Report of Assignment 6

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1 INTRODUCTION

In 1968, Ivan Sutherland, With the help of his students including Bob Sproull, created what was widely considered to be the first head-mounted (HMD) display system applied to immersive simulation: the sword of Damocles [Sutherland 1968]. Since then, researchers have started their continuous exploration of virtual reality (VR) technology. Thanks to the development of computer graphics and VR technology, some VR products for consumers such as HTC VIVE [1] and Oculus Rift [2] began to be better known. For one thing, it benefits more people by bringing them the experience of the wonderful feeling of "being there" [Barfield and Weghorst 1993; Bystrom et al. 1999; Draper et al. 1998; Held and Durlach 1992; Sanchez-Vives and Slater 2005; Sheridan 1992; Slater and Wilbur 1997] or "feeling real" [Parola et al. 2016]. For another, many unsolved problems limited by software and hardware get back to public attention, and the answer to this question that "is there a way to control the temporal perception of the user when they are in the IVEs" is exciting.

The characteristics contributing to VR technology to which people often referred are Immersive, Interactive and Imaginative [Burdea and Coiffet 1994]. However, there is no generally accepted theory of presence [Birkenbusch and Christ 2013a; Darken et al. 1999; IJsselsteijn et al. 2000; Skarbez 2016]. In 2009, Mel Slater put forward a widely accepted theory of place illusion (PI) and plausibility illusion (Psi) to the question that why participants tend to respond realistically to situations and events portrayed within an immersive VR system. They argue that when both PI and Psi occur, participants will respond realistically to the virtual reality [Slater 2009]. Different from influencing factors of "immersion" which address more on the objective technical condition of VR system [Bowman and McMahan 2007; Riva et al. 2011; Slater 1999; Slater and Wilbur 1997], the user's subjective experience is more concerned in virual environment (VE) when refers to the presence, Which includes the perception of time.

The idea of time controlling seems to be a fantasy in the real world, but VR has the potential to make it possible. In the context of time perception, light is the most important synchronizers of biological rhythms in nature, Which is referred to as zeitgebers [Aschoff 1965; Roenneberg et al. 2007]. Zeitgebers is a term that describes external or environmental cues that function to entrain the human circadian rhythms and synchronizes our biological rhythms to the Earth's 24-hour day-night cycle and 12-month cycle [Aschoff 1965; Pittendrigh 1981]. Such cues help people determine what time they are at in the day or to mark the elapsed time, namely the speed of time. The study of zeitgebers derived from the study of biological rhythms in chronobiology. Aschoff concluded that under natural conditions, the circadian period synchronized with (or entrained to) the period of the earth's rotation utilizing periodic factors in the environment, called zeitgebers [Aschoff 1965]. In 2016, Schatzschneider et al. used various virtual sun movement speeds as zeitgebers for their experiments. They use dual-task studies to test the influences of the cognitive load on time perception and proved that it is feasible to manipulate such zeitgebers to affect time judgments. Moreover, they found that increased spatial and verbal cognitive load resulted in a significant shortening of judged time as well as an interaction with the external zeitgebers [Schatzschneider et al. 2016].

Scenes with zeitgebers in reality and non-immersive environments are common, many of which are from video or computer games [Bruder and Steinicke 2014; Tobin and Grondin 2009]. Moreover, people will always report losing their sense of time passing when having fun [Sanders and Cairns 2010]. Accounting for these situations are various explanations, such as attention-based explanation [Block et al. 2010; 张义芳 and 丁峻 2011], emotion-based explanation [Angrilli et al. 1997; Droit-Volet and Meck 2007], different estimation paradigms [Block and Zakay 1997; 赵雪 and 尹艳新 2012], flow theory [Csikszentmihalyi 1997; Nakamura and Csikszentmihalyi 2014] and so on. However, in this paper, We try to figure out whether the visual modal information changed by illumination intensity or the audio modal information generated by the ticking of a clock can be used as zeitgebers to affect the user's time perception in IVEs. If so, how much do these zeitgebers affect user's time perception? Does the user's perception of time in IVEs have a relationship with the sense of presence? If so, What kind of relationship?

[1]https://www.vive.com/us/
[2]https://www.oculus.com/

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In this paper, We presented an exploratory qualitative experiment on time estimation, in which we combined cognitive load with illumination intensity or ticking speed of a clock in different levels for users in immersive and non-immersive environments. Thus the effects of zeitgebers and cognitive load on time perception and presence were explored. In the experiment, visual gains were used to describe the three levels of illumination intensity as the visual modal zeitgebers, namely the bright light, the medium light, and the dim light. Auditory gains were used to describe the three levels of ticking speed as the audio modal zeitgebers, namely the quick ticking, the medium ticking, and the slow ticking. To test the effect of cognitive load, We compared conditions with a visual-searching task and a baseline condition without a cognitive task. As we know, this is the first experiment so far to evaluate the influence of users' time perception and presence in IVEs by using illumination intensity or ticking speed of a virtual clock combined with a visual-searching task, and we also compared their interactive effects of these factors.

All in all, our article made positive contributions by analyzing the following:

- effects of the illumination intensity or ticking speed as an external zeitgeber on the user's perception of time and presence in IVEs and the difference they show in non-immersive environments,
- effects of visual-searching cognitive task with multimodal information as zeitgebers on time estimation and presence,
- feasibility of combining subjective and objective measurement methods to explore the relationship between zeitgebers and cognitive load on temporal perception and presence and
- implications for regulating the user's perception of time in IVEs.

The remaining structure of the article is as follows. Section 2 discusses the background and literatures related to this article. Section 3 describes the experiment in which we evaluate the time estimation in IVEs. The results are presented in Section 4 and discussed in Section 5. Section 6 concludes the article.

2 BACKGROUND AND RELATED WORK

In this part, We will make an overview of zeitgeber, cognitive load, time perception, and presence. Moreover, We discuss the possible influence of zeitgeber and cognitive load on time perception and presence in IVEs.

2.1 Zeitgebers

The term zeitgeber originates from German and means "time-giver". First, we differentiate between external and internal zeitgebers:

- *External (or exogenous) zeitgebers*: usually refer to environmental cues that affect the biological rhythm of the body, such as lighting [Aschoff 1965] or social cues [Ehlers et al. 1988].
- *Internal (or endogenous) zeitgebers*: something inside your body or organism, like the suprachiasmatic nucleus or nuclei (SCN) [Buijs et al. 2003] or different internal-clock models of interval timing like information processing model for example [Gibbon et al. 1984].

External zeitgebers and internal clock jointly control the biological rhythm, and the process of adjusting the internal clock to coordinate with external zeitgeber is called entrainment [Duffy and Wright Jr 2005]. Light and other environmental and social zeitgebers play an essential role in entrainment. Studies have shown that SCN located in the hypothalamus is an endogenous pacemaker that controls our circadian rhythm [Albrecht and Eichele 2003]. Light will transmit day and night information to SCN, and this process will affect the secretion of melatonin in the pineal gland. When the light is weak, it will inhibit the secretion of melatonin, While when the light is intense, it will promote the secretion of melatonin [Duffy and Wright Jr 2005]. So in this entrainment process, light unifies the internal clock with the outside world, and studies have shown that some of the oscillating cells in the body are also photosensitive, that is, We may not need to rely on our visual system to sense light.

The social zeitgebers mentioned above is another differentiation [Fleissner 2013]:

- *Natural zeitgebers*: unlike the laboratory environment, they are natural time cues, such as changes in light at dawn and dusk or different climatic conditions.
- *Artificial zeitgebers*: artificial time cues, such as artificial light sources or clocks.
- *Social zeitgebers*: refers to time clues that interact with other individuals, such as daily schedules and meal times.

However, studies have shown that the human circadian clock is predominantly entrained by sun time rather than by social time. Social cues cannot entrain the human circadian clock without behavioral intervention which caused light changes [Roenneberg et al. 2007]. In recent years, in addition to using visual modal information such as light as zeitgebers [Duffy and Wright Jr 2005; Roenneberg et al. 2007], some researchers began to explore the influence of multimodal information on time estimation such as the tempo of music [Pizarro Lozano 2016]. These attempts are valuable for understanding how to manipulate the time perception of users in virtual reality environments.

In this paper, We apply the term zeitgeber to refer to all time-related information that people can perceive in the external world, not just in the field of biological rhythm. Based on this, We further divide external zeitgebers into the following subcategories according to human's perception:

- *Visual zeitgebers*: time-related information that people can obtain by observing the environment, such as the brightness of the environment.
- *Auditory zeitgebers*: auditory information which indicates the elapse of time, like ticking of a clock.
- *Olfactory zeitgebers*: information of olfactory modal which affects time perception, such as incense.

- *Gustatory zeitgebers*: the taste which influences time perception when tasting the flavor of it, like spicy.
- *Tactile zeitgebers*: refers to the haptic information that people perceive in the environment and has effect on time perceptin, such as temperature.

The most intuitive source of time information that people can feel in their daily lives is visual and auditory zeitgebers, such as the light changes of the day [Aschoff 1965; Duffy and Wright Jr 2005; Fleissner 2013; López-Olmeda et al. 2006; Pittendrigh 1981] and the sound which indicates the elapse of time [Noulhiane et al. 2007], the most important form of tactile zeitgebers is temperature, Which has an important effect on biological rhythm [Aschoff 1965; López-Olmeda et al. 2006]. The effects of olfactory and gustatory zeitgebers on time perception may not be so direct, that is, they may affect people's perception of time by affecting people's physiological arousal or affective valence [Angrilli et al. 1997; Burle and Casini 2001; Droit-Volet and Meck 2007].

In this article, We focus on the visual and auditory zeitgebers, specifically, the intensity of the light and the speed of clock ticking, and assume that time flies under the condition of the dim light or the quick ticking of the clock. At the same time, visual and auditory zeitgebers are not expected to affect the sense of presence.

2.2 Cognitive Load

When referring to cognitive load, it refers to the attention or working memory resources required in the information processing process[Block and Zakay 1997], where the prospective time estimation paradigm requires more attention resources, while the retrospective time estimation paradigm requires more working memory resources [Block et al. 2010] (for detailed information about the time estimation paradigm, see 2.3).

In this article, instead of selecting cognitive tasks related to working memory resources like [Schatzschneider et al. 2016], a visual-searching task more relevant to attention resources is selected as the cognitive task. This experiment will use a prospective time estimation paradigm that informs the participants in advance that they need to report the elapsed time at the end of each group of experiment. The reason for choosing the visual-searching task based on attention resources as the cognitive task is as follows: per participant needs to perform multiple groups of experiments, so the retrospective time estimation paradigm is not suitable for this case [Block and Zakay 1997]. Moreover, prospective time estimation paradigm is more accurate than retrospective time estimation [杨珍 2006] (see 2.3 for more details). In this experiment, we expect to have a more significant impact on the time estimation of participants by using cognitive tasks that require more attention resources. Specifically, through using the dual-task method (see 3.3 for more details), the difficulty of secondary cognitive tasks will affect the performance of the primary task of time estimation according to the attentional resource theories [Kahneman 1973; Navon and Gopher 1979; Wickens and Kessel 1980].

In this experiment, the condition with cognitive tasks is *high cognitive load*, and the case of non-cognitive tasks is *low cognitive load*. We expected that the condition of *high cognitive load* will weaken the influence of visual or auditory zeitgeber on the time interval estimation, and the reported estimation of time will lower than the actual time interval. Besides, we assume that there are differences in physiological variables such as skin temperature and the sense of presence under the two different cognitive load conditions.

2.3 Time Perception

Time perception refers to the individual's reflection of the duration and order of time flows acting on sensory organs directly. Its classification includes temporal order perception and duration perception [宋其争 and 黄希庭 2004]. The former mainly refers to a period in which people can not only feel the sequence of events but also relate the temporal relationship between them [张义芳 and 丁峻 2011]. While the latter is part of time interval cognition, referring to the time interval between two consecutive times or the duration of an event [赵雪 and 尹艳新 2012]. The study found that there are two cognitive mechanisms for time estimation which are triggered by arousal levels: a controlled-attention mechanism for low arousal and an automatic mechanism for high arousal. For the short duration, of which the mechanism is usually the automatic mechanism, which related to motivational-survival systems and is not affected by attention, physiological arousal and so on. While for the long duration, the mechanism of it is the controlled-attention mechanism, which is affected by attention resources, working memory resources and physiological arousal [张志杰 et al. 2006].

Many factors affecting duration perception, such as different time estimation paradigm, particularly, duration estimation of prospective paradigm slightly greater than retrospective one, and due to the reason that both of them tend to underestimate the actual time, so prospective paradigm is more accurate than retrospective paradigm [Block and Zakay 1997; Buhusi and Meck 2005; Gibbon et al. 1997; 杨珍 2006; 赵雪 and 尹艳新 2012]. People always forget about time elapsing under the condition of high cognitive load [Gibbon et al. 1984]. The increase in physiological arousal will make the internal-clock of body count faster and make people feel time flies [Angrilli et al. 1997; Burle and Casini 2001]. Under the same level of arousal, people will judge negative stimuli longer than positive ones [Droit-Volet and Meck 2007; Noulhiane et al. 2007]. Moreover, people will ignore the elapsion of time when they devote themselves to the game world [Jäncke et al. 2009; Sanders and Cairns 2010; Schatzschneider et al. 2016] and so on.

In this paper, We mainly focus on whether the estimation of a long time interval in a peaceful IVEs will be affected by cognitive load, and assume that the estimation of the participants is shorter under *high cognitive load* than under *low cognitive load*.

2.4 Presence

Immersion is often more familiar than presence when it comes to virtual reality, which is both closely related and different.

A widely accepted definition of immersion is *it refers to the objective level of sensory fidelity a VR system provides* [Meehan et al. 2002], Which emphasizes more about the role of the attributes of the system in the virtual environment. Such as image fidelity [Welch et al. 1996], frame rate [Chan et al. 1996] and dynamic shadow [Slater et al. 1995].

The sense of presence is more from the user's subjective feelings, emphasizing the experience of the users' *subjective experience of being in one place or environment, even when one is physically situated in another* [Witmer and Singer 1998]. In 2009, Mel Slater proposed a new way of expressing immersion in [Slater 2009]: place illusion (PI) and plausibility illusion (PSi). The former emphasizes *the qualia of having a sensation of being in a real place*, While the latter emphasizes *the illusion that the scenario being depicted is actually occurring*. In this sense, immersion is the basis of the sense of immersion, which limits the PI.

In fact, both immersion and presence can be classified into the same research field of presence research. On the one hand, because of the different focus of the researchers, in addition to the immersion and presence mentioned previously, there are various other related definitions, like involvement [Witmer and Singer 1998], spatial presence [Hartmann et al. 2015], evoked reality [Pillai et al. 2013] and so on, which has led to a consistent debate on the definition of the user's perception of this feeling in IVEs [Birkenbusch and Christ 2013a; Darken et al. 1999; IJsselsteijn et al. 2000; Skarbez 2016]. On the other hand, due to the reason that there is no unified definition of presence, and the measurement conditions of it are not equal, so far there is no recognized universal presence measurement method [Birkenbusch and Christ 2013a].

The quantitative methods of immersion can be divided into two categories, one is subjective measurement method, which includes questionnaire [Catena et al. 2000; Nakamura and Csikszentmihalyi 2014; Schubert et al. 2001; Witmer and Singer 1998], interview [Seligman and Csikszentmihalyi 2000], quality of experience(QoE) [Zhang et al. 2017] and other methods. The other is objective measurement methods, including task performance [Schloerb 1995] and behavior measurement [IJsselsteijn et al. 2000]. The advantages of subjective methods are easy to use [Kuschel et al. 2007] and they will not interrupt the user's experience in IVEs [Birkenbusch and Christ 2013b; IJsselsteijn et al. 2000; Wissmath et al. 2010]. However, some researchers argued that the questionnaire method measures the state of "post-immersive" but not the immersive state so that the questionnaire method may measure the properties of the system more than presence per se [Steuer 1992; Witmer and Singer 1998]. Moreover, the objective measurement method, such as the physiological variables analysis method, has the advantages of not being affected by the previous experience of the subject, independent from the subject's attention and will not interfere with the experience of the subject in IVEs. However, a drawback of the objective measure method is that the collection of its data can be intrusive, which means the reason of the change of physiological variables may be irrelevant external stimuli but not the sense of presence per se [Van Baren 2004]. Furthermore, the relationship between presence and the data obtained by objective measurement methods remains uncertain [Kim and Biocca 1997; Wissmath et al. 2010].

Based on the discussion above, in this experiment, we combined the questionnaire method and self-report method as the subjective measurement method and the physiological measurement method and task performance method as the objective measurement method to jointly explain the effects of zeitgebers and cognitive load on the sense of presence. In this scope, we assume that the participants will have a different sense of presence under different level of intensity of the light or ticking of the clock, and the perceived presence with the cognitive task was "stronger" than that without the cognitive task.

3 EXPERIMENT

In this section, we described the experiment in which we analyzed the interactive influences of different external zeitgebers combined with a visual-searching cognitive task on time estimation and presence in IVEs. In the experiment, we amplified and compressed the zeitgebers through *visual gains* and *audio gains*, which represent light intensity and speed of ticking sound separately. Besides, we explored the relationship between cognitive load on time estimation and presence by combining subjective and objective measurements.

3.1 Participants

We recruited 46 participants for our experiment and divided them into the visual group and the auditory group. Among them, 22 subjects (11 female, 11 male, ages 18 - 27, M = 20.1636) participated in In the visual group experiment, the remaining 24 subjects (11 female, 13 male, ages 19 - 22, M = 20.3333) participated in the auditory group experiment. All the participants were undergraduate/graduate students at the University of Electronic Science and Technology of China. All of our participants obtained 80 CNY for compensation.

For the visual group, 12 participants had previously used HMDs, where 21 were right-handed, and the rest were left-handed. There was no blurred vision in all subjects after observing the environment and adjusting HMD. Seventeen participants wore glasses during the experiments. All of our participants had normal hearing. None of our participants reported a disorder of equilibrium or binocular vision disorders. For the auditory group, 12 participants had previously used HMDs, where 24 were right-handed, and no one was left-handed. There was no ambiguity in all subjects after observing the environment and adjusting HMD. Nineteen participants wore glasses during the experiments. All of our participants had normal hearing. None of our participants reported a disorder of equilibrium or binocular vision disorders.

The total length of each participant, including instructions, pre-questionnaires, equipment-wearing, experiment, breaks, post-questionnaires, and debriefing, was two hours. Each participant would conduct five groups of experiments, two of which were non-immersed environments, and the rest were immersive display condition, in which participants needed to wear the HMD. The duration of each group was about ten minutes. After each group of experiments, there was break of five minutes, and we asked participants to fill out a presence questionnaire during this time.

3.2 Material

We experimented with one of our showroom environments, which was sealed off during the experiment. As illustrated in Fig. 1, participants wore an HTC VIVE Pro HMD to carry our the experiment of immersive environment, which provides a resolution of 1440×1600 pixels per eye, and the binocular resolution is 2880×1600 with a refresh rate of 90 Hz and an approximately 110 degrees diagonal field of view. We tracked its position and orientation with SteamVR™tracking system.

Figure 1: Experimental setup: photo of a user wearing an HTC VIVE Pro HMD and holding a controller while seated in an office chair

We used a workstation for rendering, whose processor was 3.70 GHz Core i7-8700K processor, 24 GB of main memory and an GeForce GTX 1060 5GB graphics card. The stimuli were rendered with the Unity 3D 2018.3.8 engine. For the experimental platform, we used another workstation, which had a 4.2 GHz Core i7-7700K processor, 16 GB of main memory and GeForce GTX 1080Ti graphics card. During the experiment, the subject sat on the office chair as shown in Fig. 1. The participants could observe the environment at will by moving the mouse (non-immersive environment) or turning the head (immersive environment), but we asked the participants not to leave their seats during the experiment.

During the experiment, the subject will wear a flexible temperature patch to measure the skin temperature, a pulseSensor and a MiBand 2 to measure the heart rate of the subject. The flexible temperature patch device is the CH-T2 product produced by Chero Technology Co., Ltd. [1], the temperature measurement accuracy is $\pm 0.05°C$ and the sampling frequency is 5s/time, and there are two heart rate acquisition devices. One is the MDL0025 product from World Famous Electronics llc [2], and the other is the MiBand 2 product of Xiaomi Technology Co., Ltd.[3].

We set the virtual environment in a modern home environment where the participants will be located in the sofa in the living room with a virtual screen in front of them to present cognitive tasks, as shown in the Fig. 2. There will be a shutter in the virtual environment and we will simulate the sunlight by setting a directional light outside the room, projecting the light into the room at an angle of $Rotation = (18.64, 106.554, 0)$, using *static rendering techniques* during the rendering process. Set the shadow mode of the directional light to *Soft Shadows*. Set the shader of the object to *Standard*. In each experiment group, the light intensity is a pre-designed value, and the other properties of the light source were unchanged, including the shadow. All effects are pre-rendered to make the virtual environment as realistic as possible. In order to avoid the visual model of the clock from interfering with the time interval estimation of the participant, we only play the sound of clock ticking in the virtual environment without presenting the clock model, and the surround sound is rendered by zeroing the *Doppler effect* of the clock sound.

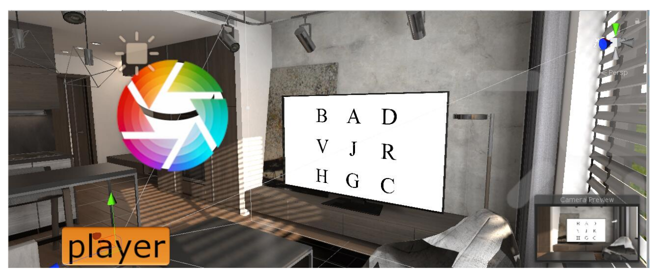

Figure 2: Experimental setup: a virtual living room with a visual-searching task presented in the TV screen

In order to maintain the participants' sense of presence in the VE, the experimenter would not have communication with the participants during the experiment. Task instructions would be completed by text and oral narration before the experiment. Participants performed the cognitive task by pressing the trigger or touchpad on a VIVE controller. During the experiment, the participants were wearing Hi-REs Audio certified headphones (immersive environment) on the HTC VIVE Pro device and isten to the sound of the clock in the virtual environment or Mi In-Ear headphones

[1]http://www.cheroee.com/
[2]https://pulsesensor.com/
[3]https://www.mi.com

QTEJ03JY (non-immersive environment) to reduce the possible interference to the outside environment.

In order to explore the effect of cognitive load on presence, we also considered a non-immersive display setup with or without a cognitive task as baseline condition. This condition used monoscopic display without head-tracking. The VE would be presented on a Changhong 60D2P display with a resolution of 4K (3840 × 2160) and a refresh rate of 60Hz. Participants wore in-ear Xiaomi QTEJ03JY headphones for the non-immersive display setup.

3.3 Methods

Ways to measure cognitive load include physiological variables measures, primary task performance, opinion surveys, secondary task performance and so on [Block et al. 2010], among which secondary task performance, i.e., dual-task method is one of the most widely used methods. Dual-task method is based on the attention resource theory [Kahneman 1973; Navon and Gopher 1979], which requires the participant to perform a secondary task while performing a primary task. The attention resources required by the secondary task (i.e., visual-searching task in this paper) usually come from the unified resource pool with the primary task (i.e., estimation of a time interval in the case of this study), which means that when the cognitive load of the primary task increases, the performance of the secondary task decrease.

At the same time, during the experiment, we will also collect physiological data such as heart rate and skin temperature of the participant. These physiological data can be used to evaluate the cognitive load [Kahneman 1973], and can also measure the sense of presence [Meehan et al. 2002; Riva et al. 2003; Wiederhold et al. 2001].

We found significant individual differences during the pilot, so we decided to use a within-subjects design for this experiment. Moreover, in the process of recruiting subjects, we asked the participants to experience an incomplete version of the formal experiment and asked the participants to evaluate the time they experienced in the virtual world. We defined *ratio* as the ratio between subjective time interval and real time interval, and only recruited participants with good time duration estimation ability ($ratio \in [0.875, 1.125]$) as subjects .

There are four variables in the formal experiment, namely the light intensity, the ticking speed of a clock, immersive or non-immersive display setup and whether there is a cognitive task. There are three different levels of light intensity, ie, (i) dim, (ii) medium, and (iii) bright presented as visual gains $g_v \in \{0, 1, 2\}$ respectively, and there are three different levels of ticking speed, ie, (i) slow, (ii) medium, and (iii) quick, which are presented as the auditory gains $g_a \in \{0, 1, 2\}$.

In the experiment, we randomly assigned the subjects to the visual or auditory group for experimentation. Whether in the visual group or the auditory group, each subject needs to carry out five groups of experiments, among which the first two groups were carried out in non-immersive display setup, and the rest three groups were all performed under immersive conditions.

For the first two sets of experiments, the variable conditions were medium light intensity, and medium speed clock sound, i.e., $g_v = 1$, $g_a = 1$. One of the first two groups had cognitive tasks, the other did not, and the sequence of them was random. This non-immersive display setup served as a baseline condition, which also ensured that the subject was clear about the task.

The latter three groups were all performed under immersive conditions. For the visual group, the subjects will perform experiments in bright, medium and dim light intensity in random order. For the auditory group, subjects will perform quick, medium and slow ticking speed randomly. Participants will draw lots to determine whether the last three sets of experiments have cognitive tasks.

In the preparation stage of the experiment, the participants needed to fill in the informed consent form and received an experimental instruction. After the above work, the participant needed to fill out a Kennedy-Lane simulator sickness questionnaire (SSQ) [Kennedy et al. 1993], an immersive tendencies questionnaire (ITQ) [Witmer and Singer 1998], and a Bio-Time Quiz (BTQ) [Breus 2016]. Then the subject will be wearing various physiological collection equipment (a skin temperature collection device Chero CH-T2 and heart rate acquisition devices, pulseSensor and MiBand 2) and we would keep all the time devices for the subjects during the experiment. Every participant practiced different conditions once at the beginning of the experiment to familiarize it and eliminate the learning effect [莫文 2008]. These trails were excluded from the analysis. At the end of each group of experiments, the participants had a 5-minute break. At the same time, the participants were required to complete a Slater-Usoh-Steed questionnaires (SUS) [Catena et al. 2000] questionnaire. After finishing the five sets of experiments, the participants needed to fill in the SSQ questionnaire again. Besides, the SUS questionnaire as well as a demographic questionnaire.

We used a prospective design [Buhusi and Meck 2005; Gibbon et al. 1997], that is, the participants knew from the beginning that they needed to report the time-interval estimation at the end of each experiment. The reasons were as follows [Block and Zakay 1997]:

- the prospective paradigm applies to repeated experiments,
- it is more accurate than the retrospective paradigm,
- and it needed more attentional resources than working memory resources.

We draw on the exploration of predecessors on the time interval of each experiment [Schatzschneider et al. 2016], and randomly set the length of the single experiment to 600-650s and told the participants that the length of each test might vary greatly, thus ensuring that the subjects did not know the specific duration of each set of experiment. The context information known to the participants was only about two hours in total, and they did not know how many experiments would be performed before the end of the whole experiment. Each group of experiments will go through three stages of black screen - experiment - black screen. After each group of experiments, the subjects need to immediately report to us how long it has been between the two black screens by specifying seconds.

To analyze the influence of cognitive load on time estimation and presence when manipulating the visual or auditory zeitgebers, we used a visual-searching task, which was a task with a high requirement for attention resources. Subjects needed to judge whether the visual-searching target appears during each trial and respond by using the VIVE controller. Participants were instructed to perform the task as well as possible.

Visual-searching Task

Visual-searching is a classic paradigm used by cognitive psychologists to study attention distribution in complex fields of view. Typical visual-searching tasks require participants to remember the search target and respond accordingly to the presence of targets in the field of view. The visual-searching task used in this experiment consists of multiple trials, each of which undergoes a three-step process of a reticle - character - letters matrix, as illustrated in Fig. 3, and the task was presented on the TV of the living room in VE (see Fig. 2). The crosshair was to control the subject's attention range, and we selected the letters matrix randomly from all the preset matrices with the same probability of occurrence. We instructed participants to press the trigger on the VIVE controller (mouse left in the non-immersive environment) when they found the target character in the letters matrix, otherwise press the pad button on the controller (right mouse button in the non-immersive environment). There are 144 trails, 24 trails count as one block, and there are six blocks in each group of experiments. At first, the environment is completely black (the first black screen mentioned above) when participant wore the HMD, and he could press any button to start the experiment. In groups with cognitive task, a countdown of six seconds will be displayed on the TV before the visual-searching task, and then the trail will be continuously displayed. There will be about 17.4s break after finishing each block. The presentation time of each reticle, target letter and alphabet matrix is about 1 s, 1s, and 0.4s respectively. The subject had about 1.4s to press the corresponding button after the appearance of the current letter matrix and before the appearance of the next centroid. After the last break of one group of experiment, the environment would go black again (which meant the end of one group of experiment).

Hypothesis

According to the existing literature, we expected that time interval estimation and sence of presence would change under different zeitgeber and cognitive load, and we define temporal judgment deviation equals to estimation of time - Real time duration. Hence, we made the following hypothesis:

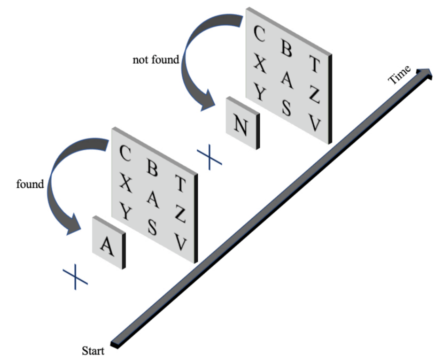

Figure 3: Dscription of visual-searching task

- H 1 Mean temporal judgment deviation differs between the three visual gain conditions in the IVEs and the deviation of group $g_v = 0$ and $g_v = 2$ is bigger than $g_v = 1$.
- H 2 Mean temporal judgment deviation differs between the three auditory gain conditions in the IVEs and the deviation of group $g_a = 0$ and $g_a = 2$ is bigger than $g_a = 1$.
- H 3 Mean temporal judgment deviation differs between the visual and auditory gain conditions in the IVEs, and the influence of visual gain is greater, i.e., the deviation of groups of visual zeitgebers is bigger.
- H 4 Mean temporal judgment deviation differs with or without visual-searching task, the task will weaken the influence of visual or auditory zeitgebers, i.e., when $g_v \neq 1$ or $g_a \neq 1$, the deviation is smaller with cognitive tasks than without cognitive tasks.
- H 5 Mean temporal judgment deviation is different between the immersive or non-immersive conditions and the deviation of immersive condition is bigger.
- H 6 Mean SUS-score are same between the visual and auditory gain conditions in the IVEs.
- H 7 Mean SUS-score differs with or without visual-searching task, with task the score is higher.

4 RESULTS

We analyzed the results with two-way repeated-measure ANOVAs and adjusted the confidence interval with Bonferroni at the 5% significance level. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity when Mauchly's test indicated that the assumption of sphericity had been violated. Furthermore, we analyzed the results with multiple linear regression method.

4.1 Time Estimation

We analyzed the effects of the different factors (visual or auditory gains & cognitive load, cognitive load & immersive condition) on time estimation in the experiment by comparing the deviation of estimated durations when the participants were immersed in the VE. Furthermore, we compared the results with the baseline and non-immersive condition without change of the illumination intensity or ticking speed of the clock. Besides, we analyzed the effects of all variables (visual gains or auditory gains, cognitive tasks, immersive condition, gender, mean heart rate, mean skin temperature, score of immersive tendencies questionnaire(ITQ) on time estimation deviation in the experiment by using multiple linear regression method.

Zeitgebers

4.1.1 Visual Zeitgebers. Through the analysis of two-way repeated-measure ANOVAs, we found no significant effect of the interaction between visual gains and cognitive load on time estimation deviation ($F(2, 12) = .021$, $p = .979$), therefore, it is necessary to interpret the main effects of the internal factor visual gains. We found no significant main effect of visual gains on the estimated durations ($F(2, 12) = .173$, $p = .843$), and there was no siginificant effect of the deviation difference between $g_v = 0$ and $g_v = 1$ ($p = 1.000$), $g_v = 0$ and $g_v = 2$ ($p = 1.000$) and $g_v = 1$ and $g_v = 2$ ($p = 1.000$).

When establishing multiple linear regression models, the effect of different visual gains may not be strictly equidistant or equivalence due to the complexity of the factors affecting the time interval estimation. So we converted three levels of visual gains into two dummy variables and incorporated them into the regression model. Through the analysis of multiple linear regression, we found no significant effect of dummy visual gains $g_v = 0$ ($p = .839$) and $g_v = 2$ ($p = .880$) on time estimation.

4.1.2 Auditory Zeitgebers. Through the analysis of two-way repeated-measure ANOVAs, we found no significant effect of the interaction between auditory gains and cognitive load on time estimation ($F(2, 18) = .256$, $p = .777$), therefore, it is necessary to interpret the main effects of the internal factor auditory gains. We found no significant main effect of visual gains on the estimated durations ($F(2, 18) = .120$, $p = .888$), and there was no siginificant effect of the deviation difference between $g_a = 0$ and $g_a = 1$ ($p = 1.000$), $g_a = 0$ and $g_a = 2$ ($p = 1.000$) and $g_a = 1$ and $g_a = 2$ ($p = 1.000$).

When establishing multiple linear regression models, the effect of different auditory gains may not be strictly equidistant or equivalence due to the complexity of the factors affecting the time interval estimation. So we converted three levels of auditory gains into two dummy variables and incorporated them into the regression model. Through the analysis of multiple linear regression, we found no significant effect of dummy auditory gains $g_a = 0$ ($p = .471$) and $g_a = 2$ ($p = .643$) on time estimation.

Cognitive Load & Immersive Condition

Through the analysis of two-way repeated-measure ANOVAs, we found no significant effect of the interaction between cognitive load and immersive condition on time estimation ($F(1, 18) = .034$, $p = .856$), therefore, it is necessary to interpret the main effects of two internal factor visual gains. We found no significant main effect of cognitive load ($F(1, 18) = .046$, $p = .833$) and immersive condition ($F(1, 18) = .107$, $p = .747$) on the estimated durations.

Through the analysis of multiple linear regression, for the gourps of visual zeitgebers, we found no significant effect of cognitive load ($p = .236$) and immersive condition ($p = .995$) on time estimation, for the gourps of auditory zeitgebers, we found no significant effect of cognitive load ($p = .666$) and immersive condition ($p = .525$) on time estimation.

Other variables

For the groups of visual zeitgebers, we build multiple linear regression model based on visual gains, cognitive load, immersive condition, gender, mean heart rate, mean skin temperature and score of ITQ questionnaire to fitting the time estimation of participants. The regression model had statistical significance ($F(7, 57) = 8.111$, $p < .001$), and adjusted $R^2 = .438$. We found the influence of three independent variable included in the model on the duration estimation of participants was statistically significant ($p < .05$). The specific results are shown in Table 1.

Table 1: Results of Multiple Linear Regression on Time Estimation Deviation of Visual Zeitgebers

Variables	Coefficient	Standard deviation	Standardized coefficient
Intercept	-3579.162	1315.337	
Gender	189.552	28.679	0.698**
Cognitive Load	57.538	27.581	0.211*
Mean Skin Temperature	93.164	34.725	0.291**

* significant at 5% level
** significant at 1% level

For the groups of auditory zeitgebers, we build multiple linear regression modle based on auditory gains, cognitive load, immersive condition, gender, mean heart rate, mean skin temperature and score of ITQ questionnaire to fitting the time estimation of participants. The regression model had statistical significance ($F(7, 62) = 4.336$, $p = .001$), and adjusted $R^2 = .246$. We found the influence of two independent variable included in the model on the duration estimation of participants was statistically significant ($p < .05$). The specific results are shown in Table 2.

4.2 Presence

We use the SUS-score represents the sense of presence of participants [Catena et al. 2000], and analyzed the effects of the different factors (zeitgebers & cognitive load, cognitive load & immersive condition) on SUS-score in the experiment by comparing the score of SUS when the participants were immersed in the VE. Furthermore, we compared the

Table 2: Results of Multiple Linear Regression on Time Estimation Deviation of Auditory Zeitgebers

Variables	Coefficient	Standard deviation	Standardized coefficient
Intercept	1019.468	1326.080	
Gender	-129.569	28.740	-0.477**
ITQ-score	-2.070	1.003	-0.222*

* significant at 5% level
** significant at 1% level

results with the baseline and non-immersive condition without change of the illumination intensity or ticking speed of the clock. Besides, we analyzed the effects of all variables (visual gains or auditory gains, cognitive tasks, immersive condition, gender, mean heart rate, mean skin temperature, score of immersive tendencies questionnaire(ITQ) on SUS-score in the experiment by using multiple linear regression method.

Zeitgebers

Through the analysis of two-way repeated-measure ANOVAs, we found no significant effect of the interaction between zeitgebers and cognitive load on SUS-score ($F(5, 30) = .892$, $p = .499$), therefore, it is necessary to interpret the main effects of the internal factors. We found no significant main effect of zeitgebers on the score of SUS ($F(5, 30) = .716$, $p = .616$).

Through the analysis of multiple linear regression, for the gourps of visual gains, we found no significant effect of dummy visual gains $g_v = 0$ ($p = .877$) and $g_v = 2$ ($p = .701$) on SUS-score. For the gourps of auditory gains, we found no significant effect of dummy auditory gains $g_v = 0$ ($p = .290$) and $g_v = 2$ ($p = .891$) on SUS-score.

Cognitive Load & Immersive Condition

Through the analysis of two-way repeated-measure ANOVAs, we found a significant effect of the interaction between cognitive load and immersive condition on SUS-score ($F(1, 18) = 5.172$, $p = .035$), therefore, it is necessary to interpret the simple effects of two internal factor visual gains.

We found a significant simple effect of cognitive load on SUS-score when participants were immersived in VE ($F(1, 18) = 5.451$, $p = .031$). When participant carried a visual-searching task, the score of SUS was 7.263 (95% Confidence Interval for Difference: .727 13.799) higher than without the task, and the difference was significant ($p = .031$).

We found a significant simple effect of immersive condition on SUS-score when participants didn't have cognitive task ($F(1, 18) = 19.617$, $p < .001$). When participants were in non-immersive condition, they got 13.579 higher than immersive condition (95% Confidence Interval for Difference: -20.020 -7.138), and the difference was significant ($p < .001$).

Through the analysis of multiple linear regression, for the gourps of visual gains, we found significant effects of cognitive load ($p = .005$) and immersive condition ($p < .001$) on SUS-score (see table 3), for the gourps of auditory zeitgebers, we found no significant effect of cognitive load ($p = .265$), but found a significant effect of immersive condition ($p < .001$) on SUS-score (see table 4).

Other variables

For the groups of visual zeitgebers, we build multiple linear regression model based on visual gains, cognitive load, immersive condition, gender, mean heart rate, mean skin temperature and score of ITQ questionnaire to fitting the SUS-score of participants. The regression model had statistical significance ($F(8, 100) = 11.116$, $p < .001$), and adjusted $R^2 = .428$. We found the influence of four independent variable included in the model on the duration estimation of participants was statistically significant ($p < .05$). The specific results are shown in Table 1.

Table 3: Results of Multiple Linear Regression on SUS-score of Visual Zeitgebers

Variables	Coefficient	Standard deviation	Standardized coefficient
Intercept	-37.210	80.002	
Gender	-4.011	1.816	-0.176*
Immersive Condition	9.400	2.278	0.046**
Cognitive Load	-4.976	1.715	-0.219**
ITQ-score	0.495	0.100	0.408**

* significant at 5% level
** significant at 1% level

For the groups of auditory zeitgebers, we build multiple linear regression modle based on auditory gains, cognitive load, immersive condition, gender, mean heart rate, mean skin temperature and score of ITQ questionnaire to fitting the SUS-Score of participants. The regression model had statistical significance ($F(8, 109) = 10.017$, $p < .001$), and adjusted $R^2 = .381$. We found the influence of four independent variable included in the model on the duration estimation of participants was statistically significant ($p < .05$). The specific results are shown in Table 2.

Table 4: Results of Multiple Linear Regression on SUS-score of Auditory Zeitgebers

Variables	Coefficient	Standard deviation	Standardized coefficient
Intercept	1694.574	1071.346	
Immersive Condition	7.118	1.858	0.378**
ITQ-score	0.192	0.048	0.299**
Mean Heart Rate	-0.304	0.098	-0.233**
Mean Skin Temperature	6.562	1.626	0.297**

** significant at 1% level

4.3 Questionnaires

We measured a mean SSQ-score of 3.11 ($SD = 3.15$) before the experiment, and a mean SSQ-score of 6.40 ($SD = 4.61$) after the experiment [Kennedy et al. 1993]. The results indicate a typical increase in silulator sickness when wearing an HMD over the time of the experiment. However, none of the subjects complained about serious discomfort during the experiment.

We measured a mean ITQ-score of 75.44 ($SD = 12.78$) [Witmer and Singer 1998]. The results indicate our participants had the tendency of involving and immersing in VE.

5 DISCUSSION

In the experiment, although we found no significant main effect or simple effect of visual gains on the deviation of estimated durations, and there was no significant of effect of the deviation difference between different visual gains, which do not support the hypothesis H1. In the condition of no task, mean temporal judgment deviation differs between the three visual gain conditions in the IVEs and the deviation of group $g_v = 0$ and $g_v = 2$ is bigger than $g_v = 1$ was satisfied and not satisfied when there was visual-searching task (see Fig. Fig. 4). The reason of this might be the lack of differentiation of different visual gains, i.e., the discrimination of illumination intensity was insufficient and the task would weaken the influence of visual zeitgebers.

Similarly, our results show that time estimation deviation was not significantly affected by auditory gains with or without cognitive task, and there was no significant of effect of the deviation difference between different auditory gains. Fig. 4 shows that when participants carried the cognitive task in IVEs, their estimation deviation was decrease with the higher level of auditory gains, which do not support our hypothesis H2, but the hypothesis was satisfied when there was no cognitive task. The result leaves us a question that whether ticking speed of a clock could be as a auditory zeitgeber? We will explore this in the future.

Fig 4 shows that the mean temporal judgement deviations are different between the visual and auditory gain conditions in the IVEs, and the deviation of groups of visual gains is smaller than groups of auditory gains, which do not support our hypothesis H3. The reason of it might be that the illumination intensity was not strong enough to made our visual gains became visual zeitgebers. Besides, there are plenty of properties of light, it is possible that illumination intensity need to combine other characters of light such as color temperature to has effect on time perception.

Our results show that time estimation deviation was not significantly affected by cognitive load when they immersed in VE, which do not support our hypothesis H4, although the wakening effect of task on the deviation of visual or auditory zeitgebers worked for $g_a = 2$, $g_v = 0$ and $g_v = 2$.

We found no significant main effect of immersive condition on the estimated durations deviation, and no significant effect of the difference of different immersive condition, i.e., the

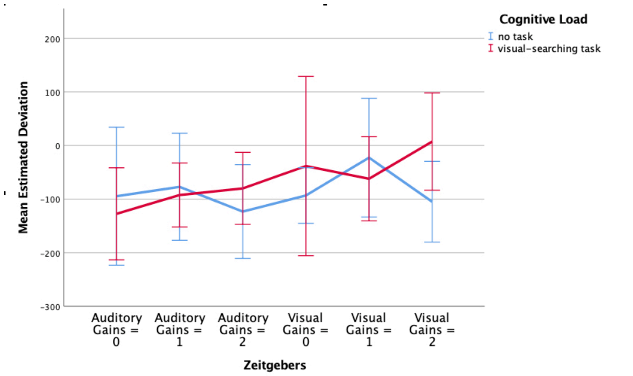

Figure 4: Pooled estimated deviation for the comparison between different cognitive load for the different zeitgebers

mean temporal judgments deviation was nearly the same between the immersive or non-immersive condition, which do not support our hypothesis H4.

To our surprise, we found a significant effect of mean skin temperature and cognitive load on time estimation in the group of visual zeitgebers when built multiple linear regression model, which indicates higher skin temperature and cognitive load will lead to bigger time estimation deviation. Besides, in line with the literature on time perception in different gender [Hancock et al. 1992], we found the influence of gender included in the regression model on the duration estimation of participants was significant both in groups of visual or auditory zeitgebers, but in a different way. In the condition of different visual gains, male's estimated deviation is smaller than female, in groups of auditory gains, however, the opposite was true.

Our results show no significant effect of visual or auditory gains on SUS-score, and no stastic significant effect of mean SUS-score differences in different zeitgebers, which supports our hypothesis H6.

However, we found a significant simple effect of cognitive load on SUS-score when participants were immersed in VE. Besides, the differences of SUS-score between low cognitive load and high cognitive load is significant, that is, the SUS-score is lower when participants carried the visual-searching task, which do not support our hypothesis H7, and this might be due to that participants were devoted into the task when they immersed in VE and forgot about other things around them and SUS questionnaire reflected more about PI but not Psi, and a new questionnaire that take both PI and Psi into account is needed.

Furthermore, we found that there were variours factors had significant effects on SUS-score when we build the multiple linear regression model. For the group of visual gains, included gender, immersive condition, cognitive load and ITQ-score had significant effects. Although immersive condition and ITQ-score still had significant effects on SUS-score for the group of auditory gains, the other two factors became mean heart rate and mean skin temperature, which in line with the literature on the effect of physiological variables on presence [Meehan et al. 2002; Sheridan 1996; Wiederhold et al. 2001].

6 CONCLUSIONS AND FUTURE WORK

In this article, we further explored the effects of manipulated visual or auditory zeitgebers, cognitived load and immersion on time estimation and presence as yet not well-studied factors of spatiotemporal perception and presence perception in VEs. We presented an experiment in which we analyzed the ability of temporal perception and sence of presence while experiencing an immersive HMD as well as non-immersive VE.

We found a significant effect of skin temperature on time estimation when participants were in different groups of visual zeitgebres, which indicates that people with higher skin temperature may have better time perception in a way, and this provide a guideline for the build of time-passing virtual environment. Besides, we found a significant effect of gender on time estimation in group of visual or auditory zeitgebers, but in a different way, i.e., male has better judgement for time than female in the group of visual zeitgebers, and female has better temporal perception than male in the group of auditory zetgebers. This suggests that we need to take gender into account when building time-related applications in order to influence users' perception of time better. Moreover, due to the limitation of SUS questionnaire, we think a new questionnaire which can take both PI and Psi into account is needed.

Higher cognitive load might lead to lower SUS-score, which provide a guidence that if we want the participants feel more place illusion, we need to ovoid overinvolving the user in their task. Not only cognitive load had significant influence on SUS-score, gender, immersive condition, and ITQ-score were also influencial in group of visual zeitgebers, immersive condition, ITQ-score, mean heart rate and mean skin temperature had significant effects on SUS-score in group of auditory zeitgebers, which could guide us to build more attracted computer-generated virtual worlds.

In the future, we plan to investigate zeitgebers with much bigger discrimination and influencial on time perception. For visual zeitgebers, we plan to take the different characters of light into acount, such as color temperature and wave length. Futhermore, we plan to investigate alternative zeitgebers such as sound of wind or rain incorporating also multimodal information such as environment temperature. Besides, we want to build more interactive and reliable scenarios, for instance, in which users can have conversation with other creature so the social zeitgebers can be take into acount.

With the advent of 5G era, apparently, VR technology will play a bigger role in the near future, and it is important to figure out how time is perceived and the sence of presence in VR. This research provides a new perspective towards understanding temporal perception and sence of presence in IVEs, and we believe that the potential of this topic will attract people to join us and explore the principles behind perceiving and even manipulating time in virtual reality environments.

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