Time Perception Research in Virtual Reality: *Lessons Learned*

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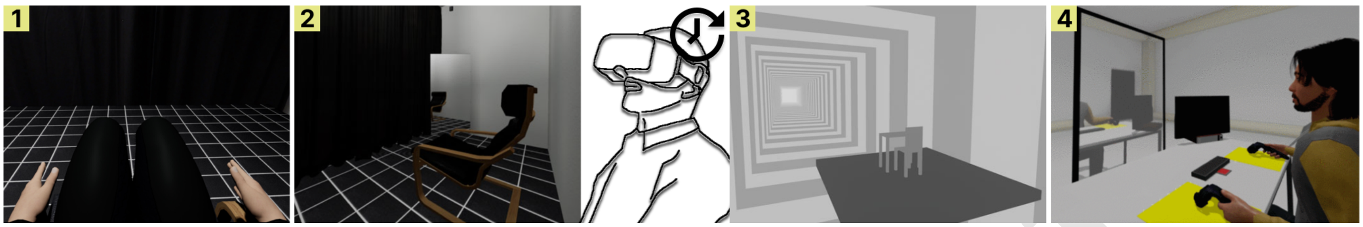

Fig. 1. The various time perception studies conducted by our research group: 1) A waiting room scenario in a real, a virtual 3D-modelled and a 360-degree-picture room[14]; 2) A waiting room scenario in a real waiting room and in VR in a 3D model of the room [23]; 3) A virtual tunnel scenario in VR [11]; 4) An interactive task scenario in VR [24].

In this article, we present a selection of recent studies from our research group that investigated the relationship between time perception and virtual reality (VR). We focus on the influence of avatar embodiment, visual fidelity, motion perception, and body representation. We summarize findings on the impact of these factors on time perception, discuss lessons learned, and implications for future applications. In a waiting room experiment, the passage of time in VR with an avatar was perceived significantly faster than without an avatar. The passage of time in the real waiting room was not perceived as significantly different from the waiting room in VR with or without an avatar. In an interactive scenario, the absence of a virtual avatar resulted in a significantly slower perceived passage of time compared to the partial and full-body avatar conditions. High and medium embodiment conditions are assumed to be more plausible and to less different from a real experience. A virtual tunnel that induced the illusion of self-motion (vection) appeared to contribute to the perceived passage of time and experience of time. This effect was shown to increase with tunnel speed and the number of tunnel segments. A framework was proposed for the use of virtual zeitgebers along three dimensions (speed, density, synchronicity) to systematically control the experience of time. The body itself, as well as external objects, seem to be addressed by this theory of virtual zeitgebers. Finally, the standardization of the methodology and future research considerations are discussed.

Additional Key Words and Phrases: extended reality, time perception, virtual environments, time manipulation, virtual time, virtual bodies, embodiment

1 INTRODUCTION

Time perception is a complex cognitive process that can be influenced by a variety of factors, and the immersive nature of VR provides a unique opportunity to investigate the interplay between environmental stimuli and cognitive processes that contribute to our perception of time. Recent studies of time perception in virtual reality have examined a variety of factors. In order to provide more clarity, we have attempted to categorize this work according to the influencing factors that have been studied: embodiment, visual fidelity, motion, and vection. An important influencing factor in VR is the embodiment of avatars. Recent studies have shown that users' perception of time can be affected when they are embodied with an avatar in a virtual environment [23, 24]. According to the results, a virtual avatar is important to avoid additional distortions of time perception in VR. In addition, the visual fidelity of the virtual world can also influence time perception [14]. Researchers have found that large visual changes that create the visual illusion of self-motion (vection) can affect the subjective experience of time [11]. Challenges in the study of time perception in VR arise from the dynamic and interactive nature of virtual environments. Factors such as attentional processes, emotional states, and the density and predictability of events can affect time perception. The presence or absence of environmental cues such as clocks or sunsets can also influence our ability to accurately estimate the duration of events [20]. The concept of zeitgebers, external cues that help synchronize our internal biological clock, plays a crucial role in our perception of time. Schatzschneider et al. (2016) [20] summarized the concept of zeitgebers and expanded the classification from internal to external zeitgebers, noting the difference between absolute and relative zeitgebers. Relative zeitgebers give us information about the speed of the passage of time, while absolute zeitgebers give us information about the point in time (time of day). It has also been suggested that time can be manipulated and controlled using external virtual zeitgebers. Factors such as speed, density, and synchrony of virtual events can be adjusted to study their effects on subjective time perception [12]. It builds on previous work by [1, 6], which showed that faster speeds and intervals with more changes can affect time perception. Validating this framework and the theory of using external virtual zeitgebers is a next step in our research. Despite the progress made in understanding time perception in VR, there are still some challenges and unanswered questions. The relationship between motion perception, body perception, and time perception in VR remains a fascinating area of research. In addition, the development of effective techniques to manipulate time perception in a controlled manner for therapeutic purposes is promising. The purpose of this article is to provide a brief summary of our recent research and lessons learned, and to motivate this topic for further

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investigation. We also discuss future challenges in the study of time perception and time manipulation in VR.

2 INVESTIGATED FACTORS OF REVIEWED STUDIES

An overview of the selected studies can be found in Table 1.

2.1 Embodiment

Recent studies have shown that the presence of an avatar in VR significantly affects time perception [14, 23]. They compared time judgments after waiting in VR with and without a virtual self-presentation. An additional real room was used as a control condition. The perceived passage of time in VR with avatar was perceived significantly faster than without avatar. In the real waiting room, the perceived passage of time was not significantly different from the waiting room in VR with avatar. In another study, different levels of embodiment in an interactive VR scenario were examined to see if they affected time perception [24]. The task was to repeatedly activate a virtual lamp and estimate the time interval until the light was on. Elapsed time ratings were given after each condition, which consisted of 45 lamp activations. Lower levels of embodiment resulted in a slower perceived passage of time compared to higher levels of embodiment. Following the "Congruence and Plausibility (CaP) Model" [13], it was concluded that medium and high levels of embodiment in VR lead to fewer incongruencies and are therefore more plausible and less deviant from real-world experience. These findings contribute to our understanding of the complex relationship between the body and time perception.

2.2 Visual Fidelity

Visual fidelity plays a role in the perception of time in VR. Lugrin et al. (2019) [14] showed that the visual fidelity of VR environments, such as 3D models or 360-degree rooms, does not significantly disrupt time perception in a waiting scenario when coupled with avatar embodiment, compared to a real waiting scenario. Previously, Schneider et al. (2011) [21] concluded that the use of a VR headset itself seems to introduce an influence in time perception. Larger visual cues, related to the size of the display, were also shown to shorten perceived time [15]. This could be related to the proposed time manipulation axes of velocity and density (higher amount of visible objects and motion), with our own movements tracked by the VR headset.

2.3 Motion Perception and Vection

Motion perception in virtual environments, especially in the context of self-motion illusion (vection), can affect time perception. In a virtual tunnel under high-speed and high-density conditions, participants tend to perceive a faster passage of time and a stronger experience of self-motion [11]. Previously, in the absence of a parallel task, no virtual sun motion was shown to influence retrospective time estimates to be significantly longer compared to virtual sun motion [20]. These findings support the idea of using external virtual zeitgebers, such as a virtual tunnel or a virtual sun, to systematically manipulate time perception in VR. The manipulation refers to the type of motion, the speed and the amount of motion. This is reflected in the proposed Metachron framework [12] about external virtual zeitgebers and their manipulation axes (velocity, density and synchronicity).

3 LESSONS LEARNED AND FUTURE DIRECTIONS

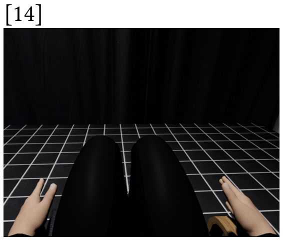
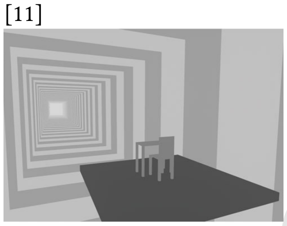
While these studies provide valuable insights, several challenges remain in the study of time perception in VR.

In a waiting room scenario a virtual avatar representation was shown to lead to additional deviations of time perception in VR when no virtual avatar was present [23]. There was no significant difference between waiting in the real room and waiting in VR (avatar, no avatar). In an interactive scenario, participants experienced a significantly slower passage of time in the low embodiment condition (no avatar) compared to when they were represented with higher levels of embodiment (medium, high embodiment = partial and full body representation). In summary, the "Congruence and Plausibility (CaP) Model" [13] seems to be a good framework to explain the results. The absence of an avatar in VR leads to more incongruities compared to the real world. Higher levels of embodiment produce more embodiment cues that seem to be congruent with real-world expectations. Visual fidelity did not significantly disrupt time perception in waiting scenarios when embodied with an avatar. We plan to validate this finding in another context as well. Finally, a virtual tunnel that induced vection was shown to affect the passage of time, and with higher tunnel speeds and segment densities, time passed faster for participants. The passage of time correlated significantly with the experience of vection. Further investigation of this promising relationship is one of our next research steps.

The development of standardized methods and measures would improve comparability and generalizability. The Inventory on Subjective Time, Self, and Space (STSS) [5] was used in the presented studies [11, 14, 23, 24]. The questions about the duration of time, the passage of time, and thinking about time were used in almost all of the studies presented. The questions on tiredness, boredom, intensity of the surrounding space, and intensity of one's own bodily experience were not used in the studies presented. Except for a minor adaptation of the question on time duration, the questions used were originally from the STSS. We plan to add questions on tiredness and boredom to gain further interesting insights. The Simulator Sickness Questionnaire (SSQ) [7] or the Virtual Reality Sickness Questionnaire (VRSQ) [10] was used to assess potential negative effects of simulation. We encourage the research community to increase the use of the VRSQ for VR experiments, as it has been adapted for such simulations and was not originally developed for classical flight simulators like the SSQ. The VRSQ consists of two subscales "oculomotor" and "disorientation" from which the "total score" is calculated.

The Virtual Embodiment Questionnaire (VEQ) measures the experience of owning a virtual body in a virtual environment. A further development of the original illusion of virtual body ownership questionnaire (IVBO) [9, 16, 22] and the alpha IVBO [19] was the VEQ [17, 18]. The VEQ has the subscales "Ownership," "Agency," and "Change." In some of the studies presented, only the "Change" subscale of the VEQ was used for the no avatar condition since the other subscales refer to a virtual body. A new subscale "Object Agency"

Table 1. Selection of recent time perception studies in VR

Reference	N Size	Methods	Lessons Learned	Measures
[14] 	75	A waiting room scenario where participants had to wait 7.5 minutes. A real waiting room was replicated using 3D models and a 360° picture. In a between-subjects design, participants were either embodied with a virtual avatar or not. The investigated environment factors: 360° picture environment, 3D modelled environment, real environment.	Different visual fidelities of VR environments did not significantly disrupt time perception in waiting scenarios when embodied with a virtual avatar.	Time estimation, STSS, SSQ
[23] 	121	A waiting room scenario where participants had to wait 7.5 minutes. A real waiting room was replicated using 3D models. In a between-subjects design, participants were either embodied with a virtual avatar or not and experienced their waiting time either in the real waiting room or in the 3D model waiting room.	Time passed significantly faster when presented with a virtual avatar than when not presented with a virtual avatar. There was no significant difference in time perception between the real and VR conditions (avatar, no avatar).	Time estimation, STSS, SSQ, VEQ, IPQ
[11] 	137, 43	The virtual tunnel environment was designed to move toward the viewer and induce vection (the illusion of self-motion). In a within-subjects design, participants experienced the tunnel with three different trial lengths (20s, 30s, 40s), two different tunnel speeds (low, high), and two different tunnel segment densities (low, high). Two studies were examined: 1) an online remote desktop study and 2) a laboratory-controlled VR study. The VR study added an additional between-groups factor: virtual hands or no virtual hands.	Time passed faster under high speed and high density conditions in a virtual tunnel environment. The experience of self-motion was also stronger in the high-speed and high-density conditions. A significant correlation was found between perceived passage of time and perceived self-motion. Subjects in the virtual reality study reported a stronger self-motion experience, a faster perceived passage of time, and shorter time estimates than subjects in the desktop study.	Time estimation, STSS, SSQ, IPQ
[24] 	55	Participants experienced a virtual room with a table, a chair, and a mirror in the center. On the table was a virtual monitor and a lamp. The interactive task was to interact with the lamp button. In a within-subjects design, participants interacted with the lamp with three different levels of embodiment as conditions: no avatar (low), hands (medium), full-body avatar (high).	In an interactive scenario, time passed more slowly in the low embodiment conditions compared to the medium and high embodiment conditions. According to the "Congruence and Plausibility (CaP) Model" [13], medium and high levels of embodiment are expected to be less incongruent in comparison to the real world than low levels of embodiment.	Time estimation, STSS, VRSQ, IPQ, VEQ

was created to examine the relationship between control and reference to the body. These adjustments could be used as guidelines for the use of these questionnaires or could be incorporated into new questionnaires on the basis of our findings.

Physiological measures should be investigated to support the results of the presented studies. For example, eye tracking could be used to better control attentional bias towards an external virtual timer. Adding physiological measures to experiments could validate the STSS questionnaire and create new methodologies. Experiments were reviewed that investigated the concept of flow and reported physiological measures [8]: blood pressure, heart rate, respiration, electroencephalography (EEG), electrodermal activity (EDA), heart rate variability (HRV), and eye tracking. Two of the eight described factors that enable the flow experience [2–4] are highlighted here: a loss of self-awareness and a loss of sense of time. Flow is characterized as a loss of sense of time, and previous work has found promising correlations with physiological measures, well summarized by Khoshnoud et al. (2020) [8]. These should also be considered when assessing the perception or experience of time. These measures could improve comparability, strengthen contributions, and improve future questionnaires.

Comparing different levels of influence on time perception and conducting physiological measurements is one of our next steps. If a faster passage of time is reported for certain levels, the pattern could potentially be detected in the physiological measurements. Detecting this pattern is the first step toward a system that might be able to respond to a slowed passage of time with increased time influencing inputs, i.e., changes in the speed of external virtual zeitgebers.

Ethical considerations, such as the potential negative effects of manipulating time perception in VR, must also be taken into account.

With a deeper understanding of the complex interactions between virtual environments, embodiment, and time perception, we can realize the full potential of VR as a tool to study and manipulate our subjective perception of time. Research should also be extended to clinical populations to better understand the effects of altered time perception in psychopathological conditions [25, 26].

Future research in this area could address the development of VR-based interventions that specifically target the manipulation of time perception. Such interventions could have applications in a variety of areas, including cognitive rehabilitation, anxiety management, and immersive storytelling.

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