Time Anomalies in Virtual Reality - Impact of Manipulated Zeitgebers on Individual Human Time Perception

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Abstract

Virtual reality (VR) technologies are becoming more and more present in recent years and are no longer limited to the well-known use case of video games, as they are also expanding their way into social networks, digital marketplaces and productive work. The more time people spend in VR, the more important the question becomes, whether a computer-generated reality can also influence human time perception. This work follows the goal of investigating the impact of zeitgebers, in particular the movement speed of a virtual sun, on human time judments in VR. The development platform Unity is used to create different VR worlds with varying sun movement speeds. In a user study with 12 participants, each person is immersed twice for a period of 10 minutes, and at the end of each scenario, they must estimate, how much time they think they have spent in the specific VR world. The evaluation reveals a trend, that the duration in a static world, without any visual objects, is estimated longer, compared to a virtual island environment with sun movement. When comparing an island world with different sun speeds, the estimated duration when experiencing a faster movement of the sun, turns out longer. The study has proven, that the presence of a virtual moving sun increases the estimation accuracy significantly, compared to conditions where no sun is visible or moving. The analysis shows no significant differences, when comparing the submitted duration estimates from each participant.

Categories and Subject Descriptors

[**Human-centred computing**]: Human computer interaction (HCI)—*Empirical studies in HCI*

General Terms

Human Factors

Keywords

Zeitgeber, Time Perception, Virtual Reality, HCI

1 Introduction

Time is *relative*. Albert Einstein first stated this in his special theory of relativity in 1905. This phenomenon, though sometimes inexplicable, remains relevant until today. Put differently, it states that the speed with which objects move depends on the eye of their observer. This makes it a challenge to find a general, yet precise definition for what time is. As such, Einstein defined the term "time" as "what a clock measures" [4]. Although in practice the physical effects of relativity are extremely small for humans on earth, we may still face situations in which it seems as if time does not always pass at the same speed. In the past, experiments have shown that people's subjective experience of time actually depends on multiple internal and external factors, such as the environment or the person's activities and emotions [2, 3].
With current Virtual Reality (VR) technologies, we are given the tools to create worlds that allow people to experience computer-generated virtual environments immersively [10, 11, 13]. In these worlds, developers can implement a custom time progression, such as a day-night cycle that mimics the one of the real world. These structures or processes that inform the user about the status and passage of time are called *zeitgebers*. A 2016 study was one of the first to explore the effects of varying zeitgebers in an immersive VR environment. The zeitgeber used for this experiment was a virtual sun. The study concluded that a natural or unnatural movement of the sun has a significant impact on human time judgments [13]. Recent developments, like the metaverse, indicate that VR technology is going to play an important role in the future. AI based algorithms, as one example, already deal with time and seasonal dependencies [8] often neglected in VR environemnts. As the knowledge about human sensitivity to temporal durations in VR is still limited, the aim of this work is to extend the current knowledge by conducting further research on zeitgebers in VR.

2 Related Work

We provide an overview on general human time perception and previous research on human temporal sensitivity in virtual reality.
An important aspects of time is that temporal judgments are highly dependent on the individual person, as well as the context and the environment [2, 3]. Droit et al. [2] concluded that "these contextual variations of subjective time do not result from the incorrect functioning of the internal

clock but, on the contrary, from the excellent ability of the internal clock to adapt to events in the environment". One aspect of research that relates to the perception of time is duration estimation [12, 3]. The estimation of a time duration refers to the human ability to approximate how much time has elapsed between two specific events by using particular time units [12]. In situations where participants are asked to explicitly judge time, cognitive psychologists make a distinction between two paradigms [7] namely (i) *Prospective timing* where participants are informed before they perform the task, that they are required to make a time-related judgment and (ii) *Retrospective timing:* where participants receive no prior warning, that they must make a time-related judgment and can only estimate the duration from memory.

Droit et al. [2] argued that studies investigating time experience should use prospective timing, because time durations are difficult to remember, since human attention is not focused on temporal information by default. The next important aspect about human time perception is the concept and functionality of zeitgebers. A zeitgeber (German loanword: literally translates to "time-giver") is used to describe environmental or external time cues that can affect the human circadian rhythm [6]. The circadian rhythm is defined as a natural biological process that repeats itself approximately every 24 hours. It is an endogenously driven process that remains in the same period even without permanent external temporal cues. A wide range of researchers have already shown that healthy humans are able to adapt their circadian rhythm to environmental zeitgebers, e.g. the earth's rotation and consequently with the natural day-night cycle [6].

The rest of this section covers what is currently known about human time perception while experiencing a virtual reality. Schatzschneider et al. [13] published one of the first papers analyzing human sensitivity to temporal durations while experiencing an immersive environment using a head-mounted display (HMD). The experiment investigated the effects of a manipulated movement of the sun as external zeitgeber, as well as the effects of cognitive load, divided into spatial and verbal tasks, on time duration estimation. The results of the study showed that, without any task, participants tend to overestimate time durations and, with additional cognitive tasks, tend to slightly underestimate time duration. Under the condition that they are given no task, the estimated duration was significantly longer if no movement of the sun was displayed, compared to a setup in which the sun moved with realistic or amplified speed. The authors concluded "that manipulations of external zeitgebers caused by a natural or unnatural movement of the virtual sun in the sky had a significant effect on time judgments" [13].

The comparison resulted in no significant differences between time estimates in the real and virtual environments [1]. The same conclusion was reached by Van der Ham et al. [14] with the result that there is no difference in the perception of temporal duration between VR and real life, and that the effect of time compression often associated with VR is most likely the result of the materials displayed rather than the medium of VR itself [14]. Igarzábal et al. [9] discovered that waiting in VR is more boring and leads to a slower perception of time than waiting in a real room. The authors stated that "participants may not have known how to react to the VR waiting situation due to its novelty and therefore may not have applied the same coping strategies they would in a real waiting scenario" [9].

3 Methodology

This chapter covers the methodology used for producing the results of our study. An overview of the overall research scheme as well as the summarized outcomes are given in Figure 1.

We draw inspiration from related work with the idea of reproducing a study on zeitgebers in VR [13] and to extend it with further findings. To allow for easy comparison of the results, the variable *time gain* (g_t) is also used in the scope of this work. The authors define time gain as the factor by which the speed of the sun in the real world is multiplied in the VR environment. The first step was to identify the technical requirements for the implementation of a VR system, to allow users an immersive experience of selected environments. This enables the setup of of the first study concept, whose goal is to verify whether a significant difference in time perception can be achieved with completely different VR environments. The first environment (see 1. Environment in Figure 2) is a completely empty area without any objects or lighting conditions. The second environment (see 2. Environment in Figure 2) consists of an island world, with lots of elements to look at (similar to Schatzschneider et al. [13] with rocks, palm trees, sun lounger, surfboard, ocean), and the presence of a zeitgeber in form of a moving sun. The evaluation of the results hinted at the need for two further study designs, comparing the exact same island world, but with different time gains:

- *Study concept 1:* Static empty world vs. dynamic sun-moving island world with $g_t = 2.5$
- *Study concept 2:* Island world with $g_t = 0$ vs. $g_t = 2.7$
- *Study concept 3:* Island world with $g_t = 0$ vs. $g_t = 1.1$

These time gains are selected to reproduce ($g_t = 0$), check slightly differences ($g_t = 1.1$) and to extend ($g_t = 2.5$ and 2.7) the previous findings of related work. All study concepts in combination provide widespread insights into the effects of manipulated zeitgebers and environments on human time perception in VR.

3.1 Hypotheses

The following are the hypotheses which we aim to answer in our study and the relevant study variables are summarized in Table 1.

- *H1:* There is no significant difference in human time perception measured by time estimation tasks between experiencing an empty static and a dynamic sun-moving island VR world.
- *H2:* The speed manipulation of a virtual moving sun has no significant effect on human time perception while being in virtual reality.
- *H3:* Human time estimation is equally accurate in the presence or absence of a working zeitgeber in virtual reality.

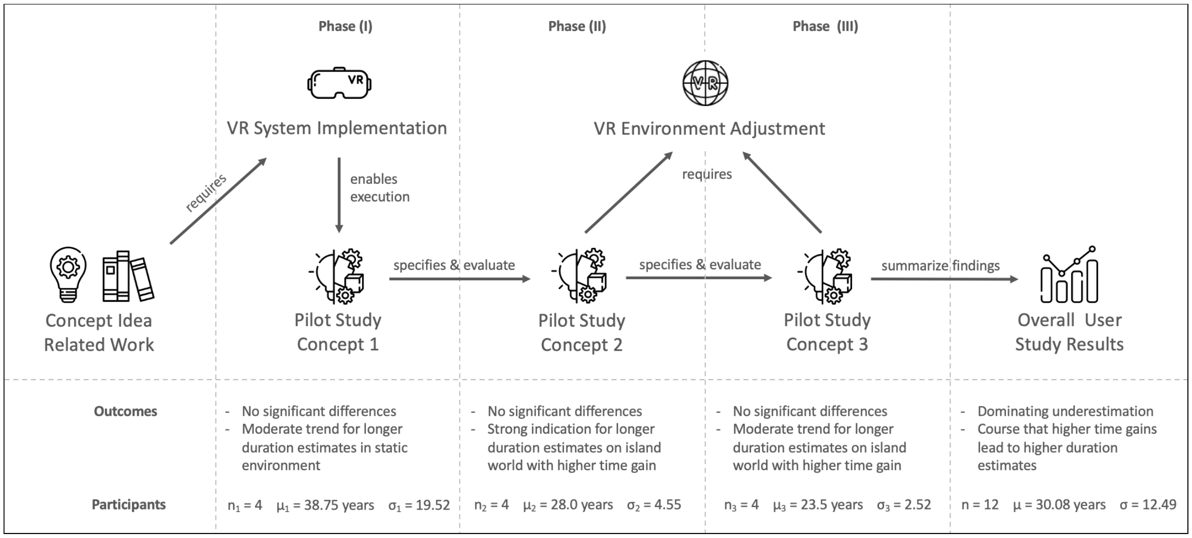

Figure 1. Overview of the overall research scheme, study concepts, and summarized outcomes achieved in the process of this work [5].

Table 1. Study variables

Variable	Description
Dependet (v_d)	Subjectively perceived time duration of the experiment from the participants view
Independent (v_i)	- Static / dynamic VR environment - Time gain (g_t)
Confounding (v_c)	Other zeitgebers and activities (social interactions, sounds, etc.)

3.2 Study Procedure

We chose a within-subjects design for the study, i.e. every participant experiences two scenarios, which can then be compared with one another. This decision was made as time perception is a subjective matter and there can be large interpersonal differences in estimating time duration. During the experiment, the participants were not given any tasks, except to look around in the virtual environment and to estimate the elapsed time at the end of each scenario. The participants were seated in a chair during the experiment and were not allowed to stand up or perform any other activities. The study is based on prospective timing, which is necessary because every person has to give an estimate for two separate durations. An illustration of the schematic and real study procedure can be seen in Figure 2. The whole study procedure was explained by the supervisor in advance during the setup process. At this point, the headset was adjusted and the participant's handling of the input controller was tested, as well. The participant was left alone in a room while being immersed in the virtual reality. This avoided the presence of other zeitgebers, like sounds or social interactions. The study room was a laboratory at the University of Passau, which ensured quiet surroundings. For the entire duration of the experiment, the user was holding the VR controller in their hand. All further instructions were presented directly in VR via slides on a floating canvas. The users controlled the speed at which new instructions were presented themselves, and had to press a button every time they had finished reading and wanted to continue. The presentation of each environment lasts exactly 10 minutes (600 seconds), which is the same as in the experiment of Schatzschneider et al. [13]. Participants were told that the actual duration is purely random and does not correspond to a fixed value. The estimation input was entered using the VR controller in minutes and seconds, but seconds could only be specified in 30 seconds intervals. The user's view in the HMD was transmitted live to a screen visible to the study supervisor to both record the participant's view and be able to react in case of any problems. The experiment took place in the winter months of January and February 2022 in Germany, Passau. For the experiment, the virtual world showed a sunset scenario due to the experiment's execution time, which was mostly in the afternoon. It is important to note that the starting point of the sun was not synchronized to the actual time of the day and remained the same for all participants, even if the daytime of the study execution differed slightly for the individual participants.

3.3 Participants

A total of 12 participants (3 female and 9 male) were recruited for the study. Participants were equally distributed among the three study concepts, such that each concept was participated in by 4 participants. The ages of the subjects ranged from 20 to 58 years, with a mean age of 30.08 years and a standard deviation of 12.49 years. Participation was completely voluntary and the subjects were randomly selected from a pool of known individuals. All of the participants had normal or corrected-to-normal vision, two of them wearing contact lenses, but everyone was able to read the presented text in VR well and without mistakes. None of the participants experienced any discomfort, balance disturbances, simulator sickness, or binocular vision disturbances during the experiment and completed the study without interruption. None of them had ever used an HMD before or had any previous experience with virtual reality. The total time per participant, including explanation of the study procedure,

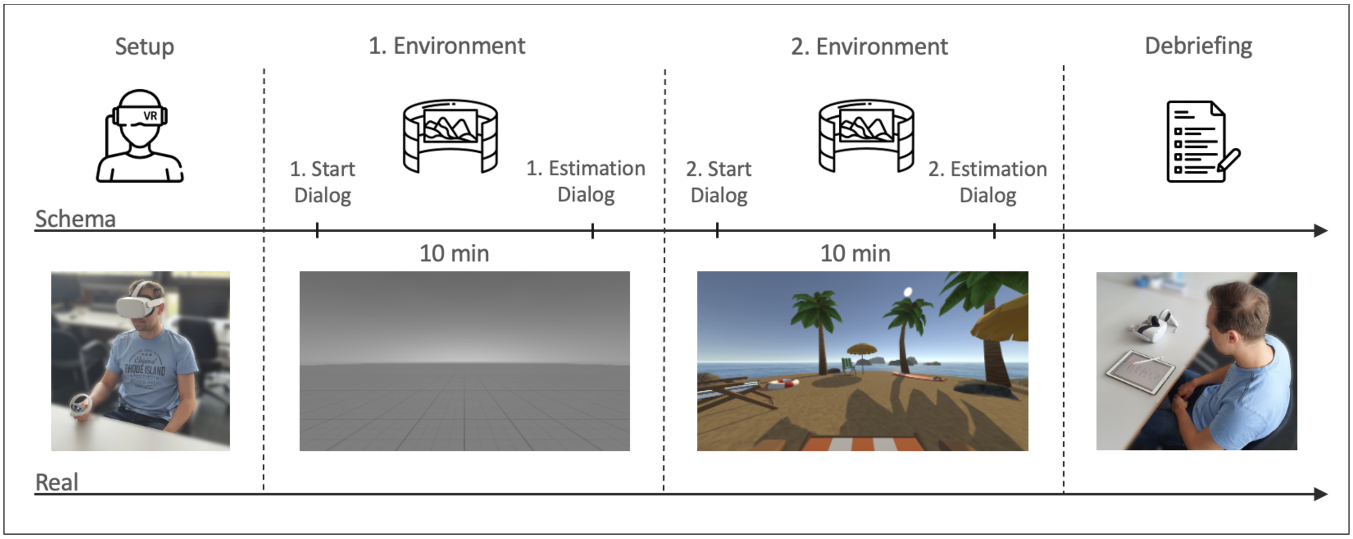

Figure 2. Schematic and real representation of the study procedure for the first study concept. Study concept 2 and 3 use the island VR environment, albeit with different sun movement speeds [5].

fitting the VR headset, verifying correct operation, the study itself, and debriefing with some questions afterwards, was 30-45 minutes.

3.4 Material and Technology

The VR environments are implemented using the game engine Unity[1] of version 2020.3.24f1 (LTS), and its prebuilt scriptable universal render pipeline of version 10.7.0. An Oculus Quest 2 HMD[2] is used to present the VR environments to the user. The device offers a single LC display with a resolution of 1832 by 1920 pixels per eye and a maximum refresh rate of 120 Hz. A special feature that sets it apart from other headsets is the standalone functionality, which allows for flexible usage and avoids impractical wiring. The device weighs 516 grams and has a specified field of view of about 95 degrees. The Oculus XR plugin of preview version 2.0.0 is used to enable easy integration of the HMD and the controllers in Unity. To further improve the frame rate, the Application SpaceWarp[3] feature is activated, which resulted in a stable frame rate of about 70 frames per second. Together with the high resolution, the Oculus Quest 2 HMD leads to a comfortable experience for all users and makes the headset well suited for a user study.

3.5 Results

The submitted time duration estimates of all participants are given in Table 2 and a graphical representation with the estimation of each participant and the average of each study concept is visualized in Figure 3. It can be noticed that only 3 out of 12 participants (P_3, P_7, P_9) estimated the duration to be longer than the actual duration of 600 seconds (10 minutes) in at least one experiment. All other participants estimated the duration to be less or equal to 600 seconds. The overall average of all time estimates is 556.25 (09:16 min) with a standard deviation of 165.73. The first study

Table 2. Duration estimates (in seconds) from all participants and study concepts

Participant	1st estimation	2nd estimation	concept
1	570	600	1
2	390	270	1
3	870	720	1
4	510	540	1
5	420	510	2
6	510	570	2
7	840	900	2
8	570	570	2
9	690	600	3
10	600	600	3
11	300	450	3
12	330	420	3

concept shows the trend of a decreasing average value from the 1st (empty world) to the 2nd experiment (island world). Study concept 2 and 3 each indicate an increase in the perceived duration of the second experiment, resulting from the higher average values (in 5 of 8 cases, the second estimate is higher). In both study designs, the island world is compared with $g_t = 0$ in the first experiment and $g_t = 2.7$ or $g_t = 1.1$ in the second experiment respectively. The chart further highlights the strong interpersonal differences in estimating a time duration, since the first experiment for P_5 - P_12 was exactly the same (seeing the island world with $g_t = 0$), but results greatly differed. The submitted durations range from 300 s (05:00 min) to 900 s (14:00 min), with an average value of 555 s (08:52 min) and a standard deviation of 161.74. The diagram shows that the average values lie in the range around the actual duration, with a tendency to be slightly lower than the actual duration. Figure 4 shows the mean of all values from the individual study results per time gain. We chose this type of representation as the re-

[1] https://unity.com/
[2] https://www.oculus.com/quest-2/
[3] https://developer.oculus.com/blog/introducing-application-spacewarp/

sults of Schatzschneider et al. [13], are presented in the same way, such that a straightforward comparison can be made. The X-axis is split into the time gains that were used in the experiments of this thesis {0, 1.1, 2.5, 2.7} and the Y-axis displays the pooled estimated duration, with the horizontal lines connecting the average of each condition and the vertical bars with two points per time gain representing the upper and lower bound of the standard error of the mean. Note that the diagram is sensitive to a person-related bias due to the strong interpersonal differences. The orange colored line at 600 s (10 min) corresponds to the true duration value of the experiments. The diagram shows that the actual duration was strongly underestimated when considering $g_t = 0$, $g_t = 1.1$ and $g_t = 2.5$. The average of the estimated duration for $g_t = 0$ is 532.5 seconds (08:52 min) with a standard error of 57.01. For $g_t = 1.1$ it is 517.5 seconds (08:37 min) with a standard error of 48.02, for $g_t = 2.5$ it is again 532.5 seconds (08:52 min) with a standard error of 95.16, and only for $g_t = 2.7$ the estimate is slightly higher than the actual duration with an average of 637.5 seconds (10:37 min) and a standard error of 88.64. Comparing $g_t = 0$ with $g_t = 1.1$, there is a slight drop of 15 seconds, and from $g_t = 1.1$ to $g_t = 2.5$ there is a small increase of 15 seconds. The average of $g_t = 0$ and $g_t = 2.5$ is identical. When comparing $g_t = 2.5$ to $g_t = 2.7$, there is an increase of 105 seconds (01:45 min) in the average estimated duration.

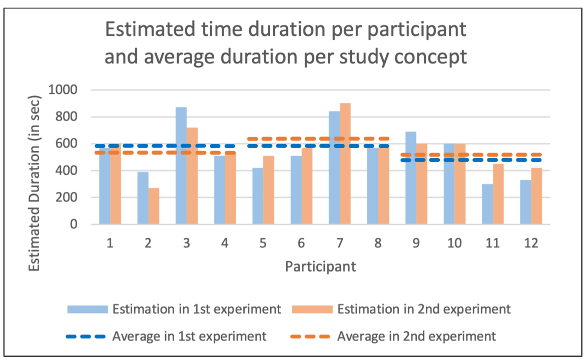

Figure 3. Duration estimates from each participant and average values per experiment and study concept.

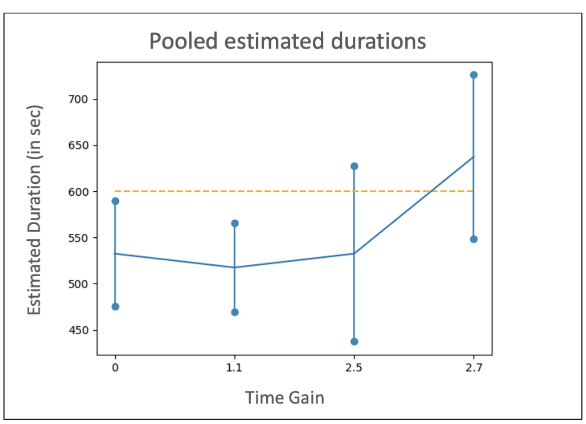

Figure 4. Pooled estimated durations per time gain. Vertical bars show the standard error of the mean.

4 Discussion

This chapter discusses the study results and interprets them in terms of their validity and possible explanations for the specific outcomes that were obtained. As it served as the basis for our research, much of the discussed results refer to the paper published by Schatzschneider et al. [13], which also investigated the topic of zeitgeber manipulations in VR. The first point when comparing the study results with those of Schatzschneider et al. [13] is, that in the context of this thesis, the time duration estimates turned out to be considerably lower. The related work states an average duration of about 750 seconds, which is 217 seconds more than what this study yielded with its 533 seconds. In Schatzschneider's study, participants overestimated the actual duration and provided much longer estimates on average, which makes the results differ greatly from the ones in this work. The results of $g_t = 0$ are based on 8 different participants, compared to 21 participants for Schatzschneider, but even so it seems unlikely that such a large bias was randomly introduced. The results with $g_t = 1$ differ as well, because in Schatzschneider's study the participants still overestimated the actual time considerably, resulting in a difference of about 670 seconds, compared to the 518 seconds in our own study with $g_t = 1.1$. However, there is a similarity in that there exists a decreasing trend between $g_t = 0$ and $g_t = 1$ in both studies. Nonetheless, the results of this work show a bias of approximately -210 to -150 seconds. The second point which we wish to address is unexpected course of the graph that was generated in the context of this study (see Figure 3) for time gains greater than 2. Schatzschneider et al. [13] investigated time gains = {0, 1, 2} and conclude that the estimated durations with $g_t = 0$ are significantly longer compared to the situations with $g_t = 1$ or $g_t = 2$. When looking at the graph about the pooled estimated durations per time gain of Schatzschneider et al. [13], one could assume the course, that an increasing time gain can lead to a decreasing duration estimate. However, the results of this work suggest that further increasing the time gain to a value of 2.5 or 2.7 can also increase the estimated duration, i.e. a faster sun movement can also be associated with a longer perceived duration. However, a person-related bias cannot be ruled out, due to the small sample size of 4 participants. Possible reasons for the general bias and the unexpected course of higher time gains are mainly suspected in the participants. The study procedure is kept similar to that of Schatzschneider et al. [13], because the VR worlds should turn out similarly comparable, and other confounding variables are eliminated as best as possible. The most likely scenario appears to be that some bias was present in the participants due to the novelty of VR. None of the participants in the study of this work had any previous experience with VR or had ever worn an HMD. Finally, the formulated hypotheses, see Section 3.1, are answered to summarize the contribution of this work. Although it is the natural expectation that time perception might be different in a static empty world compared to a dynamic island world with sun movement, a significant difference could not be detected using a paired sample t-test (significance level $\alpha = 5$ %) with a p-value of 0.177. There is a trend based on 2 participants (P_2 and P_3) that the estimated time on the island world with sun movement (g_t = 2.5) turns out lower, but this effect is not present for other participants (P_1 and P_4) as they gave almost the same or even a slightly longer estimate for the second experiment on the island world.

The results of study concept 1 reveal a noticeable trend, that the duration in a static world, without any visual objects, is estimated longer, compared to a dynamic sun-moving island environment. Since there are no significant differences in the results, Hypothesis H1 is still accepted. Study concept 2 compares g_t = 0 with g_t = 2.7 which resulted in no significant difference using a Wilcoxon signed-rank test with a p-value of 0.102 (a t-test would have indicated significance, but could not be used due to the lack of normal distribution). Study concept 3 compares g_t = 0 with g_t = 1.1, which resulted in no significant difference using a paired sample t-test with a p-value of 0.263. When performing a significance test on all outcomes, comparing the first and the second estimate from participants P_5 - P_12, it results in a p-value of 0.063 of a paired t-test, which means that it also cannot be considered as a significant difference.

The results of study concept 2 and concept 3 reveal a noticeable trend that with increasing time gain, the estimated time duration also increases. Since the results did not lead to significant differences, Hypothesis H2 is accepted. The user studies reveal, that in 8 out of 12 cases, there is an improvement of the duration estimation accuracy, when a working zeitgeber (moving sun with g_t greater than 0) is present in a VR environment, compared to a non-visible zeitgeber or a non-working zeitgeber (g_t = 0). In 2 out of 12 cases, there was a slight reduction of estimation accuracy, and in the remaining 2 cases, there was no change in duration estimation accuracy. A comparison of all accuracy values between the first experiment and the second experiment from all participants, leads to a p-value of 0.047 using a paired sample t-test, which confirms a significant difference.

The results of study concept 1-3 show that there is a significant difference in duration estimation accuracy between a VR environment with a non-visible or non-moving virtual sun, against a VR world with a moving sun acting as a zeitgeber. Since Hypothesis H3 states that no effect is expected, H3 must be rejected, as a corresponding change in accuracy has been detected. In summary, this work showed that using a sun as a zeitgeber in virtual reality may have effects on individual human time perception opposite to the ones described in related work. The results of two study concepts indicate that an increase in time gain leads to an increase in time duration estimates. However, an analysis of the experimental study with 12 participants did not show significant differences when comparing different VR environments with varying movement speeds of a virtual sun, with an experiment period of 10 minutes.

5 Conclusion and Future Work

The aim of this work is to check and extend the findings from previous related work in terms of reproducibility and applicability. A study with with 12 participants was conducted to investigate the effects of different VR worlds or the same environment with varying time gains $g_t = \{0, 1.1, 2.5, 2.7\}$. Each participant took part in two experiments, each lasting exactly 10 minutes, and at the end of each scenario, they were asked to estimate how much time they had spent in the VR world. The evaluation reveals a trend that the duration in a static world, without any visual objects, is estimated longer, compared to an environment representing a virtual island with sun movement. When comparing an island VR world with different sun speeds, the duration when experiencing a higher time gain (g_t = 0 vs. g_t = 1.1 and g_t = 0 vs. g_t = 2.7) turns out longer. In contrast to the findings of related work, the outcomes of this work suggest that a higher time gain can be associated with a higher duration estimation. Our study showed that the presence of a virtual moving sun increases the estimation accuracy significantly, compared to conditions where no sun is visible or moving. The analysis of the study results showed no significant differences in all study concepts, when comparing the duration estimate of the first experiment with the second experiment of each participant. The biggest aspect to address in future work is sample size. The conducted study should be performed with more participants, which would make the results more conclusive. Furthermore, it may become necessary to determine the time gain when movement of the sun is no longer perceived as natural, as this could impact the effects of it as a zeitgeber.

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