMD and gave them the controllers in their hands. The participants were then asked to stretch their arms out to the side to enable the calibration of the avatar. Meanwhile, they were to look at a fixation cross in VR. Once the avatar was calibrated, the test person could choose one of three avatars and confirm their selection. The training session started with the just selected avatar. The participants received auditory instructions via the headphones and were asked to follow them. The acclimatization phase included taking the same position of the avatar, looking at oneself and performing some simple actions like waving at one's mirror reflection. It lasted on average 2 minutes. Afterwards participants should activate the virtual lamp six times and estimate the corresponding delay.

Before the first condition was started, the participants were asked to briefly take off the HMD again. It was clarified whether everything was understood and whether the procedure was clear. When the participants were ready, the HMD was put back on and the first condition was started. Again, the same or, depending on the condition, slightly modified auditory instructions were heard. The virtual lamp was then activated 45 times and the respective delay was to be estimated. Each delay of 200ms, 400ms and 800ms occurred 15 times. The participants needed an average of 5.9 minutes to activate the lamp 45 times.

The participants had to take off the HMD again and answer the time perception questions, the VEQ, the IPQ and the additional embodiment question on the laptop. If the subject was feeling well and was able to continue, the next condition was started. After the third condition, the VRSQ was additionally asked. At the end of the experiment, the participants could still clarify open questions and talk about the aim of the experiment with the experimenter. A session lasted on average 1 hour.

### 3.6 Statistical Analysis

All time perception items as well as our additional embodiment item, the VRSQ, the IPQ and the VEQ ratings were analyzed on the interval measurement scale [5, 29, 48, 68].

For the comparison of the VRSQ "Total" score, the "Ownership" subscale and the "Agency" subscale, the items were analyzed with a

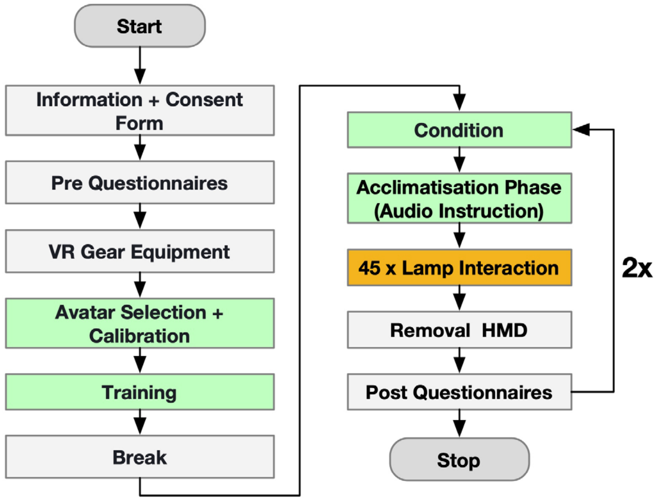


Fig. 5: Experimental procedure for each experimental trial.

dependent t-test, provided that normal distribution and variance homogeneity could be assumed. Normality was tested with the Shapiro-Wilk test and variance homogeneity with the Levene test. If no normal distribution could be assumed, a Wilcoxon signed rank test was performed. If the assumption of variance homogeneity was violated a Welch (or Satterthwaite) approximation was used.

All other items were analyzed using a One-way repeated measures Anova if normality and the sphericity assumption held true. These were tested using the Shapiro-Wilk test and the Mauchly test. If the normality could not be assumed, the Friedman test was performed. When factors violated the sphericity assumption, a Greenhouse-Geisser sphericity correction was applied. If the one-way repeated measures Anova or the Friedman test yielded a significant result, a post-hoc test was conducted. This involved testing between levels of the factor within participants using pairwise dependent t-tests or Wilcoxon signed-rank tests. To correct for multiple testing the Bonferroni correction method was used. The effect size is given in Eta-squared $\eta^2$ for the one-way repeated measures Anova and as Kendall's W for the Friedman test. The Pearson's product moment correlation coefficient was calculated to determine the correlation between the "Agency" subscale and the "Object Agency" subscale for the *medium* and *high* conditions.

## 4 Results

All results of the measures calculated between all conditions can be seen in Tab. 1.

### 4.1 Virtual Reality Sickness Questionnaire

The VRSQ "Total" scores were not normally distributed and there was no variance homogeneity. The "Total" scores were significantly higher after the VR exposure ($M = 8.30, SD = 9.65, Mdn = 4.17$) compared to the values before the experiment ($M = 5.35, SD = 6.44, Mdn = 4.17$); $p \leq .01, d = 0.32$.

### 4.2 Time Perception

The results of the Shapiro-Wilk tests showed that no normal distribution can be assumed for Time Duration estimation, Time spent in VR and Boredom. Normal distribution could be assumed for time passing and the time interval estimation. There was only a significant difference in terms of time passing. Time passed significantly faster in the *medium* and *high* conditions compared to the *low* condition (see Fig. 6) but the *medium* and *high* conditions did not differ from each other. This partially confirms our *H1* that the degree of embodiment has an effect on the perceived passage of time. In contrast to our *H2* and *H3*, there was no significant difference in duration judgements due to the degree of embodiment, neither in the millisecond nor in the minute range. Therefore, *H2* and *H3* must be rejected.

Table 1: Main results of measures calculated between all conditions. Bold rows indicate significant results in the post-hoc analysis ($p \leq .05$). Mean values in a row with the same symbols indicate a significant difference between the corresponding conditions in the post-hoc analysis.

| | low | | medium | | high | | test statistic | p-value | effect size |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Anova / Friedman | $p \leq$ | $\eta^2/W$ |
| Time Interval estimation (ms) | 388 | 95.9 | 387 | 96.4 | 395 | 101 | $F(2,94) = 0.511$ | .60 | 0.002 |
| **Time passing (STSS)** | **$45.3^{\dagger,\ddagger}$** | **21.9** | **$56.1^{\dagger}$** | **21.6** | **$52.8^{\ddagger}$** | **20.5** | **$F(2,94) = 9.632$** | **.01** | **0.044** |
| Boredom (STSS) | 61.0 | 24.9 | 54.9 | 25.9 | 52.1 | 27.5 | $\chi^2(2) = 5.03$ | .08 | 0.052 |
| Time Duration estimation (min) (STSS) | −0.78 | 3.91 | −0.14 | 2.72 | −0.01 | 3.21 | $\chi^2(2) = 3.38$ | .19 | 0.035 |
| Time spent in VR (min) | 5.77 | 0.96 | 5.92 | 1.20 | 6.10 | 1.09 | $\chi^2(2) = 4.88$ | .09 | 0.051 |
| **Change (VEQ)** | **$2.18^{\dagger}$** | **1.40** | **$2.38^{\ddagger}$** | **1.40** | **$3.16^{\dagger,\ddagger}$** | **1.72** | **$\chi^2(2)) = 13.5$** | **.01** | **0.140** |
| Object Agency | 5.81 | 0.9 | 5.66 | 1.04 | 5.83 | 0.81 | $\chi^2(2) = 0.577$ | .75 | 0.006 |
| **Owning a virtual body** | **$2.19^{\dagger}$** | **1.78** | **$3.08^{\dagger}$** | **1.91** | **$4.40^{\dagger}$** | **1.53** | **$\chi^2(2) = 39.2$** | **.01** | **0.408** |
| General Presence (IPQ) | 3.17 | 1.52 | 3.46 | 1.44 | 3.79 | 1.24 | $\chi^2(2) = 7.29$ | .03 | 0.076 |
| **Spatial Presence (IPQ)** | **$3.30^{\dagger}$** | **1.04** | **3.51** | **1.01** | **$3.85^{\dagger}$** | **1.11** | **$F(2,94) = 8.501$** | **.01** | **0.044** |
| Involvement (IPQ) | 3.05 | 1.19 | 3.43 | 1.23 | 3.20 | 1.10 | $F(2,94) = 2.481$ | .09 | 0.018 |
| Realism (IPQ) | 2.21 | 0.92 | 2.26 | 1.00 | 2.56 | 1.07 | $\chi^2(2) = 6.60$ | .04 | 0.069 |

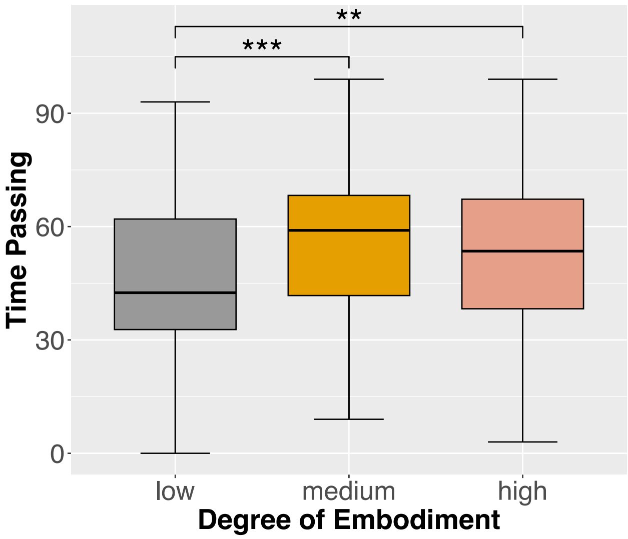


Fig. 6: Main results of the dependent variable Time Passing. Scores per condition, with error bars.

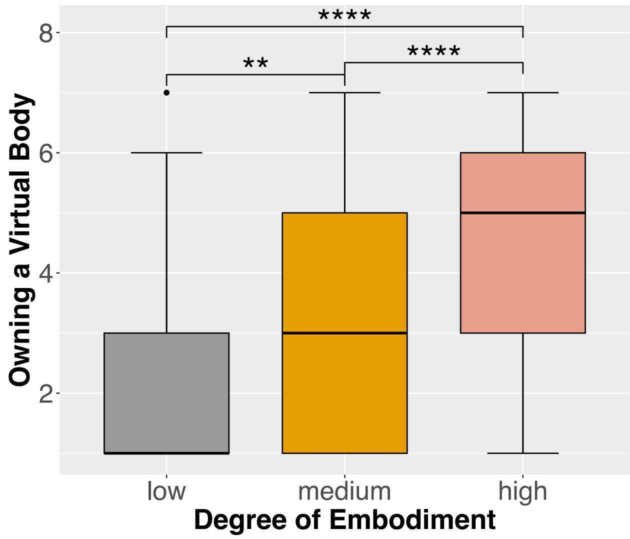


Fig. 7: Main results of the dependent variable owning a virtual body. Scores per condition, with error bars.

### 4.3 Embodiment

According to the Levene test for “Ownership", there is variance homogeneity and the data are normally distributed. There was a significant higher “Ownership" score in the *high* condition ($M = 3.94, SD = 1.26, Mdn = 4$) compared to the *medium* condition ($M = 3.34, SD = 1.45, Mdn = 3.25$); $p \leq .01, d = 0.44$.

The Shapiro Wilk tests for “Agency", “Object Agency" and “Change" do not indicate a normal distribution. Of these three, the “Agency" and the “Change" scales differed significantly between conditions. The "Agency" scores were significantly higher in the *high* condition ($M = 5.97, SD = 0.76, Mdn = 6$) compared to the *medium* condition ($M = 5.75, SD = 0.92, Mdn = 6$); $p \leq .05, d = 0.26$. Regarding the “Change" scale, the scores in the *high* condition were significantly higher than in the *medium* and *low* conditions.

The results of the Pearson’s product moment correlation coefficient indicate a strong positive correlation between “Agency" and “Object Agency" in the *medium* condition ($r(46) = 0.87, p \leq .01$) as well as in the *high* condition ($r(46) = 0.81, p \leq .01$). There was also a significant difference between all three conditions on our additional item asking for: "I had the feeling of owning a virtual body" (see Fig. 7).

### 4.4 Igroup Presence Questionnaire

The results of the Shapiro-Wilk tests show that the data of the “Spatial Presence" and the “Involvement" are normally distributed. The Friedman tests for the “General Presence" subscale and the “Realism" subscale showed significant differences, but post-hoc analysis was not able to reveal which factor differed significantly from each other. There was a significant difference in the “Spatial Presence" subscale between the *low* and *high* conditions. In the *high* condition, the “Spatial Presence" presence was significantly higher.

## 5 Discussion

The results show that there was a significant difference between the *medium* condition and the *high* condition in the “Ownership" subscale and the “Agency" subcale. In addition there was a significant difference between all three conditions in relation to our question: "I had the feeling of owning a virtual body". In combination, this validates a successful manipulation of the independent variable *embodiment*. We also controlled all three embodiment conditions for boredom and did not find any difference here. Our *H1* can be partially accepted since the passage of time was perceived to be slower in the *low* condition compared to the *high* condition. In addition the *low* and *medium* conditions differed from each other with respect to the passage of time.

These results are consistent with the initial evidence by Unruh et al. [68] but now extend the context beyond mere waiting scenarios. Notably, they reported a faster passage of time for higher embodiment while we report a slower passage of time for lower embodiment. This difference in presentation is based on the interpretation of what we accept as the baseline condition and what we see as the derivation. Here we follow the recent congruence-plausibility theory by Latoschik and Wienrich [36] and conclude that the high and medium embodiment conditions generate less incongruencies. They seem to generate more embodiment cues congruent with expectations from the real world on the perception and cognition layers compared to the low embodiment condition. Hence, the high and medium embodiment conditions are expected to be more plausible and less deviating from a real world experience. Since there was no significant difference between the high and medium conditions, it seems that both produce similarly strong incongruencies. However, the virtual embodiment could be adapted much closer to reality. People could be given a personalized and photo-realistic avatar, which would e.g. increase the emotional response [74]. We further enhanced the plausibility of the experience in our experiment by matching visual and haptic feedback [20]. The resulting congruent visuotactile cues are strong bottom-up promoters for both virtual embodiment and for presence.

Accordingly, the “General Presence" subscale, which asks for the feeling of being present in the virtual world, did significantly differ between the three embodiment conditions but post-hoc analysis was not able to reveal which factor differed significantly from each other.

In contrast, “Spatial Presence" was significantly higher in the *high* embodiment condition than in the *low* condition. The items loading on the “Spatial Presence" factor refer a lot to one’s own spatial relation to the virtual space and surrounding, i.e., the relative position, which emphasizes the body as the anchor in space (and time). We successfully manipulated the embodiment, hence the measured differences reflect the importance of one’s own body for this factor. Here, less embodiment (cues) correlated with less spatial presence, also in line with the congruence-plausibility theory [37].

Then again, “Spatial Presence" did not differ between the *low* and *medium* conditions. There are multiple potential reasons for this. For one, manipulating embodiment is tricky in VR since it can not be completely avoided. Please note that even if one does not show a user avatar at all, an often accepted minimal requirement for a VR exposure is the generation of a dynamically changing visual feedback by head-tracking. This, by definition, already establishes a closed-loop human-computer interaction based on the body, e.g., head movements of users, ultimately leading to the evocation of agency as one important factor of virtual embodiment [51]. Accordingly, our *low* embodiment conditions did not show virtual body parts of the user avatar but it included a changing perspective by head-tracking as a source for agency. Additionally, all embodiment conditions also included the display of virtual counterparts of the manipulated physical controllers moving in visuomotor synchrony, independent of potential renderings of any body parts. Even in the absence of displayed body parts, these controllers alone could have been interpreted by people as a kind of hand substitute. Although they did not match the hand position exactly, they followed the hand movements accurately except for the slight offset. Overall, the described effects could have rendered the differences between the *low* and *medium* conditions too marginal. We assume that both conditions evoked almost comparable cues with respect to the factor “Spatial Presence". Only the *high* condition elicited strong enough cues in comparison to the *low* condition to also correlate with increased “Spatial Presence".

With regard to “Experienced Realism", no differences between the conditions were identified. This does not contradict the aforementioned arguments concerning the manipulated embodiment cues and an expected plausibility since the IPQ items loading on this factor specifically ask for realism of the environment and the surrounding and not about the self-representation. Here, all participants experienced exactly the same VE.

“Involvement” probably did not differ between the conditions, as the task was identical and could be performed equally well. This is confirmed by the fact that “Object Agency” did not differ significantly between conditions. The high positive correlation between “Agency” and “Object Agency” reinforces the assumption that one can adjust the subscale corresponding to the degree of embodiment. However, since “Agency” differed between the *medium* and *high* conditions, but the conditions did not differ with respect to “Object Agency”, the use of the controller to interact with the environment appears to be the critical aspect. Of course, this still needs to be tested and validated on a larger scale.

Contrary to our *H2* there was no significant difference in millisecond time duration judgements based on the degree of embodiment. This supports initial results from Zopf et al. [90], who also found no influence of ownership on time duration estimation in the millisecond range.

However, the results of Zopf et al. are limited by the use of a tailored mixed reality system, a floating hand model without skin texture, using questionnaires developed for non-VR to measure embodiment and not measuring presence at all. Compared to Zopf et al. [90] a fully immersive system with a VR headset was used. The participants could not see their real bodies or the real environment. Sounds from the real world were also blocked out by wearing the headphones of the HMD and the occurring sounds in the virtual world. Also a more authentic virtual environment was created and photo-realistic hand models were used. Embodiment and presence were assessed using questionnaires specifically designed for VR and a condition with a full body was added.

Despite these adjustments to enhance embodiment and counteract previous limitations, it seems that the degree of embodiment does indeed not impact millisecond time duration judgements. There was also no significant difference found in the time duration judgements in the minute range based on the degree of embodiment (*H3*). This is in line with previous results from Unruh et al. [68], who let people wait for 7.5 minutes in VR with and without an avatar. Consequently, it appears that time duration judgments in the minute range are not influenced by embodiment, regardless of the level of activity.

Combining the current results and earlier results of Unruh et al. [68], it looks like the manipulation of the degree of embodiment only influences the passage of time and not time duration judgements. Often both forms of time perception are influenced by similar factors [29], but it has already been shown that these are not always directly related [76,78]. Considering that Unruh et al. [68] did not find any differences between waiting in a real room and waiting in VR without a virtual body, the changes in visual input caused by simply showing or hiding a body do not seem to be the determining factors. Rather, this suggests that the sense of embodiment in VR may be crucial.

Another result is that the values of the “Change” subscale of the VEQ were significantly higher in the *high* condition than in the *low* and *medium* conditions. This is particularly important with regard to the development of time perception based applications that aim to change the perception of the own body. To control for potential negative effects of the environment, the VRSQ was assessed before and after the experiment. Although there was a significant difference regarding the “Total" score, the average is still very low and none of the participants felt sick. When asked during the experiment, no one wanted to stop the experiment. Typical mean values of the VRSQ for a selection task in VR may well range from a “Total" score of 17 to 25 [33].

In summary, the current study shows that the results initially found in a waiting scenario also occur in an interactive scenario. Hence, virtual embodiment seems to have a particular influence on the experience of the passage of time, while leaving the perception of duration untouched. Since the same brain regions are activated in both time perception and bodily signals, two cases should be considered when implementing future VR studies: 1) If participants are not to perform a task where they interact with the virtual environment, a reduced environment and avoidance of focus on embodiment seems sufficient. 2) If participants are to perform a task in which they interact with the virtual environment one should ensure that the incongruencies arising from the embodiment are kept to a minimum.

## 6 Limitations

The main limitation of the study was the varying length of time spent in VR. Due to the study design, the time spent in VR depended on how quickly the task was performed. People who turned on the lamp more slowly and took more time to estimate the delay were consequently in VR for longer.

## 7 Future Work

We believe that our findings are another step towards understanding the relationship between body and time perception. To continue our research in the same direction, we would like to take a closer look at mindfulness meditation. "The practice of mindfulness meditation encompasses focusing attention on the experience of thoughts, emotions, and body sensations, simply observing them as they arise and pass away" [27]. This leads to a stronger self-awareness and a strong focus on one's own body. Numerous studies have shown that mindfulness meditation can lead to a change in the perception of time. An implementation in VR with a manipulation of embodiment could reveal further important connections.

In general, it seems possible to manipulate time perception with healthy participants by changing the virtual body. Since persons suffering from psychic illness have a disturbance of body perception and time perception, we would like to verify these initial results with affected persons. If it were possible to manipulate the perception of time by means of a certain virtual embodiment, it might even be possible to develop diagnosis and therapy methods.

## 8 Conclusion

This work investigated how virtual embodiment affects time perception of healthy people in VR. Participants were randomly exposed to different degrees of embodiment: i) no-avatar (*low*), ii) hands (*medium*) and iii) a high-quality avatar (*high*) whose effects were enhanced by a virtual mirror. They had to switch on a virtual lamp several times with the help of the controller. There was a random time delay of 200 ms, 400 ms and 800 ms between action and reaction (lamp on). Participants then had to estimate the duration of the time intervals in the millisecond and minute range, as well as judge the passage of time.

To the best of our knowledge, we show for the first time a significant impact of embodiment on time perception independent of the activity level of the user, and we exploit VR technology to successfully manipulate embodiment conditions otherwise hardly accessible in real physical world set-ups. In an interactive scenario time passed slower in the *low* condition than in the *medium* and *high* conditions. Combined with related research in a waiting room scenario, this effect seems to be at least partially independent from the activity level. Furthermore, the duration rating for both time ranges did not seem to be impacted by the degree of embodiment. The manipulation of embodiment appears to specifically affect the passage of time rather than the perception of the duration of time. Overall, these findings on the influence of embodiment on time perception now cover many more scenarios.

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