RUNNING HEAD: VR effects on time estimation

Ahead of its time: An exploration of virtual environment effects on time estimation

by

Donna Monbourquette

A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial
fulfillment of the requirements for the degree of

Master

In

Cognitive Science

Carleton University
Ottawa, Ontario

© 2019
Donna Monbourquette

Abstract

Virtual reality (VR) is an increasingly popular technology, yet little is known about the cognitive effects it produces. For example, no research has been done investigating time perception in virtual environments. The present work proposed and tested a model of time estimation accuracy in virtual environments. A VR flight simulator was used to engage participants in a virtual environment, where they were required to make time estimations. Video game experience, cognitive load, and VR immersiveness factors were considered potential predictors. Video game experience, presence, interactivity, and immersion - fluency were significant predictors of time estimation accuracy. Having prior video gaming experience, higher levels of presence and interactivity in the virtual environment led to more accurate time estimates. In contrast, higher levels of immersion - fluency reduced time estimation accuracy. These results inform stakeholders of VR technology and highlight the importance of understanding how these factors influence time perception in VR.

Acknowledgements

I would like to thank Dr. Chris Herdman, my committee members, Dr. Jo-Anne Lefevre and Dr. Melissa Frankel, for their insight, and everyone in the ACE Lab for their support. Special thanks to James Howell for the technical support, to Clare Coyle for helping with data collection, and to Dr. Kathy Van Benthem, for answering all of my many emails and providing incredible guidance through every step of the process. I could not have done it without you, and I am very grateful.

Alex, I would not have gotten through the last year and a half without you. Thank you for sharing in my every struggle and success. It has been a pleasure to go through this degree with you, and I have learned so much from working with you.

To my family, Emma, Adria and Nicole, thank you for listening to my stress, concern, and excitement throughout the past two years. You believing in me, and your willingness to listen, and provide encouragement was very much appreciated.

And finally, I want to thank everyone at CMTS. You have all kept me sane and helped me in ways you don't know. Thank you for being my biggest cheerleaders. Katie, thank you for never letting me give up and always being there when I needed. To Jaime and Jaime, I am tremendously grateful to both of you for always making me laugh, and always believing in me.

Table of Contents

Abstract.....	ii
Acknowledgements.....	iii
Table of Contents.....	iv
List of Tables.....	vii
List of Figures.....	viii
List of Appendices.....	ix
Introduction.....	1
Cognitive models of time estimation.....	4
Video game experience.....	6
Cognitive load.....	8
VR immersiveness.....	12
Present research.....	14
Model.....	14
Hypotheses.....	16
Methods.....	17
Participants.....	17
Apparatus and stimuli.....	17
Procedure.....	19
Materials.....	24
Independent measures.....	24
Participant attributes.....	24
Video game and VR experience.....	24

VR immersiveness.....	25
Workload.....	26
Real World Competency.....	26
Dependent measures.....	27
Time estimation values.....	27
Time difference score.....	28
Time difference ratio.....	29
Results.....	30
Data cleaning.....	30
Time estimation descriptive statistics.....	30
Time estimation accuracy and ratio scores.....	35
Time estimation model.....	40
Block 1.....	42
Block 2.....	43
Post hoc model building.....	44
Final model.....	47
Discussion.....	49
Pacemaker model connections.....	52
Limitations.....	52
Implications.....	53
Future directions.....	54
References.....	58
Appendix A: Power analysis.....	67

Appendix B: Questionnaire items.....	68
Appendix C: Ethics approval.....	70
Appendix D: Correlations between Ratio and demographic variables.....	72

List of Tables

Table 1. <i>Counterbalance descriptions for participant groups</i>	23
Table 2. <i>Likert scale conversations</i>	25
Table 3. <i>VR Immersiveness Questions</i>	26
Table 4. <i>Descriptive statistics for Ratio and Absolute TDS scores</i>	34
Table 5. <i>Descriptive statistics for ANOVA</i>	35
Table 6. <i>Correlations of potential predictors for Block 1</i>	37
Table 7. <i>Correlations of potential predictors for Block 2</i>	39
Table 8. <i>Correlations of predictors for Block 1 regression</i>	41
Table 9. <i>Correlations of predictors for Block 2 regression</i>	42
Table 10. <i>Contributions of model predictors for Block 1</i>	43
Table 11. <i>Contributions of model predictors for Block 2</i>	44

List of Figures

Figure 1. <i>Operating virtual reality device</i>	2
Figure 2. <i>Simplified version of the pacemaker model for time perception</i>	6
Figure 3. <i>Mutterlein (2018) model for VR factors</i>	13
Figure 4. <i>Proposed model of time perception in virtual environments</i>	16
Figure 5. <i>Wide display of the experimental set-up</i>	18
Figure 6. <i>Participant view from inside the Oculus headset</i>	19
Figure 7. <i>Map of the flight path and labels for each hoop</i>	28
Figure 8. <i>Histogram of participant time estimation ratios for each block</i>	31
Figure 9. <i>Histogram of participant absolute TDS for each block</i>	33
Figure 10. <i>Histogram of binned RWC scores for block 1</i>	46
Figure 11. <i>Histogram of binned RWC scores for block 2</i>	46
Figure 12. <i>Final model of time estimation accuracy in VR</i>	48

List of Appendices

Appendix A. <i>Power Analysis</i>	67
Appendix B. <i>Questionnaire Items</i>	68
Appendix C. <i>Ethics Approval</i>	70
Appendix D. <i>Correlations between Ratio and demographic variables</i>	72

Ahead of its time: An exploration of virtual environment effects on time estimation

It is believed that virtual reality (VR) may alter our experience of time, yet the influence of a VR context on time perception is not well-understood (Miller, 2016). With a variety of fields beginning to utilize VR, understanding how virtual environments impact our accuracy in estimating time durations will be useful for optimizing virtual reality applications. Accuracy of time perception in both the real and virtual worlds is relevant for daily tasks. For example, being able to time how long to spend on each section within an exam, or properly time a transit connection is mundane, but important uses of being able to accurately estimate time.

Training employees and students in virtual reality is a cost-effective alternative to traditional methods. Recent work has shown that medical students trained in VR performed significantly better on specific training procedures than students trained in a traditional environment (Lang, 2019). However, to adequately train employees for jobs using virtual reality, the perceived time in VR should map congruently on to the actual real-world time. Discrepancies between actual and perceived time duration in VR environments, particularly when experienced with high-risk activities could result in errors and poor outcomes. In the medical domain, surgeries can now be conducted via the use of VR technology. As depicted in Figure 1, robotic devices used to operate surgical instruments can be remotely controlled by surgeons in a VR environment. Surgeons operating in VR environments must experience time accurately and in the same way they would perceive time during a non-VR surgery. Without proper time perception, doctors

and medical staff would not be able to keep track of the dozens of time sensitive aspects of surgery (e.g., monitoring drug doses, controlling anesthesia).

Figure 1. VR operating device. The surgeon controls the robot via the VR system to perform surgery.

Accuracy in time estimation when training for other high-risk occupations is also important. For example, pilots are required to check their fuel tanks at specific intervals during flight. If a pilot who was trained in a virtual environment experiences the passage of time in VR in a way that is different than how they experience it in the real world, this could lead to them missing or delaying required safety checks and a problem may go unnoticed.

While it is important for some professions to have accurate time perception, for other fields, deliberately causing either over or underestimation of time is the goal. For instance, the healthcare industry views virtual reality as a strategy to help

patients manage pain during surgeries or treatments where they are awake (Schneider, Kisby & Flint, 2011). In such cases, virtual reality would be beneficial if it caused participants to perceive time passing faster than the actual duration of the procedure or treatment. The entertainment industry also has a stake in understanding and manipulating how customers experience time. In this case, it has been shown that video game players are most satisfied when they feel as though the game lasted for an extended period of time (Rau, Peng & Yang, 2006).

Literature on time perception suggests a variety of factors that may influence a person's ability to accurately perceive time and estimate durations. Rau, Peng and Yang (2006) found that level of experience in gaming influences a player's time perception while engaged in video games. Increasing or decreasing cognitive load has also been connected to altered time perception (Block & Gruber, 2014; Lontz, Doherty & Lui, 2015). However, the effects of video game experience and workload on time estimation accuracy are not clear, producing mixed effects in academic studies (Rau, Peng & Yang, 2006; Tobin et al., 2010). Furthermore, very little research has examined how time perception interacts with the novel mental demands of being in a virtual environment such as feelings of immersion and presence.

In summary, the motivation for the present work was to inform our understanding of how various factors influence time estimation in a VR context. This research examined time perception in virtual reality. Video game experience, cognitive load and VR immersiveness were used as predictors of time perception.

Cognitive Models of Time Estimation

Models of time perception are used to understand how the mind keeps track of time and is able to estimate or reproduce durations. Allan (2001) notes that most models of time perception focus on a person's internal clock rather than their periodic clock. In order to be activated, the internal clock needs to be signaled and works in intervals, rather than running in the background at all times. The periodic clock, however, is constantly running self-sufficiently and is responsible for internal processes such as the circadian rhythm.

Gibbon, Church and Meck (1984) introduced a scalar timing model, popularly known as the pacemaker model. It has since been used by researchers as a way of understanding the mechanics behind time perception (Block & Gruber, 2014). The pacemaker model consists of three stages: a clock stage, memory stage, and a decision stage (see Figure 2). The clock is responsible for transforming real time into perceived time by using a pacemaker. The pacemaker starts emitting pulses once activated, but the rate at which it pulses can be altered by a variety of environmental and cognitive factors (Allan, 2001; Gibbon et al., 1984). Altering the pulse rate of the pacemaker changes the perception of time, with more pulses corresponding to a longer judgment of elapsed duration, and vice versa. The memory aspect of the pacemaker model holds the amount of pulses that have occurred in working memory and stores information from past temporal experiences in reference memory. A decision is regarding the passage of time is reached by consolidating information from every stage to make a duration judgment. However, Maniadakis and Trahanias (2014) argue that the pacemaker

model has not yet been linked with cognitive or behavioural capabilities, and therefore is not able to accurately predict how participants estimate time durations. Testing the pacemaker model directly is difficult as there is no physical pacemaker in the body to count how the accumulated pulses change with experimental manipulations. Whittmann and Paulus (2008) point out that according to the pacemaker model, distracted individuals should overestimate time durations, but this result is not always found in time perception research (Block & Gellerson, 2010; Schneider, Kisby, & Flint, 2011). Further, this pacemaker model was not developed for time perception in virtual environments, and as such does not take into account factors that are exclusive to VR. For the present work, the cognitive aspect of the pacemaker model of time estimation, namely cognitive load, as well as other factors described below that are not included in any model but have been researched in relation to time estimation and perception will be considered.

Figure 2. A simplified version of the pacemaker model for time perception from Coslett, Chatterjee, and Aguirre (2010).

Video Game Experience

Sanders and Cairn (2010) investigated how enhancing immersion with music in video games could influence time perception for gamers. Participants played a maze game either with or without music and were required to give time estimations when they finished. All participants were stopped after 203 seconds. Participants were quite accurate at estimating elapsed time when in the no-music condition. In the music condition, however, participants significantly underestimated the amount of time that had passed. This suggests that having more immersion (music condition) led to less resources available to devote to monitoring time. Sanders and Cairn note that the maze game is not cognitively

demanding, and as such, the effects of immersion may vary based on the amount of cognitive load required for actual gameplay.

Rau, Peng and Yang (2006) investigated how time distortion effects video game players with different levels of experience. All participants played the video game Diablo 2 and were considered either an expert or a novice game player, determined by their previous experience with Diablo 2. In each of the two experience level groups, participants were randomly assigned to be cut off after thirty minutes, sixty minutes, or ninety minutes. After the video game session was complete, experimenters measured the participants' delay time (how long they took to actually stop playing after being cut off), acceptance of the break-off, satisfaction with the experience, their rating of the game playing experience (compared to sessions of game playing previously) and their time distortion (how far off they were from the actual time passed). There was a significant effect of experience level on experience, such that novice players enjoyed the experience more than expert players. Both novice and expert players overestimated the time that had passed in the thirty-minute cut off condition, but this was not a significant finding. In the sixty-minute condition, there was a marginally significant trend ($p = 0.059$) where novice players trended towards overestimating the elapsed time, while expert players underestimated the duration, however, the novice estimates were less accurate than the expert estimates. Overall, novice players experienced more time distortion than expert players, especially when the playing time was longer. Novice players also overestimated the time regardless of the length of time

they were playing for, where experts overestimated the shorter duration and underestimated the longer duration.

Tobin et al. (2010) tested time perception with gamers in an environment with more ecological validity than a laboratory: a video game café. Participants were interrupted either 12, 35 or 58 minutes into their gameplay to collect time duration estimates. They also collected data about the gamers and anticipated that the gamer profiles would be a large predictor of their estimates based on work by Rau, Peng and Yang (2006). They found significant predictors of time estimations in gamer profiles, confirming their hypothesis. Participants who spent more time playing video games each week were more likely to make less accurate time estimations, with a tendency to overestimate the duration played. Overall, this study shows that more experienced gamers tend to experience time distortion, making less accurate overestimations than less experienced players.

Wood, Griffiths and Parke (2007) investigated time loss experienced by gamers. Participants reported that time loss could be positive (unwind, escape from a stressful day), negative (missing or sacrificing responsibilities), or both (situation dependent). The authors found that the complexity and immersiveness of the game were more likely to result in time loss, as well as games that had a story or plot associated. The results of this study suggest that higher levels of immersion and complexity in a task can impact the perception of time.

Cognitive Load

Lontz, Doherty and Lui (2015) were interested in how time estimations might be altered by introducing a distraction to the task. Participants had one primary

task and three secondary tasks to complete. For the primary task, participants engaged in an Image Queue task where they were asked to identify all stimuli of a specific type (in this case, enemy tanks) in a fifteen second period. The three secondary tasks required participants to enter a digit string within ten seconds of a visual cue, accept or reject an alternative route with the goal of minimizing threats along the route and enter a random code sporadically throughout the task. During the tasks, half of the participants were exposed to a distraction - a Morse code sound that occurred at various intervals (3, 5, 6 and 9 minutes into the experience). Their task immersion, time perception, and time distortion were assessed via a questionnaire. Time perception and distortion were measured by requiring participants to reproduce a time duration of 26 seconds. They found that time estimates when a distraction was present were significantly overestimated, compared to estimates without a distraction. These results suggest that increasing cognitive load has an impact on time perception, causing participants to overestimate the actual duration.

Block and Gellerson (2010) used a simple task, requiring participants to respond to visual stimuli with five different input devices, ranging from very simple to very complex and give time estimations. The five input devices were as follows: a GUI control, a normal keyboard, an optimized keyboard with hotkeys, a display keyboard and a touch keyboard. They found that when participants were completing the task with the more complex input devices (and therefore presumably had increased cognitive load), they had a less accurate perception of time, and often underestimated the amount of time that had passed.

Block, Hancock, and Zakay (2010) conducted a meta-analysis on 117 papers that studied time perception and compared the time duration judgment ratios (time estimation/objective time) between studies. Their results showed that if a person had to divide their attention between two tasks, the time estimation judgment ratio while decreased, and there were more accurate estimations compared to time estimates where the participant was presented with only one task. Further, they found that when participants were handling a high cognitive load, they made longer estimations as opposed to participants dealing with a low cognitive load.

Pan and Luo (2011) examined the role that working memory and cognitive load have on time perception. They conducted three studies with near identical methodologies. Participants were asked to view a coloured square, which appeared on a screen for 600ms. They were then shown two differently coloured circles, one after another and asked to report which circle appeared on the screen for longer. Following their response, a second square appeared, and they were asked to indicate whether it was the same colour as the first square they saw. Regardless of whether or not the squares seen were the same colour, the durations of the two circles were manipulated. One of the circles always matched the colour of the initial square. In the second experiment, participants were shown the first square, but were not tasked with the additional memory question, or asked to remember the colour of this square. Therefore, the trial ended after they had indicated which circle appeared for longer. For the third experiment, the procedure

was identical to experiment one, however all shapes and colours were replaced by words.

In the first experiment, Pan and Luo (2011) found that in trials where the circle that matched the square appeared for a shorter duration than the mismatching circle, participants made more time judgment errors, compared to when the matching circle had the longer duration. In the second experiment, when no memory task was required, the opposite effect was found, and participants made fewer time duration judgment errors when the matching circle had the shorter duration than when it had the longer duration. The third experiment replicated the results of the first study, such that participants made more judgment errors when the word that matched the memory cue had a shorter duration, compared to when the matching word had a longer duration. These results suggest that demands on working memory moderate a person's ability to perceive and estimate time. Maintaining a stimulus in working memory can lead participants to perceive it to have a longer duration. However, repetition of a stimuli without any processing will shorten the perceived duration. Pan & Luo say that their results "suggest that the perceived duration of a stimulus can be modulated directly by [working memory], without any attentional mediation" (p. 50).

Schatzschneider, Bruder, and Steinicke (2016) looked at the effect of cognitive load on time estimations in a virtual environment. They included three conditions: one in which the participant had no task, the second condition required participants to complete a single cognitive task, and the final condition required participants to complete two concurrent tasks. They discovered that in conditions

with no cognitive tasks, participants overestimated the time duration, but when they were asked to complete a single cognitive task or a dual task paradigm, the time duration estimates were under the actual time passed.

Schneider, Kisby, and Flint (2011) provided virtual reality headsets to patients undergoing chemotherapy for three types of cancer (breast, colon, or lung cancer). Patients viewed a calming virtual scene. Once they had finished their treatment session, participants were asked to estimate how long they believed the session took. Regardless of their cancer diagnosis, participants underestimated the time that had passed during their chemotherapy session.

VR Immersiveness

Mutterlein (2018) created a model characterizing the interactions between immersion, presence, and overall user satisfaction (Figure 3). Immersion can be separated into immersion – fluency and immersion – absorption. Immersion - fluency refers to an ideal state of being challenged and concentrated, while immersion – absorption indicates that the person in question has a particular interest or motivation towards the content (Engeser & Rheinberg, 2008). For the present study, questions investigating both categories of immersion will be used.

Mutterlein (2018) hypothesized that immersion and presence are different, but related constructs and that presence has to occur before immersion. He proposed that the higher the level of presence, the higher levels of immersion that will be experienced. Mutterlein also hypothesized that higher levels of immersion would result in greater user satisfaction.

Figure 3. Mutterlein (2018) model for VR factors.

Mutterlein (2018) created a questionnaire that measured immersion, interactivity and presence in virtual environments, and validated it with experimental research. He conducted a study using customers at a virtual reality gaming center, where members of the public are welcome to come to play games in virtual reality. This location increased the ecological validity of his results. Participants were given a short demographic questionnaire after agreeing to participate in the study. They were then asked to play one of two preselected virtual experiences, followed by the questionnaire he developed.

The results confirmed Mutterlein's (2018) hypotheses and validated the questionnaire. There was a strong link between presence and immersion, and presence had a significantly positive effect on immersion. Additionally, there was a strong significant relationship between immersion and satisfaction, indicating that with higher levels of immersion, there is more user satisfaction. In the present thesis, a model of time perception in virtual environments (explored in the next

section) is proposed that used the relationships Mutterlein validated to understand how presence and immersion influence time estimations.

Present Research

The purpose of this study was to determine what factors that influence time perception in the real world would transfer into a virtual environment and affect perception. Participants flew a virtual flight simulation system and answered time estimation queries at various points during the flight. Cognitive load was manipulated, and video game experience, immersion and presence were measured and considered to be potential predictors for time estimation in virtual environments. These factors will be looked at throughout time in the experiment (as blocks, expanded upon in the Methods section).

Model

This research will test a proposed model of time perception for virtual environments. The model builds on factors included in Mutterlein's (2018) model of user satisfaction in virtual reality. Mutterlein validated the positive relationships between presence and immersion. Interactivity has been excluded from this new model because research has shown that interaction with an environment is not required for time perception (Schneider et al., 2011). However, as investigating time perception in virtual environments is a new area of research, interactivity is being considered as a potential predictor of time estimation accuracy and will be measured in the present work. If interactivity proves to be a significant predictor, it will be added to the model.

In addition to the factors from Mutterlein (2018), the most relevant factors for this model are gaming experience and cognitive load. Tobin et al. (2010) showed that gaming experience was a significant factor for time estimations, such that with more experience, less accurate time estimations were made. Block, Hancock and Zakay (2010) investigated cognitive load and found that with more cognitive load, participants made more accurate time estimates.

There has been debate surrounding whether or not cognitive load influences time perception. The proposed research will help clarify the role cognitive load has on time estimates in a virtual environment. Immersion and presence are connected, as they are expected to be highly correlated with each other (as per Mutterlein, 2018). However, since the effects of presence and immersion on time perception have not yet been studied, they are being treated separately in the model (seen in Figure 4).

Figure 4. Proposed model of time perception in virtual environments. Factors in grey have been taken from Mutterlein's (2018) model.

Hypotheses

As illustrated in Figure 4, this study has three hypotheses that correspond to the proposed model of time perception in VR. Hypothesis one is that more gaming experience will lead to worse time perception when compared to participants with less gaming experience, as suggested by the research of Tobin et al. (2010). Hypothesis two is that participants will have more accurate time estimates when undergoing the high cognitive load condition, based on the meta-analysis by Block, Hancock and Zakay (2010). Hypothesis three is that high levels of immersion and presence will lead to more accurate time perception. While these hypotheses will be tested, due to the exploratory nature of the work, effects in any direction will be investigated. In addition to the main hypotheses regarding time

perception accuracy, participant tendencies to over or underestimate time durations will be examined.

Methods

Participants

A total of 45 undergraduate students from Carleton University, in both the Psychology and Cognitive Science departments, participated in the study for course credit (2%). An a priori power analysis indicated that with a sample size of 40, and an expected moderate effect size ($p < .05$) provided an expected power of .85, just above the suggested minimum of .80. The details of the power analysis can be seen in Appendix A. Participants were expected to have normal or corrected to normal vision. Two participants were excluded from the analysis because they did not complete the experiment. Six participants were excluded due to data collection errors, and a further three participants were excluded as they did not understand the experimental tasks and therefore did not complete the experiment as expected, resulting in implausible and missing data. The final sample includes 34 participants (19 female, 1 non-binary) with a mean age of 21.

Apparatus and Stimuli

The virtual reality (VR) Cessna simulator has three physical controls - a Precision Flight Controls yoke, a custom throttle slider, and a custom flaps toggle. As shown in Figure 5, the flight controls were mounted on the flight control unit in locations that matched the location of the virtual controls in the VR Cessna cockpit. The VR graphics and sounds were presented using an Oculus Rift CV1 headset.

A Leap Motion controller was mounted on the front of the headset which captured the user's hand movements via infrared cameras and displayed virtual hands in VR.

Figure 5. Wide display of the experimental set-up. The flight control unit and Oculus headsets are visible.

Figure 6. Participant view from inside the Oculus headset, displaying the virtual cockpit.

The simulator was powered by a desktop computer running Windows 10 with an i7 7700@3.6 ghz processor and NVIDIA 1080 graphics card. Lockheed Martin Prepar3D version 4 flight simulation software was used to display the virtual environment and fly the aircraft, and the FlyInside add-on software was used to display the virtual hands. Custom software was developed in house that runs alongside Prepar3D to manage the experiment scenarios, using Lockheed Martin's SimConnect SDK. This custom software logs flight data, plays audio cues, repositions the aircraft, and provides an interface to track flight progress.

Procedure

After arriving at the experiment room, participants read and signed an informed consent form, describing the experiment's purpose and the tasks they would be asked to perform. Following the informed consent form, participants were

given a presentation with instructions on how to complete a flying task in the virtual environment. For the flying task, participants were required to fly the plane through 9 large hoops along a specified flight path. This scenario had been tested in the lab with a variety of participant groups, and was deemed to be an accurate simulation of the real experience of flying a plane, and a valid measure of cognitive load. The instructions walked them through the layout of the task, their flight pattern, and how to control the plane (Cessna 172 model flight simulation unit). Participants were only given the ability to control the yoke and speed of the simulator plane, and were given descriptions of two flight monitoring gages in the cockpit: their speed and how parallel they were to the ground while flying. Although it was not necessary to change speeds throughout the flight, participants were taught how to control the speed, and informed that they could change the speed at any time if they felt the plane was moving too quickly. Participants were also encouraged to try and keep the plane as parallel to the ground as possible during flight, except during turns. They were informed that they would be flying the plane around a closed loop circuit (a circular pattern in the airspace above an airport). Placed throughout the circuit, there were nine hoops that they would be required to fly through. This circuit and hoop combination has been used in previous studies conducted with the lab. During this time, participants were told that they may need to answer questions about their flying experience, or retain information from incoming radio calls that may be relevant later in the experiment. This was unknown to participants at the beginning of the experiment, but all questions asked to them during flight would require them to give a time estimation. These time

estimations were always referring to the two hoops they flew through most recently, and the hoops were referenced in the question to avoid confusion. Participants were also introduced to the Oculus Rift VR device and its functionality.

After the instructions, participants completed a computerized questionnaire via a Google Form to collect information about demographics, video games, virtual reality experience and fatigue levels before getting situated in the simulator. Participants were briefly shown how to operate the controls for the simulator in the physical world before entering the virtual environment. In the virtual environment, participants were again walked through the plane controls. Participants were able to take as much time as they needed to feel comfortable handling the controls for the virtual plane. Once comfortable in the environment, participants flew through a training circuit. The training circuit was an identical set up to the testing trials, however, participants were not asked to complete any additional tasks. The purpose of the training was to ensure they were comfortable with the basic flying task. When they finished flying and felt comfortable with the flying task, they started the testing trials.

As part of a larger research agenda on immersion in VR, the experimenter activated and deactivated the visibility of the opaque VR hands at various times. Participants were always told when the hands would and would not appear. This was carefully counterbalanced with the main study factors to eliminate any effect that seeing hands in VR might have. During the training phase, the hands only

appeared if participants would have the hands visible in the first section of the experiment.

Participants completed the experiment in four blocks, each block consisting of two loops of the circuit and eight time estimation queries. The first two blocks were practice with the task, and the final two blocks were the experimental trials. Following each block, participants removed the Oculus headset and completed a computerized questionnaire. The questionnaire collected an additional time estimation (for the entire block), as well as information about their levels of presence, immersion, cognitive load, and simulation sickness. In blocks where radio calls were present, the questionnaire also asked participants to recall the four call signs they heard. Three questions based on the Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum & Lilenthal, 2009) were used in the questionnaire to evaluate participant levels of dizziness, queasiness, and disorientation. After each of the two blocks of flight, subjective ratings were collected using a 7-point scale (see Appendix B). These scores were checked to ensure participants were not experiencing discomfort throughout the experiment, but were not analyzed further. Table 1 shows the breakdown of each block for both counterbalances.

Table 1. Counterbalance descriptions for each group

First Counterbalance

Condition Order	Low Workload	High Workload
Block 1	Yes	No
Block 2	No	Yes

Second Counterbalance

Condition Order	Low Workload	High Workload
Block 1	No	Yes
Block 2	Yes	No

In the Cognitive Load – High condition, participants heard two radio calls per circuit, for a total of four radio calls per block. When they finished each block of trials with radio calls, they were asked to recall the call signs from each incoming radio call at the beginning of the post-block questionnaire. Radio calls were heard at the downward arrow hoop and the question mark hoop for all participants. Radio call locations are labeled in Figure 7. In the Cognitive Load - Low condition, participants only completed the flying task with the time perception questions. They were not required to complete any additional memory tasks.

As the researchers were responsible for asking these questions, and timing is crucial for the study, a protocol was developed. Using a separate monitor, the researchers were able to see what participants were seeing in their field of view. When the hoop was no longer visible (typically when both wings of the plane had

cleared the hoop), the question was asked. This protocol kept the questions consistent between researchers and participants and ensured that participants were clearly past the hoop before asking for a time estimate.

After completing each block, participants removed the VR headset and completed the post-block questionnaire, which required them to estimate the duration of the entire block. Once they completed all blocks and their respective questionnaires, they were debriefed.

Materials

Independent measures. The following measures were collected as potential predictor variables in the model of time estimation.

Participant Attributes. Age and gender were recorded for each participant.

Video game and VR experience. Experience with traditional video games and virtual reality was indexed using a five-point eight-item scale (see Appendix B). The scale items related to level of experience, length of time using video games or VR, frequency of use, and skill level. Scores for this variable were assigned a numerical value between 0-5 for analysis, such that higher scores indicated more experience. Table 2 shows how this assignment was done.

Table 2. Guide for how numerical values were assigned to questions about video game and virtual reality experience.

How long have you been playing video games?	
Response	Numerical Value
6 months	1
1 year	2
2-3 years	3
5-10 years	4
More than 10 years	5
N/A	0

VR Immersiveness. The present work indexed VR immersiveness using 9 items based on work by Mutterlein (2018). As shown in Table 3, the questionnaire contained items related to perceived levels of presence (4), immersion (3), and interactivity (2).

Table 3. List of all VR Immersiveness questions included, separated by VR factor.

Presence
The Oculus created a new world for me, and this new world suddenly disappeared when the exercise ended.
When I removed the Oculus, I felt as if I returned to the “real world” after a journey.
I forgot about my immediate surroundings when I was using the Oculus.
The content of the Oculus seemed to be “somewhere I visited” rather than “something I saw”.
Immersion
I had no difficulty concentrating.
My thoughts and movements felt effortless.
I was totally absorbed in what I was doing.
Interactivity
The Oculus content allowed me to interact with the virtual world.
I had the feeling I could influence the virtual world of the Oculus.

Workload. Five questions from the NASA TLX questionnaire were used as a subjective measure of participant workload throughout the task. Questions measured mental workload, physical workload, performance, effort, and frustration. The NASA TLX questionnaire has been validated as a reliable measure of workload in airplane cockpits (So & Gore, 2018).

Real World Competency. After each post-block questionnaire, participants were asked to estimate how long it took them to complete the questionnaire. This gives a baseline time estimation score for the physical world. The first two-time estimates were treated as practice. The final two trials were recorded for analysis.

This variable was used as a grouping variable that represents basic estimation competency. It used a simple and familiar task (completing a survey using Google Forms), and participants were categorized into three groups: poor, medium, or good basic time estimation ability. This variable is called Real World Competency (RWC).

Dependent measures.

Time estimation values. Virtual world time estimations were required at four points throughout the circuit, and a total of eight time estimates were collected in each block. The first question was after they flew through the circle arrow and question mark hoop, the second estimate was asked for between the downward arrow and circle arrow hoop, the third estimate was after they flew through the downward arrow and question mark hoops, and the final estimate was after they flew through the question mark hoop, and the circle arrow hoop. Figure 7 shows a visual representation of the circuit with all the hoops and question locations labeled. All participants were asked to estimate how long it took them to fly between the pairs of hoops mentioned above and all of the time estimations occurred at the same place in the circuit for all participants, regardless of what they were told prior to starting. Two main dependent variables were derived from the estimates of time.

Figure 7. Map of the flight path and labels for each hoop. Q indicates where a time estimation question would be asked of participants. RC indicates where participants would hear an incoming radio call (Cognitive Load - High condition only).

Time difference score. A script was used to subtract the actual time duration value from the participant estimates of time duration to produce Time Difference Score (TDS). All negative values represent an underestimate of the time duration, and positive values represent overestimations of the time durations. For all analyses, the absolute values were used to investigate participant accuracy and ensure logical interpretation of the regression coefficients. The majority of the hoop pairs took between 25-50 seconds to complete (depending on the participant speed and accuracy in flying). To manage a few outliers, data for participants who

had a Time Difference Score of more than 60 seconds (meaning their time estimate was double or triple the actual time duration) was capped at 60 seconds. Once participants reached a difference score of 60 seconds, it was clear that they grossly overestimated the time duration, and any value beyond 60 seconds introduced extreme outliers into the data. In addition, due to the nature of the time estimations, the range of the Time Difference Score was unbalanced. Participants were only able to underestimate the time passing by a fixed amount, however, overestimates had no limit. Putting a cap on the difference scores helped to balance the range of over and under time estimates.

Time estimation ratio. A ratio value was derived from the estimated and actual time duration values. The ratio variable permits an examination of the over versus under estimations made by participants ($\text{Ratio} = \text{Estimate} / \text{Actual Time}$). Final ratio values were calculated by averaging the ratios for each trial, separated by block. Ratio values between 0 and 1 represent underestimates. A ratio value of exactly one would mean that the participant accurately estimated the actual time passed for each question. A ratio value greater than 1 represents overestimates of time. Similar to the Time Difference Score values, a cap of 2/1 was imposed on the data help balance the range of ratio values. Any ratio value greater than 2/1 means that participants estimated that more than double the amount of actual time passed.

The third and seventh time query of each block were removed from the analysis due to a technical error in capturing the actual duration of time during this segment of the flight.

Results

Data Cleaning

To account for missing data, outliers and irregularities, the following procedures were followed. There were 6 random cases where a participant did not properly fly through a hoop, or their estimate was missing from the data file. To minimize random data loss, where the actual time was missing, an average was taken of all other participant times, under the assumption that participants did not significantly differ in the time it took to fly through the hoop pairs. When a participant estimate was missing (2 cases), an average was taken of their other estimates in that block and used as an estimate for the missing hoop pair. Assumptions were checked before each statistical test. The sample size for the following analyses was 34, before removing any outliers.

Time Estimation Descriptive Statistics

The histogram in Figure 8 display the range of scores for participant ratios of time estimations in the virtual environment. Participant scores were capped at a value of 2, anything beyond that indicated that participants overestimated the time that had passed by more than double the actual duration.

Figure 8. Histogram of time ratios (Ratio = Estimate/Actual Time) separated by block.

A similar histogram was created for accuracy using absolute Time Difference Score values (Figure 9). The descriptive statistics for both the Ratio and Absolute Time Difference Score values can be found in Table 4. Participants tended to underestimate the time that had passed. While this underestimation was slightly smaller in Block 1, the difference between the ratio scores for Block 1 and Block 2 was not significant, $t(29) = -.68, p > .05$.

Figure 9. Histogram of participant absolute Time Difference Scores separated by block.

Table 4. Descriptive statistics for Ratio and Absolute Time Difference Scores (TDS).

Block					
One		Minimum	Maximum	Mean	Standard Deviation
	Absolute TDS	3.67	21	12.15	4.51
	Ratio	0.36	1.69	0.91	0.32
Two					
	Absolute TDS	3.33	29.83	13.69	6.77
	Ratio	0.24	1.69	0.94	0.38

Two 2 (Workload: High vs Low) X 2 (Order: Block 1 vs Block 2) ANOVAs were run to investigate the effect of cognitive load on both the Time Difference Score and Time Estimation Ratios. Neither revealed a significant effect of cognitive load (TDS: $F(1, 57) = 14.21, p = .19$; Ratio: $F(1, 57) = .001, p = .98$). There was a significant interaction between workload and order for the Time Estimation ratios ($F(1, 57) = 4.74, p = 0.03$), however this effect is likely an artefact of the sample and does not reflect a significant cognitive finding. Table 5 displays the descriptive statistics from both tests.

Table 5. Descriptive statistics for ANOVA tests.

Time Difference Score		
Low Cognitive Load	Mean	Standard Deviation
Block 1	11.32	4.08
Block 2	12.94	6.62
High Cognitive Load		
Block 1	12.98	4.89
Block 2	13.90	7.14
Time Estimation Ratio		
Low Cognitive Load	Mean	Standard Deviation
Block 1	1.00	.31
Block 2	.83	.35
High Cognitive Load		
Block 1	.82	.32
Block 2	1.03	.38

Time Estimation Accuracy and Ratio Scores

In preparation for building the time estimation model, correlation matrices of all factors (video game experience questions, cognitive load, VR immersion, VR interactivity and VR presence) and the absolute Time Difference Score values were compiled into the following tables. Variables that are correlated with the dependent variables were considered as potential predictors. Due to the exploratory nature of this work, variables with a p -value $< .1$ were considered as

potentially relevant predictors of time estimation. Each item from Mutterlein's (2018) questionnaire will be examined separately. While Mutterlein validated each of the VR immersiveness factors, they were not investigated in the context of time perception, and as research into time perception in virtual reality is in its early stages, it was decided to observe which scale item contributes the most predictability to time estimation accuracy. Table 6 and 7 show a correlation matrix displaying all potential predictors for Block 1 and Block 2 (respectively). As shown, factors within each construct are highly correlated with each other.

Block 1. Table 6 displays correlations for the Time Difference Score and potential predictors for Block 1. There were significant correlations between predictors and Time Difference Scores. The most strongly correlated presence question was 'The content of the Oculus was somewhere I visited' ($r = -.61$). The Time Difference Score was only significantly correlated with one predictor from interactivity ('The Oculus allowed me to interact with the virtual world', $r = 0.42$).

Table 6. Correlation matrix for the Block 1 Time Difference Scores and potential predictors. Variable names are short forms for the questionnaire item they refer to. P indicates a presence question, FI indicates an immersion-fluency question, Ab indicates an immersion-absorption question, and In indicates an interactivity question.

	1	2	3	4	5	6	7	8	9	10	11
1 Time Difference Score	-										
2 Length playing video games	-.31	-									
3 Created new world (P)	-.52**	.29	-								
4 Returned to real world (P)	-.37*	.38*	.78**	-							
5 Forgot surroundings (P)	-.12	.13	.43*	.44*	-						
6 Somewhere I visited (P)	-.61**	.45*	.58**	.64**	.36*	-					
7 No difficulty concentrating (FI)	.04	.44*	.06	.12	-.05	.11	-				
8 Felt effortless (FI)	-.29	.49**	.47*	.43*	.30	.33	-.01	-			
9 Totally absorbed (Ab)	-.32	.41*	.66**	.77**	.57**	.53**	0.4	.67**	-		
10 Interact with world (In)	-.42*	.17	.74**	.81**	.39*	.42*	-.18	.36*	.65**	-	
11 Influence world (In)	-.29	.04	.47**	.57**	.18	.31	-.25	.18	.49**	.71**	-

Block 2. Following the correlations done for Block 1, relationships between the dependent variables (Time Difference Score and Ratios) and presence, immersion and interactivity predictors were examined for Block 2. Table 7 displays the correlations between the dependent variables and predictors. There was only one presence predictor significantly correlated with Time Difference Scores for Block 2: 'The content of the Oculus was somewhere I visited', $r = -.48$). Time Difference Scores were significantly correlated with only one immersion predictor ('I had no difficulty concentrating, $r = .29$). The strongest correlation between Time Difference Scores and an interactivity predictor was 'The Oculus allowed me to interact with the virtual world', $r = -.34$

Table 7. Correlation matrix for the Block 2 Time Difference Scores and potential predictors. Variable names are short forms for the questionnaire item they refer to. P indicates a presence question, FI indicates an immersion-fluency question, Ab indicates an immersion-absorption question, and In indicates an interactivity question.

	1	2	3	4	5	6	7	8	9	10	11
1 Time Difference Score	-										
2 Length playing video games	-.34*	-									
3 Created new world (P)	-.28	.31	-								
4 Returned to real world (P)	-.16	.32	.79**	-							
5 Forgot surroundings (P)	-.08	.08	.49**	.58**	-						
6 Somewhere I visited (P)	-.48**	.43*	.72**	.76**	.37*	-					
7 No difficulty concentrating (FI)	.29	-.06	.04	-.10	.06	-.10	-				
8 Felt effortless (FI)	.21	.26	.28	.31	.11	.15	.27	-			
9 Totally absorbed (Ab)	-.01	-.14	.43*	.45*	.30	.40*	-.25	.24	-		
10 Interact with world (In)	-.36*	.18	.70**	.71*	.57**	.56**	.03	.33	.26	-	
11 Influence world (In)	-.07	.01	.55**	.65**	.31	.39*	-.10	.32	.30	.73**	-

Time Estimation Model

Two regressions were planned to investigate the potential predictors of the model on time estimation accuracy to examine each workload condition. However, as displayed in the ANOVA, there was no effect of workload. The main focus of the current study is to investigate the effect that a virtual environment has on time perception, and as such, the two regressions will instead be completed for each block of the study. The VR immersiveness factors were recorded after each block, and this allows for comparison between the VR experience across time.

A linear regression analysis tested if any of the predictors from the proposed model significantly predicted the participant's accuracy for time estimations. An initial regression was done including all the predictors that were significantly correlated with the Time Difference score. However, this resulted in signs flipping and the r^2 value to decrease, both due to multicollinearity. Thus, only the strongest significant correlation from each construct (presence, immersion and interactivity) was included in each regression. If one factor had no scale items significantly correlated with the Time Difference Score, it was excluded from the regression. In the case of Block 1, no immersion variables were correlated with the Absolute Time Difference Score values, however, an interactivity variable was. This variable was included in place of an immersion variable. The predictors that are being included in the regression for each block can be seen in the following correlation tables.

Table 8. Correlation matrix for dependent variable (Absolute Time Difference Score) for Block 1 and predictors. Variables names are short forms for the questionnaire questions they refer to.

	1	2	3	4
1. Absolute Time Difference Score Block 1	-			
2. How long have you been playing video games?	-.34	-		
3. I had the feeling I could influence the virtual world	-.42*	.17	-	
4. The content was "somewhere I visited"	-.61**	.45*	.42*	-

*Significant at $p < 0.05$. **Significant at $p < 0.01$.

Table 9. Correlation matrix for dependent variable (Absolute Time Difference Score) for Block 2 and predictors. Variables names are short forms for the questionnaire questions they refer to.

	1	2	3	4
1. Absolute Time Difference Score Block 2	-			
2. How long have you been playing video games?	-.34*	-		
3. The content was "somewhere I visited"	-.48**	.43*	-	
4. I had no difficulty concentrating	.29 ⁺	-.06	-.10	-

*Significant at $p < 0.05$. **Significant at $p < 0.01$. ⁺ Significant at $p < 0.1$.

Block 1. As shown in model 1 of Table 10, the number of years that a participant had played video games had a small but positive effect on time estimation accuracy (adjusted $r^2 = .06$). As shown in models 2 and 3 of Table 10, the effect of how long participants had been playing videos games was partially subsumed by two VR factors: interactivity and presence. In model 3 of Table 10, the presence variable was the strongest predictor of accuracy, also subsuming the effect of interactivity. The final model with length of time playing video games, interactivity, and presence was significant, accounting for 34% of the variance in time estimation accuracy, $F(3,29) = 5.541$ $p = .004$, $r^2 = .340$ (adjusted).

Table 10. Contributions of model predictors for time estimation accuracy for Block 1. Variable names representing individual questions have been shortened. VG stands for Video Games.

Model 1	B	SE(B)	β	<i>t</i>	<i>p</i>
Length of Playing VG	-.728	.445	-.295	-1.636	.113
Model 2					
Length of Playing VG	-.592	.424	-.240	-1.396	.174
Interact With Virtual World	-1.903	-.893	-.367	-2.132	.042
Model 3					
Length of Playing VG	-.110	-.421	-.045	-.261	.796
Interact With Virtual World	-1.069	.861	-.206	-1.242	.225
Somewhere I Visited	-2.035	-.753	-.495	-2.702	.012

Block 2. As shown in Table 11, the number of years that a participant had played video games had a medium positive effect on time estimation accuracy (adjusted $r^2 = .08$). This effect was subsumed by the other VR factors (presence and immersion) included in models 2 and 3. Presence is negatively correlated with time estimation accuracy, such that the more presence participants felt, the more accurate their estimates were. In contrast to the effects of presence, the immersion - fluency variable had a positive beta value, suggesting that the easier it was for participants to concentrate, the worse time estimation accuracy they had. The final model of length of time playing video games, immersion and presence was

significant, accounting for 22% of the variance in time estimation accuracy, $F(3,29) = 3.79$ $p = .022$, $r^2 = .224$ (adjusted).

Table 11. Contributions of model predictors for time estimation accuracy for Block 2. Variable names representing individual questions have been shortened. VG stands for Video Games.

Model 1	B	SE(B)	β	t	p
Length of Playing VG	-1.232	.659	-.333	-1.869	.072
Model 2					
Length of Playing VG	-.647	.692	-.175	-.935	.358
Somewhere I Visited	-2.364	1.187	-.373	-1.993	-.057
Model 3					
Length of Playing VG	-.644	.668	-.174	-.964	.344
Somewhere I Visited	-1.997	1.165	-.315	-1.714	.098
No Difficulty Concentrating	1.530	.888	.288	1.723	.097

Post Hoc Model Building

A review of the distribution of time estimation scores of participants while in virtual reality (VR) suggested that there was a very broad range of time estimation responses, where some participants did quite well, and others showed poor estimation ability (providing time responses that were twice or three times the actual time duration). The wide range of time estimation reports suggests that among a group of undergraduate students there may be a range of basic time

estimation competency may also influence estimation in the VR environment. Using a novel categorical variable based on poor, medium, and good scores from the base test of time estimation in the real world, a post hoc analysis was conducted to investigate whether a general competency factor would improve the models of prediction of time estimation in VR. The basic competency factor was derived from time estimates collected from participants after completing the short surveys while not in VR at the end of each block. These scores from the real world provided a baseline of each participant's time basic time estimation abilities. This post hoc test determined if someone's ability to estimate time related to a simple task, in a non-virtual environment would predict time estimation collected during the VR flight tasks.

Participant's absolute Time Difference Score scores from each block in the real world were split into three groups, deemed poor, medium, and good time estimation groups. A one-way ANOVA illustrated that there was no effect of real world competency on VR time estimation accuracy (Block 1: $F(2, 29) = .14, p = .87$; Block 2: $F(2, 29) = .05, p = .95$), and therefore no additional regression tests were completed for either block. As shown in Figures 10 and 11, there was a slight tendency for the lowest real-world competency scores to have the most accurate time perception in the virtual environment. While the one-way ANOVA and corresponding post-hoc tests were not significant, this pattern deserves further investigation.

Figure 10. Bar graph of Real World Competency Scores for Block 1.

Figure 11. Bar graph of Real World Competency Scores for Block 2.

Final Model

The proposed model of time perception in a virtual environment was adjusted based on the analyses completed (Figure 12). Bolded lines represent significant predictors. Presence was a significant factor, showing that with increased presence in the virtual environment, participants made more accurate time estimates. Immersion was a significant predictor, however, it had a negative impact on time estimation accuracy, such that the more concentrated participants were on the task, the worse their estimation ability was. Interactivity was a significant predictor of time estimation accuracy in VR and was added to the model. Video game experience was also significant, as participants with a longer history of playing video games had more accurate time estimations.

Figure 12. Final model of virtual reality time estimation accuracy. Bold lines are significant predictors, a dashed bold line indicates a significant, but weak predictor. Plus signs represent a positive relationship between the predictor and the dependent variable, indicating greater accuracy as scores on that variable increase, whereas minus signs represent a negative relationship between the two, such that a higher score on the factor results in more errors in time estimation (less accuracy). N.S. means that the predictor was not significant in predicting time estimation accuracy.

*This relationship refers to immersion – fluency.

Discussion

The purpose of this study was to determine what factors, thought to influence time perception in the real world, may transfer into a virtual environment and affect perception. This research aimed to identify relevant factors for VR time perception, as well as investigate how those variables affect time perception in virtual environments.

The first hypothesis was that participants with more gaming experience would have poorer time perception overall compared to participants with less gaming experience. This was not confirmed in that there was a positive relationship between gaming experience and time perception, however it was not a strong effect. Participants who had been playing video games longer, had more accurate time estimates. Findings that video game experience impacts time estimation have been shown in the literature (Rau et al., 2006; Tobin et al., 2010), and so it is likely that a larger sample size would have produced more diversity in terms of video game players, which may have led to a larger effect of video game experience on time estimation accuracy.

Hypothesis two was that participants would have more accurate time estimates when undergoing the high cognitive load condition. This hypothesis was not confirmed, as there was no effect of cognitive load on time perceptions. It is possible that the difference in cognitive load between the two conditions was not large enough to produce an effect. While participants expressed that having to pay attention to the radio calls was very mentally demanding, their performance did not reflect this. The base flying task was cognitively challenging, but the addition of the

radio call memory task did not increase the cognitive load enough to affect their performance due to cognitive workload. While it was hypothesized that an effect of cognitive load would be found, a lack of cognitive load effects on time perception is not unprecedented. Furthermore, there is no clear consensus about the role that cognitive load plays in time perception judgments, as illustrated by recent work by Walker (2019). In the past, studies have shown some effect of cognitive load on time estimation (Block et al., 2010; Pan & Luo, 2011) but effects of cognitive load manipulations are not consistent. Walker (2019) examined the relationship between cognitive load (high vs low) and time duration (8 minutes vs 58 minutes). Among the time duration effects found, there was no effect of cognitive load on participant's estimation accuracy or response time (Walker, 2019).

Hypothesis three was that the higher the level of immersion and presence that participants felt, the more accurate they would be in their time estimations. The regression confirmed that when participants experienced greater presence, they made fewer errors in their estimates, and were therefore more accurate. Interactivity was also significant, with higher interactivity scores, participants had more accurate time estimations. Immersion, however, had a negative effect on time estimation accuracy. This could be due to the fact that immersion can be split into two categories of immersion: fluency and absorption. The immersion factor used in the linear regressions represents an immersion – fluency factor (Mutterlein, 2018). The concept of flow or fluency is often described as “a state of optimal experience where one is completely absorbed and immersed in an activity” (Nah et al., 2014, p. 85). This terminology is often used when referring to video gamers

or other creative activities and is subjectively experienced as being 'in the zone' and losing track of time. Marty-Dugas and Smilek (2018) reported that in order to enter a state of flow, one needs to be both fully engaged and attentive, without forcing their attention towards the task. The results found in the present study are consistent with findings about flow and time perception. When participants are deeply concentrated, they are likely to enter a state of flow, which results in time loss. The effect of time loss during states of flow has been well documented. A study by Im and Varma (2018) looked at the presence of flow and time loss during an attention demanding task. They found that participants experienced flow when the attentional demand was moderate. Additionally, while experiencing flow, their perception of time was distorted, such that time seemed to pass much quicker in this state. While no time estimates were required in the Im and Varma study, participants experienced time as passing more quickly, indicating that they had a distorted experience of the actual time duration due to being in a state of flow. Research done by Engeser and Rheinberg (2008) found that when participants were experiencing a state of flow, they performed better on a series of tasks, that had varying degrees of enjoyment (taking a statistics exam, playing Pac Man and voluntarily learning French). The results suggested that enjoyment could play a factor in whether or not people enter a state of flow. This factor should be taken into account for future research on virtual reality and time perception.

Other than the present work, little research has been done aiming to connect these VR immersiveness factors to time perception. Further examination of the connection between time estimation and VR immersiveness/fluency factors

may help to increase our understanding of how fluency in VR environments alters time perception. In particular, there appears to be a difference in the effects of fluency versus absorption on time estimation in virtual environments so these factors should be investigated separately in future studies.

Pacemaker Model Connections

In the pacemaker model working memory plays a role in the perception of time, but the present research did not find any effect of working memory on time estimation accuracy. It has been shown that cognitive load and working memory do not have a clear effect on time perception (Block et al., 2010; Walker, 2019), so this result is not entirely unprecedented. It is possible that if working memory and cognitive load impact time perception, it does not affect accuracy but instead affects a different facet of time perception that was not examined in this research.

Limitations

This study had some limitations that may have affected the final results. While an initial power analysis suggested 40 participants would be sufficient, due to errors in data collection and participant comprehension, the sample size was smaller than anticipated and likely reduced the chances of finding significant effects. Many predictors were examined, reducing the chance of confounding variables, therefore, low study power associated with the sample size, rather than issues with the study design, may have caused the non-significant medium effect sizes for cognitive load.

Implications

While it was hypothesized that cognitive load would have an impact on time perception, there was no significant effect. If the present research is correct, and cognitive load does not mediate time estimation accuracy, this has varied implications. Pilots are frequently managing many tasks at a time, resulting in a high cognitive load. Time perception is crucial to their activities during flight, and any training taking place in VR needs to sufficiently prepare them for flying in the real world. Doctors who are training to perform complex surgeries need to have an accurate perception of time, and they are often in situations where they deal with high cognitive loads. Further work needs to be done to understand what effect (if there is truly one) cognitive load has on time perception in order to ensure pilots and doctors have accurate time perception during VR training sessions. On the other hand, VR is beginning to be used to help patients through painful treatments. However, it is not always possible for patients to be highly cognitively engaged during their treatment, so having other factors that impact time perception is good. The results of this study show that high levels of VR immersiveness (in particular, presence) in the task/environment is more important than a high mentally demanding task. Focusing on creating more immersive environments will lead participants to have a less accurate perception of how much time is passing. Future work should focus on what factors lead participants to be less accurate and underestimate time durations. This type of work would be helpful for some studies specific to burn patients.

Researchers have investigated the use of VR technology to help burn victims cope with the pain of treatments (Silva, 2000). Burn wounds are among the most painful wounds to treat, and currently, they require large doses of opiates for patients to manage the pain. The goal of the researchers was to use VR as a way to reduce the use of opiates and their side effects during treatment. They found that when VR was used during treatment sessions, pain perception was reduced, and the researchers believe that is due to a limited amount of attention and stimuli that can be processed when engaged in VR, but more research would be required to prove this belief. If using VR distracted patients from the pain they were experiencing because of a lack of attentional resources, it is also likely that being engaged in VR could affect their perception of time.

Future Directions

In the research by Walker (2019), participants only gave time estimations for an 8-minute condition or a 58-minute condition. Due to the nature of the study, this information could not be released beforehand, so all participants who signed up were under the impression that the study lasted for 90 minutes. Once they arrived, they were told that the system would run the experiment for at least 2 minutes, but it could last for up to 90 minutes. Providing participants with the range of time for the experiment that would not interfere with the actual time estimates gave them boundaries for their estimations. Implementing a system like this in the current work may have prevented some participants from estimating that double or triple the actual time had passed, which lead to their data being capped or removed altogether.

As Tobin et al. (2010) point out, ecological validity is a problem many academic studies have. While the present research did reproduce a real-life scenario (flying a general aviation plane), the target population of pilots is just one occupation that could benefit from well-informed VR research. Future research regarding time estimation in VR may include designs and populations that correspond to the other occupational scenarios and eventually, daily life.

Switching the focus from cognitive load to variables such as engagement, immersion and enjoyment could give insight to what factors influence time perception, especially in more ecologically valid set-ups. These factors have been shown to impact time perception, particularly in the gaming industry as shown by Rau et al. (2006) and Sanders and Cairn (2010). Work should be done focusing on this relationship between real world competency and their time estimation accuracy in a virtual environment to confirm whether the pattern from the current study, where a higher baseline time estimation accuracy skill is related to lower time estimation accuracy in virtual environments, is accurate.

Although the present study took many factors into account, there is a large variety of factors that could influence time perception and accuracy. One study examined the role regular meditation plays in time perception and found that participants who meditated regularly had better focus, and therefore more accurate time perception than those who didn't meditate regularly (Maclean et al., 2010). Another study demonstrated that while people often feel like they don't have enough time in the day, volunteering their time can actually increase the subjective amount of time that they believe they had each day (Mogilner, Chance & Norton,

2012). Like the majority of predictors in the current study, these factors have not been investigated in a virtual environment, and future studies should take them into consideration.

The present study examined the effects of video game experience cognitive load and VR immersiveness factors on time estimation accuracy within a virtual environment. Cognitive load did not have an impact on estimation accuracy, but aspects of video game experience and VR immersiveness were significant predictors of estimation accuracy. Regarding video game experience, the level of experience was a significant factor in the model, such that participants with more experience made more accurate estimates. This result suggests that as people spend more and more time in virtual environments, for example, over months or years of training, their time estimation abilities should not be negatively impacted. Three VR Immersiveness factors were included in the model: presence, immersion and interactivity. Presence and interactivity had positive relationships with estimation accuracy. The more presence and interactivity felt by users, the more accurate their time estimates were. The opposite was found for the fluency aspect of immersion, where the easier participants found it to concentrate, the worse their time estimates. These findings can be applied across various fields to help produce the desired experience. For example, video game developers may want to focus on inducing immersion - fluency, to keep people in the game for longer. Virtual reality programs being developed for training may choose to limit immersion - fluency, and instead increase the amounts of presence and interactivity, to provide a more realistic experience and promote more accurate time perception. Prior to

the present research, very little was known about the impact that being in a virtual environment had on time perception. This thesis examined factors relevant to time perception and virtual reality in order to uncover how time estimation may change in virtual environments. Video game experience, presence, interactivity, and immersion - fluency were all found to influence time estimation accuracy. While more research should be conducted to validate these results, these findings can be used to influence development decisions for future virtual reality content.

References

- About Robotic-Assisted Surgery. (n.d.). Retrieved from <https://my.clevelandclinic.org/health/treatments/16908-about-robotic-assisted-surgery>
- Allan, L. G. (2001). Comments on current ratio-setting models for time perception. *International Encyclopedia of the Social and Behavioural Sciences*, 24, 15696-15699. doi:10.3758/bf03199742
- Allen, D. (2019, August 07). Osso VR Expands Its Reach, Shares Study Results. Retrieved from <https://www.mddionline.com/osso-vr-expands-its-reach-shares-study-results>
- Block, & Gruber. (2014). Time perception, attention, and memory: A selective review. *Acta Psychologica*, 149, 129-133. Retrieved September 9, 2018.
- Block, F., & Gellersen, H. (2010). The impact of cognitive load on the perception of time. *Proceedings of the 6th Nordic Conference on Human-Computer Interaction Extending Boundaries - NordiCHI 10*. doi:10.1145/1868914.1868985
- Block, R. A., Zakay, D., & Hancock, P. A. (1999). Developmental Changes in Human Duration Judgments: A Meta-Analytic Review. *Developmental Review*, 19(1), 183-211. doi:10.1006/drev.1998.0475
- Block, R. A., Hancock, P., & Zakay, D. (2016). Physical load affects duration judgments: A meta-analytic review. *Acta Psychologica*, 165, 43-47. doi:10.1016/j.actpsy.2016.01.002
- Chance, Z., Mogilner, C., & Norton, M. I. (2011). Giving time gives you time.

PsycEXTRA Dataset. doi:10.1037/e620972012-070

Coslett, H., Chatterjee, A., & Aguirre, G. (2010). Carving the Clock at Its Component Joints: Neural Bases for Interval Timing. *Journal of Neurophysiology*, 104, 160-168. Retrieved July 15, 2019.

Devicic, I. I. (2017, June 1). How to Fix Your Broken Perception of Time. Retrieved July 12, 2019, from <https://zapier.com/blog/fix-time-perception/>

Eagleman, D. M. (2008). Human time perception and its illusions. *Current Opinion in Neurobiology*, 18(2), 131-136. doi:10.1016/j.conb.2008.06.002

Edwards, A. M., & McCormick, A. (2018). Time Perception, Pacing And Exercise. *Medicine & Science in Sports & Exercise*, 50, 176. doi:10.1249/01.mss.0000535664.16353.00

Engeser, S., & Rheinberg, F. (2008). Flow, performance and moderators of challenge-skill balance. *Motivation and Emotion*, 32(3), 158-172. doi:10.1007/s11031-008-9102-4

Engeser, S., & Rheinberg, F. (2008). Flow, performance and moderators of challenge-skill balance. *Motivation and Emotion*, 32(3), 158–172. doi: 10.1007/s11031-008-9102-4

Failing, M., & Theeuwes, J. (2015). Reward Alters Perception of Time. *Journal of Vision*, 15(12), 449. doi:10.1167/15.12.449

French, R. M., Addyman, C., Mareschal, D., & Thomas, E. (2014). Unifying Prospective and Retrospective Interval-time Estimation: A Fading-gaussian Activation-based Model of Interval-timing. *Procedia - Social and Behavioral Sciences*, 126, 141-150. doi:10.1016/j.sbspro.2014.02.348

- Gergel, T. L. (2013). Illness perception, time perception and phenomenology - an extended response to Borrett. *Journal of Evaluation in Clinical Practice*, 19(3), 501-508. doi:10.1111/jep.12047
- Glicksohn, J. (1996). Entering Trait And Context Into A Cognitive-Timer Model For Time Estimation. *Journal of Environmental Psychology*, 16(4), 361-370. doi:10.1006/jevp.1996.0030
- Glicksohn, J. (2001). Temporal Cognition and the Phenomenology of Time: A Multiplicative Function for Apparent Duration. *Consciousness and Cognition*, 10(1), 1-25. doi:10.1006/ccog.2000.0468
- Grondin, S., & Laflamme, V. (2015). Stevens's law for time: A direct comparison of prospective and retrospective judgments. *Attention, Perception, & Psychophysics*, 77(4), 1044-1051. doi:10.3758/s13414-015-0914-5
- Hancock, & Block. (2016). A New Law for Time Perception. *The American Journal of Psychology*, 129(2), 111. doi:10.5406/amerjpsyc.129.2.0111
- Im, S., & Varma, S. (2018). Distorted Time Perception during Flow as Revealed by an Attention-Demanding Cognitive Task. *Creativity Research Journal*, 30(3), 295-304. doi:10.1080/10400419.2018.1488346
- Ivry, R. B., & Schlerf, J. E. (2008). Dedicated and intrinsic models of time perception. *Trends in Cognitive Sciences*, 12(7), 273-280. doi:10.1016/j.tics.2008.04.002
- Jones, T., Moore, T., & Choo, J. (2016). The Impact of Virtual Reality on Chronic Pain. *Plos One*, 11(12). doi:10.1371/journal.pone.0167523
- Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993).

- Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *The International Journal of Aviation Psychology*, 3(3), 203-220. doi:10.1207/s15327108ijap0303_3
- Klapproth, F. (2007). Time Perception, Estimation Paradigm, and Temporal Relevance. *Perceptual and Motor Skills*, 104(3), 749-757. doi:10.2466/pms.104.3.749-757
- Knodler, M., Keklikoglou, A., Samuel, S., & Fitzpatrick, C. (2017). Examining Distracted Drivers' Underestimation of Time and Overestimation of Speed. Retrieved February 28, 2019.
- Lang, B. (2019, August 08). UCLA Surgical Training Study Shows VR Beats Traditional Training by 130%. Retrieved from <https://www.roadtovr.com/ucla-vr-surgical-training-study-osso-vr/?platform=hootsuite>
- Lontz, K., Doherty, S. M., & Liu, D. (2015). Time perception during retrospective and prospective paradigms with a distraction. *Proceedings of the Human Factors and Ergonomics Society 59th Annual Meeting*. Retrieved October 2, 2018.
- Lozano, R. P., Slater, M., & Maldonado, J. G. (2016). *<i>Its About Time: The Illusions of Time Perception and Travel in Immersive Virtual Reality</i>* (Unpublished master's thesis). Tesi doctoral - Universitat de Barcelona. Departament de Personalitat, Avaluació i Tractament Psicològic.
- Maclean, K. A., Ferrer, E., Aichele, S. R., Bridwell, D. A., Zanesco, A. P., Jacobs, T. L., . . . Saron, C. D. (2010). Intensive Meditation Training Improves

- Perceptual Discrimination and Sustained Attention. *Psychological Science*, 21(6), 829-839. doi:10.1177/0956797610371339
- Maniadakis, M., & Trahanias, P. (2014). Time models and cognitive processes: A review. *Frontiers in Neurorobotics*, 8. doi:10.3389/fnbot.2014.00007
- Marty-Dugas, J., & Smilek, D. (2018). Deep, effortless concentration: Re-examining the flow concept and exploring relations with inattention, absorption, and personality. *Psychological Research*. doi:10.1007/s00426-018-1031-6
- Matthews, W. J., & Meck, W. H. (2014). Time perception: The bad news and the good. *Wiley Interdisciplinary Reviews: Cognitive Science*, 5(4), 429-446. doi:10.1002/wcs.1298
- Matthews, W., & Gheorghiu, A. (2016). Repetition, expectation, and the perception of time. *Current Opinion in Behavioural Sciences*, 8, 110-116. Retrieved April 19, 2019.
- Monteiro, D., Liang, H., Xu, W., Brucker, M., Nanjappan, V., & Yue, Y. (2018). Evaluating enjoyment, presence, and emulator sickness in VR games based on first- and third- person viewing perspectives. *Computer Animation and Virtual Worlds*, 29(3-4). doi:10.1002/cav.1830
- Mütterlein, J. (2018). The Three Pillars of Virtual Reality? Investigating the Roles of immersion, presence, and interactivity. *Proceedings of the 51st Hawaii International Conference on System Sciences*. doi:10.24251/hicss.2018.174
- Nah, F. F., Eschenbrenner, B., Zeng, Q., Telaprolu, V. R., & Sepehr, S. (2014,

- January). Flow in gaming: Literature synthesis and framework development. *International Journal of Information Systems and Management*, 1(1/2), 83-124. doi:10.1504/ijisam.2014.062288
- Navarro-Haro, Modrego-Alarcón, Hoffman, López-Montoyo, Navarro-Gil, Montero-Marin, . . . García-Campayo. (2019). Evaluation of a mindfulness-based intervention with and without virtual Reality Dialectical Behavior Therapy® Mindfulness Skills Training for the Treatment of Generalized Anxiety Disorder in Primary Care: A Pilot Study. *Frontiers in Psychology: Psychology for Clinical Settings*. Retrieved July 05, 2019.
- Pan, & Luo. (2012). Working memory modulates the perception of time. *Psychon*, 19, 46-51. Retrieved April 16, 2019.
- Panjwani, L. (2017, August 31). Virtual “SnowWorld” Helps Burn Victims Cope with Extreme Pain. Retrieved May 16, 2019, from <https://www.rdmag.com/article/2017/08/virtual-snowworld-helps-burn-victims-cope-extreme-pain>
- Rau, P. P., Peng, S., & Yang, C. (2006). Time Distortion for Expert and Novice Online Game Players. *CyberPsychology & Behavior*, 9(4), 396-403. doi:10.1089/cpb.2006.9.396
- Rose, T., Nam, C., & Chen, K. (2018). immersion of virtual reality for rehabilitation - Review. *Applied Ergonomics*, 69, 153-161. Retrieved May 16, 2019.
- Roseboom, W., Fountas, Z., Nikiforou, K., Bhowmik, D., Shanahan, M., & Seth, A. K. (2017). Time without clocks: Human time perception based on

perceptual classification. *BioRxiv*. doi:10.1101/172387

Sanders, T., & Cairns, P. (2010). Time perception, immersion and music in videogames. Retrieved April 02, 2019.

Schatzschneider, C., Bruder, G., & Steinicke, F. (2016). Who turned the clock? Effects of Manipulated Zeitgebers, Cognitive Load and immersion on Time Estimation. *IEEE Transactions on Visualization and Computer Graphics*, 22(4), 1387-1395. doi:10.1109/tvcg.2016.2518137

Schneider, S. M., Kisby, C. K., & Flint, E. P. (2010). Effect of virtual reality on time perception in patients receiving chemotherapy. *Supportive Care in Cancer*, 19(4), 555-564. doi:10.1007/s00520-010-0852-7

Silva, D. (2000, March 20). Hypnosis, virtual reality help burn victims. Retrieved May 16, 2019, from <https://www.bizjournals.com/cincinnati/stories/2000/03/20/focus3.html>

So, P., & Gore, B. (2018, April 27). NASA TLX Task Load Index. Retrieved from <https://humansystems.arc.nasa.gov/groups/TLX/>

Soares, S., Atallah, B. V., & Paton, J. J. (2016). Midbrain dopamine neurons control judgment of time. *Science*, 354(6317), 1273-1277. doi:10.1126/science.aah5234

Thönes, S., Arnau, S., & Wascher, E. (2018). Cognitions about time affect perception, behavior, and physiology – A review on effects of external clock-speed manipulations. *Consciousness and Cognition*, 63, 99-109. doi:10.1016/j.concog.2018.06.014

Thönes, S., Arnau, S., & Wascher, E. (2018). Cognitions about time affect

- perception, behavior, and physiology – A review on effects of external clock-speed manipulations. *Consciousness and Cognition*, 63, 99-109. doi:10.1016/j.concog.2018.06.014
- Tobin, S., Bisson, N., & Grondin, S. (2010). An Ecological Approach to Prospective and Retrospective Timing of Long Durations: A Study Involving Gamers. *PLoS ONE*, 5(2). doi:10.1371/journal.pone.0009271
- Van den Berg, D., Van der Ham, C., & Van der Kuil, M. (2017). *Time perception in virtual reality* (Unpublished master's thesis). Leiden University.
- Veen, H. A., Distler, H. K., Braun, S. J., & Bühlhoff, H. H. (1998). Navigating through a virtual city: Using virtual reality technology to study human action and perception. *Future Generation Computer Systems*, 14(3-4), 231-242. doi:10.1016/s0167-739x(98)00027-2
- Wittmann, M., & Paulus, M. P. (2008). Decision making, impulsivity and time perception. *Trends in Cognitive Sciences*, 12(1), 7-12. doi:10.1016/j.tics.2007.10.004
- Wood, R. T., Griffiths, M. D., & Parke, A. (2007). Experiences of Time Loss among Videogame Players: An Empirical Study. *CyberPsychology & Behavior*, 10(1), 38-44. doi:10.1089/cpb.2006.9994
- Zakay, D. (2012, August). Experiencing time in daily life. Retrieved July 12, 2019, from <https://thepsychologist.bps.org.uk/volume-25/edition-8/experiencing-time-daily-life>
- Zakay, D. (2014). Psychological time as information: The case for boredom. *Frontiers in Psychology: Psychology for Clinical Settings*. Retrieved April

05, 2019.

Özgör, C., Özgör, S. Ş, Duru, A. D., & Işoğlu-Alkaç, Ü. (2018). How visual stimulus effects the time perception? The evidence from time perception of emotional videos. *Cognitive Neurodynamics*, 12(4), 357-363.
doi:10.1007/s11571-018-9480-6

Appendix A – Power Analysis

Appendix B – Questionnaire Items

Construct

Video Game Experience (all questions scored from 0-5)

What is your video game experience?

How long have you been playing video games?

How often do you play video games?

How good do you feel you are at playing video games?

Virtual Reality Experience (all questions scored from 0-5)

What is your virtual reality experience?

How long have you been using virtual reality?

How often do you use virtual reality?

How good do you feel you are at using virtual reality?

Simulator Sickness (all questions scored on a 5 point Likert scale)

How queasy are you feeling right now?

How dizzy are you feeling right now?

How disoriented are you feeling right now?

VR Immersiveness (all questions scored on a 5 point Likert scale)

Presence

The Oculus created a new world for me, and this new world suddenly disappeared when the exercise ended.

When I removed the Oculus, I felt as if I returned to the “real world” after a journey.

I forgot about my immediate surroundings when I was using the Oculus.

The content of the Oculus seemed to be “somewhere I visited” rather than “something I saw”.

Interactivity

The Oculus content allowed me to interact with the virtual world.

I had the feeling I could influence the virtual world of the Oculus.

Immersion

I had no difficulty concentrating.

My thoughts and movements felt effortless.

I was totally absorbed in what I was doing.

Workload (all questions scored on a 7 point Likert scale)

How mentally demanding was the task?

How physically demanding was the task?

How successful were you in accomplishing what you were asked to do?

How hard did you have to work to accomplish your level of performance?

How insecure, discouraged, irritated, stressed, and annoyed were you?

Attention (all questions scored on a 7 point Likert scale)

How frequently did you find yourself distracted?

How frequently did you find your mind wandering elsewhere?

Appendix C – Ethics Approval

Office of Research Ethics
5110 Human Computer Interaction Bldg | 1125 Colonel By Drive
| Ottawa, Ontario K1S 5B6
613-520-2600 Ext: 4085
ethics@carleton.ca

CERTIFICATION OF INSTITUTIONAL ETHICS CLEARANCE

The Carleton University Research Ethics Board-B (CUREB-B) has granted ethics clearance for the research project described below and research may now proceed. CUREB-B is constituted and operates in compliance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS2).

Ethics Protocol Clearance ID: Project # 109649

Research Team: Dr. Kathleen Van Benthem (Primary Investigator)

Donna Monbourquette (Co-Investigator)

Dr. Chris Herdman (Research Supervisor)

Project Title: Time perception and cognitive load in virtual reality [Donna Monbourquette]

Funding Source (If applicable):

Effective: **October 31, 2018**

Expires: **October 31, 2019.**

Please ensure the study clearance number is prominently placed in all recruitment and consent materials: CUREB-B Clearance # 109649.

Restrictions:

This certification is subject to the following conditions:

1. Clearance is granted only for the research and purposes described in the application.
2. Any modification to the approved research must be submitted to CUREB-B via a Change to Protocol Form. All changes must be cleared prior to the continuance of the research.
3. An Annual Status Report for the renewal of ethics clearance must be submitted and cleared by the renewal date listed above. Failure to submit the Annual Status Report will result in the closure of the file. If funding is associated, funds will be frozen.
4. A closure request must be sent to CUREB-B when the research is complete or terminated.

5. During the course of the study, if you encounter an adverse event, material incidental finding, protocol deviation or other unanticipated problem, you must complete and submit a Report of Adverse Events and Unanticipated Problems Form, found here: <https://carleton.ca/researchethics/forms-and-templates/>

Failure to conduct the research in accordance with the principles of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans 2nd edition* and the *Carleton University Policies and Procedures for the Ethical Conduct of Research* may result in the suspension or termination of the research project.

Upon reasonable request, it is the policy of CUREB, for cleared protocols, to release the name of the PI, the title of the project, and the date of clearance and any renewal(s).

Please contact the Research Compliance Coordinators, at ethics@carleton.ca, if you have any questions.

CLEARED BY:

Date: October 31, 2018

Bernadette Campbell, PhD, Chair, CUREB-B

Natasha Artemeva, PhD, Vice-Chair, CUREB-B

Appendix D – Correlations between ratio and demographic variables

Correlation matrix displaying demographic questions and VR dependent variables for both blocks using Time Estimation Ratio as the dependent variable. VG stands for Video Games.

	1	2
1. Ratio Block 1	-	
2. Ratio Block 2	.80**	-
3. Gender	-.01	-.05
4. Cognitive Load	.29	.28
5. What is your video game experience?	-.05	-.11
6. How long have you been playing video games?	-.15	-.10
7. How often do you play video games?	-.07	-.08
8. How good do you feel you are at video games?	-.09	-.20

*Significant at $p < 0.05$. **Significant at $p < 0.01$.