UNIVERSITAT DE BARCELONA

It’s About Time: The Illusions of Time Perception and Travel in Immersive Virtual Reality

Rodrigo Pizarro Lozano

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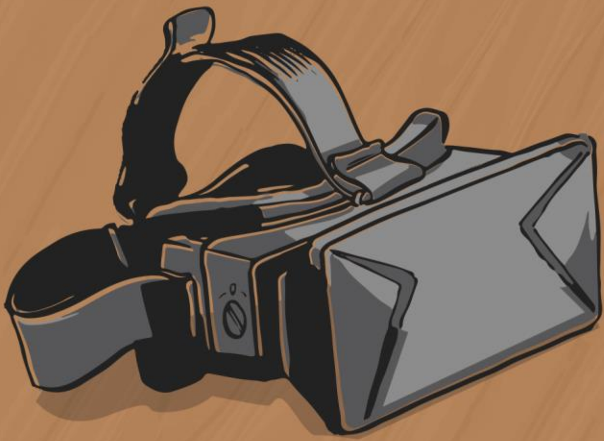

Abstract

What would it be like if we could manipulate time?

Rodrigo Pizarro Lozano

rodrigo.pizarro@ub.edu

IT'S ABOUT TIME: THE ILLUSIONS OF TIME PERCEPTION AND TRAVEL IN IMMERSIVE VIRTUAL REALITY

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Rodrigo Pizarro Lozano

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Director:

Prof. Mel Slater

EVENT Lab: Experimental Virtual Environments Laboratory for Neuroscience and Technology, Universitat de Barcelona

Tutor:

Prof. José Gutiérrez Maldonado

Department of Personality, Assessment and Psychological Treatments, Universitat de Barcelona

"*Time is an illusion*"

Albert Einstein

"I don't understand people who say they need more "Me Time." What other time is there? Do these people spend part of their day in someone else's body?"

Jarod Kintz

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CONTENTS

LIST OF PUBLICATIONS

This document contains the description of several studies performed during the course of this thesis. Some of this work has already been published in scientific journals, and other experiments are currently in submission process. In this Section we provide a list of publications and work in progress.

CHAPTER 4

Spanlang, B., Navarro, X., Normand, J.-M., Kishore, S., Pizarro, R., & Slater, M. (2013). Real time whole body motion mapping for avatars and robots. In *Proceedings of the 19th ACM Symposium on Virtual Reality Software and Technology* (p. 175). New York, New York, USA: ACM Press. http://doi.org/10.1145/2503713.2503747

CHAPTER 5

Pizarro, R., Kilteni K., Seinfeld S, Slater M, Sanchez-Vives MV. Time estimation in an immersive virtual reality scenario: impact of musical tempo and heart rate. (In submission).

CHAPTER 6

Pizarro, R., Slater M. How does embodiment change your temporal perception? (In submission)

CHAPTER 7

Friedman, D., Pizarro, R., Or-Berkers, K., Neyret, S., Pan, X., & Slater, M. (2014). A method for generating an illusion of backwards time travel using immersive virtual reality - an exploratory study. *Frontiers in Psychology*, *5*(943). http://doi.org/10.3389/fpsyg.2014.00943

Pizarro, R., Berkers, K., Slater, M., & Friedman, D. (2015). How to Time Travel in Highly Immersive Virtual Reality. In M. Imura, P. Figueroa, & B. Mohler (Eds.), *ICAT-EGVE 2015 - International Conference on Artificial Reality and Telexistence and Eurographics Symposium on Virtual Environments* (Vol. 0, pp. 1–8). The Eurographics Association. http://doi.org/10.2312/egve.20151318

Osimo, S. A., Pizarro, R., Spanlang, B., & Slater, M. (2015). Conversations between self and self as Sigmund Freud—A virtual body ownership paradigm for self counselling. *Scientific Reports*, *5*(July), 1–15. http://doi.org/10.1038/srep13899

Other publications

Galayko D., Pizarro R., Basset P., Paracha AM. (2007). AMS modeling of controlled switch for design optimization of capacitive vibration energy harvester. *Behavioral Modeling and Simulation Workshop*, 2007. BMAS 2007. IEEE International, 115-120.

Gonzalez-Franco M., Cermeron J., Li K., Pizarro R., Thorn J., Hannah P., Hutabarat W., Tiwari A., Bermell-Garcia P. Immersive Augmented Reality Training for Complex Manufacturing Scenarios. *arXiv*, 2016.

Poster presentations

Pizarro R., Hall M., Bermell-Garcia P., Gonzalez-Franco M. (2015). Augmenting Remote Presence For Interactive Dashboard Collaborations. *Proceedings of the 2015 International Conference on Interactive Tabletops*, 235-240.

ABSTRACT

Changing the passage of time is a concept that has captured the imagination of many philosophers and writers throughout history, but we have no evidence of anyone being capable of altering it at a macroscopic level. But what if it were possible? This question formed the basis of our research, and in this thesis we describe a series of experiments carried out to address this.

In this thesis we report three main experiments. The first considered whether the perception of elapsed time can be influenced by the tempo of music. We placed participants in an immersive virtual reality environment where they heard in the background two versions of a musical piece, varying only in tempo, for 7.5 minutes in two separate sessions. Volunteers retrospectively estimated the length of each session. The results show that participants' estimates were not correlated with background music tempo.

In the second experiment we considered whether previous findings that body size and age influence the perception of space might also influence the perception of time. In this experiment we immersed participants in a virtual reality scenario in which they performed a task for 200 seconds while embodied in one of three avatars that depicted three different age groups. Volunteers underwent two trials where the only change was the avatar they embodied, and compared the length of the sessions. The results suggested that time perception was not affected by body shape, but the task performance was.

In the third experiment we addressed the notion of time travel itself, and considered whether virtual reality can be used to give people the illusion of having travelled back through time. We immersed participants in virtual reality where they experienced a series of events that unknowingly led to a violent incident. Immediately after they were either transported in time to the beginning of the developments or they simply restarted the session, depending on the condition. We found that participants felt as if they had travelled back in time whenever subjective levels of other three illusions were high. We also describe an application of the technology that was developed for the time travel to a psychological counselling situation, where people could maintain a conversation with an embodied version of themselves.

We set the background of this thesis in reviewing the major themes of virtual reality research, including the concepts of presence and its constituent elements of 'place illusion' and 'plausibility' – the sense of being in the place depicted by the virtual environment, and the illusion that events are real. Of particular importance in our work is the concept of 'body

ownership' – the feeling that a co-located virtual body seen from first person perspective is the participant's real body, and we present a critical review of the relevant literature showing how this thesis relates to past work and is a further contribution.

Finally, in order to carry out the scientific work reported in this thesis we have made technical advances in virtual reality, including the development of a software platform that integrates compatibility for several different devices.

The conclusion of the thesis is that more research is necessary in the field of time perception and time travel in immersive virtual reality. We have seen that body shape can affect cognitive task performance, and further studies should expand the knowledge by analysing more variables. Additionally, a novel kind of illusion is presented in this thesis. Its potential and limits should be explored in future experiments, possibly with completely different applications. Indeed, the technology involved was applied in a study, reported in this thesis, concerned with personal counselling.

Overall, this thesis contains several different angles on the illusions of time perception and time travel. We present a thorough review of the literature involving the perception of time and the illusions of presence, body ownership and agency, as well as the technical background. Furthermore, the description of three studies that take a novel approach to time perception and time travel is included. Finally, we discuss our results and outline a future work direction.

Resumen

Alterar el paso del tiempo es un concepto que ha capturado la imaginación de muchos filósofos y escritores a través de la historia, pero no tenemos ninguna evidencia de nadie que haya sido capaz de alterar el tiempo a nivel macroscópico. Pero, ¿y si fuese posible? Esta pregunta forma la base de nuestra investigación, y en esta tesis describimos una serie de experimentos llevados a cabo para evaluarla.

En esta tesis reportamos tres experimentos principales. En el primero examinamos si la percepción del tiempo puede ser influenciada por la música de fondo. Pusimos a participantes en un entorno virtual inmersivo donde oyeron dos versiones de una misma pieza musical de fondo, con la única variación del tempo, durante 7,5 minutos en dos sesiones distintas. Los voluntarios estimaron retrospectivamente la duración de cada sesión. Los resultados indican que las estimaciones no estaban correlacionadas con el tempo de la música.

En el segundo experimento analizamos si los resultados de estudios anteriores, que encontraron que la edad y la forma corporal afectan a la percepción espacial, se pueden aplicar también en la percepción del tiempo. En este experimento pusimos a voluntarios en un escenario de realidad virtual en donde realizaron una tarea durante 200 segundos, mientras su cuerpo era substituido en realidad virtual por avatares que representaban a tres grupos distintos de edad. Los participantes experimentaron dos sesiones donde el único cambio era el avatar, y compararon la duración de las sesiones. Los resultados sugieren que la percepción del tiempo no fue alterada por la forma del cuerpo, pero el rendimiento sí.

En el tercer experimento evaluamos la noción de viajar en el tiempo propiamente, y examinamos si la realidad virtual puede ser usada para dar la ilusión de viajar atrás en el tiempo. Pusimos a varios participantes en un escenario virtual donde experimentaron una serie de eventos que, sin saberlo, llevaban a un incidente violento. Inmediatamente después eran transportados en el tiempo hasta el inicio de los eventos, o simplemente se reiniciaba la sesión, dependiendo de la condición. Encontramos que los voluntarios tuvieron la ilusión de haber viajado atrás en el tiempo siempre y cuando los niveles subjetivos de otras tres ilusiones fueran altos. También describimos una aplicación de la tecnología que fue desarrollada para el viaje virtual en el tiempo para una situación de asesoramiento psicológico, donde la gente podía mantener una conversación con una versión virtual de su cuerpo.

Establecemos los conocimientos previos de esta tesis revisando los temas más importantes en la investigación de realidad virtual, incluyendo conceptos como el de presencia y sus elementos básicos 'ilusión de lugar' y 'plausibilidad' – el sentimiento de estar en el sitio representado por el entorno virtual, y la ilusión de que los eventos que ocurren son reales. Es de particular importancia el concepto de 'propiedad del cuerpo' – la sensación de que un cuerpo virtual en la misma posición que el real y visto desde la perspectiva de primera persona es el cuerpo real del participante, y presentamos una revisión crítica de la literatura relevante, mostrando cómo esta tesis se relaciona con el trabajo anterior y cuales con las contribuciones.

Finalmente, para llevar a cabo el trabajo científico descrito en esta tesis, hemos implementado adelantos y desarrollos técnicos para la realidad virtual, que incluyen una plataforma de software que integra compatibilidad para diversos dispositivos.

La conclusión de esta tesis es que más investigación es necesaria en el dominio de la percepción del tiempo y en el de los viajes virtuales en el tiempo. Hemos visto que la forma del cuerpo puede afectar el rendimiento en una tarea, pero estudios futuros deberían expandir el conocimiento analizando más variables. Además, se presenta en esta tesis una nueva ilusión. Sus límites y su potencial deberían ser explorados en experimentos futuros, posiblemente en aplicaciones completamente distintas. En efecto, la tecnología empleada fue utilizada en un estudio, descrito en esta tesis, que concierne el asesoramiento personal.

En general, esta tesis contiene distintos ángulos en las ilusiones de percepción del tiempo y de viaje en el tiempo. Presentamos una revisión exhaustiva de la literatura que concierne la percepción del tiempo y las ilusiones de presencia, propiedad del cuerpo y agencia, así como el conocimiento técnico. Además, se incluyen las descripciones de tres estudios que toman un enfoque novedoso a la percepción del tiempo y a los viajes en el tiempo. Finalmente, se discuten los resultados y se perfila una dirección para el trabajo futuro.

1 INTRODUCTION

Manipulating time has been the inspiration behind numerous science fiction stories, since it is an unexperienced phenomenon in physical reality whose consequences are unknown. In particular, time travel to the past raises scientific and philosophical questions, as it can imply running into paradoxes. The Grandfather paradox is one of the examples of contradiction, where someone would travel to the past and kill an ancestor, which would prevent that person being born in order to travel back in time in the first place; see (Deutsch, 2011) for extensive discussion. However, to our knowledge, time travel is not possible at a human scale. A study (Nemiroff & Wilson, 2013) aimed at finding time travellers living in the present time by searching in social networks for evidence of knowledge of relevant events before they had happened, but could not find any. A major shortcoming of the paper, on the other hand, is in the very nature of their research, since publishing such a study would have alerted the possible future time travellers to avoid interaction through social networks prior to the study if they did not want to be discovered.

Regardless of whether time travel is physically possible or not, we attempted in this thesis to answer the question – what if it were possible? We aimed at exploring the experience by simulating it. Since current technology does not support physical time travel, we explored Immersive Virtual Reality (IVR) as an alternative. IVR has been a widely used tool for behavioural psychology. Many studies (Rovira & Swapp, 2009; Slater, 2009) showed that people immersed in IVR tend to react in the same way as they would in an equivalent real situation. Therefore, since we could expect realistic responses from participants, and given that a travel through time is currently feasible to simulate in IVR, we decided to use this as the main tool for the purpose of this thesis.

Some researchers have also used immersive technologies to explore new approaches to traditional problems. For example, in (Pan & Slater, 2011) the authors compared this technology to the traditional questionnaires for moral dilemmas. In that study, participants were either immersed in a virtual reality scenario through a CAVE system (Cruz-Neira & Sandin, 1992) or experienced that same scenario in a traditional desktop screen. They were put in a similar situation as the classic trolley scenarios (Hauser, Cushman, Young, Kang-Xing Jin, & Mikhail, 2007), interacting with a joystick and some buttons.

Further research areas like treatments for Post-Traumatic Stress Disorder (PTSD) or phobias have also explored the use of IVR equipment. For example, Virtual Reality Exposure Therapy (VRET) is a specific type of exposure therapy that uses immersive technologies, and has already shown promising results (Meyerbröker & Emmelkamp, 2010; B O

Rothbaum, Hodges, Ready, Graap, & Alarcon, 2001). Also, fields such as time perception have been explored through IVR. Popular expressions such as "Time flies when you are having fun" convey the concept that humans' perception of time is malleable and is affected by the context and other stimuli, but the exact factors and its influence is still a research subject. Indeed, numerous studies (Block, Hancock, & Zakay, 2010; Droit-Volet & Meck, 2007) have shown correlations with a large array of different ambient factors such as background music, cognitive load, and physiological state, among many others. Given the amount of variables influence part in time perception, we limited the scope to observe the effect of just one of them, background music tempo. Previous experiments reported contradictory results on the interaction between music tempo and time perception, but crucially, to our knowledge, none of them compared the same musical piece with different tempo. We believe this to be critical, since many other studies (Kellaris & Kent, 1992; North & Hargreaves, 1999; Noseworthy & Finlay, 2009; Sanders & Cairns, 2010) found relationships between other music properties and time perception, therefore comparing two different musical pieces with time perception could introduce an uncontrolled interaction of different variables. We hypothesized that participants' time estimations provided after listening to background music immersed in a virtual scenario would follow the predictions from the theoretical time perception models.

Several authors have also studied spatial perception too. Indeed, some have observed in previous studies that it can be affected by the relative scale of the avatar seen in first person perspective (1PP) with respect to the virtual environment (Noë, 2004; Proffitt, 2006; van der Hoort, Guterstam, & Ehrsson, 2011). In particular, they observed how shrinking participants caused an overestimation of objects' sizes. Banakou et al. (2013) expanded this idea by not just manipulating the scale, but also displaying a child as the avatar representing the participant. The results of that experiment showed that the spatial perception was affected to a greater degree when individuals saw the child avatar as their virtual body compared to when they saw a shrunken adult avatar. This suggests the existence of a high-level cognitive mechanism that relates self-attributes to perception. Given the results of (DeLong, 1980; Mitchell & Davis, 1987), which showed that temporal perception is also affected by the perceived scale of the environment, we hypothesized that the spatial perception mechanism shown in (Banakou et al., 2013) would have a parallel for time perception. To test that assumption, we designed an experiment in which participants were embodied in either an avatar that represented a child, an adult, or an elderly adult and we examined how that affected temporal perception.

1.1 Research problem

Traditionally, research about time in psychology has focused primarily on time perception or mental time travel. Since (Ornstein, 1969), several studies have found multiple factors that affect our perception of time (Block et al., 2010; Droit-Volet & Meck, 2007). Nonetheless, the complexity of the knowledge in time perception research has grown significantly since then, because many variables have been found to affect perception in contradicting ways. Therefore, methodical and ecological procedures should be used. Nevertheless, those methodologies are not yet clear. Mental time travel, on the other hand, consists in mental processes where participants would imagine past or future events (Botzung, Denkova, & Manning, 2008; Suddendorf & Corballis, 1997). However, actually experiencing time travel could potentially have deeper consequences in participants. To our knowledge, to this date time travel is a phenomenon that has not been possible at a human scale, and therefore its potential has not been researched.

In this thesis we aimed at (i) examining the effects of two different variables on time perception inside IVR, and (ii) exploring the concept of time travel illusion in IVR. To address the first proposition, we carried out two experiments using immersive equipment. In each, we manipulated a variable and studied its effect on participants' time estimations. To explore the second one, we defined another experiment that contained a reasoning model capable of maintaining a narrative consistency after travelling in time. Furthermore, we combined the reasoning model with an IVR simulation to allow participants to endure time travel as a first person perspective experience.

1.2 Research questions

This thesis addresses three research questions with respect to the illusions of time travel and time perception, described below:

Research question 1: *Does background music tempo affect time perception in IVR?* Previous studies have found several variables that alter people's temporal perception, but relatively few were carried out in IVR. Chapter 5 contains an experimental study performed using immersive technologies that examined the effects of manipulating background music tempo.

Research question 2: *Does body shape affect time perception in IVR?* A recent study found that spatial perception can be manipulated by changing the shape of the embodied avatar. However, there is no evidence that the same happens for temporal perception. In Chapter 6 we detail an experiment aimed at examining the possible relationship between body shape and time perception.

Research question 3: *Is there a novel illusion in IVR that can provide the feeling of having travelled back in time?* This would be a new IVR illusion. We present in Chapter 7 a framework to develop experiences that trigger time travel illusions, and a study confirming the existence of such an illusion.

1.3 Scope

In this thesis we present research about time perception and manipulation inside IVR. Several studies (Block & Gruber, 2014; Meissner & Wittmann, 2011; Roper & Manela, 2000) have focused on various aspects and variables of time perception. Some of them (Brodsky, 2001; Down, 2009; North, Hargreaves, & Heath, 1998; Zakay, Nitzan, & Glicksohn, 1983) have investigated the effects of background music tempo in the perception of time. Furthermore, some researchers have studied how relative scale of the environment can affect temporal perception (DeLong, 1980; Mitchell & Davis, 1987). The focus of this thesis is studying the effects of two variables (background music tempo and body ownership), on time perception. Additionally, we will not centre attention in small (less than a few seconds) or very large periods of time (hours or years), and this research will aim only at studying intervals on the order of a few minutes.

Finally, some authors have investigated time travel from a mathematical and philosophical standpoint (Deutsch, 2011; Grey, 1999). Although we do offer an approach from a logic reasoning perspective, extensive mathematical and philosophical analysis is also beyond the scope of the current research.

1.4 Contributions

Overall, the research in this thesis aims at a better understanding of how we perceive time and how we can distort it to create time travel illusions. We carried out four experimental studies and we found that:

(i) *There is not enough evidence to conclude that changes in background tempo affect people's time perception inside IVR*. This was tested by developing a virtual scenario where participants heard a computer-generated musical piece in the background with a high or slow tempo, depending on the condition, while immersed in an IVR scenario. We did not find results that followed what the theoretical models (Ornstein, 1969) and (Zakay, 2000) predict.

(ii) *Body size and age representation do not appear to influence time perception*. This was to test whether temporal perception was affected through the same mechanisms shown to affect spatial perception (Banakou et al., 2013). This study's results indicate no relationship between temporal perception and the manipulated variable.

Given the evidence, we cannot conclude that either background tempo nor body shape are related to time perception inside an IVR experience.

Additionally, we present:

(iii) *A novel illusion in IVR arises when we simulate time travel*. This illusion was tested by developing two components: a logical reasoning model and an IVR simulation. The reasoning mode could store a series of events forming a sequence called history, go back to an arbitrary point in that history, and replay those events. Most importantly, after going back it allowed for new interactions that could invalidate sequences, and replace invalid events for valid to ensure history was always correct. This reasoning engine was coupled with the second component; a simulation implemented using IVR, which gave participants a first person perspective of the simulated time travel. Results indicate that participants indeed felt the illusion of traveling back in time provided they had a high sense of body ownership, presence and copresence with other virtual humans. This technique was also employed in a study to implement a variation of the empty chair technique in psychotherapy (Paivio & Greenberg, 1995; Perls, Hefferline, & Goodman, 1951), where participants were able to switch between two alternate bodies, one representing themselves and the other Sigmund Freud as a way of giving counselling to themselves (Osimo, Pizarro, Spanlang, & Slater, 2015).

2 BACKGROUND

In this Chapter we provide a comprehensive assessment of the most relevant aspects related to the work presented in this thesis. In particular, we examine current knowledge in the fields of IVR, time perception and several concepts of behavioural psychology, which form the knowledge base for the studies presented in this thesis.

2.1 Immersive Virtual reality

Throughout this thesis we made use of several features and illusions, some unique to IVR, which arise when participants are immersed in an IVR setup. In the following Sections we describe the concepts of immersion, presence, body ownership and agency in richer detail. We are particularly interested in them since, as we will see, several studies have shown that given a high sense of presence, body ownership and agency participants tend to experience virtual scenarios as they would in real world equivalents. These notions are therefore fundamental to our thesis since all of our experiments were performed in IVR.

2.1.1 IMMERSION

The concept of immersion in the field of virtual environments refers to a set of characteristics that the technology features in order to provide computer generated stimuli to participant's senses (Slater & Wilbur, 1997; Slater, 2009). According to this view, an ideal immersive system should be able to completely substitute physical reality for all of senses with at least as much resolution and fidelity as participants are able to perceive in the real world while the technology itself should not be noticeable. Even though such system does not currently exist, our research questions required that our experimental scenarios be performed using highly immersive equipment since participants would need to have felt as if they were in the virtual world and not the real one.

Typically, virtual reality setups have focused on visual display. Examples of highly immersive setups are CAVEs (Cruz-Neira & Sandin, 1992) and Head Mounted Displays (HMDs). Sound is another sense that has received notable attention. Surround-sound systems, sound spatialization or binaural recordings are some of the technologies that have been used to immerse participants in digital worlds. However, given the predominance of vision over the other senses, most of the effort and research has been directed at improving visual displays.

Furthermore, the digitally generated content should reflect changes in the participant's movements. This motion produces a proprioceptive feedback in the participant that must have a matching digital counterpart. This can be addressed with body tracking, or at least head tracking. Throughout this thesis we used several different immersive systems that, although not ideal, are highly immersive. Those setups, detailed in Chapters 3, 5, 6, 7, and Section 7.6 were controlled through the HUMAN (Spanlang et al., 2013) software library and the subsequent version, called SILVER, described in Chapter 4.

Even though immersive technology alone is not sufficient to give rise to the illusions described in the following Sections, it is a necessary condition to induce them (Slater & Wilbur, 1997; Slater, 2009).

2.1.2 Presence

Our third research question (*Is there a novel illusion in IVR that can provide the feeling of having travelled back in time?*) implies that participants have the illusion that they are in a particular scenario before attempting to travel back in time in that same scenario. This illusion is what is called *presence,* and can be described as the feeling of actually being in the place depicted by the virtual environment, situation referred to as Place Illusion, and behaving as if the events happening in the virtual world were real, i.e. Plausibility Illusion (Sanchez-Vives & Slater, 2005; Slater, 2009).

Since presence is a state of consciousness, it has traditionally been assessed through questionnaires (Slater, Usoh, & Steed, 1994) filled by participants after undergoing virtual experiences. Nevertheless, questionnaires alone cannot evaluate presence effectively (Slater, 2004). Some authors have attempted to measure presence in a more objective and behavioural way. For example, (Meehan, Insko, Whitton, & Brooks Jr, 2002) used physiological responses, i.e. galvanic skin response and hear rate, to examine their correlation to established methods to determine presence. They hypothesised that a greater sense of presence in a given virtual scenario would evoke similar physiological responses as those evoked by the equivalent real world scenario. Evidence suggests that this is the case, which opened the door to more ways to measure presence using physiological responses. Indeed, later studies (Meehan, Razzaque, Insko, Whitton, & Brooks, 2005) also used physiological reactions as a measure of presence.

Regardless of how presence is measured, given a high degree of it, participants tend to respond in the same manner as they would in the same situation in the real world (Slater, 2009). Not only participants tend to respond realistically to virtual environments, but they also do so with virtual avatars within those environments. For example, a study (Rovira & Swapp, 2009) immersed participants (all of them Arsenal Football Club supporters) in a virtual bar where they engaged in a conversation about football with a virtual avatar that wore an Arsenal shirt. After a few minutes, another avatar stepped in the dialogue and started a violent argument with the first avatar, which played the role of victim (Figure 2.1).

Figure 2.1: Violent discussion between virtual avatars. Image from (Rovira & Swapp, 2009).

Even though all participants knew that the situation was not real, they got quite involved with the scenario, and some of them even tried to intervene to stop the argument. This behaviour shows that IVR can generate similar thoughts, emotions and reactions as a similar situation in reality would.

A later reprise of this experiment (Slater et al., 2013) grouped participants depending on whether they supported Arsenal Football Club (in-group) or not (out-group). Additionally, the authors included a variable that determined if the victim avatar would occasionally look at the participant or not. In this experiment they measured the number of physical and verbal interventions.

The most relevant result of the experiment showed that in-group participants intervened verbally and physically more than the out-group ones. Additionally, they found that the number of physical interventions was associated with their conviction that the victim avatar was looking at them, for those who were in the in-group. These findings suggest that affiliations play an important role in IVR scenarios, as they do in real life, arguably strengthening the idea that people react realistically during IVR exposure.

Perhaps the most paradigmatic example of this idea is the virtual reprise of the Stanley Milgram's controversial experiment (Slater et al., 2006). In that study they recruited participants to administer a series of word association memory tests to a virtual avatar, female, displayed in a screen in front of them (Figure 2.2). They were further instructed to give an "electric shock" to the virtual avatar whenever she answered incorrectly, higher for every wrong answer. In one of the conditions participants saw and heard the virtual human, whereas in the other the communication was text-based only.

Figure 2.2: A virtual avatar playing the role of a subject in the virtual replica of the Milgram's experiment. In the bottom the machine that simulated electrical stimuli. Image from (Slater et al., 2006).

The authors found that even though all participants were clearly aware that none of what they were experiencing was actually real, those who heard and saw the virtual woman responded realistically at a subjective, behavioural, and even physiological level.

All of these previous results point to the idea that IVR is a great tool to explore situations that would be dangerous, unethical to perform or downright physically impossible given the current technology. In this thesis we used IVR to explore concepts that fall into the latter category. In the following Section we review the importance of the participant's body representation inside a virtual environment.

2.1.3 *BODY OWNERSHIP AND AGENCY*

With current technology participants can experience virtual scenarios through immersive setups that occlude physical reality. As a consequence, participants' real bodies are also occluded, and it is up to the developer of the virtual experience to include a representation of the participant's body. When there is such a representation in 1PP and in a matching body posture, the illusion that the seen virtual body is in fact the participants' real body may arise. That illusion is called body ownership (Kilteni, Maselli, Kording, & Slater, 2015; Maselli & Slater, 2013; Petkova & Ehrsson, 2008) and it is central for all the experiments presented in this thesis. Indeed, all of them included virtual body representations and results show body ownership levels were significantly correlated with several experimental variables in most experiments.

The virtual body ownership illusion is based on its physical reality counterpart, which has its foundation in the well-known rubber hand illusion (Botvinick & Cohen, 1998). In that study, experimenters placed a rubber hand in front of participants and hid the real one. They then synchronously stroke the rubber hand and the real one in corresponding spatial locations (Figure 2.3). After a short period, in the order of tens of seconds, of synchronous stimulation, participants reported feeling the touch on the rubber hand, thus effectively experiencing ownership of that rubber hand.

Figure 2.3: Experimenter strokes the participant's hand (on the right) and the rubber hand (on the left) synchronously. Image from Flickr. Credit: Alexander Gorlin.

Full body ownership illusions have also been elicited. In a study (Petkova & Ehrsson, 2008), experimenters placed two cameras on the head of a manikin which fed the displays of an HMD worn by the participant, as depicted in Figure 2.4. In that case, the authors stroke the torso of participants and the manikin synchronously. Body ownership was later replicated in IVR using virtual avatars (Pomés Freixa, Slater, Pomés, & Slater, 2013; Slater, Perez-Marcos, Ehrsson, & Sanchez-Vives, 2009).

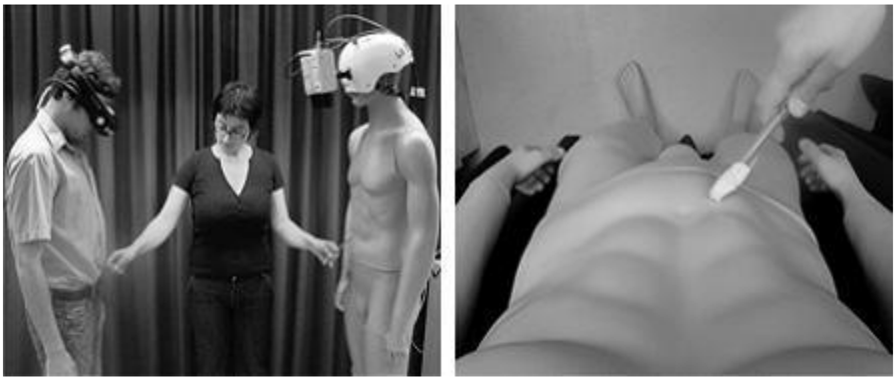

Figure 2.4: On the left, a participant is immersed with a display that shows the perspective of a manikin. The experimenter stimulates the participant by synchronously stroking the participant and the manikin. On the right, what the participant is seeing. Image from (Petkova & Ehrsson, 2008).

Studying body ownership in IVR, can have several advantages, however. For example, it is relatively simple to implement realistic body movement inside IVR, whereas the physical counterpart would require advanced robotic skills. On top of that, some more complex manipulations can be easily represented in IVR. For example, some authors examined the limits of body ownership changing the body shape (Kilteni, Normand, Sanchez-Vives, & Slater, 2012). In that study, they immersed participants in a virtual room where they could see two virtual arms coincident with their real arms. The length of one of the virtual arms was multiplied by a factor of up to four, depending on the condition (Figure 2.5). Participants experienced ownership of the virtual arm even when its length was up to three times that of the real arm. These results show how flexible human brain is in terms of accepting different shapes and anatomy. This fact is very relevant in the context of our thesis, since two of our experiments explored the effects of changing the participant's body appearance inside a virtual environment.

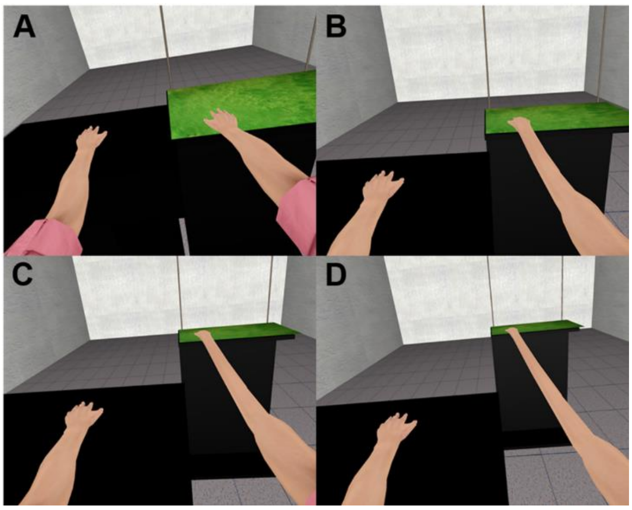

Figure 2.5: A) Virtual arm not modified B) Length of the arm multiplied by 2 C) Length of the arm multiplied by 3 D) Length of the arm multiplied by 4. Image from (Kilteni, Normand, et al., 2012).

While body ownership is concerned with the sensation that the seen virtual body is one's own, agency refers to the feeling that one is controlling that virtual body (Tsakiris, Prabhu, & Haggard, 2006). In several studies (Maselli & Slater, 2013; Slater, Perez-Marcos, Ehrsson, & Sanchez-Vives, 2008), participants passively received visuo-tactile stimulation to induce partial or full body ownership, but did not necessarily experience agency over the virtual representations. However, body ownership is usually combined with agency to create much more powerful experiences (Banakou et al., 2013; González-Franco, Pérez-Marcos, Spanlang, & Slater, 2010).

The visuo-motor correlation can be addressed through real-time full body tracking. In that case, the real movements of participants are captured and fed into the virtual reality application which applies them in the virtual body so that the virtual representation matches the real one. In the experiments implemented in this thesis, we used the HUMAN software library (Spanlang et al., 2013) and a subsequent version called SILVER to perform that operation and induce agency in participants. Additionally, a description of the setups used in the experiments of this thesis can be found in (Spanlang et al., 2014).

Embodiment is usually the most efficient way to achieve a high sense of body ownership and agency over a virtual body (Kilteni, Groten, & Slater, 2012). It refers to experiencing the virtual environment from the perspective of a virtual avatar that moves matching how the participant moves, or in other words entering and controlling a virtual avatar. Some studies have explored the boundaries of embodiment and how it shapes our behaviour. For example, (Kilteni, Bergstrom, & Slater, 2013) embodied participants in two different avatars, depending on condition, and instructed them to play a West-African Djembe. At first, experimenters took a baseline measurement of movement patterns while participants were represented by just a pair of virtual hands coincident with participants' real hands. Next, they embodied participants in either a casual-dressed dark-skinned avatar, or a formal-dressed light-skinned one.

Participants had a strong sense of body ownership illusion towards both avatars, which suggests that the human brain is very plastic in terms of accepting body representations different from one's own in dressing or in race, even in a very short period of time. Perhaps more interestingly, the authors found that those who embodied the casual dark-skinned avatar showed a significant increase in their movement patterns while drumming compared to their baseline.

These findings indicate that our body representation shapes our behaviour, in line with other studies in the field. Indeed, (Peck, Seinfeld, Aglioti, & Slater, 2013) performed an experiment in which Caucasian participants were administered an Implicit Association Test (IAT) (Greenwald, Nosek, & Banaji, 2003) at least three days prior to a virtual experience and they repeated it immediately after. During the IVR part, participants embodied either a dark-skinned, light-skinned or purple-skinned avatar, depending on condition, and could look at themselves in a virtual mirror. The authors found that participants who embodied dark-skinned avatars reduced their implicit racial bias after the virtual experience, significantly more than the other conditions.

Even though body ownership and agency are not the main areas of research in this thesis, they are of great importance for the experiments described here. Combined with a high degree of presence, participants experience virtual scenarios as they would in real world equivalents. Since physical reality counterparts are not possible for the experiments explained in Chapters 6 and 7, it is vital that participants are engaged in the virtual environments with the maximum possible degree of presence, body ownership and agency to explore how participants would react if those circumstances were conceivable. Moreover, in Section 7.6 we describe a study we carried out in which participants embody a well-known wise figure, and according to (Kilteni et al., 2013; Peck et al., 2013) we should expect changes in participants' behaviour.

2.1.4 Summary

In this Section we reviewed the constituents of IVR that make behavioural studies that use that technology possible. Additionally, we reviewed previous literature that led to the current state of art and understanding of the illusions that IVR can elicit. Finally, we described the necessary conditions to develop virtual experiences that engage participants to behave as they would in real world equivalents.

The illusions mentioned (presence, body ownership and agency) are central not just to the fundamental knowledge of illusions in IVR, but also for many studies that are considered dangerous or unethical to perform (Slater et al., 2006). In the specific case of this thesis, those elements are essential since, to our knowledge, the experiments explained in Chapters 6, 7, and Section 7.6 cannot be replicated in physical reality, and the experiment detailed in Chapter 5 depends heavily on its ecological validity.

In particular, Chapter 5 describes an experiment where the experimental variable has been shown to be influenced by many environmental factors. The fact that it can be executed in an IVR setup is a clear improvement over the same design performed in physical reality.

The design of the experiment explained in Chapter 7 is unlikely to be possible to replicate in physical reality. In that experiment, participants experience time travel and we examine if such illusion exists in IVR. Therefore, all the components and illusions described in this Section are used to create an experience that would induce the same behavioural reactions in participants as they would in the real world.

The experiment reported in Section 7.6 has a similar issue. Participants in that study swapped their perspectives between different virtual bodies. This would of course be impossible to perform in the real world, so we carried it out in IVR having the elements described in this Section as central to the study.

2.2 Time perception

In this Section we review the literature on time perception. This is important since our first and second research questions are focused on this topic, and two of the performed experiments explored the relationship between the perception of time and some variables. In particular, we studied the influence of background music tempo and body ownership over time perception. In what follows we provide a comprehensive summary of the literature relating time perception and some relevant factors.

2.2.1 Time perception paradigms

The processing of time is an innate ability of many animals that plays a fundamental role in survival. Even seemingly simple actions like walking or climbing a few stairs require a precise coordination of a large number of muscles, finely tuned for each specific circumstance.

Since James (James, 1890) began studying the perception of time, many authors have followed the research, and yet, time perception remains largely an open field in science. Several reviews have shown that time perception is alterable and malleable (Block et al., 2010; Caspar, Christensen, Cleeremans, & Haggard, 2016; Droit-Volet & Meck, 2007; Grondin, 2010), and can be influenced by various environmental factors. Stimulants and disorders have also been shown to greatly alter how the brain responds to time (Wittmann, Leland, Churan, & Paulus, 2007). In an effort to be able to predict time estimations, some authors have developed theoretical models. In the following Sections we review the most accepted ones and we also provide an in-depth look at previous work involving the environmental factors studied in this thesis.

2.2.1.1 Prospective paradigm

It is widely accepted that the most important factor is the awareness or lack thereof that one will be required to estimate the length of a period of time. In the case where participants are aware, called *prospective* paradigm, the most established theoretical model to predict estimations is called Attentional Gate Model (AGM) (Zakay & Block, 1995; Zakay, 2000), based on the Scalar Timing Theory (R M Church, 1984) and Treisman's model (Treisman, 1963). According to all these models, participants allocate cognitive resources to keeping track of the time. The models also describe an internal pacemaker that produces pulses that are counted by an accumulator whenever the attention is focused on the temporal task. Consequently, the more simultaneous cognitive tasks competing for resources, the less pulses will be counted, and therefore the estimations will be shorter.

Despite the amount of research in the area, the exact nature of the pacemaker is still unknown. Some authors (Meissner & Wittmann, 2011) have found correlations between subjective cardiac awareness and duration reproductions, suggesting that Heart Rate (HR) could be involved in the role of the pacemaker. In contrast, (Schwarz, Winkler, & Sedlmeier, 2013) studied the diving reflex to disassociate HR and time perception. This phenomenon consists in holding the breath for some time and as a consequence HR drops while arousal increases. The findings of that study suggest that arousal is a much better predictor than HR with respect to time perception. Additionally, recent papers in neuroscience suggest that the brain could contain multiple timekeeping regions (Droit-Volet, 2013; Ju, Dranias, Banumurthy, & VanDongen, 2015). Each section tracks different scales of time, from milliseconds to years or predictions of the future. These findings could explain why no single pacemaker was previously found.

2.2.1.2 Retrospective paradigm

The opposite paradigm, called *retrospective*, participants do not know in advance that they have to monitor time, and they give an estimation only after the interval. A first theoretical model for this paradigm, called the memory-based model, was introduced by Ornstein (Ornstein, 1969). According to this model, the estimation is calculated by retrieving remembered events from the time period and comparing them with similar events whose duration is known. An alternative and more recent theoretical model is the contextual-change model (Block & Reed, 1978; Block, 1990), which posits that it is rather the changes in stimuli than increase the perceived duration.

With respect to HR, no previous literature described a relationship with time perception in the retrospective paradigm. This could be due to the fact that Ornstein's memory-based model does not include a pacemaker mechanism. If the model is accurate, we would not expect to find correlations between time perception and HR. In Chapter 5, we describe an experiment we performed using the retrospective paradigm in which we measured HR. As predicted in the model, we did not find a relationship perceived duration and HR.

The paradigm, however, is not the only variable to influence time perception. Indeed, experimental evidence shows influence of various factors such as non-temporal stimuli, memories, cognitive load, current goals, physiological states and emotions, background music amongst others (for review see (Block et al., 2010; Droit-Volet & Meck, 2007)). In what follows we describe in further detail the influence of the factors this thesis is focused in.

2.2.2 *TIME PERCEPTION AND MUSIC*

In Chapter 5 we describe an experiment performed to investigate the relationship between background music tempo and time estimates. Indeed, music is a stimulus that has been frequently associated with people's time estimations, both in prospective and retrospective paradigms (Schäfer, Fachner, & Smukalla, 2013). Its presence alone has been shown to shorten perceived durations (North & Hargreaves, 1999; Sanders & Cairns, 2010), and several musical features such as volume and modality have been correlated to retrospective time estimates (Kellaris & Kent, 1992; Noseworthy & Finlay, 2009). Tempo is another researched variable; however, studies have revealed contradictory results. In a study by (Noseworthy & Finlay, 2009) retrospective perceived durations were negatively correlated with the tempo of music played in background while participants were engaged in a recreation of a casino. On the other hand, (Oakes, 2003) revealed opposed results; participants waiting in a queue retrospectively estimated longer durations when listening to fast tempo background music, as the theoretical memory-based model predicts. Furthermore, (North et al., 1998; Oakes & North, 2006) and a series of marketing studies (Caldwell & Hibbert, 1999, 2002) could not find significant differences in retrospective time estimates when either fast or slow tempo background music was present. On the prospective paradigm (Zakay et al., 1983) showed a positive correlation between music tempo and time estimates, in accordance with the AGM theoretical model.

Several reasons can account for such conflicting results. First of all, as (Block et al., 2010; Droit-Volet & Meck, 2007) report, there are many variables that influence our perception of time, and uncontrolled scenarios could result in one or more of them interacting in opposing directions with the manipulated variable. Studies by (Caldwell & Hibbert, 1999, 2002), for instance, were performed in a restaurant, where many potential factors could have dispersed the effect of the background music tempo. Additionally, those experiments often used different musical pieces. However, music is known to influence emotional and physiological states (Bernardi, Porta, & Sleight, 2006), which in turn have been shown to modulate time perception (Droit-Volet & Meck, 2007). Given this link between emotion and time perception, using different musical pieces introduces another variable, often overlooked, in the study of the relationship between tempo and time estimation. Moreover, as explained earlier, evidence in several studies (Kellaris & Kent, 1992; Noseworthy & Finlay, 2009) revealed a connection between several musical parameters and the perception of time. Therefore, it is preferable to use the same musical theme to avoid the interaction of additional uncontrolled variables. Chapter 5 contains the description of an experiment in which the main manipulation was changing the tempo of a musical piece. We generated two versions of the same piece programmatically to avoid the interaction of all factors other than tempo.

2.2.3 Time perception and IVR

Although people's temporal perception inside IVR environments is a relatively unexplored field, several authors have carried out experimental studies. For example, Schneider et al. (2011) examined how immersing people in IVR applications shortened the perceived duration of a chemotherapy treatment. In particular, they analysed the influence of age, gender, state anxiety, fatigue, and diagnosis on time perception while participants were receiving chemotherapy and being immersed in an IVR environment. Their results showed that IVR was indeed a distractor that helped mitigate chemotherapy-related symptoms, and that diagnosis, gender, and anxiety were three predictors for time perception.

Another study (Schatzschneider, Bruder, & Steinicke, 2016) examined the effects of zeitgebers (a German-original word which means "time-giver") over the perception of time. The authors refer to zeitgebers as all the elements that provide temporal cues. In their experiment, the manipulated zeitgeber was the simulated movement of the Sun inside a virtual environment. Notably, they designed three conditions in which the Sun either moved at a natural speed, at double the speed, or did not move at all. They found that the zeitgeber manipulation did have a significant effect on prospective time judgments, where no movement of the Sun resulted in the longest estimates and double the natural speed of the Sun resulted in the shortest when participants did not perform any cognitive task simultaneously. These results indicate that manipulating temporal cues affect time perception inside IVR environments. However, those results should be interpreted with care. Participants were immersed for two hours in IVR, which is a comparatively very long time. During that time they performed either one of two cognitive tasks or no task in separate ten-minute trials, and it was not reported whether the trials were randomized or not. In the negative case then it is very likely that the engagement varied greatly in participants throughout the experience. Since this was a within-subjects experimental design then trial results not comparable. Also, the movement of the Sun might be too slow to be the only factor explaining the differences. For example, the authors report that participants were allowed to take rests by closing their eyes but not taking the HMD off. Moreover, they did not report how often that happened nor for how long or in which conditions, if it did. If that happened consistently during the same conditions, it could have a major impact on the results. Finally, the authors not only simulated the movement of the Sun, but also the chromatic changes in the emitted light. Therefore, it could be that the chromatic change is what is actually affecting time estimations.

The field of time perception inside IVR environments is relatively unexplored, but with many possibilities. As Schneider et al. (2011) pointed out, it is imperative to understand the effect of each potential variable. Chapters 5 and 6 constitute a contribution to this field, with two experiments. In those studies, we analyse the effects of background music tempo and body shape on time judgments.

2.2.4 Summary

In this Section we reviewed the theoretical models of time perception along with several studies of the same field. Although there has arguably been a substantial amount of research in the area, there are still several unanswered questions, such as the exact nature of the pacemaker in the prospective paradigm, or how and how many factors influence time estimations both in prospective and retrospective paradigms. On top of that, given the amount of variables shown to affect time perception, it is imperative to find new methodologies to perform research on this area.

In the experiment detailed in Chapter 5 we used musical stimuli obtained from the InfinitunesTM repository, generated with Melomics (Diaz-Jerez, 2011; Melomics, 2012). With that technology, we produced two versions of a musical piece where the only variable manipulated is the tempo. Additionally, we implemented an IVR application in which we immersed participants to achieve high ecological validity. Given what we have reviewed, such a setup should provide a much more controlled environment that removes the interaction of the many variables that have been shown to influence time perception.

In the experiment described in Chapter 6 we examined the influence of the virtual body depicted in a virtual environment over time perception. Since we have seen in prior experiments that manipulating the virtual body appearance can lead to changes in behaviour and perception (Banakou et al., 2013; Kilteni et al., 2013; Peck et al., 2013), we hypothesised that it could also influence temporal perception.

2.3 Psychological Background

In the course of this thesis we performed several experiments, described in Chapter 7 and Section 7.6, that deal with different areas of human behaviour. The studies propose new techniques to be used in psychological treatments or different approaches to established fields in psychology. In this Section we review the relevant concepts explored throughout our studies.

2.3.1 MORAL DILEMMAS

Chapter 7 includes the description of an experiment that depicts a situation in which participants had to choose between several alternatives that could result in a violent incident involving one or more people, and in an instant they had to produce a moral judgment. The psychology behind participant's decisions in situations that involve moral judgments has traditionally been assessed through questionnaires presented after describing an example of such circumstances. (Foot, 1967; Thomson, 1971) proposed two moral dilemmas, often called classic trolley scenarios, which include six people divided in two groups, five in one group and the remaining one alone, unaware of an imminent danger represented by an out of control trolley. In one of them if no action is taken the trolley will kill the group of five people. The story includes a switch which, if used, would save five people, but ultimately sacrifice the one. After reading about the scenario, participants were asked whether they would push the button or not. The other moral dilemma includes a different type of interaction. It describes a person wearing a heavy backpack capable of stopping the trolley, if this person were pushed onto the track this would save the other five lives but sacrifice that person. The authors then asked participants if they would push that person towards the danger. In this case the main difference is that the action is a violent one, with a direct death as a result, which makes it a much more active and conscious decision.

These much studied scenarios have been replicated across cultures and countries with several variations. Typically participants have a utilitarian response i.e. they sacrifice the one to save the five, although specific results depend on the variation and other factors. Nevertheless, questionnaire-based studies in moral dilemmas have a clear limitation. Because of the very nature of the situations they investigate, it would clearly be unethical to perform in real life, and therefore questionnaire results cannot be contrasted with real life behavioural counterparts.

On the other hand, IVR provides the community with tools that have two main advantages: the first is removing the limitation of unethical procedures, since the experiences are not real and participants are aware of that at all time. The second advantage, equally important, is that this technology has been proven to trigger realistic behaviours in participants (Pertaub, Slater, & Barker, 2002; Rovira & Swapp, 2009; Slater et al., 2006). Combining the two mentioned advantages it is possible to design a scenario in IVR that studies behaviour in a moral dilemma.

Indeed, (Pan, Banakou, & Slater, 2011) investigated the feasibility of developing IVR-based moral dilemma studies, concluding that such studies were possible. Later, (Pan & Slater, 2011) performed an experiment in which participants experienced a virtual environment with the same underlying principle as the traditional trolley scenarios. In that study, participants were immersed in a virtual art gallery and they could control a moving platform with which five avatars went to an upper floor and another one stayed in the ground floor. A seventh avatar entered the gallery and requested to be taken to the upper floor. Upon arrival, the avatar started shooting the others and the participant had the choice of acting by taking the gunman to the ground floor and endangering the one that stayed there, or taking no action and letting the shooter kill the group of five avatars in the upper floor.

That study contained two conditions: one in which participants were immersed in an IVR setup and another one where participants experienced the virtual scenario in a traditional desktop 2D monitor, and volunteers had always the choice of saving the 5 or the 1. In addition, they performed for a separate group of people an online survey that contained five moral dilemmas; the classic trolley scenarios and variations adapted to reflect the virtual experience.

Participants first underwent the IVR experience and then they answered the classic questionnaire-based trolley scenarios to see if their moral choices were altered as a result of the experiment.

Results confirmed that participants' behaviour was in line with the online survey data. Both participant behaviour and online questionnaires suggested that people tend to act to prevent the deaths of the five and sacrificing the one, i.e. they gave utilitarian responses. The post-questionnaires were also consistent with their behaviour during the virtual experience.

In Chapter 7 we describe a follow up of this study, in which participants were immersed in an IVR scenario also depicting a virtual art gallery with two floors and a shooting. Our environment, however, is different to the previous study in the sense that there was an ideal solution in which the outcome was completely avoiding the shooting. Also, in our experiment we allowed participants to travel back in time and intervene, to investigate if people felt guiltier or more moral when avoiding the disaster.

2.3.2 Virtual Reality Exposure Therapy

Time travel has potential for applications in therapy. In fact, in Chapter 7 we report an experiment which we discuss it could be a novel approach to treating the sequels of very bad and vivid memories. Indeed, some events such as accidents or violent encounters can be shocking enough to leave prolonged psychological disorders. Symptoms can include periodical flashbacks of that particular episode and high anxiety levels, and it is commonly referred to as Post-Traumatic Stress Disorder (PSTD) (Ehlers, Clark, Hackmann, McManus, & Fennell, 2005).

This disorder became particularly relevant after the return of the Vietnam War combatants (B O Rothbaum et al., 2001). The large number of people with difficulties readjusting to society led to a great interest in treatments for PTSD. Over time, several psychological treatments were explored. In (Van Etten & Taylor, 1998), the authors reviewed several methods and determined that Cognitive Behavioural Treatment (CBT) is a comparatively more effective technique to treat PTSD.

While several authors have researched different approaches for CBT, the most successful are the ones based on exposure therapy, which consists in repetitively exposing participants to the trauma memory (Ehlers et al., 2005). CBT and the concept of repeated exposure is also exploited in some treatments for phobias and anxiety disorders (for review see (Opriş et al., 2012; Parsons & Rizzo, 2008)), which consists in recreating the conditions that induce those disorders in a controlled manner. This exposure has traditionally been performed in three different ways: writing about the event, recreating it in one’s mind, or revisiting the site. While those approaches have been largely successful, Virtual Reality Exposure Therapy (VRET) allows for a much more vivid and controlled experience, and has already shown promising results, being at least as effective as state-of-the-art exposure in vivo (Meyerbröker & Emmelkamp, 2010; B O Rothbaum et al., 2001), sometimes even combined with traditional medication treatment (Barbara Olasov Rothbaum et al., 2014).

Furthermore, since VRET relies on IVR, it opens possibilities that would be unethical, dangerous or impossible to perform. For example, a possible physical counterpart of VRET for acrophobia could be to make participants stand up near the edge of cliffs or buildings. Needless to say, this could be extremely dangerous, even if performed one step at a time since participants who suffer from phobias can become irrational and very unpredictable when directly exposed to their phobias.

With VRET, on the other hand, participants can safely stand on top of a virtual building (Figure 2.6, A)) and be exposed to their phobias in a controlled environment. Even though they are consciously aware that none of what they see is real, they still behave subconsciously in a similar way, provided they have a strong sense of presence (Meyerbröker & Emmelkamp, 2010).

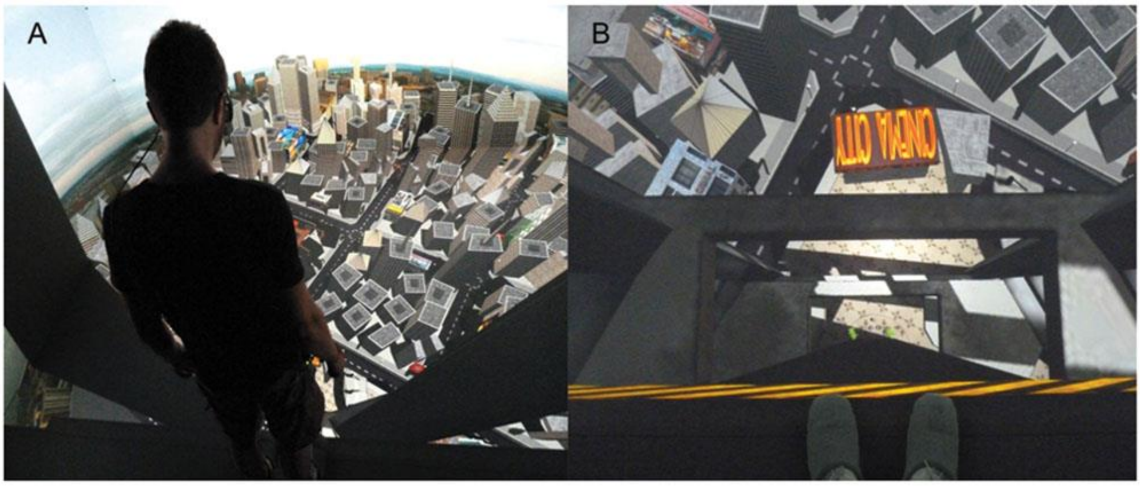

Figure 2.6: A) Participant standing on the elevator of a very tall virtual building B) Participant's perspective. Image from (Seinfeld et al., 2015).

In the context of this thesis, in (Friedman et al., 2014), described in Chapter 7, we explored the possibilities of IVR as a tool to expose participants to traumatic events by letting them relive past events as if they were really happening. One of the possible future applications of such a technique could be a treatment for PTSD that would empower participants to realise that they did everything in they could have done given the circumstances. Such approach combined with CBT has proven to be effective in other contexts, and our contribution could open a door to new methods and treatments.

Moreover, in Section 7.6 we report a study in which the same principles and technology were used to implement a virtual variation of "the empty chair" technique from Gestalt Therapy.

2.3.3 *EMPATHY*

IVR can be used as an excellent tool to place oneself in someone else's shoes. Since it is arguably easy to design and implement virtual scenarios in which participants are represented with a different body than their own, some authors have studied the consequences of body ownership over different bodies in the context of empathy. In this sense, several experiments have explored the impact on racial bias (Fini, Cardini, Tajadura-Jiménez, Serino, & Tsakiris, 2013; Maister, Sebanz, Knoblich, & Tsakiris, 2013; Peck et al., 2013). In general, it has been found that embodying an avatar of a different race causes a reduction in the implicit racial bias. One of the most accepted explanations is that body ownership over an outgroup body tends to generate an association between the self and the outgroup, which as a consequence transfers some positive attributes associated with the self towards the outgroup.

Traditionally perspective-taking (Batson, Early, & Salvarani, 1997) has been addressed by imagining a situation in which one is in another person's location, or seeing oneself from the outside. Classic applications such as the "empty chair technique" from Gestalt Therapy (Paivio & Greenberg, 1995; Perls et al., 1951) put participants in front of a physical chair and use cognitive perspective-taking to start a dialogue, discussions or even arguments with an imaginary person sitting on the chair. The method usually has participants physically switching sides every time the conversation switches interlocutor, and requires participants to pretend being the person who is imaginarily sitting on the chair they are physically sitting on.

IVR can enhance such setups in the sense that it does not rely on participants' imagination. A recent study (Falconer et al., 2014), for example, used this technology to help reduce self-criticism. In that experiment, participants were immersed in a virtual scenario where they embodied an avatar and compassionately comforted a crying virtual child that was sitting in front of them. Later, participants took the perspective of the child and the scene was replayed with their voice and motion applied to their first avatar.

In this thesis, we show how the technology developed for time travel was used in an application that mimicked aspects of the 'empty chair' technique from Gestalt Therapy. Section 7.6 contains the description of an experiment we carried out in which participants switched perspective several times in a virtual version of the empty chair technique.

2.3.4 Summary

In this Section we reviewed some fields of research in psychology related to this thesis. The first field - moral dilemmas - was up until recently an area dominated by questionnaire-based studies. The reason to use questionnaires is that situations involving moral dilemmas are unethical to perform in real life, e.g. the classic trolley scenarios. (Pan et al., 2011) proposed another approach; using the power of IVR, researchers could test if the questionnaire-based results matched behaviours observed when participants are immersed in virtual scenarios that recreate the dilemmas described in their text counterparts.

Chapter 7 describes a follow-up experiment of (Pan & Slater, 2011) in which participants were immersed in a virtual environment similar to one of the classic trolley scenarios. In that experiment we allowed participants to travel back in time and amend the final outcome, and examined their feelings of guilt and morality compared to their previous baseline.

The second field described in this Section is VRET. CBT with repeated exposure has been a successful methodology to treat PTSD, anxiety disorders and phobias. Nevertheless, incorporating IVR has opened the door to new approaches where in vivo exposure was unethical to perform. Studies suggest that even if the exposure is virtual, treatments are at least as effective as if the stimuli was real (Meyerbröker & Emmelkamp, 2010).

VRET is relevant in this thesis especially in Chapter 7, when participants experienced a time travel illusion in an IVR scenario. We argue that such a technique could form the basis of future treatments for PTSD in which participants relive the traumatic event, but then insert new information or outcomes into it.

Finally, in this chapter we provided the background concerning empathy and perspective-taking. These concepts are heavily used in Section 7.6, in which we report an experiment where participants swapped perspectives in a virtual scenario, in a similar fashion as the empty chair technique from the Gestalt Therapy (Paivio & Greenberg, 1995; Perls et al., 1951).

2.4 Summary

In this chapter we have examined the constituents and basic concepts used throughout this thesis. First of all we analysed the fundamental building blocks to develop powerful applications in IVR, capable of engaging participants to behave during virtual experiences as if they were in real-world counterparts. We reported the definition of the most relevant terms in the field of IVR, such as immersion, presence, body ownership, agency and embodiment along with the characteristics, measures and preconditions related to them. All the experiments of this thesis make use of highly immersive equipment and aim at delivering high feelings of presence and body ownership.

In addition, we have reviewed the literature on time perception, including the predominant theoretical models for prospective and retrospective paradigms. Furthermore, we examined several experiments on time perception carried out in IVR, and we have seen some of the factors shown to affect temporal judgments. Moreover, we overviewed the literature in the context of the relation with background music, revising several previous studies on the field. This knowledge forms the basis to understand the design and conclusions of the experiments described in Chapter 5 and Chapter 6.

Finally, we reviewed some of the relevant psychological background, used in the experiments of this thesis. For example, Chapter 7 details a study that contains a moral dilemma, and the virtual time travel technique implemented for it could form the basis of a form of VRET as a virtual version of the empty chair technique from the Gestalt Therapy.

3 MATERIALS AND METHODS

In this Chapter, we describe the common technologies and methods used throughout the experiments explained in this thesis. In particular, we describe the methodology used to induce embodiment and the procedures used across all studies.

3.1 Embodiment

All the experiments aimed at eliciting a high sense of presence, body ownership illusion, and in some cases, agency, in a highly immersive setup. As explained in Chapter 2, these requirements can be met with a combination of software and hardware that must include at least a highly immersive stereoscopic display and head tracking. In the following Sections we detail the systems used in our experimental studies.

3.1.1 SOFTWARE

To display the 3D content on the displays and update it according to the participants' movements we used a combination of existing software with additional development. The main environment employed to program the experiments was Unity3D[1]. We opted for this platform because it is a popular game engine that contains many built-in features such as path-finding, animation support and mesh rendering that would be needed for all experiments of this thesis. It does not, however, include specific functionality for IVR, e.g. body tracking support or side-by-side stereoscopic rendering for many devices. Although recently the engine developers started supporting some IVR features, at the time when the experiments were implemented they were not yet present.

To overcome this limitation, we implemented the successor of a library (Spanlang et al., 2013) that connected existing tracking standards and that supported IVR displays. The aim of this development was twofold: the first being to be able to connect the devices to Unity3D environment, and the second one to be able to provide a unified interface for devices that offer similar features. The first one was a prerequisite to be able to use the development platform we chose, while the purpose of the second one was to provide a much more flexible environment to test and iterate fast.

Both goals were achieved by adding a level of abstraction developed with Unity3D's tools for existing solutions for tracking such as VRPN (Ii et al., 2001) or the development kits of the providers of tracking devices. In order to support IVR displays, we opted for a side-by-

[1] www.unity3d.com

side rendering option, since the use of HMDs was suitable for our needs and those could use this technique to display stereo images.

Tracking data can be thought of as the description of a hierarchy and some data for each node, composed at least of a position and a rotation. The main issue is that there is no standard hierarchy and no standard definition of what the data represents exactly. For example, some body tracking systems provide tracking data for 17 nodes or less with relative positions and rotations, while others stream 21 nodes or more with positions and rotations in absolute coordinates. Furthermore, some systems represent rotations with Euler angles while others use quaternions. The permutations get more complicated when the lack of standard virtual avatars is taken into account, which frequently vary in number of bones, neutral-pose rotations and hierarchy organization. Our level of abstraction defines an intermediate skeleton with a common hierarchy and data representation, onto which all tracking data gets mapped per tracking system. After that, we retarget the intermediate skeleton onto avatars applying a simple quaternion transformation.

With respect to the HMDs, the implemented approach was similar in terms of device abstraction. We grouped the common characteristics of every HMD and developed a system that only required providing the physical characteristics of the device. For devices that require special rendering such as optical distortions e.g. Oculus Rift, the manufacturers' development kits were used.

With such a solution, we were able to drive the body of any virtual character and display a virtual world in 1PP. For further details of software implementation, see Chapter 4. In the following Section we describe the hardware equipment used during the experiments described in further chapters.

3.1.2 Hardware

As (Spanlang et al., 2014) describes, there are many possible combinations of hardware to achieve an effective illusion of presence and embodiment. In this thesis we used HMDs, full body tracking systems and head tracking systems. The following is a description of the components utilized.

3.1.2.1 Head Mounted Displays

The choice of the display used to immerse participants in the virtual world is one of the most important factors to elicit the desired illusions. Although there are multiple kinds of displays capable of providing appropriate virtual experiences for many applications, the effective illusion of time travel requires that a participant cannot see one's real body. Therefore, this prerequisite limited our scope to HMDs.

One of the most important parameters of an HMD is the Field of View (FoV). In this thesis we used two different devices: the NVIS nVisor SX111 and the Oculus Rift DK2 (Figure 3.1). The former features a refresh rate of 60Hz and provides stereoscopic view through dual SXGA displays with 102°H × 64°V degrees FoV per eye. In total the field of view is 111° horizontal and 64° vertical, with a resolution of 1,280 × 1,024 per eye. The Oculus Rift DK2 includes a 75Hz refresh rate screen, 100° nominal FoV with a resolution of 960×1080 pixels per eye.

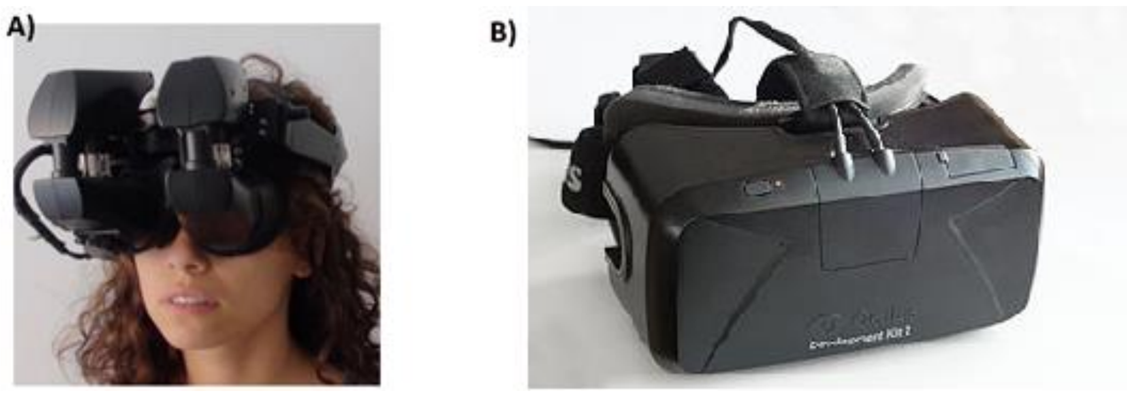

Figure 3.1: A) NVIS nVisor SX111 B) Oculus Rift DK2. Image under Creative Commons, credit: Ats Kurvet

Having an appropriate display device, however, is not enough to elicit presence or agency when participants move while immersed in a virtual world. A head tracking device alone may be sufficient if they are instructed to remain in a static position matching a virtual avatar's pose. Otherwise, a body tracking system is also necessary to deliver a correct virtual experience that triggers all the illusions necessary for our research. In what follows we describe the tracking systems used during our experiments.

3.1.2.2 Tracking systems

While modern HMDs include head tracking, older ones do not. For example, Oculus Rift DK2 includes a built-in rotation and positional tracking through a sensor fusion that includes gyroscope, magnetometer and accelerometer data updating at 1000Hz, and a separate camera with which it can calculate the relative position of the HMD using what is called constellation technique. That method requires multiple infrared LED emitters placed in known formations near the surface of the HMD, with which computer vision algorithms can precisely position the HMD. On the other hand, other HMDs such as nVisor SX111 do not contain any tracker, and therefore an external device is needed.

In order to get head tracking for the nVisor SX111, we opted for an Intersense IS-900[2] system (Figure 3.2), capable of streaming high-precision 6 degrees of freedom data at 180Hz. This tracking hardware is based on inertial-ultrasonic hybrid tracking technology. The system is composed of a fixed structure that contains several ultrasonic pulses emitters, and a small portable device that encloses accelerometers, gyroscopes and ultrasound microphones. These inputs are processed in a dedicated server to achieve positional and rotation tracking with a resolution of 0.75 mm and 0.05° and a typical delay of 4ms. The data is sent through the network via the VRPN protocol (Ii et al., 2001) and captured by our software.

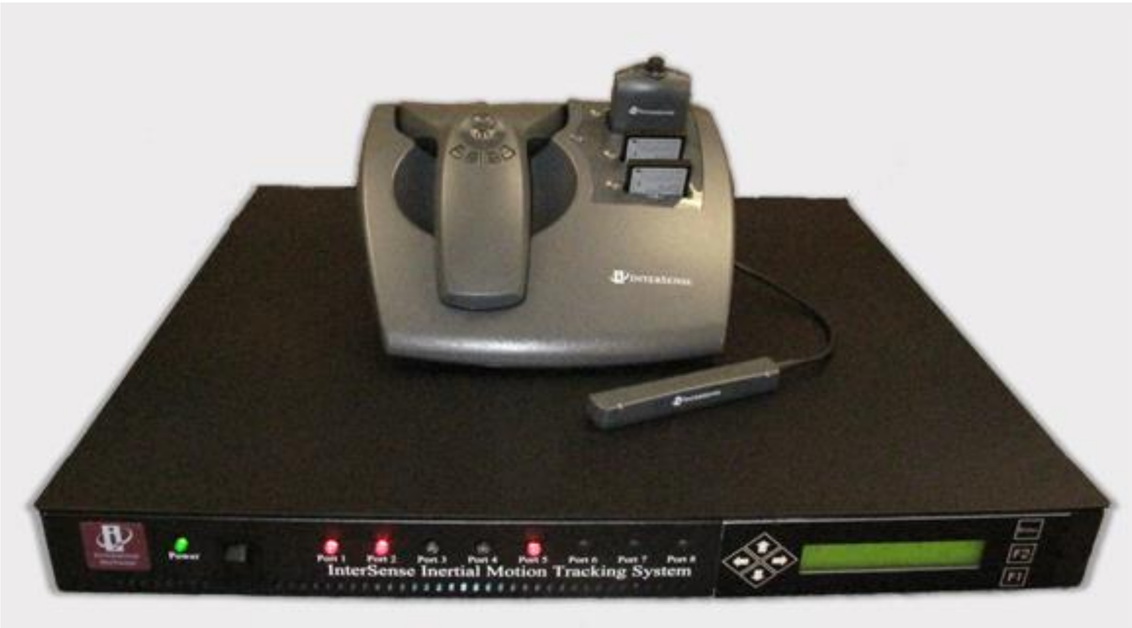

Figure 3.2: Intersense IS-900 head tracking system. © 2016 Thales Visionix, Inc. All Rights Reserved.

In terms of the rest of the body, we used two different tracking systems. One of them is an Xsens MVN Link body tracking suit (Figure 3.3) and consists of 17 inertial sensors transmitting body tracking data at 240Hz with a delay of 20ms. This hardware is coupled with the proprietary software MVN Studio, which streams the participants' motion through the network in the manufacturer's protocol and is captured by our software library. The other system (Figure 3.4) is a NaturalPoint Optitrack motion capture system, which is composed by several elements. First of all, several infrared cameras (our setup has 12 Flex 13 cameras) are fixed in a rigid structure. The construction also contains infrared light emitters, and tracked participants wear a special suit which has several reflective markers (in our case 37) placed at specific joints, defined by the application. The combination of all those components plus a calibration process provides enough information for algorithms to

[2] http://www.intersense.com/pages/20/14

estimate where each marker is in space, and with enough points tracked an accurate representation of the participants' motions can be calculated. All this information is processed in NaturalPoint's Motive application at 120Hz, which then streams body tracking data in a NaturalPoint format known as NatNet. A more in-depth description of both body tracking systems can be found in (Spanlang et al., 2014).

Figure 3.3: Xsens MVN Link body tracking suit.

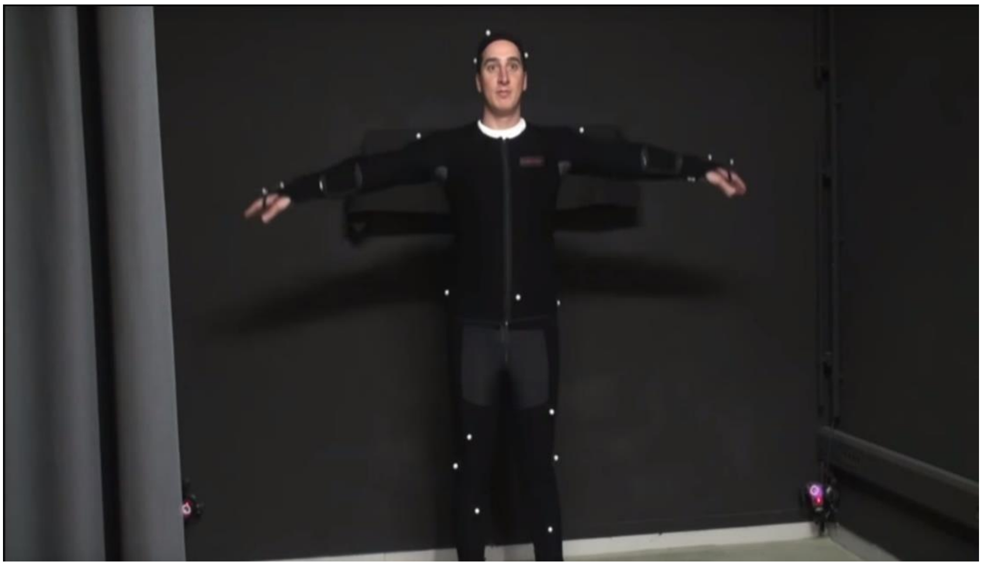

Figure 3.4: Optitrack motion suit and capture system.

The final setup for the experiment detailed in Chapter 7 included headphones with a microphone to deliver recorded instructions, record the participants' voice and play it back after time travel simulations (Figure 3.5).

Figure 3.5: IVR setup. Body tracking Xsens suit, head tracking Intersense IS-900, NVIS nVisor SX111 HMD, and headphones with a built-in microphone.

3.2 Time travel implementation

One of the technical constraints for good IVR experiences is that the frame rate must consistently match the screen refresh rate. Otherwise screen tearing may appear, which is usually so noticeable in HMDs that it typically destroys all the elicited illusions.

A positive outcome, however, is that as a consequence IVR developers can rely on constant frame rates. In the context of time travel, we took advantage of this fact to implement the time travel illusion.

One of the methods to elicit the illusion of travelling back in time is by recording all participant's actions during an arbitrary amount of time and playing it back. In particular, it is sufficient to record the tracking data from our software library (described in Chapter 4) and the participant's voice over that period. In this case, the complexity lies in the synchrony between the motion and sound playbacks, adjusted with the speed of the execution during the reproduction. Because during our experiments the execution is performed at a constant frame rate, we can ensure an accurate and synchronized replay.

While this approach is valid for participant-controlled avatars, it is not generic, i.e. it cannot be reused for different objects with other behaviours, and does not allow for new interaction caused by participants during the playback. In Chapter 7 we describe a complex scenario that contains such problems, which are solved through a separate engine that performs logic operations to determine how objects respond during time travels. The other experiments did not require such techniques.

3.3 Procedures

All the experiments described in this thesis were approved by the Universitat de Barcelona Ethics Committee (Spain). In addition to that, all participants were given prior information about the studies they participated in, gave written informed consent according to the declaration of Helsinki, and were paid for their participation.

Additionally, to ensure high ecological validity and reduce experimenter's bias we recorded all instructions for participants in audio files and were played in each session. Furthermore, at the end of the instructions participants were urged to ask any questions they might have. This way, all participants would hear consistent directions and had minimal exposure to environmental conditions.

In terms of how participants experienced the virtual environments, since the goal was always to deliver a high sense of body ownership, all the experiments were designed and developed to show the virtual world from a 1PP. In addition, the participants' bodies were always represented by gender-matched virtual avatars.

With respect to body tracking, the experiment described in Chapter 5 is the only one that did not specifically need it. Since the aim of that study was not embodiment, we simply instructed participants to remain seated in a fixed position matching the pose of the virtual avatar that represented participants in the virtual world. All the other experiments, on the other hand, did include body tracking.

3.4 Summary

In this chapter we reviewed the technology employed to immerse participants in virtual experiences that can successfully trigger the illusions described in the previous chapter. More specifically, we described the necessary requirements for displays to be able to deliver a high level of immersion and the tracking elements employed to provide the developed applications with enough data to control avatars in a virtual world.

Moreover, we described the underlying software components that form the common environment with which all the experiments were developed. Not only did we use existing solutions for IVR-specific problems, but we also implemented a software library to connect them, described in detail in Chapter 4.

Additionally, we provided an overview of the implementation of time travel in IVR using the equipment and software (Spanlang et al., 2013).

Finally, we reported the common procedures applied during the experiments of this thesis detailed in subsequent chapters.

4 SILVER: Software Interface Library for Virtual Environments and Robots

4.1 Introduction

The field of IVR has dramatically changed over the last few years. From being a highly specialised set of hardware devices and software to now becoming a consumer-oriented mainstream industry. Together with the rapid advancements in computer graphics, we can now get immersed in highly realistic and highly interactive virtual worlds, at a fraction of the cost and space needed not that long ago. However, the surge of new devices of different kinds generates a new problem: how to support them all. Given the development cycles of applications and devices, it is a hard problem to solve. Developers cannot predict which devices will be available when they finish their project, and even worse, the diversity of hardware makes guessing which devices will be the most effective for their needs very hard.

Although there have been several attempts to solve this problem, at the moment of this writing there is yet no widely accepted set of tools. Those attempts have typically been either entire development environments dedicated to IVR, such as XVR (Carrozzino & Tecchia, 2005) and VRJuggler (Bierbaum et al., 2001), or plugins over existing rendering or game engines, such as Viargo (Valkov & Bolte, 2012), MRToolkit (Shaw, Green, Liang, & Sun, 1993) or Virtual Reality Peripheral Networks (VRPN) (Ii et al., 2001). As explained in Section 4.2, each option has several benefits and drawbacks. The approach taken in this thesis is the design of a plugin for rendering engines and the implementation for Unity3D game engine. In this Chapter we offer the description of the design and describe some of the most relevant implementation details.

This development contributes mainly to the virtual reality field, although its completion has been of fundamental help for several scientific projects, some of them already published. The library described in this Chapter accelerated the development of many projects and has allowed a number of researchers to set the focus on tasks related to the specifics of their experiments.

The development of this library was funded by the European Research Council Project TRAVERSE (#227985) and is in review in Presence: Teleoperators and Virtual Environments[3] journal.

[3] www.mitpressjournals.org/loi/pres

4.2 Background

There are currently several HMDs, such as Oculus Rift (Figure 3.1), HTC Vive [4] and Playstation VR [5] that have shown great potential to become mainstream IVR hardware. Tracking systems also have several companies such as Noitom[6] or Microsoft[7] developing products that could potentially end up being a common setup for IVR applications. Given the great variety of systems, it is clear that IVR applications should support as many devices as possible to be compatible with big masses of consumers. However, including support for several devices is a tedious and typically expensive process because an application must be tested against every device.

Additionally, there is a recent trend of using a Smartphone's display and gyroscope as a very low cost but effective HMD (Olson, Krum, Suma, & Bolas, 2011; Steed & Julier, 2013; Surale & Shinde, 2014). Two of the most successful implementations of this approach being Google Cardboard [8] and Gear VR [9] (albeit the latter uses external gyroscopes). Hence, ensuring cross-platform compatibility is also an important requirement.

Furthermore, given the current investment in the field, all of the mentioned devices will be superseded in the near future by subsequent versions or new products from other companies. Consequently, applications that aim at keeping up with the industry's state-of-the-art should be developed using frameworks designed to be as flexible as possible with respect to adding and removing support for devices. Those frameworks should also be able to support those new devices through simple updates. Finally, it can be argued that many of the future IVR applications will depend on user's collaboration inside virtual worlds, as it has happened with many desktop projects. Therefore, IVR frameworks should support that feature.

Some existing frameworks already meet many of these requirements. As mentioned in the introduction, they do so by either developing entire rendering engines or separate plugins for other platforms. VRJuggler or XVR are very successful examples of the former. They provide, amongst other features, an abstraction layer over the operating system and the graphics APIs, and contains many of the required features to develop in IVR. However, we argue that this approach requires labour-intensive maintenance to keep up with new

[4] http://www.htcvr.com/
[5] https://www.playstation.com/es-es/explore/ps4/features/playstation-vr/
[6] http://perceptionmocap.com/
[7] https://dev.windows.com/en-us/kinect
[8] https://www.google.com/get/cardboard/
[9] https://www.oculus.com/ja/gear-vr/

techniques and rendering methods since computer graphics and IVR are extremely fast-paced fields.

Alternatively, some popular development engines such as Unity3D or Unreal 4 have recently begun to include some of the features into their core. They included provision for a few HMDs, however, at this point there is no body tracking support. Nevertheless, the remaining features can be added through plugins. Some toolkits such as Viargo (Valkov & Bolte, 2012) or MRToolkit (Shaw et al., 1993) can potentially couple with the game engines to deliver all requirements, although usually multi-engine libraries are hard to use and require advanced programming skills. In addition, they do not provide collaborative support, therefore only provide support for collaboration through the engine they are coupled with. OSVR[10] is potentially a candidate to include all required features, but currently it is still under development.

Dealing with many different tracking devices can be a daunting task. Each manufacturer usually provides its own tools, with specific parameters and configurations. To overcome this problem, most approaches have created a higher level of abstraction and a common interface to deal with all devices in the same manner. VRPN, OpenTracker (Reitmayr & Schmalstieg, 2005) and Ubiquitous Tracking (Ubitrack) system (Huber, Pustka, Keitler, Echtler, & Klinker, 2007) are examples of this method, and they all have in common a client-server architecture in which they process the specific sensor information in clients and distribute it across the network. However, those systems are not specifically designed to work with body tracking. Even though they can be adapted to deal with full body information, the workarounds are neither elegant nor particularly efficient, and they do not provide any retargeting features.

In that sense, other authors have developed specific functionality for body tracking retargeting. Monzani et al. (Monzani & Baerlocher, 2000) introduced the concept of intermediate skeleton. This is a description of a hierarchy of bones, common for every motion source and avatars to retarget to. This is an elegant solution to the underlying problem of retargeting body motion, which is that there is no standard to define hierarchies of bones, so motion providers (animations or real time body tracking) usually deliver data in different forms, and motion receivers (humanoid characters) also have different descriptions that may not match that of any motion provider. Several authors (Kulpa,

[10] http://www.osvr.com/

Multon, & Arnaldi, 2005; Lu, Liu, Sun, & Sun, 2009; Multon, Kulpa, Hoyet, & Komura, 2008) used this concept to develop methods or libraries that perform body retargeting.

Our approach, presented in this Chapter, is a plugin framework that groups the best practices and concepts explained in the previous paragraphs. In what follows we provide an in-depth description of the design of the framework developed for this thesis and we include some details about its implementation.

4.3 The system

SILVER is a plugin library developed for Unity3D, used in the implementations of the experiments presented in Chapter 6 and Section 7.6. The design focuses on modularity. In that sense, the framework is divided into four main areas: tracking, camera setup, collaborative support, and robot support. However, given the scope of this thesis only the modules of tracking and camera setup will be described. The full contents will be available in the form of a publication in the future.

4.3.1 TRACKING

Tracking devices, albeit each in its own manner, typically contain three functions: starting the system, capturing data and closing the system. Some devices may have implemented those functions as blocking calls, which halt the execution of the entire program until the functions finish. An application blocked for an excessive amount of time results in a poor or even nauseating experience since for that period the display does not update with respect to the head movements. This problem is worsened considering the fact that many applications use one device to drive multiple objects across the scene, or the fact that many tracking systems provide data for multiple simultaneous users.

A naïve implementation could result in many unnecessary calls to retrieve data or to start tracking systems. Our design (Figure 4.1), however, minimizes them using software design patterns such as singleton class TrackingSystemFactory. This class contains a list of all instantiated tracking devices and prevents duplicate instances of the same tracking system. Additionally, the design includes a TrackingSystemActor class, which provides data for a simultaneously tracked user and instances are reused for all entities that retarget that data. With this design, calls to initialize, close and per-frame data retrieval are minimized. Finally, these operations can be executed in parallel or asynchronously to the main application, avoiding the problems caused by blocking calls.

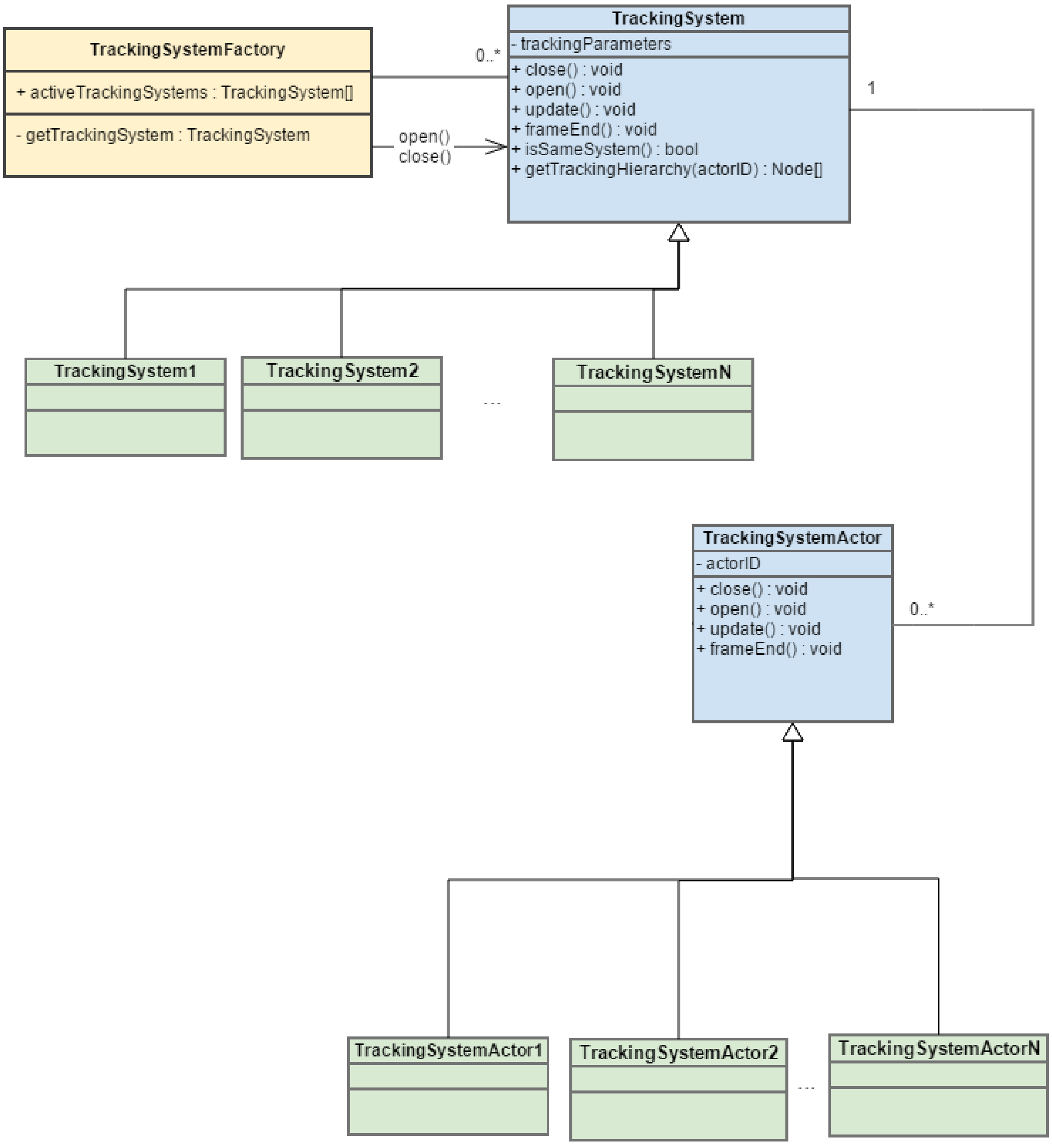

Figure 4.1: Tracking design overview.

After the tracking data retrieval, there is a retargeting process. As mentioned earlier, we follow a similar method to that of the intermediate skeleton (Monzani & Baerlocher, 2000). However, we generalized the idea to fit broader needs. In particular, we define three kinds of "Intermediate Data Structures" (IDS), one for skeletons, another one for hands, and a third one for single objects. Those definitions are bundled inside the library and are independent of the devices or virtual objects. We define the IDS for skeletons as a hierarchy of 21 bones forming a T-pose when the rotations of all bones, expressed as absolute rotations, are identity quaternions (Figure 4.2 bottom right).

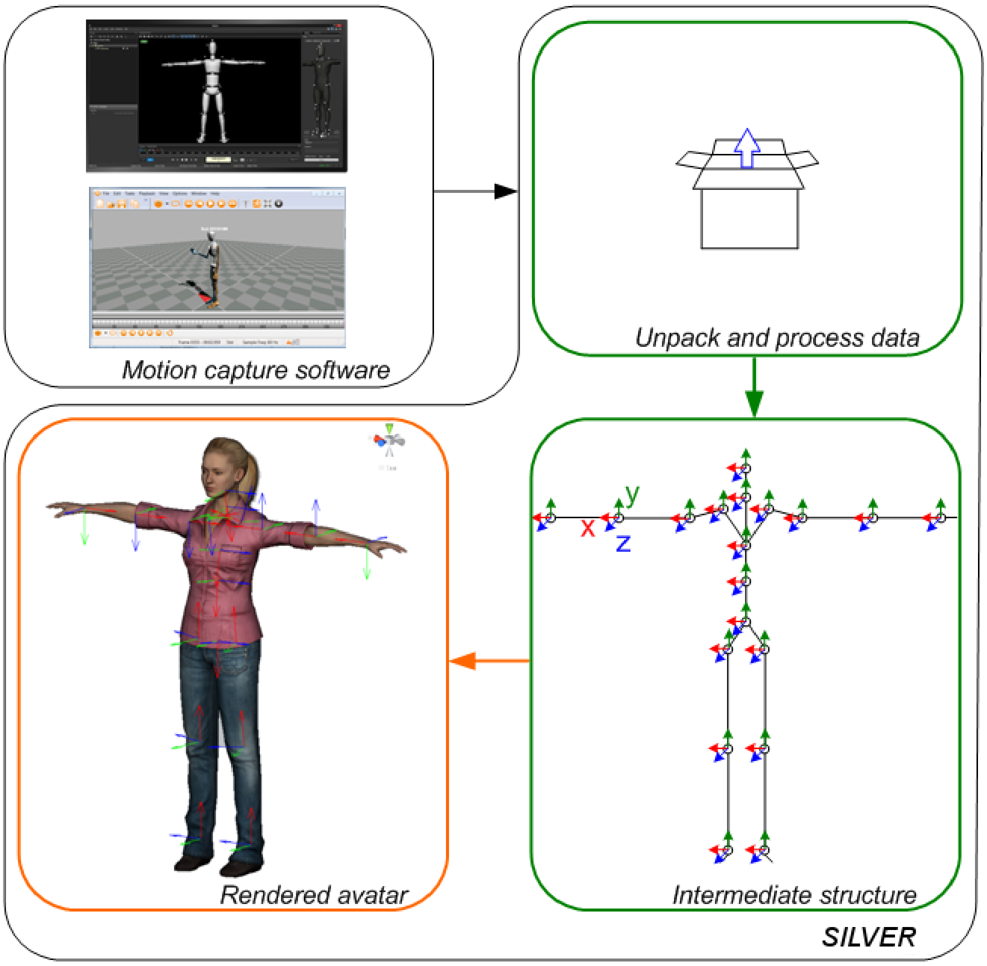

Figure 4.2: The tracking pipeline for body tracking. First transformation in green and second transformation in orange.

In most cases tracking devices' data does not match our convention. For example, some systems may deliver data expressed in Euler angles, or as local rotations, or even with a different bone hierarchy. Therefore, there is a need for a first transformation (Figure 4.2). After this first operation, we have tracking data retargeted into an IDS, which is not yet our goal. A second transformation is needed from the IDS to the rendered entity (an avatar, avatar's hands or rigid objects). There are multiple options to perform this operation that may include Inverse Kinematics (IK) or sophisticated filters to reduce noise and errors. The design of the library (Figure 4.3) allows for different user-defined implementations. For the purpose of this thesis, we implemented a fast retargeting method based on adding the rotation from the IDS to the initial rotation of each bone, performed as a quaternion multiplication.

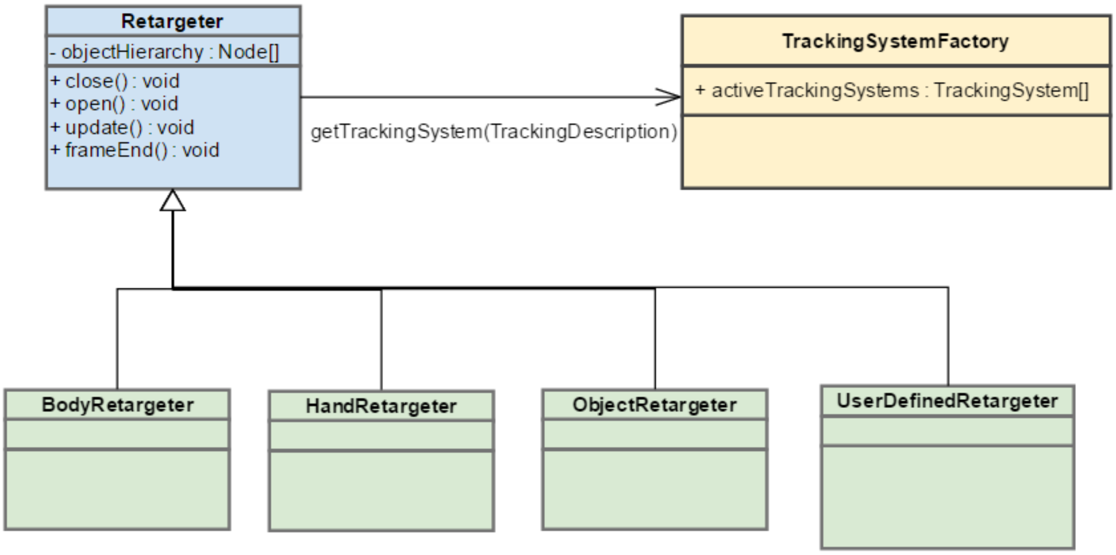

Figure 4.3: Class design overview of the retargeting pipeline.

Overall, this two-step retargeting design is very flexible in terms of support for new hardware devices, since only partial implementations are needed per device. More specifically, whenever a new tracking system is to be added, only two classes need to be reimplemented, and they can simply be wrappers of existing software. Similarly, if a user wanted to retarget tracking data to other types of entities (e.g. virtual animals), only a new Retargeter implementation would be needed.

However, this design by itself does not solve two issues that users may frequently encounter. The first one is the possible mismatch of hierarchies between avatars and IDS, and the second is the overlap of tracking systems (e.g. full body tracking that includes head tracking and a dedicated head tracking).

The first problem arises due to the lack of a standard to define humanoid avatar skeletons. Some authors (Fêdor, 2003; Kulpa et al., 2005; Lu et al., 2009; Monzani & Baerlocher, 2000; Multon et al., 2008) have attempted to solve this problem in a generic manner, typically through IK techniques. However, those methods tend to be slow and computationally expensive, making them less desirable for real time applications. During the implementations of this thesis we only encountered a substantial mismatch in the area of the neck, we opted for a specific solution for that region that performs a similar operation as a reparenting.

The second problem is a frequent one. Most, if not all, body tracking systems include tracking data for the head. At the same time, modern HMDs include high-precision and low-latency trackers for head motion. This means we have two sources of data for the same body region. On the other hand specific head trackers typically deliver higher quality than the ones included in full body tracking. This assumption is based not just in observation, but from the fact that, as we have seen in Section 2.1.2, high-quality head tracking is essential for high feelings of presence in IVR. SILVER allows the user to prioritize specific head tracking over body tracking by performing a sensor fusion algorithm that overrides body postures to match what head tracking data delivers (specifically head, neck and spine bones). On top of that, if that were not the case, i.e. body tracking data delivered high quality head tracking, a user would simply need not to add a separate head tracker.

4.3.2 CAMERA SUPPORT

With respect to how the library deals with virtual cameras, we follow a similar approach as that of tracking, i.e. device abstraction. Other authors, such as the ones responsible for AVANGO (Tramberend, 1999), have also presented similar designs. The idea is to define a hierarchy of virtual camera types (Figure 4.4).

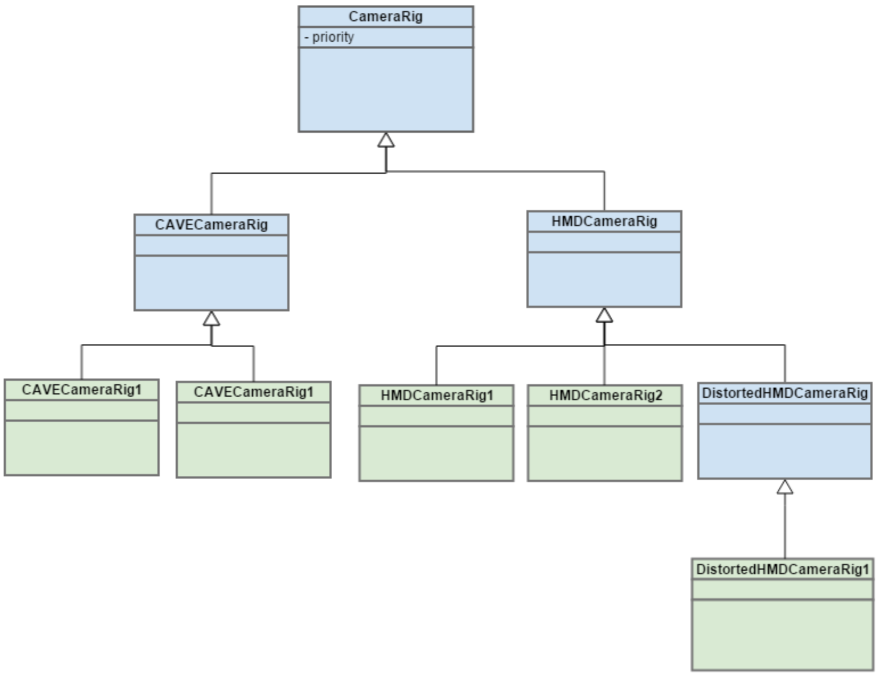

Figure 4.4: The class hierarchy of camera rigs.

In addition to the correct creation of cameras to provide stereo-vision, it is essential to place them in adequate positions. For example, a high degree of body ownership can only be achieved when participants are immersed in the virtual world in a 1PP from a virtual avatar (Maselli & Slater, 2013). Although this could be achieved by a manual or scripted operation, it would be a repetitive task that is avoided by built-in SILVER functionality, which analyses the avatar and places the virtual cameras in the midpoint between the avatar's eyes.

In addition to the positioning, many new affordable IVR displays are based on near-eye screens coupled with lenses to improve FOV. However, these kinds of setups introduce image distortions and chromatic aberrations that need to be corrected. Manufacturers usually include functionality to solve that problem, although typically bundled with their own products. We included a generic method based on Brown-Conrad model of distortion (Watson & Hodges, 1995):

$$x_f = k_1 x + k_2 x(x^2 + y^2) + k_3 x(x^2 + y^2)^2 + k_4 x(x^2 + y^2)^4$$

$$y_f = k_1 y + k_2 y(x^2 + y^2) + k_3 y(x^2 + y^2)^2 + k_4 y(x^2 + y^2)^4$$

Where, *(x, y)* represent the original location of the pixel, (x_f, y_f) represent the final transformed location of the pixel, and k_1, k_2, k_3, and k_4 represent lens parameters, defined by the lens optical properties.

If this method is not convenient, it can be replaced by others, including the ones provided by HMD manufacturers. In this thesis when we used the Oculus Rift we set the distortion method to be the one provided by Oculus. The nVisor SX111 did not need any undistorting mechanisms.

4.3.3 *IMPLEMENTATION*

One of the main implementation decisions was the language used to program the library. The design could have been implemented in many different ones, but we opted for C# to include multi-platform compatibility without need to recompile per-platform. In addition, it includes reflection features, which facilitates the implementation of several features. For example, device support discovery is carried out by detecting all available implementations of the TrackingSystem class, and a similar operation is done for CameraRig and all HMDs supported.

The other main decision was which development environment to use. We opted for a popular game engine, Unity3D, because of its native C# support and the simplicity of use of engine's editor. To couple the library's implementation with this environment we developed an extra thin layer that includes two components: SilverTracking (Figure 4.5) and VRCamera (Figure 4.6). These allow the user to set all the configurations and send start, stop and update callbacks to the library to initialize, close and acquire data respectively.

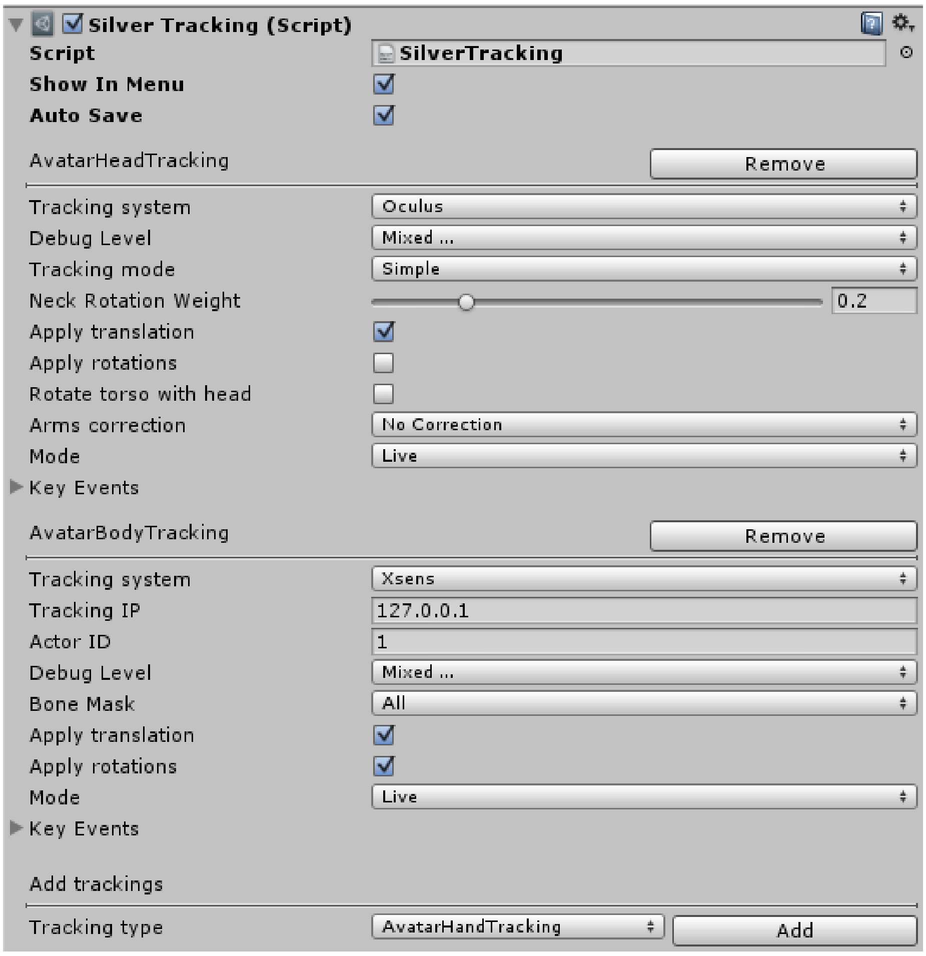

Figure 4.5: Tracking component in Unity3D.

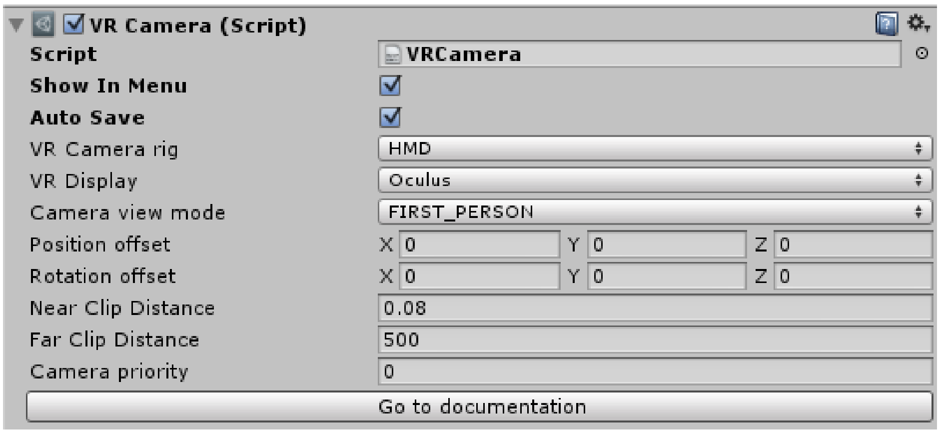

Figure 4.6: VRCamera component in Unity3D.

4.3.3.1 Integrated hardware

During this thesis we made use of several tracking systems and IVR displays. However, the library supports several other devices, detailed in Table 4.1.

Table 4.1: Working implementations for the specified hardware.

Body Tracking	Object or Head Tracking	Finger Tracking	Display	Robots
MVN Xsens	Oculus/GearVR	Leap Motion	Oculus/ GearVR	Robothespian
Optitrack Arena/Motive	Gyroscope	Perception Neuron	NVIS nVisor SX111	Aldebaran Nao
Perception Neuron	VRPN devices		VR2GO	
Microsoft Kinect 1/2	Optitrack Motive		Sensics ZSight	
			VR 1280	

4.4 Results

Given the design and implementation of SILVER, we expected it to be a very good system performance-wise. To evaluate that assumption, we designed a stress test and compare results with those of previous authors. The test focuses on the retargeting features, since the camera features do not affect the performance, and it also focuses on the stress of the CPU because that is where the retargeting happens.

The design of the test included an empty scene in which copies of an avatar with tracking applied would be added until the application's frame rate remained at a stable 50 frames per second. This was carried out in several platforms, including a computer with an Intel i7-2600 CPU, 4 GB of memory and an Nvidia GeForce GTX 580, running Windows 8.1 64 bits. Additionally, we ran the same application in two Smartphones, a LG Nexus 5 and a LG Nexus 4. The rendered avatar was chosen to be a low resolution one to avoid the GPU being the bottleneck, and had 775 vertices and 816 triangles[11]. Table 4.2 shows how many simultaneous avatars could be tracked per platform and tracking device.

Table 4.2: Performance test to evaluate the retargeting system. Maximum number of avatars rendered simultaneously with body tracking applied for each platform, while maintaining a stable 50 FPS framerate. Percentage of CPU used by tracking in parenthesis.

Body Tracking system	PC	Nexus 5	Nexus 4
MVN Xsens	389 (39%)	103 (24%)	72 (24%)
Optitrack Arena	375 (39%)	136 (29%)	85 (22%)
Optitrack Motive	370 (40%)	126 (27%)	80 (24%)
Microsoft Kinect 2	398 (36%)	-	-

[11] http://opengameart.org/content/base-human-models-low-poly-for-blender-25x

Even though the test was designed for the CPU to be the bottleneck, we can observe relatively low percentages of CPU use. This may be due to the amount of information having to travel from the CPU to the GPU in slow buses. Alternatively, it could be because of the amount of triangles being rendered, e.g. 65280 for the 80 avatars in the Nexus 4 when performing Optitrack Motive tracking, which may have saturated the GPU. It is likely that other tests which can focus even further on being CPU-limited would yield even better results.

These figures can be compared to other retargeting systems (Kulpa et al., 2005; Monzani & Baerlocher, 2000; Multon et al., 2008), which report either not working in real time or "up to a few dozen" avatars retargeted simultaneously. Our results show a considerable improvement.

Regardless of which of the hardware components actually limited the execution, compared to many previous approaches it shows an excellent performance. For example several authors (Kulpa et al., 2005; Monzani & Baerlocher, 2000; Multon et al., 2008) have developed approaches that can drive up to a few dozen avatars, and some do not even work in real time. In contrast, our results show our method can deal with hundreds of avatars with relatively modern hardware, and over a hundred in mid-end mobile devices.

With respect to the ease of use of the system we found no objective measures in the literature to evaluate it. A possible measure could be the number of projects that have used the system. In that sense, SILVER has been the basis of several published papers (Banakou et al., 2013; Friedman et al., 2014; Kokkinara & Slater, 2014; Osimo et al., 2015; Pizarro, Berkers, Slater, & Friedman, 2015), and several more are under preparation or in review process. It is clear that many of the developments stated in this Chapter, such as VRPN and VRJuggler, have enjoyed a wider adoption, although that may be explained by the fact that this development is not yet published while others have been so for a relatively long time.

4.5 Summary

This Chapter contains the software architecture design description of the library used throughout this thesis to develop the experiments detailed in following chapters. The SILVER library contains out-of-the-box features to develop IVR applications, such as virtual cameras support with a correct 1PP placement for avatars, real time tracking through several hardware devices and even support for telepresence with humanoid robots and real time video streaming.

For the purposes of this thesis, however, this Chapter only focused on the features related to IVR. We also reviewed some details of the implementation decisions and evaluated the performance of the library. Finally, we briefly reviewed the adoption of this development in the scientific community outside of this thesis.

The following chapters compose the main part of this thesis. In them, we detail the experiments carried out to provide the answers to the research questions stated in Chapter 1. Finally, we conclude by referring back to the contributions and reviewing how they have been realised.

5 TIME PERCEPTION AND MUSIC

5.1 Introduction

The goal of this Chapter is to evaluate the effects of manipulating background music tempo on time perception while immersed in IVR environments. There has been comparatively very little research in time perception using immersive technologies. Indeed, some authors (Schneider et al., 2011) already pointed out some of the potential benefits of using this technology to alter people's temporal perception, but it is still a relatively unexplored field. Outside IVR, several studies have examined various factors that affect our perception of time. These experiments generally apply more conventional technologies such as video or music playback. Other studies observed people´s behaviour in casual settings such as restaurants or queues (see Chapter 2.2). On the other hand, we know relatively little about which variables affect time perception while immersed in virtual environments. This Chapter attempts at examining a potential factor and providing an answer for the first research question of this thesis: *Does background music tempo affect time perception in IVR?*

In order to do so, we designed and carried out an experiment using IVR to observe the effect of background music tempo over time perception, a factor which has already shown to affect time perception outside virtual environments (North et al., 1998; Noseworthy & Finlay, 2009; Oakes & North, 2006; Oakes, 2003).

Overall, this experiment contributes mainly to the field of time perception. As we have seen in Section 2.2, knowing how people's temporal judgments respond to manipulations while immersed in virtual environments can be extremely important in many scenarios.

5.2 Background

The present study investigates the influence of musical tempo on participants' time estimation under a retrospective paradigm, addressing at the same time their attention, memory, quality of experience and physiological state in order to unravel underlying interactions. Given that most of the studies discussed in Chapter 2.2.2 related to time estimates and musical tempo were performed in uncontrolled environments, we used immersive technologies with which all the presented visual and auditory stimuli were reproduced in an identical way for every participant. Moreover, since several authors reported that people tend to have significant inter-individual differences when estimating time periods (Block & Gruber, 2014; Schatzschneider et al., 2016), we used a within groups experimental design. In two different conditions, participants were immersed in a virtual scenario that depicted a museum with visitors while the same musical piece with either fast or slow tempo background music was reproduced. We predicted that some of the participants would become aware of the purpose of the study after experiencing the first session and would, thus, behave as predicted by prospective models during their second experience. To assess this possibility, we controlled for the degree to which participants suspected they had to calculate time in the second experimental session.

We hypothesized that fast tempo background music would lead to longer perceived retrospective time-estimations compared to the slow tempo condition, given that more information will be stored and retrieved from memory when more Beats Per Minute (BPM) are provided. On the other hand, we expected participants who followed prospective models in the second half of the experiment to give shorter time estimates when being stimulated with a high tempo, since the number of stimuli of the non-temporal task would be higher compared to the amount of stimuli from slow tempo music. We further hypothesized that HR would be affected by the condition participants were assigned to, in line with Bernardi et al. (2006). Finally, we anticipated that participants who were not monitoring time would remember less details of the scene in the fast tempo condition, in agreement with the results of Oakes et al. (Oakes & North, 2006).

5.3 Materials and methods

5.3.1 Participant recruitment

Thirty-five participants (13 male; mean age: 21 years, range: 18-32 years) were recruited by advertisement around the University campus. Upon arrival, participants were given basic information of the experiment without revealing the purpose of the study and asked to sign an informed consent form. All participants answered a questionnaire giving demographic information before the experiment. Participants were asked to attend the laboratory on two different occasions separated by approximately one week, in order to avoid possible carry over effects between conditions. After completing the two experimental conditions, all participants were compensated with 10 euros, and debriefed about the purpose of the study.

5.3.2 Experimental design

We opted for a within-groups design where the only independent variable manipulated was the musical tempo, resulting in two conditions; slow and fast. Although experimental studies on time estimation typically opt for a between-groups design, our pilots revealed great inter-individual differences on time estimates. This motivated our within-groups design, where each individual experienced and calculated time for both conditions. The two conditions were presented in counterbalanced order.

5.3.3 *Ethics statement*

The study was approved and carried out in accordance with the regulations of the Bioethics Committee of the University of Barcelona. Participants gave written informed consent on a form devised for this purpose that had been approved by the said Committee.

5.3.4 *Equipment*

Participants were donned an nVisor SX111 Head-Mounted Display (HMD). This has dual SXGA displays with 76H°x64V° field of view (FOV) per eye, totalling a wide FOV of 111° diagonal, 102° horizontal and 64° vertical, with a resolution of 1280x1024 per eye displayed at 60Hz. Head tracking was performed by a 6-DOF Intersense IS-900 device. Physiological data was acquired using the GMOBIlab (g.tec, Guger Technologies OEG, Graz, Austria) for recording Electrocardiography (ECG) at 256 samples per second and storage of the HR data were handled by a custom Simulink model in Matlab. Participants wore Asus HS-1000W earphones over the HMD to listen to the musical stimuli.

5.3.5 *Musical pieces*

Musical stimuli for this experiment were obtained from the InfinitunesTM repository, powered by Melomics technology (Diaz-Jerez, 2011; Melomics, 2012). These themes are particularly useful for music studies, as they are newly composed by a computer and therefore, are less likely to elicit an emotional meaning. Two variations of a "chill out" electronic musical piece were developed; one at fast (150 BPM) and one at slow (50 BPM) tempo. Both were previously surveyed by an independent sample of 26 participants. Here, people were requested to listen to four musical pieces (two different electronic music themes, each reproduced at 50 or 150 BPM) and rate how fast they perceived the piece to be and how much they liked it on a 7 point Likert scale. The results show that the fast and slow versions of each theme are perceived differently in terms of speed. No significant differences were detected between the slow and the fast version of each theme in terms of liking or not the music. However, for the first theme, 13 participants showed a preference for the slow version of the theme with respect to its respective fast version, 8 participants preferred the fast version and 5 gave the same score. In contrast, for the other theme, 8 preferred the slow version, 7 preferred the fast one and 11 gave the same score. Therefore, we chose to use the second theme that more equally distributed likeness scores between the two versions.

5.3.6 *Virtual scenarios*

Two different instances of the same IVR scenario were developed, one for each session, to avoid participants getting habituated to identical events. Both depicted the same museum

(Figure 5.1) with several paintings hanging on the walls and virtual visitors (i.e. avatars) entering the room at a constant pace to look at the paintings. These virtual visitors followed pre-programmed paths, where they walked to and stopped in front of every painting and carried out a programmed animation. Slight differences were introduced, such as modifications in the physical appearance of the virtual human visitors, the paths they followed, and the paintings hanging in the museum's walls. However, the number of visitors and paintings were kept the same in order to ensure that the number of events and cognitive load were identical.

Figure 5.1: Virtual museum. During the experimental condition, participants saw a virtual museum with virtual characters walking inside and standing in front of the paintings for 7.5 minutes. Depending on the condition, participants listened to either slow or fast tempo background music..

5.3.7 PROCEDURES

During both sessions, participants were seated on a chair and donned an HMD through which they saw from a first person perspective a gender-matched avatar sitting in the same posture as themselves. In order to ensure that all participants received the same instructions, these were pre-recorded and provided through headphones. On their first visit to the laboratory, participants were alternatively assigned to the fast or the slow condition in counterbalanced order.

Each experimental condition started with the baseline measurement of the HR in a neutral virtual room (different from the virtual museum), and participants were instructed to relax for two minutes. Following this, the HMD display faded to black and participants were told that their task was to simply observe the scenario. They were informed that the study would start when they heard an auditory cue (beep), and that everything before that was not part of the actual experiment. Participants were then immersed in the virtual scenarios described above. After 450 seconds, a second beep was heard, the HMD display faded to black and then the HMD was removed. This time span was chosen to minimize rounding effects, since it falls in the middle of five and ten minutes. Immediately after each session, participants were asked to complete a questionnaire about their experience, where the first question was to estimate the elapsed time during the virtual experience.

Several extra questions were given to divert participants from guessing the true purpose of the study between the first and the second session. Since we opted for a within-groups experimental design and given that we aimed to use the retrospective paradigm for time estimation, it was crucial that participants did not suspect that they would be asked to estimate time during the second session. For this reason, additional items were inserted in the post experiment questionnaire (e.g. whether they would visit a virtual museum and under which conditions). To divert them even further, after the questionnaire of the first session participants were asked to complete an additional questionnaire that addressed their personality traits (NEO-FFI (Costa & MacCrae, 1992)). To address the effectiveness of the diversion, after the questionnaire of the second session participants were asked to fill in an additional questionnaire that addressed their time awareness, and explicitly asked them whether they had guessed the purpose of the experiment prior to the second trial.

5.3.8 PHYSIOLOGICAL SIGNALS ACQUISITION

ECG was obtained by a GMOBIlab device (g.tec—Guger Technologies OEG, Graz, Austria) and in this case three electrodes were collocated on the left and right collarbones and the lowest left rib of each participant. The physiological signals were processed and recorded in a Physio Recording Matlab Simulink Model at a sample rate of 256 Hz. Offline analysis of the physiological signals was performed using gBSanalyze from g.tec, customized in MATLAB (Mathworks, Inc., Natick, MA).

From the ECG signal the main measurement analysed was Heart Rate (HR), defined as beats per minute (bpm). To carry out ECG analysis we detected automatically the QRS (ventricular contraction) complexes in the ECG time series based on a modified Pan-Tompkins algorithm (J. Pan & Tompkins, 1985), followed by a visual inspection to correct missing or wrongly assigned points. Based on this method we determined the distance in time from one heart contraction to the next one (RR intervals).

Participants' HR was recorded during the baseline and during the experimental period for both conditions in order to assess any possible changes in their level of arousal produced by different musical stimuli. To ensure that participants' physiological state had been stabilized, only the average HR of the last 60 seconds was extracted and taken into account in the analysis. The average HR for the entire experimental period was then expressed as a percent of change with respect to the corresponding baseline. Specifically, the percentage of change was calculated based on the following formula: Percentage of change = (experimental HR – baseline HR)/baseline HR (Davidson, Scherer, & Goldsmith, 2003).

5.3.9 *RESPONSE VARIABLES*

A specific questionnaire was designed in order to address the perceived duration of the experimental period (between the two beeps), the degree of attention participants paid to the scene, time and music, the amount of information they could recall from the scene, their perceived familiarity, speed, likeness and appropriateness of the music in the museum context, and whether they were in a hurry that day or not. Each question was scored on a seven point Likert-type scale (Table 5.1). The main measure of the study was the subjective perception of the duration of each condition, something that could be influenced by environmental factors between the end of the experiment and its assessment. Therefore, the first question included in the questionnaire of each session was the time estimate (in hours, minutes and seconds) of the elapsed duration starting from the first beep to the second one. Additional items included to divert participants (e.g. NEO-FFI), were not included in the analysis.

Table 5.1: Post experiment questionnaire and corresponding response variable names. Each question after the first was scored on a 1-7 Likert scale, where 1 meant 'not at all' and 7 meant 'a lot', except for time estimation and paintings description.

Category	Today, during this first/second session...	Variable name
Estimation	How much time you perceived that the virtual reality experiment lasted (from the first beep was heard until the second beep)? Please include minutes and seconds.	estimation
Current state	How much in a hurry were you before starting the virtual reality experiment?	hurry
Attention	How much attention did you pay to the virtual reality experience, including the scenario and the music?	attentionAll
	How much attention did you pay to the music?	attentionMusic
	How much attention did you pay to time in this virtual reality experience?	attentionTime
Music characteristics	How much did you like the music in this virtual experience?	likenessMusic
	How familiar did the music seem to you in this virtual experience?	familiarMusic
	How much did you think the music was appropriate for this kind of museum?	appropriateMusic
	How fast did the tempo of the music you heard seem to you?	fastTempo

Virtual Reality	How boring did this virtual experience seem to you?	boringVR
	How much did you like this virtual experience?	likenessVR
	How much did you have the feeling that you were inside the museum?	presence
	How real did it feel the experience of being in a museum?	realism
	How fast did the time seem to pass during the virtual experience?	fastTime
Memory	How many virtual characters (avatars) were male, excluding the character representing you? How many virtual characters (avatars) were female, excluding the character representing you? How many paintings do you think there were in the top floor of the museum? How many paintings do you think there were in the ground floor of the museum?	memoryScore
	Please describe the paintings you remember (only those with specific details will count)	paintingsDescScore

Memory recall scores were calculated through participants' answers to various questionnaire items (Table 5.1). These items addressed their memory concerning various features of the virtual scene and were answered either numerically or by an open-ended question that asked them for a detailed description. Those descriptions were categorized by the experimenters in scores ranging from 0 to 2, depending on whether the description was inaccurate or very precise, respectively. This process was done blindly with respect to the condition, and experimenters only knew the phase and the descriptions.

Finally, in order to validate whether our method for diverting participants from the true purpose of the study was indeed effective in maintaining a retrospective paradigm in both sessions, we asked in a separate questionnaire (Table 5.2) with a 1 to 7 Likert scale whether they had suspected that they would be asked about time in the second session.

Table 5.2: Question regarding how much participants suspected about the goal of the experiment. This was a 1 to 7 Likert scale question.

Today, in the second phase of the experiment, before we asked you to estimate again the duration of the experience…	**abbreviation**
Did you have any suspicion that you were going to be asked to estimate the time?	*suspiciousness*

5.4 Results

5.4.1 *STATISTICAL ANALYSIS*

Statistical analysis was carried out using Stata version 12. Data sets and residual errors were assessed for normality using the Shapiro–Wilk test. Within groups differences were statistically compared with a random-effects linear model of time estimation on condition, considering *suspiciousness* as covariate and setting participants' ids as random effects. Between group differences in questionnaire responses were analysed using Wilcoxon Signed-rank tests.

5.4.2 *POST EXPERIMENTAL QUESTIONNAIRE*

Table 5.3 shows participants' scores for the questionnaire items and for each condition. Participants rated the fast tempo music as significantly less appropriate for the context of the museum (Wilcoxon Signed-ranks test, $z = 3.318$, $p<0.001$) and perceived it as significantly faster in comparison to the slow tempo condition (Wilcoxon Signed-ranks test, $z = -4.630$, $p<0.001$), without any significant difference in the likeliness and familiarity with the pieces. With respect to the attention statements, participants paid attention to the virtual scene and music in both conditions without any significant differences. Concerning the virtual scene, participants rated with a high score the degree to which they liked the virtual scenario, and reported strong sensations of realism and being inside the virtual museum. The virtual environment, however, was judged as slightly more boring in the fast condition compared to the slow one (Wilcoxon Signed-ranks test, $z =-2.341$, $p=0.019$) with both medians though being low. No other significant differences were found.

Table 5.3: Subjective Ratings per condition (n=35). This shows medians (interquartile ranges) of the questionnaire responses for the Fast and Slow conditions.

Questionnaire Item	Slow condition	Fast condition	p-value (Wilcoxon signed-rank test)
hurry	3(3)	4(3)	0.139
attentionAll	6(2)	6(0)	0.764
attentionMusic	5(2)	6(1)	0.211
attentionTime	3(2)	4(2)	0.285
likenessMusic	4(2)	4(3)	0.240
familiarMusic	5(3)	4(3)	0.250
appropriateMusic	5(2)	3(4)	**0.001**
boringVR	3(2)	4(2)	**0.019**
likenessVR	5(2)	5(1)	0.080
presence	5(1)	5(1)	0.342

realism	5(1)	5(2)	0.653
fastTime	5(1)	4(3)	0.520
fastTempo	3(2)	5(1)	**0.000**
memoryScore	0.83(0.5)	0.67(0.5)	0.941
paintingsDescribedScore	9(9)	6(8)	0.566

5.4.3 Time estimations

Duration estimations in the slow condition (M=525.7s, SD=302.5s) and in the fast condition (M=531.4, SD=284.6s) are not significantly different (Wilcoxon Signed-ranks test, z=-0.14, p=0.890). Moreover, time estimations are not significantly correlated with any of the questionnaire items. The range in time estimates can be observed in Figure 5.2, which show the histograms of participants' estimations as a whole, and also grouped by condition.

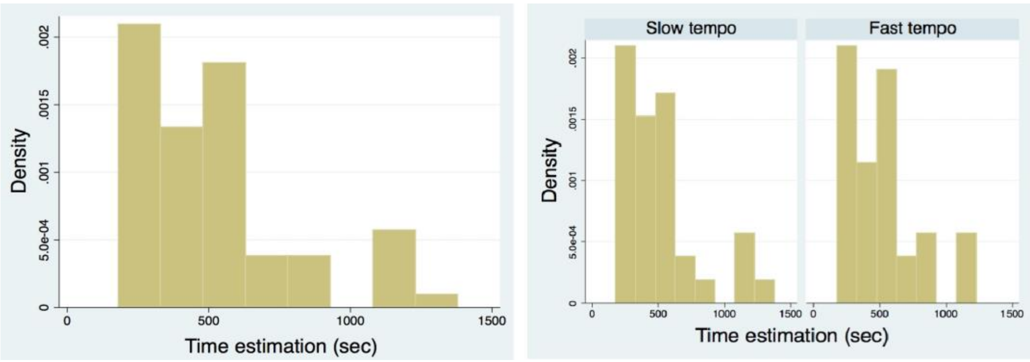

Figure 5.2: On the left the overall histogram of time estimations. On the right the histogram of time estimations by condition.

Given that if the participants suspected that the experiment was related to time perception this would play an important role in time estimations, we analysed these by taking into account the scores of suspiciousness. Since participants rated this statement only after the second condition, we assumed that during the first condition no subject suspected the purpose of the study and hence, monitored time accordingly; that is, in the first condition we set the value of suspiciousness to one (the minimum) for all participants.

We then performed a random-effects linear model of time estimation on condition, considering suspiciousness as a covariate, and setting the participants as random effects. There is a trend for condition (z = 1.79, p=0.073), no main effect of suspiciousness (z=0.54, p=0.59), and a trend for the interaction between condition and suspiciousness (z = -1.82, p = 0.069), but the residual errors are not normally distributed (Shapiro Wilk test, p<0.001). Visual inspection of the data led to the exclusion of 3 individual values (Figure 5.3).

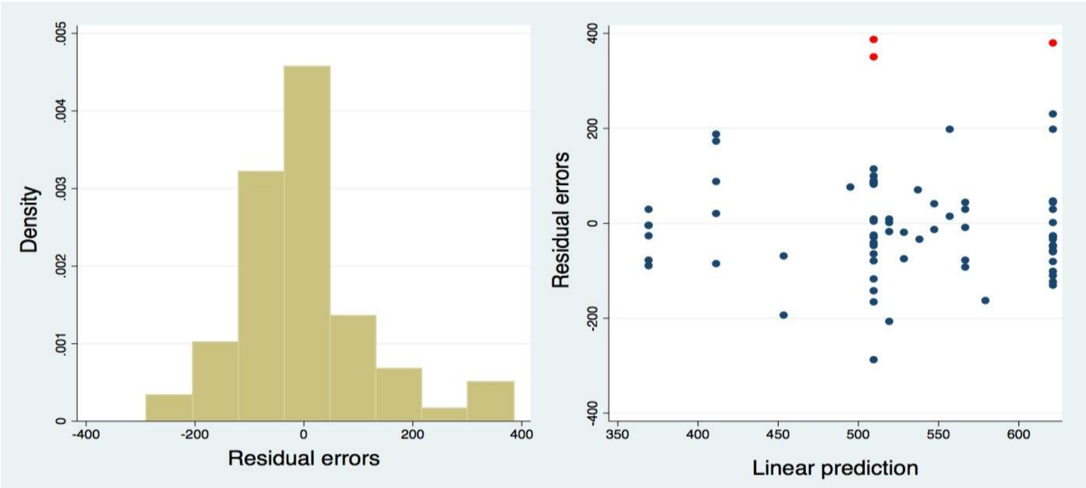

Figure 5.3: Left: Histogram of the residual errors after performing a random-effects linear model of time estimation on condition with suspiciousness as covariate. Right: Scatterplot of the residual errors with the linear predictions. Three outliers are detected, marked in red.

Excluding these outliers, we found a significant main effect of condition (z= 3.06, p= 0.002) with the fast tempo condition leading to longer perceived durations compared to the slow tempo one. There is also a significant interaction between suspiciousness and condition (z = -2.96, p = 0.003) with increasing values of suspiciousness reducing the time estimations in the fast condition. Residuals are now normally distributed (Shapiro Wilk test p = 0.52). Figure 5.4 shows a scatterplot of time estimations by suspiciousness per condition, without the three outliers.

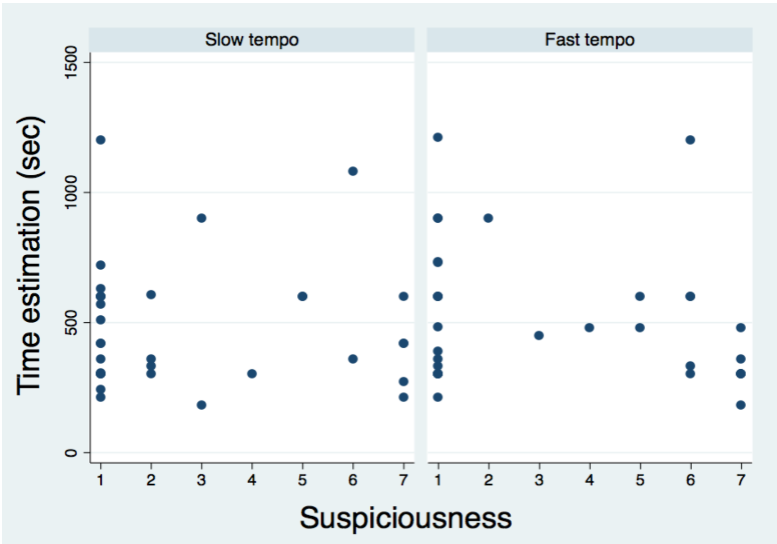

Figure 5.4: Scatterplot of estimations on suspiciousness per condition, without the three outliers.

The model suggests that fast background music leads to longer duration estimates with respect to slow when there is not time monitoring. Nevertheless, these estimations become shorter the more participants are aware of the purpose of the study, i.e. monitor time.

Running the same analysis but setting the suspiciousness values to 3 instead of 1 in the first session (as a more conservative view), gives similar statistical effects.

5.4.4 *HEART RATE*

Eight participants were excluded from this analysis due to bad or incomplete HR registrations. HR data for the remaining 27 participants while they went through the 2 conditions generated 54 values. One outlier was detected and removed, and since this was a within design we removed the data for both conditions. Fifty two of the values indicated changes in HR, ranging between -0.1 and +0.2 percent of change over the baseline. There are no significant differences between slow (M=0.022, SD=0.05) (2.2% change) and fast (M=0.035, SD = 0.04) (3.5% change) tempo conditions (Wilcoxon Signed-ranks test, z = -1.003, p = 0.3158, n=52). Figure 5.5 shows the scatterplot of time estimations by the percentage of HR change. Additionally, a correlation analysis revealed a positive correlation between HR changes and time estimates: rs(50) = 0.38, p = 0.005.

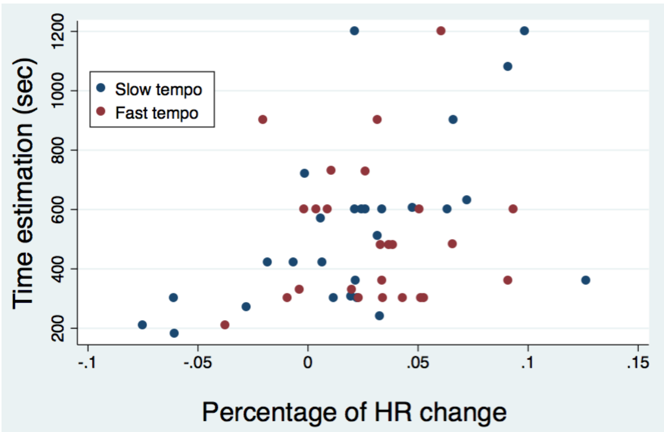

Figure 5.5: Scatterplot of time estimations over percentage of HR change data, with the outlier removed (n=52). The percentage of HR change is significantly correlated with time estimations.

5.5 Discussion

This study focused on the influence of background music tempo on time perception, by using an IVR scenario. Additionally, we investigated the effects of music tempo on memory recall and physiological state, variables that have been related to time perception in previous studies. Our results indicate that participants reported longer durations in the fast tempo condition compared to the slow tempo condition when they did not suspect that they had to estimate time. Finally, we found a positive correlation between HR changes and time estimations, which indicate that an increase in physiological arousal is related to longer self-reported time estimates. In the following paragraphs, we discuss our findings in relation to the literature around time perception.

Our results related to music tempo seem to be in accordance to several studies (Caldwell & Hibbert, 1999, 2002; North & Hargreaves, 1999; Oakes & North, 2006), which found that tempo had no effect on time estimates. However, a more detailed analysis reveals that when grouping participants who reported being aware of the time task and those who did not, we find that tempo did indeed influence time perception. This deeper analysis is in line with the memory-based and contextual-change models (Block, 1990; Ornstein, 1969) for the retrospective paradigm, which suggests a positive relationship between the quantity of stored stimuli in memory and time estimations. In the present study, the difference in BPM between the two musical pieces appears to be sufficient to form different sets of stored events and lead to different temporal estimates. Furthermore, the analysis revealed that being aware of the purpose of the experiment, and therefore monitoring the elapsed time, reduces time estimations. This is in line with the prospective AGM model (Zakay, 2000) and Scalar Timing Theory (Russell M. Church, 2003) that suggest a negative relationship between the attention paid to non-temporal tasks and time estimations. In this sense, results indicate that the fast tempo music distracts the pacemaker involved in monitoring time and this leads to shorter perceived durations. However, during this analysis we discarded three samples before reaching significance. This severely weakens the conclusions drawn from the results, and therefore results should be confirmed by similar future studies.

With respect to questionnaire responses, participants rated the music significantly more appropriate for a museum in the slow tempo condition, and significantly more boring in the fast one. To our knowledge, neither appropriateness nor boredom have been shown to affect time perception. Additionally, participants rated the background music tempo as faster in the fast tempo condition, as expected.

In the present study, we also investigated whether music tempo affects memory recall, but we did not find a significant correlation. This could be explained by the fact that many of the participants experienced the second session under a prospective paradigm. However, based on our experimental design we cannot reliably extract this conclusion. Further studies should focus on elucidating the precise relationship between memory recall and tempo under a retrospective paradigm.

One novel contribution of our study is that we additionally investigated the relationship between music tempo, physiological signals and time estimates. Previous studies (Meissner & Wittmann, 2011; Schwarz et al., 2013) aimed at establishing a connection between physiological arousal and time perception under the prospective paradigm, motivated by theoretical models, which predict the existence of a pacemaker. In the memory-based or contextual-change models (Block, 1990; Ornstein, 1969) on the other hand, there is no theoretical pacemaker and thus no expectation for cardiovascular activity to correlate with time estimates. We did, however, find a positive correlation between HR change and time estimations. It could be interpreted as a relationship between change in physiological activity and time estimations, which indicates that time estimation may be affected by physiological responses regardless of the paradigm and external stimuli. However, nearly 25% of the observations were not available or removed and therefore these findings are not robust enough to make strong conclusions. Also, we did not find any significant differences in HR between the slow and the fast tempo conditions, in contrast to other studies (Bernardi et al., 2009, 2006), that showed that faster background tempo leads to an increase of HR. This could be explained by the lower level of participants' engagement with the music, since in our study they were immersed in a virtual reality system while in theirs they had their eyes closed and only focused on music.

Furthermore, an important contribution of the present study concerns the employed methodologies for studying time perception. How people perceive and calculate time has been shown to be influenced by numerous factors including both environmental stimuli as well as participants' internal state (Block et al., 2010; Droit-Volet & Meck, 2007). Especially concerning experimental studies that opt for the retrospective paradigm, the number of the presented stimuli (e.g. visual, auditory, and tactile) should be under the full control of the experimenters. On the other hand, some studies have showed IVR is a suitable solution for many studies since IVR applications can consistently reproduce the same stimuli, allowing for diverse real-life scenarios under strict experimental control, while preserving a high ecological validity. While some authors have already used this technology to study time perception (Bruder & Steinicke, 2014; Schatzschneider et al., 2016), there are comparatively very few studies using this type of hardware. In addition to the setup, our design includes two computer-generated musical pieces, which differ only in the tempo. Since several studies have found a variety of musical factors that affect time perception, we believe that minimizing the differences between musical pieces is fundamental. For this reason, we consider that further studies examining relationships between music and temporal perception should replicate our methodology.

Finally, regarding the research questions of this thesis, this experiment attempted at answering the first one: *Does background music tempo affect time perception in IVR?* However, our results are non-conclusive. We could not find a relationship between background music tempo and time perception, and we also cannot conclude that there is none. Future studies could find a relationship in the prospective paradigm, or even in the retrospective one changing the experimental design. In the following Chapter we describe a further experiment aimed at examining a potential variable to affect time perception.

6 Time perception and embodiment

6.1 Introduction

In the previous Chapter we examined whether background music can alter one's perception of time. Even though the results were not conclusive, as we have seen in Section 2.2, time perception can be affected by many different variables. A factor we wished to explore in this direction is the type of one's virtual body representation.

An earlier study found that spatial perception is altered by the shape of the embodied virtual avatar (Banakou et al., 2013). In that experiment, 30 adult participants were embodied in a virtual four-year-old avatar and a scaled-down version of an adult body that matched the height of the toddler avatar. The results of this experiment indicated that the shape of the body does influence spatial perception. Therefore, it could be the case that virtual body shape also affects temporal perception.

Following that idea, this Chapter analyses the second research question of this thesis: *Does body shape affect time perception in IVR?* We hereby present a study designed to examine whether participants' perception of time is affected by the shape of the avatar they embody while they are immersed in IVR.

Overall, this experiment contributes mainly to the field of time perception and embodiment. The results of this study add knowledge of the relationship between the shape of participants' embodied virtual avatar and temporal perception.

6.2 Background

In the child embodiment experiment of (Banakou et al., 2013) the movements of the avatar synchronously matched those of the participant. Additionally, the authors included another two control conditions (asynchronous conditions), identical to the two initial ones except for the fact that the virtual avatar movements did not match the participant's.

The results showed similar high levels of body ownership in both synchronous conditions (embodied as adult or child). With respect to size perception, participants overestimated object sizes compared to a non-embodied baseline, significantly more when they were embodied in the virtual child than when they embodied the scaled-down version of the adult. In the case of the asynchronous conditions, however, no differences in size perceptions were found between the adult and child body. This suggests that the shape and looks of the embodied avatar influences spatial perception, provided there is a strong sense of body ownership. Other authors (Noë, 2004; Proffitt, 2006; van der Hoort et al., 2011) had previously found a relationship between spatial perception and virtual avatars' relative scale. Furthermore, several studies also show an association with scale and temporal perception (DeLong, 1980; Mitchell & Davis, 1987). However, the findings in (Banakou et al., 2013) go one step beyond since they show that the shape of the avatar increases this perceptual distortion. This suggests the idea that there is a high-level cognitive process that links perception to body shape.

In (Banakou et al., 2013) authors also observed a behavioural change in participants. In particular, they measured through a personalized IAT a shift of attitudes towards more child-like attributes, which indicates that not only was perception affected by the embodied avatar, but so was behaviour. This is in line with several other studies that found for example, how embodying an avatar of a different race reduced implicit racial bias right after the exposure (Maister, Slater, Sanchez-Vives, & Tsakiris, 2014; Peck et al., 2013), or induced changes in their behaviour (Kilteni et al., 2013). The underlying hypothesis for this powerful phenomenon is that, at some unconscious level, the brain does not distinguish between physical and virtual reality, and after as little as a few seconds it accepts the seen virtual body as one's own. At that point, there is a transfer of self-attributes towards that body and a transfer of the expected behaviour of the seen avatar towards one's attitudes.

Therefore, seeing and controlling a virtual body from first person perspective has an impact on spatial perception. The question that arises is whether this is the case for temporal perception too. Recent behavioural and neurodevelopmental studies have examined the differences between how adults and children perceive time (Droit-Volet, Meck, & Penney, 2007; Droit-Volet, Ramos, Bueno, & Bigand, 2013; Droit-Volet, Tourret, & Wearden, 2004). In these, the authors conclude that although children do have a sense of time, it is much more variable than that of adults. However, this is a relatively unexplored subject with little evidence available. Moreover, to our knowledge, there is no study that observed interindividual changes based on age.

In order to examine these changes, we designed a further experimental study. Our prediction was that high-level cognitive changes that participants endured in the experiment described in (Banakou et al., 2013) would reveal an equivalent effect in temporal perception. In particular, given the evidence in prior experiments involving time perception in children (Droit-Volet et al., 2007), we predicted that participants would overestimate the length of a session when embodying a child compared to when embodying an adult avatar. We also wished to explore whether there was an equivalent change in the opposite direction, i.e. when participants got older, with no particular expectations whatsoever. In what follows we describe the study we conducted and the main findings.

6.3 Materials and methods

6.3.1 *PARTICIPANT RECRUITMENT*

Thirty-two participants (15 male; mean age: 22.7 years ±2.93, range: 18-31 years) were recruited around the University campus through advertisement. Participants were given basic information of the experiment upon arrival (Appendix: Time perception and embodiment), consisting of a general description of the equipment and the fact that they would perform a task. The purpose of the study was not revealed. They were also asked to sign an informed consent form and to complete a form giving basic demographic information before the experiment.

6.3.2 *EXPERIMENTAL DESIGN*

Participants were embodied in an adult body, a child body, or an elderly body. The embodiment sessions were divided in two groups:

- Child-Adult: n = 16, each participant experienced an adult or a child body in counter balanced order.
- Elderly-Adult: n = 16, each participant experienced an adult or more elderly body in counter balanced order.

During each session participants performed a task adapted from (Slater, Sadagic, Usoh, & Schroeder, 2000). Participants were located in a room where some walls displayed a set of words in random order. The task was to compile the words into a well-known phrase or saying.

Each participant did this twice, once embodied in an adult body, gender-matched and approximately the same age as themselves, and the other in the child or elderly body. We refer to the child or elderly body as the 'Other' body.

6.3.3 *ETHICS STATEMENT*

The study was approved and carried out in accordance to the regulations of the Bioethics Committee of the University of Barcelona. Participants gave written informed consent on a form devised for this purpose that had been approved by the said Committee.

6.3.4 *EQUIPMENT*

During the virtual experience participants wore a NaturalPoint Optitrack suit (Figure 3.4), and were also equipped with an Oculus DK2 (Figure 3.1B), as in one of the setups described in (Spanlang et al., 2014). The instructions were pre-recorded audio files, played through a YAMAHA speakers system.

6.3.5 *VIRTUAL SCENARIO*

The virtual environment participants were immersed in depicts a big room with minor decorative elements. Three mirrors were placed in that room surrounding the participants' position. The mirrors were distributed so that they could see themselves reflected in at least one of them at all times (Figure 6.1).

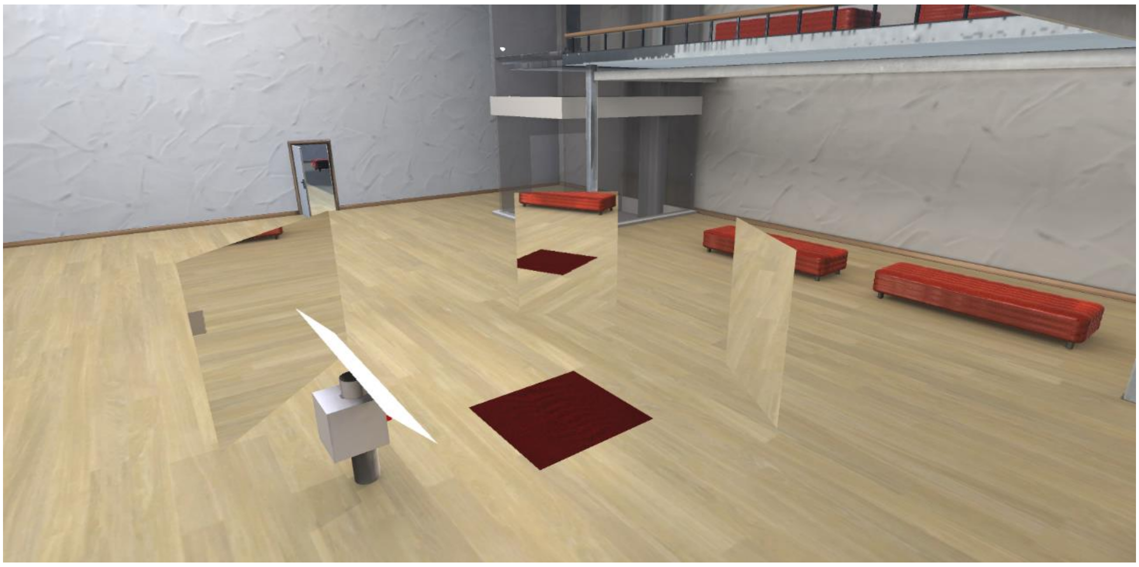

Figure 6.1: The virtual room. Contains three virtual mirrors that surround the participant and a panel.

The experiment and scenario was implemented in Unity3D version 5.2.0f3. The runtime version of Oculus' SDK was 0.6.0.1, and the software to control all the tracking systems was SILVER (Chapter 4). The adult and old-looking avatars were taken from the Rocketbox library[12], and the child avatars were generated using DAZ3D[13].

[12] http://www.rocketbox.de/
[13] http://www.daz3d.com/

Figure 6.2: Avatars embodied by participants. On the left, the child avatars. In the middle the adults and on the right the old-looking virtual avatars.

6.3.6 *PROCEDURES*

Participants were assisted putting on the tracking suit and the HMD after they filled in the consent form and the demographic questionnaire. Subsequently, they were immersed in the virtual scenario. They then heard the audio recordings explaining the structure of the experiment. They were told that the experience was divided in two sessions in which they would perform the same task. This assignment was adapted from (Slater et al., 2000), and consisted of compiling words in the correct order to form a known phrase or saying. The words appeared randomly in different positions across the room (Figure 6.3 right side), and as they were selected they were displayed on a panel in front of the participant (Figure 6.3 left side). Once the sentence was complete, the panel was cleared and the same process started again. The recording also explained how they could amend any mistakes, should they need to.

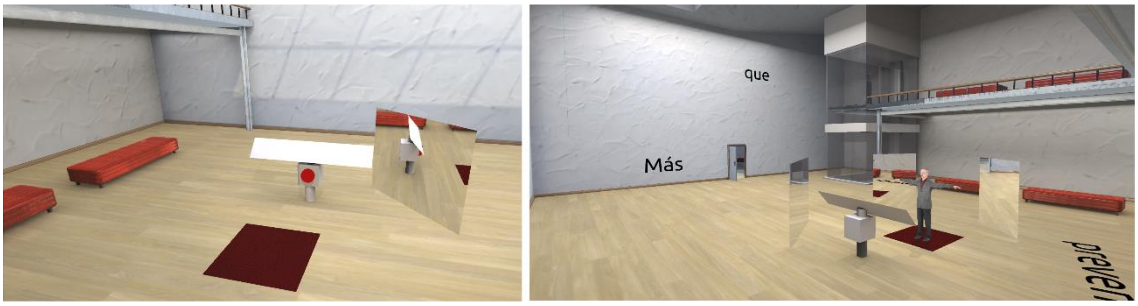

Figure 6.3: The virtual scenario in which participants were immersed. On the left, the virtual room with the panel where words are displayed after being selected. On the right, an avatar embodied by a participant, surrounded by mirrors and words placed randomly around the room.

Every time a sentence was completed, a red rectangle on top of one of the mirrors would be displayed (Figure 6.4), and participants were instructed to face that mirror and perform some movement with their arms. While listening to the instructions, participants did not have a virtual body, but they could see a pair of hands collocated with their real hands, with the help of the body tracking system.

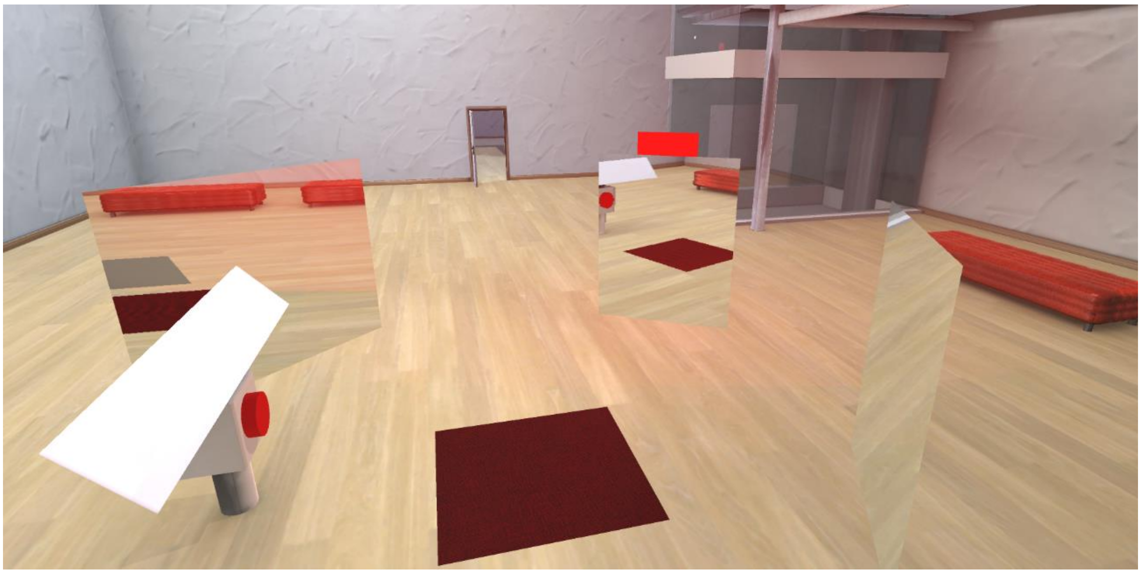

Figure 6.4: A red square over one of the mirrors is lit. Participants are instructed to look at their body in that mirror and perform some motions with their arms.

After listening to the instructions participants were told to practice compiling a few sentences until they felt familiar with the interaction. When the experimenter judged that the subject was comfortable enough with the task, they were asked if they wanted to move on to the next stage. If participants agreed, they started the embodiment session in which they saw a virtual body from 1PP moving synchronously with their real body, whilst another recording instructed them to perform several motions for a few minutes in front of a mirror. The avatar they saw depended on the condition, and was either a gender-matched child, young adult or an elderly adult. The movements included looking directly at their own virtual body and also through their reflection in the mirror. The goal of this section was to make participants aware of their virtual body that they could naturally control. When the set of movements was successfully performed, participants were told that the first session of the experiment would start immediately after an auditory cue.

This session lasted 200 seconds regardless of participants' performance, and they had to perform the task they had practiced at the beginning. Another auditory cue signalled the end of that session, and then the environment disappeared. At that point the body ownership and agency questions (Appendix: Embodiment questions) were shown directly on the HMD, and participants responded verbally.

Participants were immersed once again in the same environment, only this time they embodied a different avatar. The rest of the procedure was identical. As before, when the session was over participants answered the embodiment and agency related questionnaires, as well as some additional questions, including a forced binary choice as to which session they felt lasted longer and how confident they were of that answer. They were also asked how enjoyable they thought the task was, and finally some standard presence questions (Appendix: Presence questions).

6.4 Results

6.4.1 Body Ownership Illusion

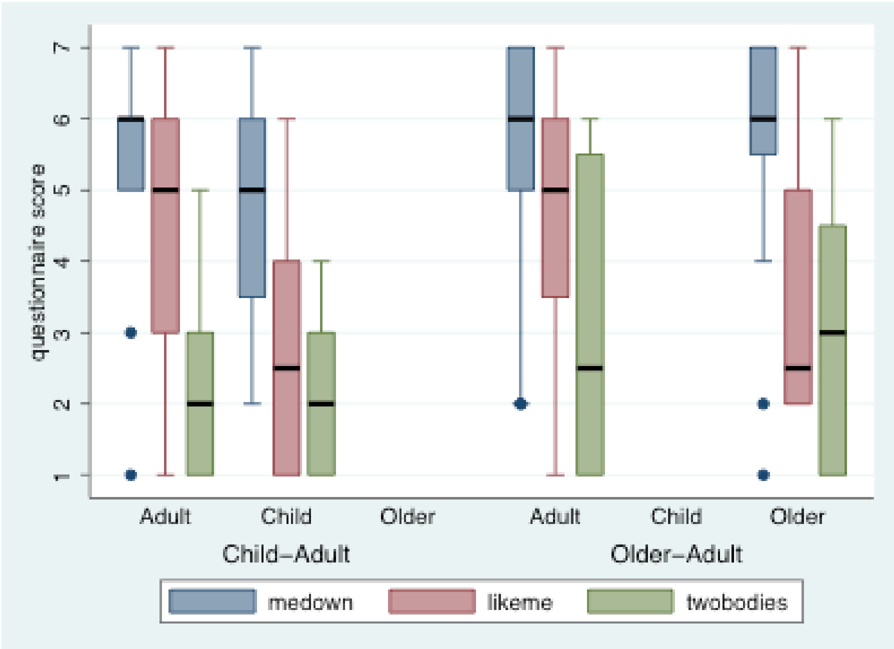

Figure 6.5: box plot of body ownership questions.

Results on body ownership are summarized in Figure 6.5. The boxplot shows the subjective scores for the question *medown* (how much they felt as if the virtual body they saw was their own) and the two control questions *likeme* (how much they felt the body was similar to theirs in appearance) and *twobodies* (how much they felt as if they had two bodies). Those questions were formulated in a 1-7 Likert scale where 1 means maximum disagreement and 7 maximum agreement with the presented statement.

We can conclude from the figure that participants had a high sense of body ownership across all conditions. With respect to the *likeme* question, we can observe coherence since the highest values correspond to the young adult body condition in both groups, which is to be expected since participants were young adults too. The other control question, *twobodies* is clearly different from the *medown* question.

These results indicate that the setup (1PP + visuomotor synchrony) was sufficient to elicit a strong illusion of body ownership regardless of the body type, as it has been found in many other previous studies (see Chapter 2.1.3).

6.4.2 *Task Performance*

The two variables related to performance are *wordselections* and *completesentences*. The former is the number of word selections during a session, and the latter is the number of sentences that were correctly completed in a session.

There is a strong correlation (Spearman's rho = 0.60, $P < 0.00005$) between the two values, as expected. Figure 6.6 shows a scatter diagram of the two values. An outlier with 59 word selections but only 4 complete sentences can be seen in the diagram.

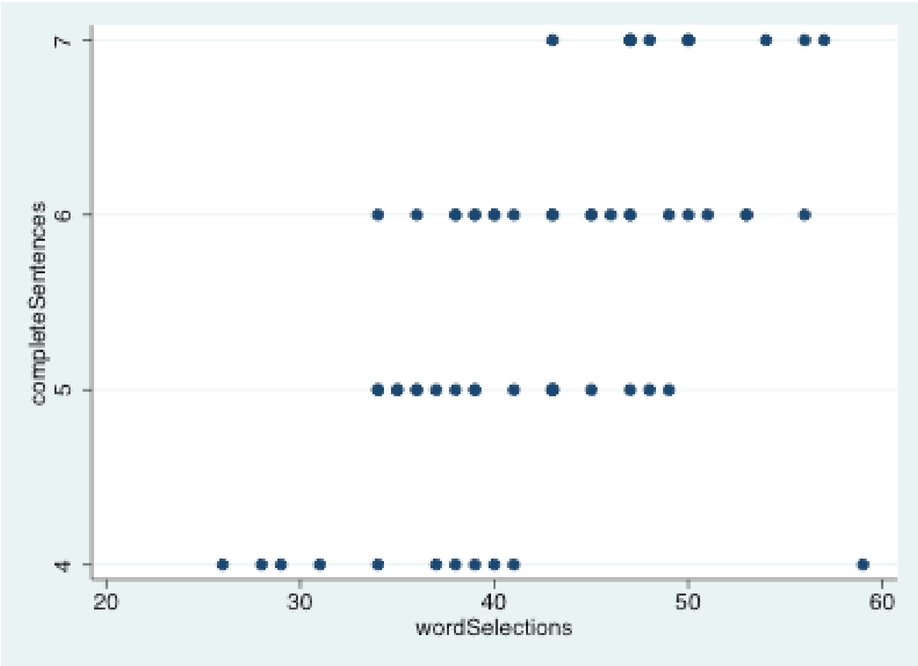

Figure 6.6: Scatter diagram of completeSentences on wordSelections.

We are interested in examining the influence of the body type in performance. The variable to do so is the number of word selections (*wordselections*) divided by the number of completed phrases in a session (*completesentences*), and we refer to it as *wordrate*. The performance is inversely proportional to this variable, since a greater number means that participants tried more words before correctly completing one sentence.

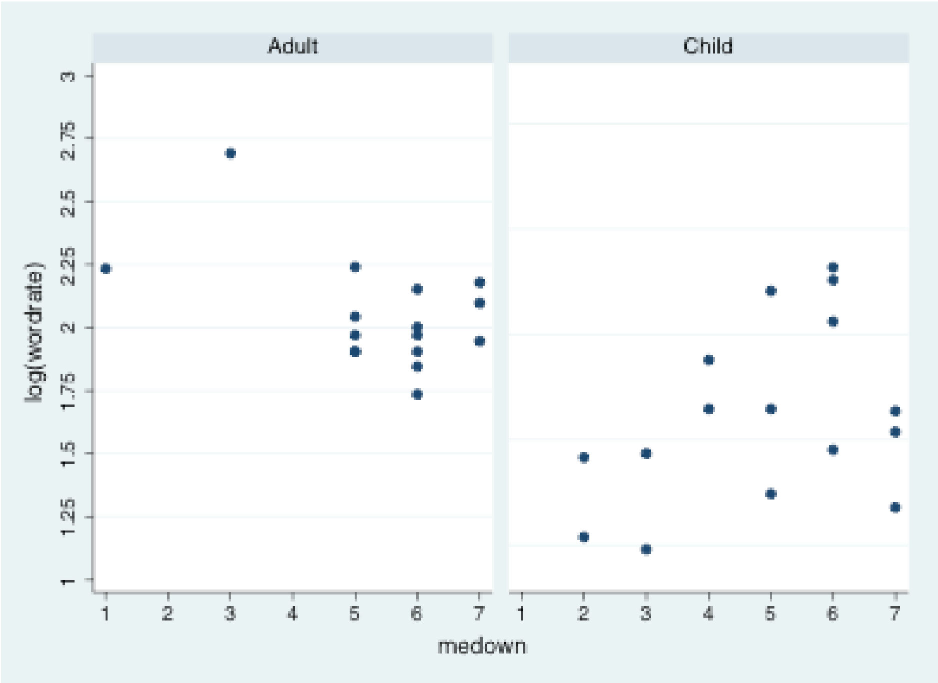

Figure 6.7: Scatter diagram of wordrate on medown by BodyType for the Child-Adult group. Wordrate = wordselections/completesentences. (The outlier in Figure 6.6 is excluded).

Figure 6.7 is the scatter diagram of log(*wordrate*) on *medown*, and it indicates that greater body ownership values result in lower *wordrate* when embodying a young Adult avatar. In the case where a child is embodied, the tendency is the opposite.

We performed a mixed effects Poisson log-linear model having *wordselections* as the dependent variable and offset *completesentences.* Body Type (Adult = 0, Child = 1) is the fixed effect, and random effects over the individuals. This analysis means that the effective response variable is log(*wordselections*/*completesentences*). We conservatively use 'robust standard errors', which gives greater standard errors of estimates, in order to allow for possible model violations.

Table 6.1: Mixed Effects Poisson log-linear Regression of *wordselections* on Body Type and *medown*. The offset term is *completesentences* (Wald Chi-Squared(3) = 10.29, P = 0.016)

Term	Coefficient	S.E.	Z	P	95% CI	
Constant	-0.10	1.05	-0.09	0.925	-2.15	1.95
Body Type (Adult = 0, Child = 1)	-3.10	1.38	-2.24	0.025	-5.81	-0.39
medown	-0.39	0.18	-2.24	0.025	-0.74	-0.05
BodyType×medown	0.68	0.25	2.72	0.007	0.19	1.17

Table 6.1 shows the results, which match Figure 6.7. In particular, the interaction term indicates that there is a positive relationship between body ownership and *wordrate* for the Child Body Type, an association which is negative for the case of Adult Body Type.

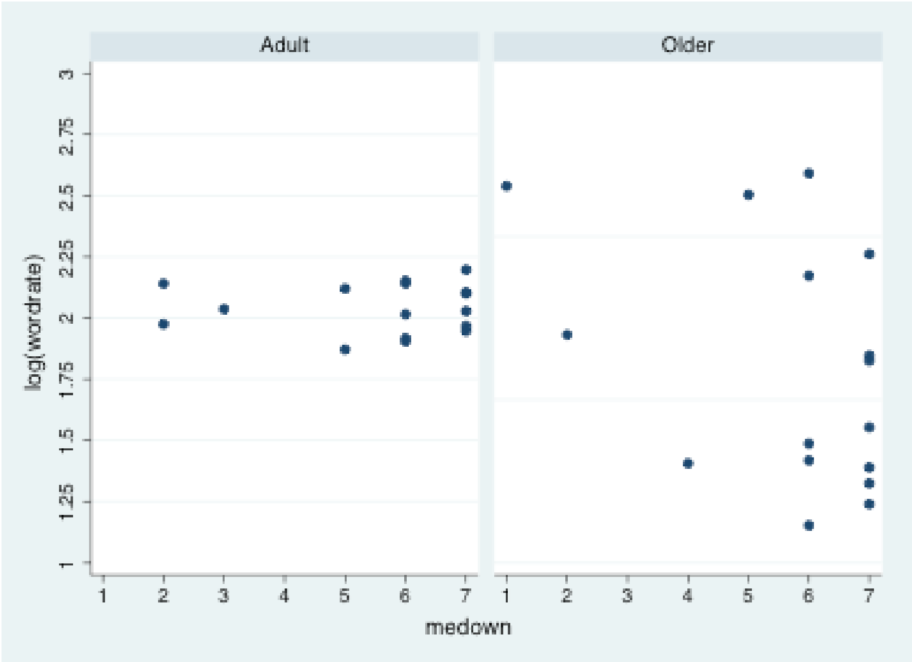

Figure 6.8: Scatter diagram of *wordrate* on *medown* by BodyType for the Older-Adult group. Wordrate = *wordselections/completesentences*.

We performed the same analysis for the Older-Adult group. In Figure 6.8 we can observe a possible negative relationship between body ownership and *wordrate*, opposite to what we found in the Child condition, and in this case, no relationship in the Adult condition. The interaction term has significance P = 0.096, and the two main effects with P > 0.06. The overall Wald Chi-Squared(3) = 3.77, P = 0.29. On eliminating the interaction term nothing is near significance (the two main effects have P > 0.25, and the overall Wald P = 0.52).

These last results suggest that the two leftmost points in Figure 6.7 in the Adult panel, are outliers and therefore there is no relationship between body ownership and *wordrate* for the Adult Body Type. In fact, that would make more sense since participants are young adults in real life and thus no apparent reason for them to improve performance with greater ownership of the Adult body. A possible explanation could be that the low level of body ownership was a distractor that reduced the performance. Taking that into account, Figure 6.7 and Figure 6.8 suggest that the log(*wordrate*) is approximately 2 for the Adult body regardless of the level of body ownership.

We can conclude that while there is evidence to support that the embodying a child affects performance, there is not enough to make the same assessment between Adult and Older body.

6.4.3 *Time Perception*

Table 6.2: Answers to Forced-Choice Question about the Perceived Duration of Each Session. Other = Child in the Child-Adult condition and = Older in the Older-Adult condition.

	Which session took longer?		
Group	**Adult**	**Other**	**Total**
Child-Adult	9	7	16
Older-Adult	7	9	16
Total	16	16	32

Table 6.2 shows the results of the forced-choice question. Given the scores we can conclude that Body Type does not influence the choice of which of the two sessions were longer.

Participants also rated how confident they were about the choice on a scale of 0 to 1, where 1 would be absolutely certain. In fact values are at least 0.5 because otherwise they would have chosen the alternative session.

In this case we are interested in examining whether there is a relationship between the confidence level and the illusion of body ownership for those who chose the session in which they embodied the 'Other' body. Figure 6.9 points to the idea that there is such an association, and that it is positive (n = 16).

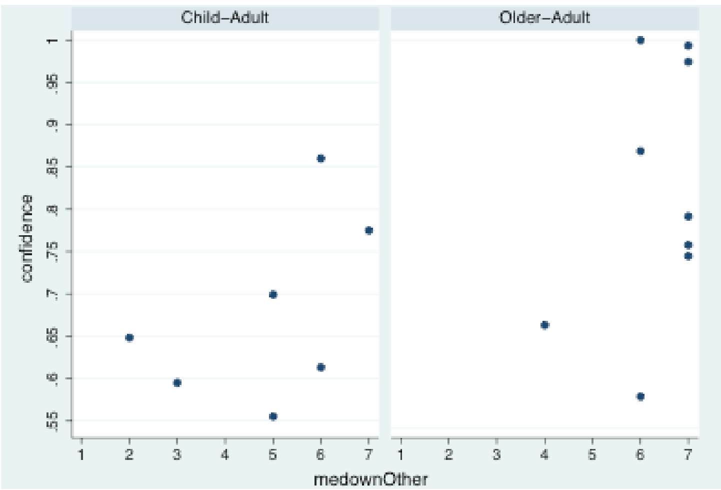

Figure 6.9: Scatter plot of confidence of choice of Other (Child, Older) amongst those who made this choice, by the corresponding level of *medown*.

A regression of *confidence* on *medownOther* and Group does not have a significant interaction nor significant main effect for Group. However, eliminating group results in the coefficient of *medownOther* as 0.05 ± 0.023 with 95% confidence interval 0.003 to 0.01. With robust standard errors P = 0.005, with normal standard errors P = 0.04, effect size $\eta^2 = 0.27$. When using log(*confidence*) instead of using *confidence* (to iron out some of the more outlying points above) then the normal model has P = 0.038 with 95% CI (0.005 to 0.13).

We can conclude that although the choice of the session which felt longer was not influenced by the Body Type, the confidence with which they made the assessment may be influenced by the level of body ownership over the embodied avatar. In particular, the greater the illusion of body ownership over Child or Older avatars, the greater the reported confidence in the choice of the session perceived as longer.

6.5 Discussion

We can extract three main results from this experiment. The first one is that a strong illusion of body ownership is achieved even if the virtual avatars' bodies look very different from the participants' real bodies. In this case participants embodied either a child, a young adult or an elderly adult, with no significant differences among them. Embodying one or the other did, however, affect the performance on the task in conjunction with body ownership. In particular, we found that the greater the body ownership while embodying a child, the worse is the performance. The opposite trend was observed in the Older condition, although not significant. In the Adult condition, on the other hand, performance does not correlate with body ownership as would be expected. Finally, with respect to time perception, we did not find a relationship between body type and the choice of which session felt longer. Nonetheless we did find that participants with higher subjective scores of body ownership were significantly more confident of the choice. In the following paragraphs we discuss these findings in greater detail.

The results on body ownership confirm our expectations and are in line with several previous studies (Banakou et al., 2013; Kilteni et al., 2013, 2015; Kilteni, Normand, et al., 2012; Maselli & Slater, 2013). Indeed, we have seen that visuomotor synchrony coupled with a 1PP can be enough to elicit strong body ownership illusions even if there is a great difference between the participants' real bodies and the embodied avatars. Given those previous studies we could predict that subjective body ownership scores would be high across all conditions and without significant changes among them.

With respect to the performance differences found, we can hypothesize several explanations. As we have seen in other studies, a change in body appearance can be associated with alterations in behaviour and cognitive capacities. In (Osimo et al., 2015), for example, participants who embodied an avatar that looked like a well-known person for his wisdom (in that case Dr. Sigmund Freud) provided better solutions to their own personal problems. The authors hypothesized that a high level of body ownership over the wise avatar could open access to some mental resources, rarely available in physical reality. Another study (Kilteni et al., 2013) showed how Caucasian participants were significantly more active in their movement patterns while drumming when embodying a dark-skinned avatar. Based on those results we could speculate that participants in our study could have had their abilities, either motor or mental, affected while embodying a child.

Nevertheless, this hypothesis does not account for the results in the Older condition. Elderly people are associated with experience and wisdom, particularly with well-known phrases and sayings, and we could have predicted that participants with higher levels of body ownership while embodying an elderly adult would perform better. In contrast, older individuals are also thought of as people with low mobility and motor coordination issues. Such problems could affect the overall performance, since the assigned task required constant limb movements. We could have therefore predicted lower performance scores for participants with great body ownership levels. Since the effects are contradictory, they might have cancelled out, which would explain the lack of significance in the Older condition. Alternatively, it could be that the task was too easy to see significant improvements, and therefore get a ceiling effect. Future studies could expand on this by further refining the task, e.g. designing a complex cognitive task with no body movement required.

Finally, in terms of how participants perceived time, unlike our prior expectations, the analysis did not reveal a temporal equivalent to what some authors had observed for spatial perception changes (Banakou et al., 2013; Noë, 2004; Proffitt, 2006; van der Hoort et al., 2011). In particular, they had found that shrinking participants' avatars in relation to the environment led to objects size overestimations. Interestingly, in (Banakou et al., 2013) the authors found that embodying a child had a stronger effect over this distortion in spatial perception compared to embodying an adult-shaped body of the same size. This phenomenon led them to believe that there is an underlying mechanism that connects perception to body shape.

We hypothesized that participants would see their temporal perception altered through the same high-level cognitive process. In particular, we anticipated that participants would overestimate the length of a session in the condition where they embodied a child compared to the Adult condition. With respect to the elderly adult versus younger adults we had no particular expectations. The analysis, however, clearly contradicts this hypothesis. Participants did not perceive any condition as longer than the rest. Furthermore, our results seem to contradict those of earlier papers (DeLong, 1980; Mitchell & Davis, 1987). In our case though, participants were not virtually scaled down in any condition. In other words, the scale in which the virtual environment was displayed was not modified, which explains the divergence between those earlier results and ours.

Additionally, we found a significant association between the confidence in the choice and the illusion of body ownership. Nonetheless, the interpretation of this last result is not trivial. We can only speculate that participants who provide high subjective levels of body ownership are usually more engaged and present in the virtual environment, and much more confident about the answers to questions about what happens in the virtual world they are immersed in.

In conclusion, we have seen that the same process that affected spatial perception in participants in other experiments (Banakou et al., 2013; Noë, 2004; Proffitt, 2006; van der Hoort et al., 2011) is not triggered for temporal perception in our setup. However, the experiment presented in this Chapter does not rule out the possibility of existence of a high-level cognitive process associated with time perception. Such a mechanism could exist, but according to our results it would not be related to body self-attributes. After performing this experiment, we predict that if it does exist, it could be affected by temporal manipulations, e.g. altering the pace of time in a virtual environment. Future studies could examine this prediction to validate it.

In relation to the second research question of this thesis - *Does body shape affect time perception in IVR?* - the experiment presented in this Chapter is non-conclusive, as the study described in Chapter 5. So far we can only conclude that there is not enough evidence to establish a relationship between time perception and body shape. On the other hand, our results cannot rule out the opposite either. Future studies could find the association with different or more extreme manipulations of the body shape. In the next Chapter we report the experiment carried out to answer the third research question.

7 A VIRTUAL TIME TRAVEL ILLUSION

7.1 Introduction

Many authors have explored the intricacies of time travel from the point of view of literature and multimedia. Classical movies such as *Back to the Future* or *The Terminator* have put the mechanics of travelling to the past or the future at the centre of their plots. Usually all the intrigue stems from changing something in one time dimension to improve the outcome in another time dimension. However, such circumstances raise scientific and philosophical issues (Dowe, 2000; Grey, 1999). The most notable of the time travel complications is the grandfather paradox, where one would travel to the past and kill one of his or her own ancestors. As a result, that person would never be born and therefore not travel back in time to kill the ancestor. One of the solutions found in the science fiction literature is creating parallel universes or timelines and protagonists would jump from one to another. Other solutions can be found in the literature too (see (Deutsch, 2011) for extensive review).

Perhaps because of the current lack of means to experience time travel and due to the complexities associated with it, research on the subject has focused mainly on determining whether the phenomenon could be actually possible or not from the physics standpoint. On the other hand, as mentioned in Chapter 2.1, IVR has previously opened the door for researchers to study the behaviour of people in situations that would be impossible or unacceptable in the physical world. For example, it has been used to study the field of moral dilemmas (Pan et al., 2011; Pan & Slater, 2011) in which participants faced the dramatic choice of sacrificing one person to save five others. Other examples include the virtual reprise of the Milgram experiment (Slater et al., 2006), threatening body parts or even out-of-body experiences (Lenggenhager, Tadi, Metzinger, & Blanke, 2007; Pomés Freixa et al., 2013).

This Chapter analyses the third research question of this thesis: *Is there a novel illusion in IVR that can provide the feeling of having travelled back in time?* We present an exploratory study designed to examine whether participants immersed in IVR can experience a backwards time travel illusion. In addition, we report a further experiment carried out with the aim of exploring applications for the results of the first one.

This experiment contributes to basic knowledge in behavioural psychology, specifically with contributions to the field of moral dilemmas, and also to the field of mental time travel, with a new and different approach and methodology. Additionally, the opening the door to future research in different forms of treatment that use similar procedures as the proposed in the following Sections.

7.2 Background

As mentioned in the introduction, IVR has been a key technology for studying human behaviour in fields that were previously enclosed with theoretical and questionnaire-based studies. In the area of moral dilemmas, for example, experiments were mainly based in texts where participants imagined a situation and the experimenters offered a limited amount of answers for the subject to choose. On the other hand, as reviewed in Chapter 2.3.1, a recent study (Pan & Slater, 2011) immersed participants in IVR in a similar situation as the classic trolley scenarios (Foot, 1967; Thomson, 1971) and observed their behaviour. The findings of that experiment were in line with previous results, thus strengthening the idea that IVR is a powerful and appropriate tool for behavioural research.

IVR scenarios typically exploit the three types of illusions described in Chapter 2.1: presence, body ownership and agency. Researchers have shown surprising effects associated with high levels of those illusions. For example, the authors of (Peck et al., 2013) observed a reduction in the implicit racial bias after embodying Caucasian volunteers in a dark-skinned avatar for a few minutes, and other experimenters (Kilteni et al., 2013) reported behavioural changes after a similar operation (see 2.1.3 for more details). What those experiments and many others have in common is that the effects are usually correlated with presence and body ownership illusions. Therefore, unravelling new illusions could lead to the discovery of novel effects. In this Chapter we attempted at studying the illusion of backwards time travel.

Even though the time travel illusion is a novel concept in the virtual reality community, some of the difficulties involved have already been explored in other fields. Our approach is a simulation of time travel to the past, which, as overviewed in Section 3.2 is implemented by recording the participants' inputs (motion and voice) while the subject is embodied in an avatar and replaying those inputs later on another avatar that represents the past instance of the participant. In order to be effective, this approach requires a precise synchronization between all the different timings: the motion playback, the sound playback and the current execution. If those fall out of synchronization, an observer could see how body language does not match voice, or feel that the other avatar moves and speaks at a strange pace. These situations would destroy the Plausibility Illusion and therefore break the feeling that the participant is actually experiencing what the virtual scenario depicts.

Furthermore, one of the most relevant features of IVR is the possibility of interaction with virtual objects in a given scenario. In our case, this adds another layer of complexity with respect to synchronization during time travel. Objects in a scene not only must respond to participants' interactions, but also to the participants' past ones. The approach taken for avatars is not applicable for objects, since there is no tracking associated to them. Moreover, a bespoke solution for each object is not desirable if we want scenarios with multiple dynamic elements that respond to events occurring in the scene.

Distributed games have solved similar challenges to synchronize gameplay across multiple distributed clients. Some solutions involve authoritative centralized servers and dumb clients, concentrating the logic and effort on the server (Steed & Oliveira, 2009). While this approach can be valid in many cases, whenever network latency increases, it can cause clients to receive the server's resolutions to conflicts too late, causing visible corrections between the client's state and the server's state. Another strategy, lockstep synchronization (Steed & Oliveira, 2009), ensures that all the clients have the same state before continuing. This approach is better suited when behaviours want to be kept always deterministic, but can cause the execution to halt in all clients if a client disconnects or cannot keep up with the rest. This solution, however, is much better suited to our needs: we are synchronizing two copies of a virtual history separated in time in a single machine, we do not have disconnection and performance issues, but we cannot accept unpredictable behaviours. With this in mind, we designed the time travel application as two separate layers that run separately and are synchronized by lockstep.

Synchronization alone, however, does not solve the issue of sorting the conflicts that may appear when past participant's actions contradict current ones, in other words, when a participant is trying to change the past. A possible option could be automated reasoning about digital narrative. While this solution was not adopted in this study, it has been previously used to sort similar challenges that concern narrative consistency, typically by means of AI (Artificial Intelligence) methods such as planning (Mott & Lester, 2006; Riedl & Young, 2006; Young & Riedl, 2003).

In the following Section we describe the methods and procedures of our experiment. We introduce two conditions, *Time Travel* and *Repetition*. We detail the precise approach taken and the differences between conditions, along with the methods employed to induce the time travel illusion in participants to end showing the results and discussing about them.

7.3 Materials and methods

7.3.1 THE SCENARIO

The designed virtual scenario depicted an art gallery in a museum (Figure 7.1) with two floors, a lift, and a platform that contained several buttons, a clock and a mirror (Figure 7.2). This configuration is based on prior work (Pan & Slater, 2011). Participants were instructed to take the museum visitors to the upper floor using the lift when they requested it.

Figure 7.1: The virtual art gallery. On the bottom right the platform where participants interacted with the scenario.

The lift was operated through two buttons on the platform, marked with an up and a down arrow, and a red button, which stopped the lift and also activated a set of alarms that consisted in red blinking lights distributed around the gallery and a loud beeping alarm sound (Figure 7.2). Participants received haptic feedback when they pressed any of those buttons. The clock always started at 12:00 and was updated at a real time pace. The mirror was also updated to reflect the movements of participants so they could have visuo-motor synchrony. The remaining objects in the table were non-functional and were added for decoration purposes only.

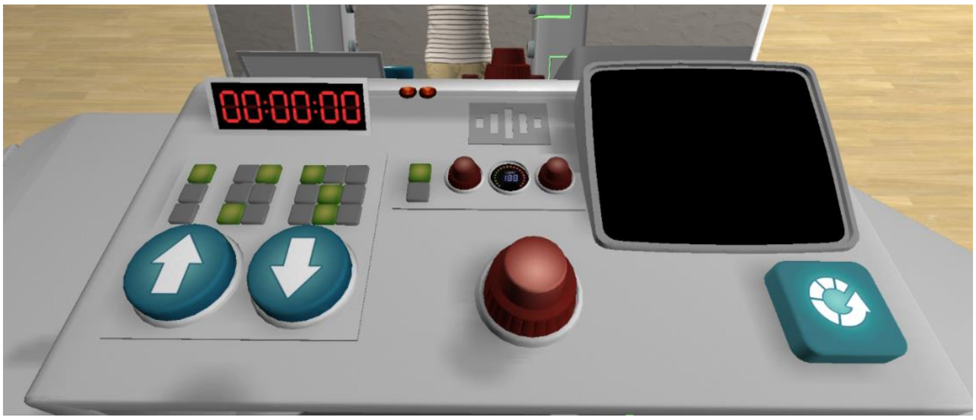

Figure 7.2: The platform. On the left the buttons that send the lift up and down. In the center the red button that stops the lift and triggers the alarm. On the top, the mirror. On the top left a clock.

When the experiment began, virtual visitors started entering the gallery and five of them requested participants to take them to the upper floor. Another avatar entered the room and stays on the ground floor browsing the paintings. Later, a seventh person entered the gallery, requested to be taken upstairs and, on arrival he immediately pulled a gun and started shooting at the people in that level (Figure 7.3) while still standing on the lift.

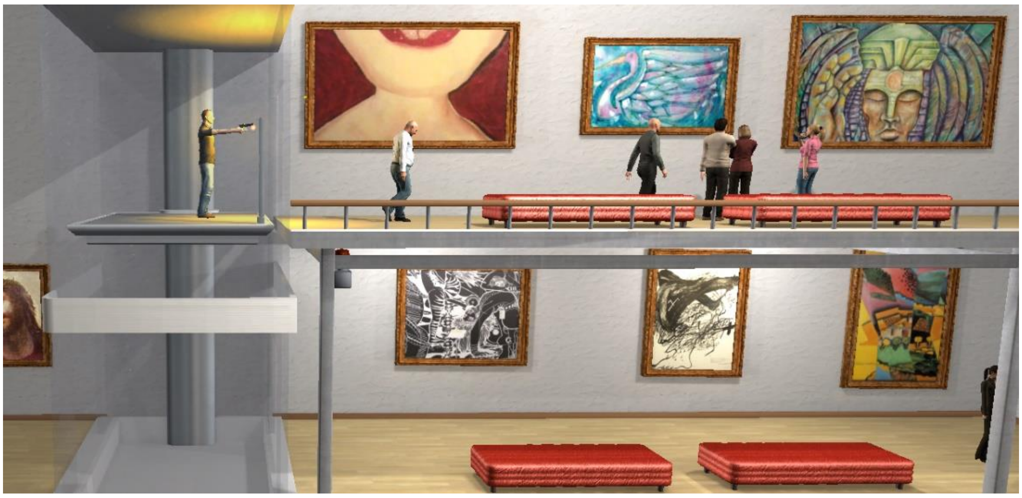

Figure 7.3: The seventh visitor starts shooting at the people on that level, while still standing on the lift.

At this point, the participant had several options: move the lift towards the ground floor – potentially endangering the person in that level – pressing the alarm – which would have no real effect on the situation since the gunman is already shooting – or doing nothing. After a few moments the situation stabilized (depending on the option chosen by the subject) and the scene fades out. Right after that, the participant was taken back to the start, right before the first visitor entered the room.

It is in that moment when the differences between conditions became apparent. In the *Repetition* condition, there was no change and all the events happened as in the first phase.

During this second phase, participants could change the outcome based on their recent experience. In the *Time Travel* condition, on the other hand, participants could see and hear past actions represented by another avatar, looking exactly as the avatar they embodied (Figure 7.4). If participants took no action in the second trial of this condition, events unfolded exactly as they happened before. In both conditions there were three trials.

Figure 7.4: Time travel condition. The participant (standing on the platform) is looking at her previous clone.

In the following Section we describe in detail our approach with respect to the implementation of the time travel illusion, which applies only to the *Time Travel* condition.

7.3.2 REPRESENTATION OF TIME TRAVEL

To deal with the synchronization issues and maintain coherence between timelines in a simple and generic manner, we designed two levels of abstraction: the narrative layer and the IVR layer. The narrative layer deals with a high level description of the scenario and events, and the IVR layer has a low level description of the virtual world, dealing with all the details of the IVR rendering and simulation. In what follows we describe both layers.

7.3.2.1 The narrative engine

This layer was designed by Dr. Doron Friedman and implemented Keren-or Berkers. One of the primary goals was to be generic and reusable for different applications. However, some parts are dependent on the specific scenario and should be reformulated for other situations. We define four concepts in our model: entities, history, states, and events. Entities are any dynamic objects or humans in the scenario (static objects like decoration are irrelevant to our model and are not discussed). We distinguish three types, simulated differently:

- Objects, which follow deterministic behaviour.
- Agents, i.e. simulated human beings. These entities can trigger events.
- The participant. This entity is free to interact with any other entity at any time, and there is always exactly one. When a participant goes back in time, an agent is created which performs the previous interactions with the scene.

These entities have states with their own state variables: the variable definition is application-dependent, although generic objects could be defined shared across applications. The entities in the elevator scenario and their corresponding state variables are described in Table 7.1.

Table 7.1: Entity state variables.

Entity	Variable 1	Variable 2
Visitors	Location	Life
Elevator	Location	Motion
Alarm	State	
Shooter	Location	Gun state

For this application there are four possible values for location: outside, ground floor, inside elevator, or upper floor. Additionally, there are two possible motion values: moving or stationary. Finally, the gun state can be pulled or hidden, and the alarm state value can be on or off. Although the participant and agents generated from time travel are essential to this application, they do not need to have state variables.

History is modelled as a sequence of events. The possible events are described in Table 7.2:

Table 7.2: The events defined in the narrative engine for the time travel scenario.

Entity	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6
Visitors	Enter gallery	Enter elevator	Wait in elevator	Exit elevator	Watch paintings	
Shooter	Enter gallery	Enter elevator	Wait in elevator	Shoot	Pull gun	Hide gun
Alarm	Toggle (on/off)					
Participant and clones	Press Up	Press Down	Press Alarm			
Lift	Start going up	Start going down	Stop			

More specifically, a history *h* is a combination of an initial state *s0* and a sequence of events *E*: {*s0*,*E*}. The state at any given point of the history can be calculated deterministically by sequentially applying the events, starting from *s0*. All events are treated in this layer as instantaneous, so an event *e* is associated with a specific time t_e. However, in the IVR layer events may trigger animations that are not instantaneous, and may contain visually separate states. Let us consider the action of shooting: in the narrative layer this could be a single event, but in the IVR layer this is decomposed into two different animations, pulling the gun out of a pocket and shooting. Displaying a shooting without pulling the gun out would cause a very important visual break in continuity that would in turn break the Plausibility Illusion, and if the gun is already pulled, then it should not be pulled out again. To handle such situations, events are split to match the animations.

All events have a set of preconditions and post-conditions. Those conditions are a combination of the state variable *r* of an entity *n* and one of the possible values of the variable *v*, expressed as <*n,r,v*>. Given a precondition <*n,r,v*>, an event *e* can only occur if at time t_e, the value of the variable *r* of entity *n* is equal to *v*. Similarly, having <*n,r,v*> as a post-condition of *e*, then after applying *e* the value of variable *r* of entity *n* is set to *v*.

We can distinguish three types of events, each for a type of entity:

i) Events triggered by autonomous agents.

ii) Events triggered by the participant.

iii) Events that affect inanimate objects.

Events triggered by agents do not have any specific treatment. On the other hand, as mentioned earlier, participants can take actions that trigger events at any time, i.e. pressing lift and alarm buttons, so preconditions are always met. Finally, events that affect inanimate objects are not needed in the history, since they can be deterministically computed by the other two classes of events.

The objects' behaviour is based on state machines. The state machines are designed specifically for each object, therefore this step is also application-dependent. Nevertheless, the engine supports any configuration of state machines provided they meet two basic requirements: they cannot initiate events, and they must always respond deterministically based on their current state and external events. For example, the lift's behaviour can be described with the following state machine:

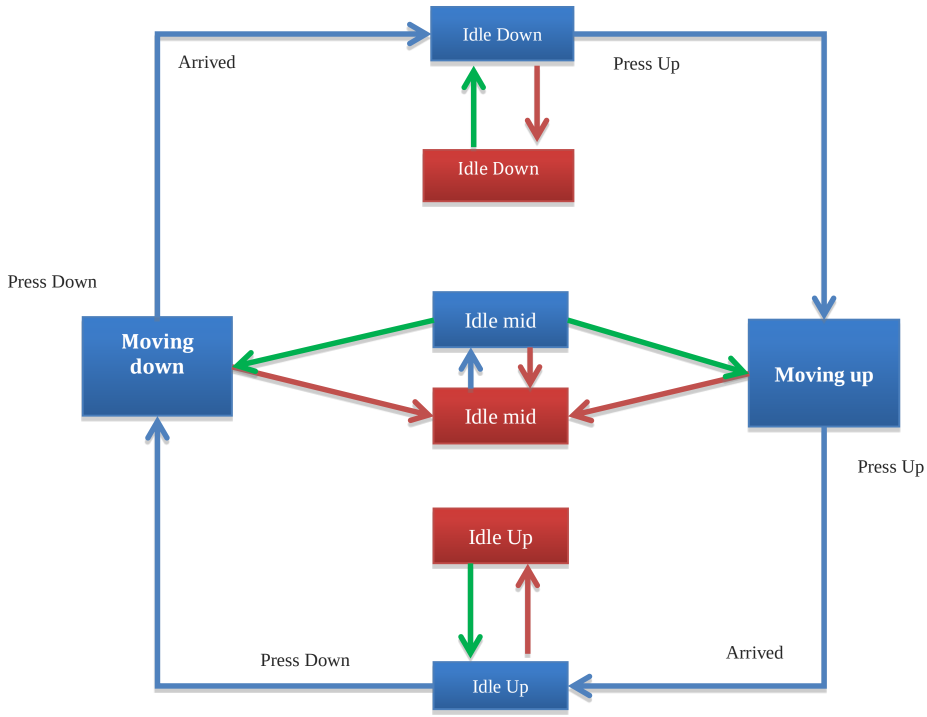

Figure 7.5: The state machine controlling the lift. Red arrows are transitions triggered when the alarm is turned on, and green arrows are transitions triggered when the alarm is turned off.

Every execution starts with an empty history *h*. There are two alternatives to fill *h*: either supplying a sequence of events from an execution or a valid complete history. The former has the advantage of ensuring correctness by design, while the latter has the advantage of being able to jump to any time from the beginning. We opted for the former, a scripted narrative that supplies events to the engine. In what follows we provide a few examples of histories, including travels in time and interaction between timelines. For brevity we show only the most relevant subset of the history and skip to the part when all visitors are already in the gallery and the shooter enters.

Let us examine an execution of the first trial of the application:

Table 7.3: Execution example of an execution of the first time around. The first column specifies the time from the beginning of the session, in seconds. The second column specifies the entity responsible for the event and the third column specifies the event and its parameters.

Time	Entity	Event
125.4	Participant	press down
125.4	Elevator	start moving
132.4	Elevator	stop moving
132.4	Shooter	enter elevator
132.4	Elevator	open doors

134.7	Elevator	close doors
137.5	Participant	press up
137.5	Elevator	start moving
143.6	Shooter	pull gun
144.5	Elevator	stop moving
145.7	Shooter	shoot V5
147.7	Shooter	shoot V1
149.7	Shooter	shoot V0
150.6	Participant	press A
151.6	Shooter	shoot V4
153.7	Shooter	shoot V3
155.7	Shooter	hide gun

This example shows how the shooter requesting to be taken upstairs and the participant taking the lift down. After that, the shooter entered the elevator and the participant took him upstairs. Right before reaching the upper floor, the shooter pulled the gun and started shooting the visitors on that floor, represented by the events *shoot V5, shoot V1* and so on. The participant pressed the alarm, expressed in the table as event *press A*. This had no effect and the gunman shot the remaining visitors.

Now let us consider an example where the participant travels back in time and decides to intervene. An intervention, as discussed, may render some events invalid and therefore removed from the sequence of occurrences. However, similar or equivalent events may be possible at that point. To maintain coherence at a conceptual level and believability in the experience, the engine tries to replace events in those cases. In our application replacement takes place for two events:

i) Shooting a visitor.

ii) Visiting a certain floor in the gallery.

If the lift is not ready to take a visitor to the top floor by the time it was supposed to visit it, the narrative engine sends them to watch the paintings in the ground floor. Similarly, if the gunman is on the upper level when he is supposed to shoot a visitor but has a line of sight with another visitor in the ground level, he shoots that visitor. Table 7.4 shows the sequence of events of two consecutive time arounds with a time travel and an intervention in the second time around. For convenience we display the two timelines side by side:

Table 7.4: Participant intervenes after travelling in time. Presses the alarm and prevents the lift from going up. The shooter then kills just one visitor.

Time (trial 1)	Entity	Event	Time (trial 2)	Entity	Event
112.4	Shooter	enter floor	112.4	Shooter	enter floor
125.4	Participant	press down	125.4	Participant	press down
125.4	Elevator	start moving	125.4	Elevator	start moving
132.4	Elevator	stop moving	132.4	Elevator	stop moving
132.4	Shooter	enter elevator	132.4	Shooter	enter elevator
132.4	Elevator	open doors	132.4	Elevator	open doors
			133.8	Participant_1	press A
134.7	Elevator	close doors	134.7	Elevator	close doors
137.5	Participant	press up	137.5	Participant	press up
137.5	Elevator	start moving			
143.6	Shooter	pull gun	143.6	Shooter	pull gun
144.5	Elevator	stop moving			
145.7	Shooter	shoot V5	145.7	Shooter	shoot V2
147.7	Shooter	shoot V1			
149.7	Shooter	shoot V0			
150.6	Participant	press A	150.6	Participant	press A
151.6	Shooter	shoot V4			
153.7	Shooter	shoot V3			
155.7	Shooter	hide gun	155.7	shooter	hide gun

In this case, the participant (represented by the entity called Participant_1 during the second trial) chose to press the alarm before the gunman was taken upstairs, blocking the elevator in the ground floor with the shooter inside, with line of sight with the visitor that stayed in the ground floor. The event *shoot V5* is replaced by *shoot V2* and the story is maintained coherent by removing all the events that cannot meet the new preconditions.

There are two alternatives for intervention after a travel in time to change the final outcome so that no visitor gets shot: a participant can keep all visitors in the ground floor by taking the lift upstairs and pressing the alarm to block it there, or blocking the gunman half-way through the floors, trapping him there.

7.3.2.2 The IVR engine

While the narrative engine can deal with events at a high level of abstraction, a visual representation of the virtual scenario needs much richer details. The IVR engine is in charge of inducing presence, body ownership and agency to participants. In order to maintain plausibility, we need to apply animations to avatars in a realistic manner.

The narrative engine drives the execution at a high level sending and receiving events to the IVR engine. The architecture of the application to link the two engines includes Low Level

Controllers (LLC) coupled with each entity, and deals with the specifics of that entity. For example, button press events are triggered by the physics of the rendering engine, and are translated into high level events sent to the state machine of the entity and to the rendering engine to adjust how the button is displayed (Figure 7.6).

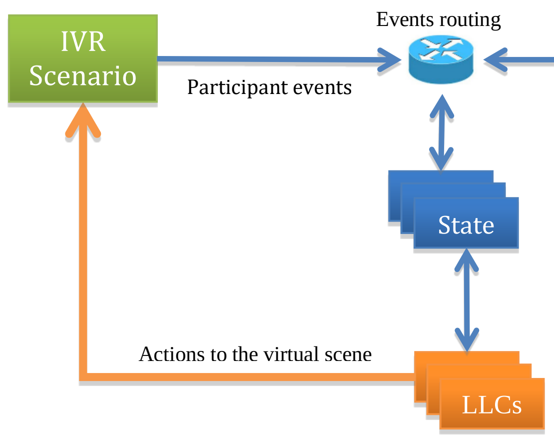

Figure 7.6: Architecture of the application, linking the IVR engine and the Narrative Engine.

Some entities may interact with others, e.g. the alarm's state influences the lift's state, and there must be some element of communication between them. We developed a routing system in charge of directing events to the appropriate state machines. The latter subscribe to the router with the events they want to receive, and the router always sends all the events to the narrative engine. With this design, the narrative engine can check the preconditions and save the events into the history.

The other task the IVR engine is responsible for is synchronization. The strategy of recording and playback for avatars, discussed in Section 3.2, consists mainly on recording the avatar's state in each frame and replaying those states later. For objects, however, we opted for a lockstep synchronization approach (Steed & Oliveira, 2009). With this methodology, objects do not immediately react to inputs happening in the scene, but are rather sent to the narrative engine, which in turn can send events that end up affecting those objects. This procedure is simple and is considered a valid one for low latencies. In our case, because both engines run in the same machine, latencies never exceed 1/60 seconds.

7.3.3 THE EXPERIMENT

7.3.3.1 Participant recruitment and ethics statement

Thirty-eight volunteers agreed to participate in the experiment. On arrival, they were assigned to one of the two groups, Time Travel or Repetition, alternatively. Each subject was requested to be present at the laboratory two times, separated approximately by a week.

Both groups had the same number of males and females, although the data of six participants was discarded due to technical failures (four participants) or because they did not attend the second part.

All participants were given a paper sheet containing basic information about the study and signed an informed consent form when they agreed to take part of each phase of the study. The real purpose of the study was not revealed prior to completion. They were paid 5€ for participating in the first session and 5€ more when they came back for the second session. The study was approved by the Bioethics Committee of the University of Barcelona.

7.3.3.2 Equipment

The virtual environment was implemented in Unity3D and displayed through the NVIS nVisorSX111 (Figure 3.1A), described in Section 3.1.2.1. Head tracking was performed by a 6-DOF Intersense IS-900 device (Figure 3.2), shown in Section 3.1.2.2. Participants wore AsusHS-1000W[14] earphones over the HMD.

An Arduino Uno[15] board was used to provide tactile feedback. It was connected to the computer via USB and it controlled and powered two small vibrator devices (Figure 7.7). Those devices were placed in the palmar areas of the middle fingers of each hand and responded with vibration when the participant touched the buttons that control the elevator in the virtual environment.

Figure 7.7: The Arduino Uno board enclosed in a box. On the bottom right, the vibrator devices.

[14] https://www.asus.com/Headphones--Headsets/HS1000W/
[15] https://www.arduino.cc/en/Main/arduinoBoardUno

Participants embodied a gender-matched human virtual body during the experience. The avatar moved in real time with the movements of the participant. In order to achieve this we used an Xsens body tracking suit for motion capture and MVNStudio software (Figure 3.3) and the library described in Section 3.1.1.

7.3.3.3 Procedures

After signing the informed consent form of the first phase, participants completed a demographic questionnaire described in the Appendix. Next, they performed two IATs (also included in the Appendix). In completion they were donned an HMD and earphones and were immersed in the virtual environment. They were instructed to look around and describe the environment. The first virtual environment was a simple room to habituate participants to the feeling of immersion and to show them their virtual body. In this phase they did not wear a tracking suit, so they were asked to maintain a posture matching that of the avatar. After this familiarization period the screen dissolved and they were transported to the art gallery where they saw some virtual visitors arriving and taking the lift to go to the upper level or visiting the ground floor browsing through the paintings. After a few minutes the experience finished and the HMD was removed. They were then asked to think about three past personal decisions that they regretted along with a rating from 1 to 100, where 100 meant the greatest regret. Participants were told to write this information on a sheet of paper without disclosing it to the experimenters, and were informed that this information would be sealed in an envelope until the next phase. Finally, they read a short passage about the meaning of time travel to prime them with the idea that whenever past history changes then the original history actually never happened. Before leaving, they were paid for their attendance.

Approximately 1 week later they returned to the laboratory. This time they were asked to put the motion capture suit on, the HMD and the headphones, in the setup described in Section 3.1.2 (Figure 3.5). They heard pre-recorded instructions to show them how the lift was operated, how the alarm worked, and they were asked to practice with the buttons until they felt comfortable operating everything. Throughout the experience, whenever they touched the any button they received a corresponding vibrotactile response in the hand they used to touch the virtual button. This was implemented to enhance their control over the virtual scenario. After this habituation and introduction process, the actual experiment started, the clock time was saved, and they were exposed to the experience described in Section 7.3.1. In the *Time Travel* condition, every time they travelled back in time, they did to that point, and the clock was also restarted to that value.

An important aspect of the design of the experience was that participants could hear their voice through their previous incarnations, represented as identical avatars. During pilots we observed the importance of this fact, and we designed a natural way to induce participants to say at least a few words early on. This mechanism included a visitor that always asked the participant for the time. Thus, the subsequent times around the participants could hear their own voice played back answering to the avatar and telling the time.

Time travel was manually activated by experimenters. The criteria was to initiate time travel after 7 seconds from the last shot if the gunman had no possibility of shooting again, either trapped inside the lift or with the lift stopped in either floor with all visitors of that floor dead. At the end of the third trial, the experiment was terminated.

During every trial, participants were primed with a shape appearing in front of them for a frame every 15 seconds. Given that the application was running at 60Hz, the exposure time was approximately 16.67 milliseconds. For every trial, the shown shape was different, always in the same order for all participants (see Avatar choice in the Appendix).

Our hypothesis was that participants under the time travel condition would associate the entire experience with a single time period, and that fusing the temporal perception would cause a spatial perception fusion too. To test this hypothesis, before removing the HMD participants were asked to choose between a shape that combined the individual shapes, or one that displayed them in sequential order (see Avatar choice in the Appendix). Both shapes were displayed side by side in random order, and participants had to choose one by stating their preference out loud.

Upon completion of the virtual phase, the HMD was removed and participants were asked to perform the same IATs they had completed in the first visit, but in reverse order. When they finished they filled some questionnaires about body ownership, presence, agency (Table 7.6) and the illusion of time travel. Participants were then shown two videos in random order, each with an avatar stating a false sentence (see Avatar choice sentences in Appendix), and one of the avatars was the same one they had just embodied. Volunteers were asked to choose which avatar they trusted more. The hypothesis behind this test was that participants who saw their avatars make mistakes in the past, i.e. experienced the time travel condition, would trust the avatars they embodied less.

Once finished, they were asked to remember the bad decisions they had rated in the last visit and rate them again in the same scale. Experimenters could only view the scores, and registered them. Participants were then removed from all the equipment and interviewed. Finally, they were debriefed and paid.

7.4 Results

7.4.1 Response variables

In the two visits to the laboratory participants underwent two IATs, described in Section IATs of the Appendix. One was concerned with feelings of guilt based on (Xu, Bègue, & Bushman, 2012). The other one has been shown to correlate well with actual moral behaviour, and was based on (Perugini & Leone, 2009).

The Guilt IAT taken after the second visit VR experience resulted in 5 missing values due to procedural or participant errors and so could not be used. On the other hand, there were no missing values in the other IAT data. We refer to the two moral IAT scores as *PreIAT* and *PostIAT* for the scores in the first and second week respectively (the second of course taken after the VR experience).

With respect to the three bad decisions participants rated both the first week and after the end of their experience in the second week, we averaged the ratings and calculated the mean of the three decision scores each week. The corresponding variables are *PreRegret* for the mean score in the first week, and *PostRegret* for the mean score at the end of the VR experience in the second week.

PostIAT and *PreIAT* are treated as continuous variables, where greater values are associated with more moral behaviour. *PreRegret* and *PostRegret* are likewise treated as continuous variables with greater values indicating greater discomfort about the three past decisions. Our model fitting strategy allows the "Post" variables to be influenced by the "Pre" variables, in other words the "Pre" variables appear on the right hand sides of the equations defining the model.

Finally, at the end of the questionnaire the participants read five moral dilemma scenarios—three were based on the boxcar problem (equivalent to the trolley problem), and two were based on the actual dilemma in the gallery (see the Moral Dilemma Scenarios Section of the Appendix). For each one they were asked whether or not they would "push the switch"—in each case resulting in the deaths of 5 people or 1. We restrict attention to the boxcar problem of which there were three variants each with a yes/no answer:

a) Boxcar 5—the boxcar by default will kill 5, throwing the switch will divert the boxcar to kill 1 instead. Question: would you throw the switch?

b) Boxcar 1—the boxcar by default will kill 1, throwing the switch will divert the boxcar to kill 5 instead. Question: Would you throw the switch?

c) Boxcar footbridge—the boxcar by default will kill 5. If a man with a heavy backpack is pushed onto the track from a footbridge where he and the observer are standing then the 5 will be saved but the man will be killed. Question: would you push the man off the footbridge onto the track?

From these three we construct a new variable representing the number of scenarios out of the three in which 1 will be saved rather than the 5 [pushing the switch in (a), not pushing it in (b) and not pushing the man in (c)]. We refer to this variable as *save1*, which ranges from 0 to 3. We treat this as a binomial random variable, where greater values indicate a greater propensity to save the 1 (non-utilitarian) rather than the 5 (utilitarian). Also we single out the footbridge question since this has a different element involving actively killing 1 by pushing him to save 5. Hence we will also use *footbridge*, which is a binary variable, in place of *save1*. *footbridge* is treated as a binary (Bernoulli) random variable, 1 indicating a "yes" answer to pushing the man to stop the boxcar (utilitarian), and 0 "no" (non-utilitarian).

7.4.2 Subliminal Priming and Avatar Choice

We did not find any significant differences with respect to the participants' choice of shape after the subliminal shape priming. Table 7.5 contains the results of the choices per condition.

Table 7.5: Participants' choice of shape per condition after the subliminal priming. One value was missing.

Condition	**Subliminal choice grouped shape**	**Subliminal choice separated shape**	**Total**
time travel	6	9	15
repetition	7	9	16
Total	13	18	31

The choice of avatar after the video did not result in any significant differences either.

7.4.3 PRESENCE AND BODY OWNERSHIP

Table 7.6 contains the questions asked after the second exposure to IVR.

Table 7.6: Questions for body ownership, agency, presence, and guilt. All responses are on a 1-7 Likert scale with 1 meaning most disagreement and 7 most agreement with the statement.

Concept	Variable name	Statement
Body ownership	*mirror*	Even though the virtual body I saw did not look like me, I had the sensation that the virtual body I saw in the mirror was mine.
	down	Even though the virtual body I saw did not look like me, I had the sensation that the virtual body that I saw when I looked down at myself, was mine.
	other	I felt that the virtual body that I saw was someone else.
	mybody	Overall even though the virtual body I saw did not look like me I had the sensation that the virtual body I saw was my body.
Agency	*agency*	The virtual body moved according to my movements.
Presence	*placeillusion*	I had the sensation of being in the gallery
	plausibility	There were times when the gallery was more real for me than the laboratory in which everything was really taking place.
	copresence	How much did you find yourself responding to the visitors as if they were real people?
Guilt and self-assessment	*guilt*	Do you feel any guilt about what happened to the visitors?
	triedmybest	I tried my best to save the visitors from the shooting.

Figure 7.8 contains box plots for these questions. With the exception of guilt and self-assessment, all of them were based on previous work (Banakou et al., 2013). A similar process was carried out to obtain a global score for each concept. In particular, the body ownership illusion was assessed with four questions (*mirror*, *down*, *other*, *mybody*) and a global score, *Ownership*, was obtained. A principal component factor analysis was performed with Stata[16] and found that the *Ownership* factor explains 76% of the total variance of the original data. Agency was assessed with only one question – *agency* – since this is a factual statement – did the virtual avatar move when the participant moved? Moreover, the application was developed with the specific goal of delivering a high sense of agency, so we can consider this variable as a measure of the system's performance. As can be seen in Figure 7.8, scores were very high (median 6), and all participants reported a score of 5 or above. We can also observe the high levels of subjective presence from *placeillusion* and *plausibility,* which have a median of 6 and interquartile range 5–7. Although slightly

[16] http://www.stata.com

lower, *copresence* – the feeling that other virtual avatars are real people – also had high scores (median 5).

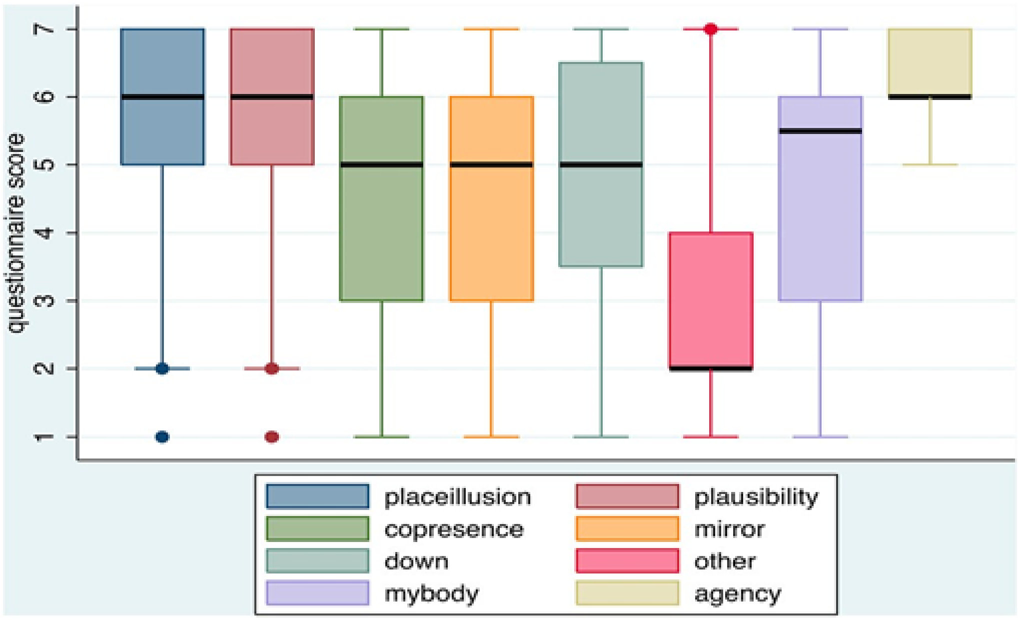

Figure 7.8: Box plots for the presence and body ownership and agency illusion questions. The thick horizontal lines are the medians, and the boxes the interquartile ranges. The whiskers extend 1.5 the interquartile range or the extreme values in both directions. Values outside of this are shown as single point outliers.

Given these findings we can conclude that the system did deliver a high level of presence, body ownership and agency, as was the aim. No differences were found on any of these variables with respect to condition (*Repetition, Time Travel*) or gender.

7.4.4 *HOW PARTICIPANTS ADDRESSED THE MORAL DILEMMA*

As described in Section 7.3.1, just before the end of each trial participants were faced with three main options when the gunman started shooting. One of the options was to send the shooter down, endangering the visitors in that floor. Another option was doing nothing, and the third option, non-existent in the classical moral scenarios, was to press an alarm. Even though this action was of no use to stop the shooting in the first time around, the majority of participants (28 out of 30) pressed it as their first reaction, and 2 pressed the Down button (to save the 5) (data on 2 participants was not available). Some participants took more actions, in particular 40% of them pressed the Down button as a second action, and 6 out of 30 pressed the Down button as a third action. Despite the amount of Down button presses, only one case resulted in the lift ending in the ground floor, and 64% ended in the upper floor, 32% between floors. In terms of visitors killed, in the first trial 80% of the cases ended with 5 visitors shot (4.8 mean, ± 0.81 standard deviation).

The second time around participants in the *Time Travel* condition had to counteract actions taken by their previous clones, which resulted in significant difference of almost double the number of actions (Table 7.7) with respect to participants in the *Repetition* condition (Wilcoxon rank-sum test, $P = 0.012$). There was no significant difference between conditions with respect to the number of shots (Table 7.8).

Table 7.7: Mean and standard errors of numbers of actions by condition.

Condition	2nd time around		3rd time around	
	Mean	S.E.	Mean	S.E.
Repetition	2.1	0.51	2.1	0.52
Time Travel	4.5	0.74	3.5	0.58

Table 7.8: Mean and standard errors of number of shots by condition.

Condition	2nd time around		3rd time around	
	Mean	S.E.	Mean	S.E.
Repetition	2.3	0.48	1.2	0.43
Time Travel	2.2	0.58	1.5	0.49

During the third time around, participants in the *Time Travel* condition who had already found a solution did not need to carry out any action. This explains the reduction of actions (Table 7.7) to a similar level as that of the Repetition condition. The number of shots decreased similarly on both conditions (Table 7.8).

7.4.5 Path analysis

The path diagram shown in Figure 7.9 corresponds to the statistics of Table 7.9. It was derived from the hypothesis that a strong feeling presence and body ownership illusion combined with a scenario capable of showing participants' previous actions would lead to the illusion of time travel and that this illusion may affect participants' behaviour outside IVR. The diagram only includes significant paths, and also main effects of significant terms even if they are not significant.

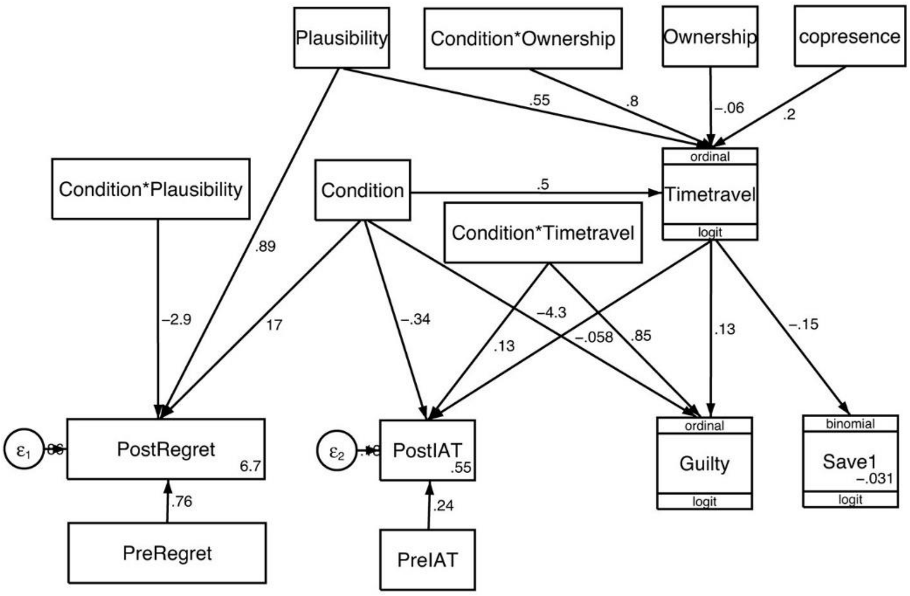

Figure 7.9: Path analysis corresponding to Table 7.9. The directional edges represent hypothesized directions of causality. The numbers on the edges are the coefficients of the linear predictor of the corresponding model fit. The variables in plain boxes are treated as linear normal models, and the specific model is otherwise shown in the remaining boxes.

Table 7.9: Path analysis corresponding to Figure 6.9, n = 32. In the first column the dependent variables are shown in bold. Condition has Repetition = 0, Time Travel = 1. Constant refers to the intercept term of the linear predictor of each model equation. *Refers to an interaction term. Standard Errors are robust and allow for non-independence (clustered on gender). P = 0.000 means P < 0.0005.

	Estimate of coefficient	Standard error	P	95% Confidence interval	
save1					
timetravel	−0.151	0.065	0.021	−0.279	−0.023
Constant	−0.031	0.319	0.923	−0.656	0.594
guilt					
timetravel	0.131	0.284	0.644	−0.425	0.688
Condition	−4.302	1.777	0.015	−7.784	−0.820
*Condition*timetravel*	0.849	0.070	0.000	0.712	0.985
postIAT					
timetravel	−0.058	0.000	0.000	−0.059	−0.058
Condition	−0.344	0.250	0.169	−0.835	0.146
*Condition*timetravel*	0.130	0.018	0.000	0.095	0.165
preIAT	0.241	0.115	0.036	0.015	0.468
Constant	0.548	0.014	0.000	0.521	0.575
timetravel					

*Condition*Ownership*	0.804	0.259	0.002	0.297	1.311
Ownership	−0.060	0.050	0.230	−0.159	0.038
plausibility	0.548	0.071	0.000	0.408	0.687
Condition	0.503	0.754	0.504	−0.974	1.981
copresence	0.198	0.053	0.000	0.093	0.303
PostRegret					
plausibility	0.892	0.524	0.089	−0.136	1.920
Condition	16.832	3.486	0.000	9.999	23.665
PreRegret	0.764	0.119	0.000	0.530	0.997
*Condition*plausibility*	−2.901	1.226	0.018	−5.303	−0.499
Constant	6.679	12.222	0.585	−17.276	30.634

The diagram reflects that *timetravel* is influenced by several factors, which are *plausibility*, *copresence* and the interaction between *Ownership* and *Condition*. In that sense, the *timetravel* variable is positively associated to *Ownership* only in the *Time Travel* condition. The other associations are also positive. This variable is endogenous and therefore can be predicted within the model. The significant correlation (Spearman's rho = 0.53, $P = 0.002$) between fitted values and observed values shows the model fits adequately to the observed data.

With respect to *PostRegret*, it is positivel influenced by *PreRegret* and negatively influenced by *plausibility* when condition is *Time Travel*. This can be interpreted as participants reporting lower regret scores when they experienced the *Time Travel* condition as highly realistic. The model adjusts well to the data (Spearman's rho = 0.60, $P = 0.0003$).

PostIAT is positively influenced by *PreIAT* and negatively influenced by *timetravel* under the *Repetition* condition, but positively in the *Time Travel* condition, which means there is an interaction effect between Condition and *timetravel*. This result can be interpreted as higher feelings of time travel illusion lead to an implicit self-categorization as moral outside IVR. As for previous results, the model adjusts well to the observations (Spearman's rho = 0.52, $P = 0.002$).

guilt, an endogenous variable in the model, is positively associated with *timetravel*, albeit only in the *Time Travel* condition. Figure 7.10 shows a scatterplot of *timetravel* against *guilt*. Again, the fitted values of the linear predictor for the variable are correlated with the observations (Spearman's rho = 0.62, $P = 0.002$).

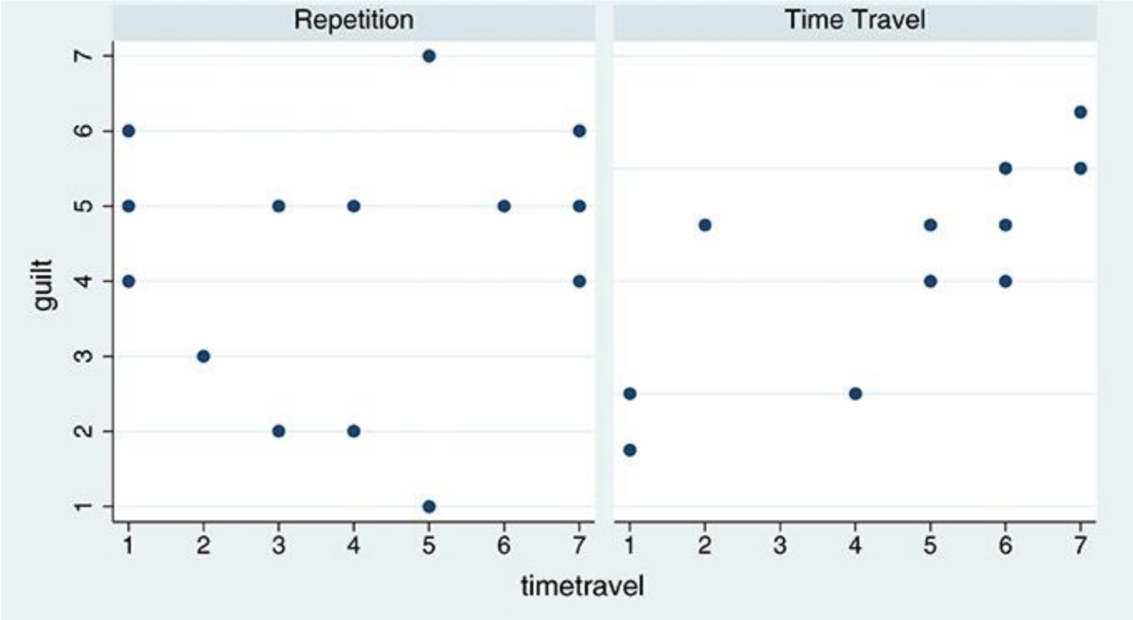

Figure 7.10: Scatter diagram of *guilt* by *timetravel* for each of the two Conditions (Repetition and Time Travel).

The self-reported performance of participants with respect to their intention save the visitors is summarized in the variable *triedmybest*. The score 5 (IQR = 2) suggest they did, and it is correlated with guilt. However, this correlation is different depending on the condition. Table 7.10 shows the summarized results of an ordered logistic regression analysis of *guilt* on Condition, *timetravel* and *triedmybest*. In particular, we observe that *triedmybest* is negatively correlated with *timetravel* through the interaction with Condition under the *Time Travel* condition (coefficient =−1.1, $P < 0.0005$) (Figure 7.11). This can be interpreted as participants in the *Time Travel* condition feeling lower guilt when they felt that they have tried their best. On the other hand, in the *Repetition* condition the correlation between *timetravel* and *triedmybest* is positive. *timetravel* in the *Time Travel* condition is positively associated with *guilt* with a similar magnitude as the one shown earlier, only with opposite signs (coefficient = 1.0, $P < 0.0005$), which means that when participants in that condition felt a strong illusion of time travel and a strong belief that they had done their best then the two effects cancel each other.

Table 7.10: Ordered logistic regression for guilt, n = 32. Condition has Repetition = 0, Time Travel = 1. The same conventions as Table 7.9 apply.

	Estimate of coefficient	Standard error	P	95% Confidence interval	
guilt					
Condition	0.038	1.122	0.973	-2.162	2.238
timetravel	0.034	0.291	0.907	-0.536	0.604

triedmybest	0.542	0.027	0.000	0.490	0.595
*Condition*timetravel*	1.013	0.003	0.000	1.007	1.020
*Condition*triedmybest*	-1.065	0.045	0.000	-1.154	-0.976

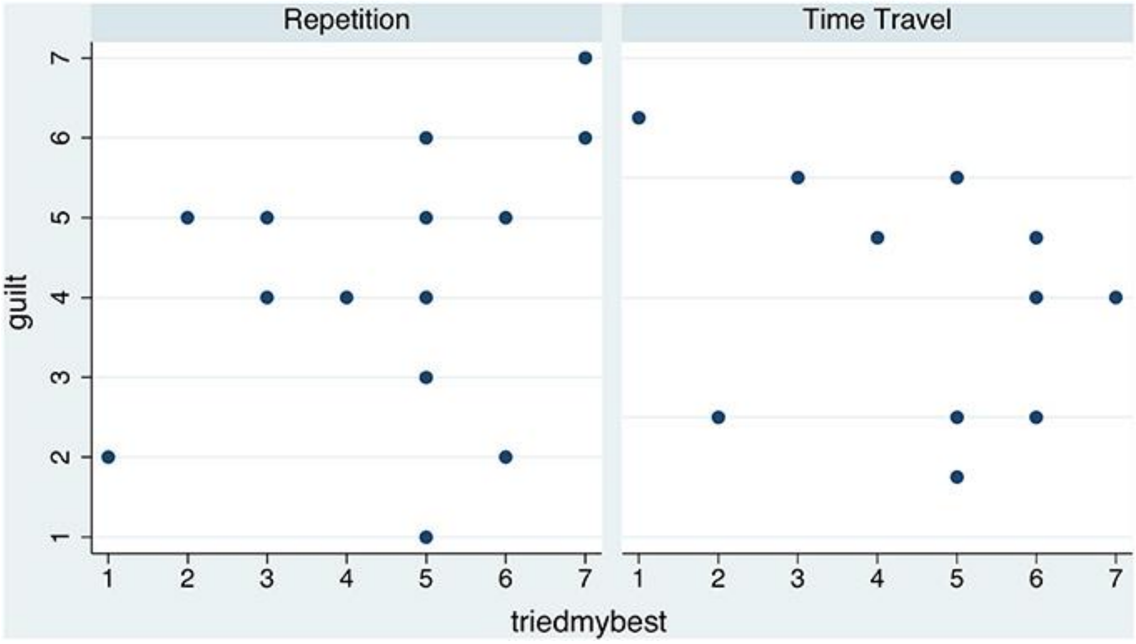

Figure 7.11: Scatter diagram of guilt by *triedmybest* for each of the two Conditions (*Repetition* and *Time Travel*).

Participants' utilitarian behaviour is summarized in the variable *save1*. It is an endogenous variable that represents the tendency to save the 1 instead of the 5. It is negatively associated with *timetravel*, which can be interpreted as participants who subjectively felt a strong illusion of time travel also tended to have a more utilitarian behaviour, albeit with greater guilt. The model fits well the observed data (Spearman's rho = 0.41, P = 0.02).

7.5 Discussion

This experiment was an exploratory study to research a novel illusion: the time travel illusion. As such, the main focus was to measure the illusion, however, the novelty of the question and therefore the lack of background literature narrowed the options in terms of measuring it. Future work should find more accurate subjective and objective measures. Nevertheless, the present experiment also includes measures for other questions, discussed below.

The main result concerns the existence or not of the illusion of time travel. Even though the evidence suggests that the conditions alone were not enough to generate a subjective illusion of time travel, the combination with body ownership, plausibility and copresence did. In other words, participants experienced the *Time Travel* condition as a subjective time travel whenever they had a strong sense of body ownership and agency, plausibility and copresence. Future studies should elucidate carefully the influence of each element towards the time travel illusion, especially for body ownership. A control condition without a virtual body could help determining the importance of the body ownership and agency factors.

This experiment also considered the possible effects and consequences of the time travel illusion. In particular, we hypothesized that since at a subconscious level our brains do not distinguish virtual reality from physical reality, exposing participants to a virtual travel in time could make them accept the notion that the past is mutable. Therefore, bad memories could become less important because according to this principle they could be changed. We tested that hypothesis through an IAT focused on moral categories, and our findings suggest that indeed subjective time travel illusion is positively correlated with an implicit self-classification as moral. Moreover, these results are in line with those of (Segovia, Bailenson, & Monin, 2009), who performed an experiment in which participants watched avatars carry out moral and immoral actions.

In addition to self-categorizations on morality, we examined the implications of the exposure with respect to the feelings of guilt. In particular, we observed that harm caused to the virtual visitors may be positively correlated with the subjective illusion of time travel. A possible explanation is that when participants relive their own actions in the virtual scenario they may subconsciously associate responsibility of their previous actions or inactions. Therefore a strong time travel illusion may strengthen the feelings of guilt. Moreover plausibility is positively correlated with the illusion of time travel, which may contribute to the idea that the events actually happened. However, this is speculation since we have no way of determining causality. Future work should clarify these hypotheses and determine the directions of causality.

Another area of interest in this study is the moral dilemma included in the experiment. This is summarized in the variable *save1*, which we have seen is negatively correlated with the subjective illusion of time travel. This finding suggests that people are more utilitarian whenever they experience a strong feeling of having travelled in time. Moreover, if we examine more extreme versions of utilitarianism, summarized in the variable *footbridge*, we again find a positive relationship with the time travel illusion (coefficient = 0.36, $P = 0.001$). This is an interesting result since the *footbridge* variable represents the direct and deliberate cause of death of the 1 to save the 5, and is not normally chosen by a majority of participants in other studies. A possible explanation for this finding could be that subjectively experiencing time travel could diminish the negative impact of the death of the

1, since the consequences have been already faced. Future studies should follow up the research concerning the relationship between the time travel illusion and utilitarian behaviour.

With respect to participants' actions during the first time around, we also found an interesting result. The overwhelming majority of participants in previous studies (Navarrete, McDonald, Mott, & Asher, 2012; Pan & Slater, 2011) saved the 5, whereas in the present study the first time around resulted in almost all virtual visitors from the group of 5 getting killed. The fundamental difference in this experiment was the addition of an extra button, the alarm, which is not helpful at all at the moment of shooting in terms of saving visitors. We can hypothesize that this may be due to cultural particularities, in which people are told to call authorities whenever dangerous situations rise, and an alarm button may be a culturally correct action.

Future studies should expand this idea even further and resolve some unanswered questions. In particular, there are a few variables that did not show any statistically relevant results. For example, we did not observe any correlation between the subliminal priming and the choice of the shape. However, we cannot conclude that subliminal priming combined with time travel is not correlated with spatial coherence, because maybe using other shapes or different exposures we could have observed the effect. Also, participants carried out a different number of actions in each condition, but that can be explained by the different situations on each condition. Perhaps a different experimental design could unravel behavioural differences. Finally, due to technical failures, some variables contained a substantial amount of missing values and were therefore not included in the analysis. Future studies could replicate this experimental design and observe the variables that were discarded in our analysis.

With respect to this thesis, this study aimed at answering the third research question: *Is there a novel illusion in IVR that can provide the feeling of having travelled back in time?* The main result provides a positive answer when participants have a strong sense of body ownership, agency and presence. In that sense, the experiment described in the following Section was designed taking these results into account. The study aimed at inducing those illusions and used the concept of time travel to explore a potential novel approach to an existing technique.

7.6 Application of the Time Travel technology

As we have seen, an important aspect of the previous experiment was the developed technologies and methods, and these can be reused to solve real life problems. We examined the possibility of adapting an existing form of psychological therapy, and we focused on a Gestalt therapy technique known as "the empty chair technique" (Paivio & Greenberg, 1995; Perls et al., 1951) (see Section 2.3.3 for more details).

Unpleasant situations can leave mild or even strong memories that can stay stuck in people's brains for a significant portion of their lives. Many people deal with them silently talking to themselves (inner speech). This is a common process that helps resolve personal problems, and it is one of the basis of self-awareness (Morin, 2005) and self-related processing (Morin & Michaud, 2007). This raises the question: what if we could actually externalize this conversation into a spoken-out-loud dialog?

In this Section we summarize an experiment in which participants embodied alternatively two virtual avatars (for the full description see (Osimo et al., 2015)). One of them represented themselves, and was generated from a 3D scan of their own bodies (Figure 7.12). The other virtual body represented a counsellor with whom participants engaged a dialog about a personal problem. At first participants embodied their own avatar to explain a personal problem, and during that period, all motions and sound were recorded in the background. Once they finished describing their problem, their perspective was transferred to the body of the counsellor. The application of the system described above for the time travel experiment was used so that they could experience the recordings of what they just did and said were played back from the counsellor's perspective, and they could respond give advice as the counsellor. After that, they were transferred back to their lookalike virtual bodies where they could hear themselves giving the advice, to which they respond. This alternation between lookalike virtual body and counsellor went on until participants decided to stop.

Figure 7.12: The scanning procedure setup.

This design included two conditions; in one of them the counsellor was represented by an avatar looking like Dr. Sigmund Freud. In this condition, when participants heard their voice coming from the counsellor, they heard in fact a transformed recording (see Voice Transformation Section of (Osimo et al., 2015) for more details about the voice transformation). The reasons behind the choice of Freud are explained in Section Choice of Counsellor in (Osimo et al., 2015). In the other condition, the counsellor was represented by another lookalike avatar. The full description of the procedures can be found in the Methods section of (Osimo et al., 2015).

Figure 7.13: Virtual room where participants were immersed. On the left, the virtual representation of the participant. In the middle, a table with a panel and a mirror. On the right, the counsellor. In the Freud condition, the

counsellor was represented by a virtual avatar that looked like Freud. In the Self condition the counsellor was represented by a clone of the participant's virtual body.

The underlying hypothesis is that achieving a high sense of body ownership over the virtual body of a person known to be wise would give participants access to new mental resources they would not normally use while embodying their own bodies. This idea is based on previous results where participants changed their perception and behaviour after being embodied in virtual bodies of different characteristics from their own. For example, an experiment (Banakou et al., 2013) found that embodying adults in the body of a child resulted in overestimations of sizes and a change of behaviour to a more childish one. Another study (Peck et al., 2013) showed how Caucasian participants reduced their implicit racial bias after embodying a dark-skinned avatar.

We also learned from previous experiments the importance of movements' synchronicity (González-Franco et al., 2010; Maselli & Slater, 2013; Slater, Spanlang, Sanchez-Vives, & Blanke, 2010). During virtual reality experiences, if bodies or body parts do not move in accordance as the participants' real counterparts, the body ownership illusion can be broken and participants will no longer feel agency. However, these breaks of illusions can also be used to test the influence of embodiment over other dependent variables. In this sense, we included another condition, in which all participants embodied Freud as a counsellor, but with visuomotor asynchrony. We refer to this condition as Async, while the condition in which participants synchronously embody Freud as a counsellor is referred to as Sync. Based on previous research (Banakou et al., 2013; Banakou & Slater, 2014) the expectation is that asynchronicity would result in weaker illusions of body ownership. In turn, we can also expect the Sync condition to be more effective than the Async with respect to improvement in the participants' mood after the experiment.

In that sense, mood assessment was performed with two main tests. The first, Profile of Mood States (POMS) (McNair, Droppleman, & Lorr, 1992) has been used in several other fields such as dietary weight loss (McAuley et al., 2006) depression (Linden et al., 2012) and quality of life with cancer (Bergman & Laviana, 2014). The second technique was the Self Assessment Manikin (SAM) (Bradley & Lang, 1994), which is a visual representation of a mood scale along with the intensity, and has been used in several other studies of different fields (Friederich et al., 2006; Strathearn, Fonagy, Amico, & Montague, 2009; Valenza, Citi, Lanatá, Scilingo, & Barbieri, 2014).

Additionally, body ownership and agency was also assessed through various questions, reported in Table 7.11.

Table 7.11: Body ownership and agency questionnaire. Each statement was scored on a 1–7 Likert scale where 1 indicates no agreement and 7 complete agreement.

Variable Name	Statement
MeDown	Even though the body I see might not physically look like me, I feel that the virtual body I see when I look down towards myself is my body.
MeMirror	Even though the body I see might not physically look like me, I feel that the virtual body I see reflected in the mirror is my body.
MyMovements	I feel that the movements of the virtual body are caused by my own movements.
LikeMe	The body I see in the virtual world physically looks like me.

7.6.1 Results

Our results show that all body ownership scores are higher in the Sync conditions compared to Async. Median scores are high, 6 out of the maximum of 7, measured with *MeDown* and *MeMirror* scores. Agency, is clearly higher in the Sync condition (6-7 IQR in Sync compared to 1-3 IQR and median 1 in the Async condition). The physical resemblance of the virtual counsellor to the participant, assessed with the variable *LikeMe*, was low in the Async condition, as expected. In the Sync and Self condition, scores were high, also as expected. However, in the Sync and Freud condition, the median score was 4 with a large IQR, not showing a clear preference.

No significant differences were found between the two Sync conditions for *MeDown*, *MeMirror* and *MyMovements* variables*.* With respect to *LikeMe,* we tested the hypothesis that the difference between the two distributions (Self, Freud) has 0 median with a Wilcoxon paired signed rank test, P = 0.008 (two-sided). Therefore, we can assume that Sync&Self condition results in higher *LikeMe* scores compared to those of the Sync&Freud condition. With respect to the differences between Sync and Async conditions, *MeDown*, *MeMirror* and *MyMovements* show significantly different scores (Wilcoxon rank sum tests P=0.003, 0.015 and 0.0001 respectively). Results on LikeMe show a trend indicating some evaluation of the virtual body as more similar to that of the participant than in the asynchronous condition (P=0.110).

Pre- and post-experiment scores on mood and happiness improved. PrePOMS and PostPOMS are significantly different in the Async condition (Wilcoxon signed-rank test, P =

0.005). In the Sync condition, PrePOMS and PostPOMS also show significant differences (P=0.0001). Significant differences were also found for SAMHappy in both Sync and Async conditions (P=0.027 and 0.0003 respectively). No differences, however, were found in SAMIntensity.

A more detailed description of the experiment's results can be found on the Results section of (Osimo et al., 2015).

7.6.2 Discussion

The main result of the experiment reported in this Section is that the experience improved mood and happiness, and was reported as a positive one (see Results Section of (Osimo et al., 2015) for full details). A deeper analysis reveals that not all conditions result in equal mood and happiness improvement. In that sense, talking with Freud results in greater improvements compared to talking to another Self, and visuomotor synchrony improves those further compared to the asynchronous condition. Also, as expected, visuomotor synchrony is closely related to body ownership and agency. We can conclude from these findings that while embodying the Freud avatar ownership and agency illusions have a stronger positive effect on mood and happiness than the Self virtual body.

There are several explanations for these results. A possible one is an association of positive self-attributes towards outgroups derived from embodiment in a representative of the outgroup. For example, several experiments (Fini et al., 2013; Kilteni et al., 2013; Maister et al., 2013; Peck et al., 2013) showed how after embodying a different race causes a reduction in the implicit racial bias. Those findings point to the idea that body ownership can cause an illusion of resemblance between the self and the outgroup. This illusion can result in an association of positive self-attributes to the outgroup. In this experiment, however, there does not seem to be a bias to any outgroup, therefore this reasoning does not apply.

Also, as we have seen in Section 2.3.3, perspective taking or self-compassion could explain the general mood improvement (Batson et al., 1997). In our case, participants directly saw and interacted with themselves from another person's perspective, which may have led them to associate a more neutral or positive attitude towards their problem. This is the same principle used in "the empty chair technique" from Gestalt Therapy. Our findings, however, also show differences depending on the form of the embodied avatar (Self or Freud), indicating that perspective taking, self-compassion or the similarity to the empty chair technique alone cannot explain our results.

Previous results in similar setups also point to the idea that these explanations are not enough. A recent study (Falconer et al., 2014) used IVR with a non-clinical sample of excessively self-critical people to enable them to give themselves compassion (Gilbert, 2009). In that experiment participants delivered a compassionate speech to a virtual child, which was recorded and played back while they were either embodying the child or from a non-embodied 3PP. The authors found that participants who embodied the child reported a higher degree of self-compassion, but found no differences for those who did not embody an avatar. These findings are aligned with ours, suggesting that a change of perspective alone is not enough to explain them, and that embodiment must play a role.

In that sense, an open question remains with respect to the influence of the choice of counsellor. It could be the case that any other body could have yielded the same results. However, our speculation is that this is not the case. For example, embodying an obvious criminal could cause the self-dialog to be constrained by the lack of trust to the avatar. Nevertheless, further studies are needed to answer that question precisely.

Furthermore, the findings of this experiment do not reflect long-term effects nor the impact over severe problems. Further studies should consider researching into clinical samples to evaluate the effectiveness of this method, and perform a long-term follow-up to assess if this technique is valid as a form of treatment

8 CONCLUSIONS

During the course of this thesis we described a series of experiments to evaluate the effects of manipulating time using immersive technologies. In particular, we examined the differences with the perception of time inside IVR, the existence of the time travel illusion, which are the constituents of the research questions stated in Chapter 1. Additionally, we report an application of the technology involved in virtual time travel for a novel approach to psychological treatment.

8.1 Time perception

8.1.1 TIME PERCEPTION AND MUSIC

In Chapter 5 the goal was to answer the first research question of this thesis: *Does background music tempo affect time perception in IVR?* We designed and performed an experiment to analyse the influence of background music tempo on time perception inside a virtual scenario. The theoretical models of the retrospective paradigm (Block, 1990; Ornstein, 1969) predict a positive relationship between the quantity of stored stimuli in memory with time estimations. In this case, the stimuli were the beats per minute that the background music contained. It is important to notice that the music used was computer-generated to eliminate some of the possible effects found in other studies that related time perception to several musical properties (Kellaris & Kent, 1992; Noseworthy & Finlay, 2009).

The experiment's results showed no association between tempo and time perception when analysing the entire sample. However, the experiment's design was within-groups, and therefore participants experienced the virtual scene twice. This generated some suspicion in several individuals that the study was about timing. Since the aim was to analyse retrospective time perception, we asked participants how much they suspected that they had to pay attention to how long the experience was. Taking those scores into account we split the sample in two, with those who suspected in one group and those who did not in the other. Even after this procedure we did not find enough evidence to support a relationship between the beats per minute and the time estimates, as predicted by the theoretical models. However, we cannot determine whether it is the stimuli which are not correlated with time perception, or that it is IVR that affects participants' perception of time. Indeed, previous studies (Caldwell & Hibbert, 1999, 2002; North et al., 1998; Oakes & North, 2006) found no significant differences in time estimates between fast and slow tempo background music. Alternatively, it could be the case that we needed a broader sample size to detect the effect. Our study was carried out with only thirty-five volunteers, whereas many other studies in the same field usually have approximately an order of magnitude higher in number of participants.

8.1.2 *TIME PERCEPTION AND EMBODIMENT*

The study described in Chapter 6 was carried out to test the second research question of this thesis: *Does body shape affect time perception in IVR?* Previous studies had shown that the size of a body influenced spatial perception (Noë, 2004; Proffitt, 2006; van der Hoort et al., 2011), and in (Banakou et al., 2013) they went one step further by showing that the body shape, i.e. a child versus an adult, enhanced this effect of object size overestimation. We expected to find a similar mechanism with temporal perception since other studies (DeLong, 1980; Mitchell & Davis, 1987) had already observed analogous effects relating time perception to the scale of the environment. In our study we wanted to make a parallel step further in temporal perception as the authors in (Banakou et al., 2013) did for spatial perception.

The experiment consisted in immersing participants in a virtual environment where they performed a task twice in two separate sessions, while embodying either a child, a young adult, or an elderly adult. In each session the embodied avatar was different. After that, we asked them to choose which session they perceived as longer.

The results showed significant associations between how individuals performed in the task and their subjective levels of body ownership in the condition where they embodied a child. We did not, however, find a relationship between the embodied body types and the choice of the longer session. Therefore, there is not enough evidence to support the idea that embodying avatars of different appearances affects temporal perception.

8.1.3 *THE ROLE OF IVR IN TIME PERCEPTION*

Overall, after the two previous experiments we have no evidence of new variables associated with time perception. However, the range of conceivable factors that can possibly affect temporal perception in IVR is vast. Several authors (Bruder & Steinicke, 2014; Schatzschneider et al., 2016) have already explored some elements, such as simulating the movement of the Sun. Schneider et al. (2011) showed an example of the potential benefits to society of this kind of setups. In their experiment, chemotherapy patients were exposed to IVR applications, and experimenters analysed which factors made participants feel that time passed more quickly. The authors argue that understanding the constituents of time perception inside IVR experiences could allow clinicians to improve coping strategies. Future studies should continue the line of work proposed in this thesis, examining the relationship between different variables and time perception.

8.2 A Virtual time travel illusion

In Chapter 7 we aimed at answering the third research question of this thesis: *Is there a novel illusion in IVR that can provide the feeling of having travelled back in time?* First, we designed a computer system to accurately simulate time travel and we developed a framework to experience this phenomenon in highly immersive virtual reality. We then performed an experiment in which thirty-eight students participated and where we found that participants did indeed feel as if they travelled back in time whenever they had a strong sense of body ownership and agency, plausibility, and copresence.

The concept of mental time travel has recently seen a growing interest. Reliving past events through one's imagination and foreseeing future episodes or alternative outcomes for the past is not only a common daily experience for many people, but can also be part of psychotherapies such as CBT. Evidence suggests that these mental exercises of examining past, future, or alternative timelines share the same neurological cognitive processes (Botzung et al., 2008). This idea is also supported by linguistic analysis (Stocker, 2012), and indicates that mental time travel could be a broader subject that included all those processes (Schacter, Addis, & Buckner, 2007; Suddendorf & Corballis, 2007). With respect to whether this is an ability restricted to humans, that is a question yet to find a definitive answer (Suddendorf & Busby, 2003; Suddendorf & Corballis, 2007).

It could be argued that the same benefits that apply to mental time travel can apply to virtual time travel too. Given the results of our experiment, we now know that such an experience is possible, which opens the door to new methods in psychological therapies. For example, mental time travel has been used in PTSD treatments (Ehlers et al., 2005). These methods, however, require a considerable imaginative process. With virtual time travel, on the other hand, participants could directly experience relevant episodes, with the benefit of being able to observe events from an outsider's perspective if necessary.

The study described in Chapter 7 is focused on proving the concept of virtual time travel and its limitations. Future studies should address more ambitious goals and refine the knowledge of the boundaries. In particular, research should focus on studying the underlying hypothesis which is that because at an unconscious level the brain doesn't distinguish between reality and IVR, it can implicitly learn that the past is mutable. Thus, bad memories could become less traumatic because according to this principle they can be changed. Also, the studies conducted in this thesis have focused on travelling to the past, but travelling to the future could also be worth researching.

In that sense, most scenarios could use simplified versions of the frameworks described in this thesis related to IVR and time travel. More effort, however, should be placed on developing more believable AI systems that drive virtual avatars. As we have seen, copresence and plausibility are key factors for the illusion of time travel, so stronger and more appropriate AI solutions would enhance the experience.

Moreover, future work could go in the direction of reusing the methods described to carry out research in other fields. For example, we performed a study in which participants engaged in a dialog with themselves embodied in two different avatars. This scenario was implemented using the technology developed for the time travel illusion. It included a lookalike avatar generated from scanning participants in 3D and a counsellor, which was represented by either a copy of the lookalike avatar or one that resembled Dr. Sigmund Freud, depending on the condition. The dialog was about participants' personal problems, and the aim was to test if participants felt any better about those after the experience. We also tested whether visuomotor synchrony influenced this change of feelings towards their personal problems with a separate condition.

The main result, described in Section 7.6.1 is a general mood and happiness improvement across all conditions. However, this improvement was greater when participants were embodied synchronously with Freud as the counsellor.

Perspective-taking could explain the general improvement (Batson et al., 1997). Nevertheless, since the results show that embodying different avatars cause different levels of improvement, it is clear that embodiment must play a role. A similar experiment (Falconer et al., 2014) is in line with our results.

This last study shows the potential applications of the techniques developed throughout this thesis. Future work should explore further possible applications of this technology, and expand the reach of the time travel illusion. In what follows we outline our suggestions for further research.

8.3 Future work

This thesis contains answers to exploratory questions and, as such, the boundaries to the knowledge acquired during the process of this thesis are yet to be defined. The studies hereby presented open new research fields that should be explored. We can outline further exploration in two different directions: time perception using immersive technologies and virtual time travel.

8.3.1 *Time perception using immersive technologies*

Chapter 5 and Chapter 6 contain the description of two studies that examine the relationship between two different variables and time perception. In particular, the first experiment examined the effects background music tempo, and the second of body shape, and both were performed using virtual reality equipment and technology.

Both experiments were inconclusive. One of the reasons could be the relatively low sample size of our studies. Many studies concerning time perception have used much larger samples, and perhaps future work could find conclusive results by replicating our studies and an increased sample size.

Moreover, future studies should cover many other aspects on the field. For example, a future research line could be to compare results of previous studies that compared music tempo in the prospective paradigm with similar experiments using IVR. Some research in this direction is already available, but the amount of variables to examine is vast.

With respect to the potential relationship between body shape and time perception, future studies could also use the prospective paradigm, or even change the design to include multiple types of tasks.

8.3.2 *Virtual Time Travel*

In this thesis we provide an exploratory study along with a framework to examine the illusion of travelling back in time. Given that the illusion was mediated by the sense of embodiment, plausibility, and copresence, it could be the case that the scope of this illusion could be broadened. In what follows, we present a few possible directions in which future studies could expand the knowledge in this field.

8.3.2.1 Travel to the future

Chapter 7 focused on how to travel back in time and whether or not people perceived it as such. However, in IVR there is no limitation on the direction of the travel. Therefore, travelling to the future would be perfectly conceivable. The difficulty in this case could rely on the fact that predicting the future is not trivial at all, if not nearly impossible with current technology. However, if the prediction is for a short period of time (a few minutes) after the present, the assumption of temporal continuity would probably facilitate the design. In that sense, if the research question aimed only at finding out how travelling to the future can be simulated, the obstacle of accurate or at least plausible prediction could be minimized. If, however, the aim were to have a relatively big time jump, considerable effort should be put on designing a plausible scenario and making characters reactions believable, as we have seen in our results. Such studies could potentially be useful to treat bad memories too, since participants could experience the consequences of bad decisions and realize that they are not so severe. In that case, the brain could implicitly learn that bad decisions do not carry dire consequences, in a similar process as the one in backwards time travel.

8.3.2.2 Travel to distant pasts

In this thesis we have explored virtual time travel to a previous timeline with just a few minutes of difference. However, IVR technology has no intrinsic limitation over the time distance in time travel. Therefore, future experiments could study the differences between shorter and longer travels to the past. Such studies would contribute to the knowledge of the boundaries of the time travel illusion.

A travel to an earlier point in the life of a participant could also be used as part of a VRET treatment for PTSD. In fact, several authors (Beck, Palyo, Winer, Schwagler, & Ang, 2007; Gamito et al., 2010; Rizzo et al., 2009) already have used these techniques with war veterans and vehicle accident victims. However, the tools employed are not personalized, but are rather general simulators that reproduce situations commonly faced by all participants which include events similar to those which caused the trauma. This, though, cannot be considered virtual time travel. Future studies, on the other hand, could include scenarios that accurately represent the traumatic events lived by each participant to trigger the time travel illusion and compare the efficacy as a treatment with respect to traditional methods.

8.3.2.3 Other forms of time travel

Science fiction stories provide different representations of how time travel works. For example, the film Predestination offers a view that fate is predefined and travelling back in time inevitably leads to one predefined outcome. Other films such as Back to the future, on the other hand, rely on the concept of different timelines where the past and future are mutable. Since this is a phenomenon that, to our knowledge, has not yet been possible, we cannot determine which one correctly represents the mechanics of time travel, if that is even possible. Future studies could explore these alternative approaches to virtual time travel to find the boundaries and differences with the one presented in this thesis.

8.3.2.4 Further applications for the virtual time travel method

In this thesis we provide in Section 7.6 a study as an example of an application that used the techniques developed for the time travel illusion. Since we have seen how powerful other illusions can be, further work should be spent designing applications that use those methods.

With respect to future work along the lines of the experiment described in Section 7.6, further studies could also expand its current reach. For example, we intentionally limited the scope for ethical reasons. Participants were told to discuss only moderately uncomfortable problems inside the IVR scenario because we could not predict whether the method would have a positive effect in all conditions. Therefore, addressing intense issues could potentially have triggered equally intense severe reactions, which would have been clearly unethical. The results, however, suggest that across all conditions participants felt better after the experience, which opens the door at accepting more serious personal problems. Also for the same reasons, the sample was screened prior to the experiment to ensure only healthy participants volunteered in the study. After the results, further studies should consider researching into clinical samples to evaluate the effectiveness of this method, and perform a long-term follow-up to assess if this technique is valid as a form of treatment.

8.3.3 TECHNICAL CHALLENGES

As we have seen throughout this thesis, and especially in Chapter 7, the technology developed has a big potential. However, some aspects still have challenges to overcome. For example, there is no ideal solution with respect to the equipment necessary to induce the illusions described in this thesis. Full body tracking hardware has seen big improvements recently, but systems are still very bulky, expensive or imprecise.

Moreover, the results of Chapter 7 show that plausibility and copresence are necessary components to induce the illusion of time travel. In that sense, generic methods to drive avatar behaviour are necessary. Artificial Intelligence, however, is still an active research area unable of recreating a person's behaviour.

Finally, avatar creation from a real person's 3D scan is still a technical challenge. Even though there is extensive research in the area, the workflows usually involve several manual steps using specialised software and hardware tools. In order to make applications similar to the experiment described in Section 7.6 practical, the process should be much more automatized and intuitive.

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APPENDIX

List of abbreviations

AGM	Attentional Gate Model
HMD	Head Mounted Displays
FOV	Field Of View
IVR	Immersive Virtual Reality
1PP	First Person Perspective
3PP	Third Person Perspective
MPFC	Medial Prefrontal Cortex
VMPFC	Ventromedial Prefrontal Cortex
IK	Inverse Kinematics
IAT	Implicit Association Test
VRET	Virtual Reality Exposure Therapy
PTSD	Post-Traumatic Stress Disorder
CBT	Cognitive Behavioural Treatment
HR	Heart Rate
BPM	Beats Per Minute
VRPN	Virtual Reality Peripheral Network
AI	Artificial Intelligence

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Materials for experiments

CONSENT FORM

CONSENTIMIENTO INFORMADO DEL PARTICIPANTE

El voluntario deberá leer y contestar cuidadosamente las siguientes preguntas:

¿Ha leído toda la información sobre este estudio? SI/NO

¿Ha tenido la oportunidad de preguntar y comentar cuestiones sobre el estudio? SI/NO

¿Ha recibido respuestas satisfactorias a todas las cuestiones? SI/NO

¿Ha recibido la suficiente información sobre este estudio? SI/NO

¿Qué investigador le ha hablado sobre el estudio?……………………………………… (nombre y apellidos)

¿Ha comprendido que usted es libre de abandonar este estudio? SI/NO

- En cualquier momento SI/NO
- Sin dar ninguna razón SI/NO

¿Ha comprendido y aceptado los riesgos asociados con el uso de la Realidad Virtual? SI/NO

¿Está de acuerdo en tomar parte en el estudio? SI/NO

¿Está de acuerdo en ser grabado en vídeo? SI/NO

¿Está de acuerdo en ser grabado en audio? SI/NO

Yo certifico que no padezco epilepsia.

Yo certifico que no conduciré ni coches, ni motos, ni bicicletas ni usaré ningún tipo de máquinas complejas que puedan ser peligrosas para mí o para otros, durante las tres próximas horas después de acabada la experiencia.

Firmado…………………………………………………………… Fecha……………………………

Nombre completo ……………………………………………………………

En caso que usted desee hacer alguna pregunta o comentario de este estudio en el futuro por favor contacte con:

Mel Slater
EVENT Lab for Neuroscience and Technology
Facultat de Psicologia, Universitat de Barcelona, Departament de Personalitat, Avaluació i Tractaments Psicològics,
Campus de Mundet - Edifici Teatre

Passeig de la Vall d'Hebron 171, 08035 Barcelona, Spain
Tel. +34 93 403 9618   www.event-lab.org

LA INFORMACIÓN OBTENIDA DE SU EXPERIMENTO NUNCA SERÁ PUBLICADA INDIVIDUALMENTE. LOS DATOS SERÁN ANALIZADOS EN GRUPOS Y AQUELLOS COMENTARIOS VERBALES, EN EL CASO QUE SE PUBLIQUEN, SERÁN PRESENTADOS DE FORMA ANÓNIMA.

INFORMATION SHEETS

Time perception and music

INFORMACIÓN DEL EXPERIMENTO

Este experimento forma parte de una serie a través de la cual intentamos aprender cómo responden las personas a las experiencias de realidad virtual.

En este estudio se pondrá un casco de realidad virtual que le mostrará un mundo virtual en tres dimensiones. En la siguiente foto se muestra un ejemplo del equipamiento:

Cuando mueva su cabeza, verá efectos particulares dentro de la realidad virtual.

Dentro del mundo virtual se le pedirá que realice una tarea. Una vez finalizada, se quitará el casco. Después se le pedirá que rellene un cuestionario. Finalmente, se le realizará una entrevista relacionada con la experiencia. El objetivo del experimento será explicado al finalizar. Al terminar se le darán 5€ en compensación por su participación.

Por favor, no discuta los detalles del experimento con otros ya que la ingenuidad es crucial para los resultados.

Recuerde que es libre de abandonar el experimento en cualquier momento y sin dar explicaciones. Si tiene alguna pregunta, por favor no dude en preguntar.

IMPORTANTE

Cuando la gente usa un sistema de realidad virtual, algunas personas experimentan cierta sensación de nauseas. Si en algún momento del estudio desea parar por esta o cualquier otra razón, por favor dígalo y pararemos la experiencia.

Algunas investigaciones se sugieren que la gente que usa un casco de realidad virtual, puede experimentar alguna pequeña perturbación visual poco después.

También han sido documentadas ocasiones en las que después de 30 minutos hay quien tiene 'flashbacks' pasajeros relacionados con la experiencia virtual.

Con algunos tipos de video hay la posibilidad de generar un episodio epiléptico, como se ha informado que ocurre en algunos videojuegos.

Información de contacto:

Rodrigo Pizarro **Tel:** +34 654 928 913 **Email:** rodrigo.pizarro.lozano@gmail.com

Time perception and embodiment

INFORMACIÓN DEL EXPERIMENTO

Este experimento forma parte de una serie a través de la cual intentamos aprender cómo responden las personas a las experiencias de realidad virtual.

En este estudio se pondrá un casco de realidad virtual que le mostrará un mundo virtual en tres dimensiones. En la siguiente foto se muestra un ejemplo del equipamiento:

Cuando mueva su cabeza, verá efectos particulares dentro de la realidad virtual.

Dentro del mundo virtual se le pedirá que realice una tarea. Una vez finalizada, se quitará el casco y el traje. Después se le pedirá que rellene un cuestionario. Finalmente, se le realizará una entrevista relacionada con la experiencia. El objetivo del experimento será explicado al finalizar. Al terminar se le darán 5€ en compensación por su participación.

Por favor, no discuta los detalles del experimento con otros ya que la ingenuidad es crucial para los resultados.

Recuerde que es libre de abandonar el experimento en cualquier momento y sin dar explicaciones. Si tiene alguna pregunta, por favor no dude en preguntar.

IMPORTANTE

Cuando la gente usa un sistema de realidad virtual, algunas personas experimentan cierta sensación de nauseas. Si en algún momento del estudio desea parar por esta o cualquier otra razón, por favor dígalo y pararemos la experiencia.

Algunas investigaciones se sugieren que la gente que usa un casco de realidad virtual, puede experimentar alguna pequeña perturbación visual poco después.

También han sido documentadas ocasiones en las que después de 30 minutos hay quien tiene 'flashbacks' pasajeros relacionados con la experiencia virtual.

Con algunos tipos de video hay la posibilidad de generar un episodio epiléptico, como se ha informado que ocurre en algunos videojuegos.

Información de contacto:

Rodrigo Pizarro

Tel: +34 654 928 913

Email: rodrigo.pizarro.lozano@gmail.com

A Virtual time travel illusion

INFORMACIÓN DE LA PRIMERA FASE DEL EXPERIMENTO

Este experimento consta de dos fases, y forma parte de una serie a través de la cual intentamos aprender cómo responden las personas a las experiencias de realidad virtual.

En esta primera fase del experimento se pondrá un casco de realidad virtual que le mostrará un mundo virtual en tres dimensiones. En la siguiente foto se muestra un ejemplo del equipamiento:

Cuando mueva su cabeza, verá efectos particulares dentro de la realidad virtual.

En esta primera fase, primero se le pedirá que realice dos test. Una vez finalizados, se pondrá el casco y se le pedirá que explore el mundo virtual al principio y después que ejecute una tarea concreta. Finalmente, se le realizará una entrevista relacionada con la experiencia. El objetivo del experimento será explicado al finalizar la segunda fase. En esta primera fase del experimento se le darán 5€ en compensación por su participación. En la segunda fase se le darán otros 5€. La segunda fase se realizará otro día, a determinar entre usted y el experimentador.

Por favor, no discuta los detalles del experimento con otros ya que la ingenuidad es crucial para los resultados.

Recuerde que es libre de abandonar el experimento en cualquier momento y sin dar explicaciones. Si tiene alguna pregunta, por favor pregunte.

IMPORTANTE

Cuando la gente usa un sistema de realidad virtual, a menudo algunas personas experimentan cierta sensación de nauseas. Si en algún momento del estudio desea parar por cualquier razón, por favor dígalo y pararemos la experiencia.

Algunas investigaciones se sugieren que la gente que usa un casco de realidad virtual, puede experimentar alguna pequeña perturbación visual poco después. No conocemos estudios de largo término, pero hay estudios que prueban la presencia de este efecto después de 30 minutos.

También han sido documentadas ocasiones en las que después de 30 minutos hay quien tiene 'flashbacks' pasajeros relacionados con la experiencia virtual.

Con algunos tipos de video hay la posibilidad de generar un episodio epiléptico, como se ha informado que ocurre en algunos videojuegos.

Información de contacto:

Rodrigo Pizarro

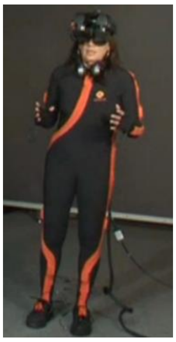
Tel: +34 654 928 913

Email: rodrigo.pizarro.lozano@gmail.com

INFORMACIÓN DE LA SEGUNDA FASE DEL EXPERIMENTO

Este experimento consta de dos fases, y forma parte de una serie a través de la cual intentamos aprender cómo responden las personas a las experiencias de realidad virtual.

En esta segunda fase del experimento se pondrá un casco de realidad virtual que le mostrará un mundo virtual en tres dimensiones. También llevará un traje especial que nos ayudará captar tus movimientos en tiempo real. En las fotos siguientes se muestran ejemplos del equipamiento:



Cuando mueva su cuerpo y su cabeza, verá efectos particulares dentro de la realidad virtual.

Primero se le pedirá que explore el mundo virtual al principio y después que ejecute una tarea concreta. Más adelante, se le pedirá que realice dos test y rellene un cuestionario. Finalmente, se le realizará una entrevista filmada relacionada con el experimento. El objetivo del experimento será explicado al finalizar el experimento, y se le darán 5€ en compensación por su participación.

Por favor, no discuta los detalles del experimento con otros ya que la ingenuidad es crucial para los resultados.

Recuerde que es libre de abandonar el experimento en cualquier momento y sin dar explicaciones. Si tiene alguna pregunta, por favor pregunte.

IMPORTANTE

Cuando la gente usa un sistema de realidad virtual, a menudo algunas personas experimentan cierta sensación de nauseas. Si en algún momento del estudio desea parar por cualquier razón, por favor dígalo y pararemos la experiencia.

Algunas investigaciones se sugieren que la gente que usa un casco de realidad virtual, puede experimentar alguna pequeña perturbación visual poco después. No conocemos estudios de largo término, pero hay estudios que prueban la presencia de este efecto después de 30 minutos.

También han sido documentadas ocasiones en las que después de 30 minutos hay quien tiene 'flashbacks' pasajeros relacionados con la experiencia virtual.

Con algunos tipos de video hay la posibilidad de generar un episodio epiléptico, como se ha informado que ocurre en algunos video juegos.

Información de contacto:

Rodrigo Pizarro

Tel: +34 654 928 913

Email: rodrigo.pizarro.lozano @gmail.com

DEMOGRAPHICS QUESTIONNAIRES

ID	
Edad	
Genero	Hombre Mujer
Tienes problemas con tu visión?	Si No En caso afirmativo, por favor detállelos:
Ocupación	Estudiante de Grado Estudiante de Máster Estudiante de Doctorado Investigador Empleado de la universidad Profesorado Personal administrativo Otros
¿Está tomando alguna medicación?	Si No Si afirma, especifique cual

¿Ha consumido más de dos unidades de alcohol en las últimas 6 horas? *(2 unidades de alcohol = 1 cerveza o 2 copas de vino)*	Si No
Por favor indique su nivel de conocimientos en informática dentro de una escala del 1 al 7 (principiante) 1 2 3 4 5 6 7 (experto)	
Por favor indique su nivel de experiencia en programación informática: (principiante) 1 2 3 4 5 6 7 (experto)	
¿Ha tenido alguna experiencia con Realidad Virtual anteriormente? (ninguna experiencia) 1 2 3 4 5 6 7 (experiencia extensa)	
¿Cuántas veces ha jugado con videojuegos (en casa, el trabajo, el colegio, sitios públicos como centros comerciales…) en el último año?	Nunca 1 - 5 6 - 10 11 - 15 16 - 20 21 - 25 > 25
¿Cuántas horas a la semana juega con videojuegos?	0 < 1 1 - 3 3 - 5 5 - 7 7 - 9 > 9
¿Estás de acuerdo q te llamemos una semana después del experimento para preguntarte sobre tu experiencia?	Si ☐ No ☐

	En caso afirmativo, danos tu numero:

TIME TRAVEL PRIMING

Time Travel

Have you ever thought about time travel, the ability to go back to the past? What would be the consequences if this were possible? Perhaps you would like to think of some event in which you were involved where the outcome was not what you wanted. Now you think to yourself "If only I had done …something different … I could have changed how things turned out".

Time travel makes this possible. Did you know that if you were able to go back and change the past then what happened before never actually happened? If you went back to the past you could even visit a place and time where you had been before and perceive yourself carrying out actions and doing whatever you did then. You might be able to even change the consequences of your past actions by interfering with events in the past.

There are different theories of time travel. In some theories your past self would see your time travel self, and you could interact with your past self. In other theories your time travel self would not be visible to your earlier self.

But the most important thing of all is that if you travelled back in time and changed something, then that change could have repercussions and change the future.

There is a famous science fiction story where a time traveller went so far back in time that there were still dinosaurs roaming the earth. By accident he stepped on a tiny creature and killed it. When the time traveller returned to the present, there were no humans – only seemingly lizard-like creatures. When he went back to the past he had inadvertently killed a precursor of mammals, and so human beings never developed.

Change the past and you change the future. What happened, now never happened.

When you change the past what happened before never happened. History itself has changed.

Do you think that you will ever experience time travel?

MORAL DILEMMA SCENARIOS

Scenario 1

You are the operator of a lift in a gallery that shows paintings. You can see the gallery and the lift directly and you operate the lift using two buttons, the up and the down button. You are not in the lift but operating it from a small distance away. The lift itself is a platform surrounded by glass walls. There are two floors in the gallery (ground floor and upper floor) and the only access to the upper floor is by the lift. A person standing on the lift after it has reached the upper floor cannot see the area of the ground floor where visitors might be looking at the paintings.

There are 5 visitors on the upper floor and 1 on the ground floor. One other person steps on the lift and you push the switch to take this person to the upper floor. When the lift arrives at the upper floor, this person takes out a gun and starts shooting at the 5 people on the upper floor. One of the people on the upper floor is immediately killed, and the remaining 4 are clearly in danger of their lives. The attacker is still on the lift. If you move the lift downstairs immediately you will save the 4 people on the upper floor. However by doing so you are putting the life of the one person on the ground floor in danger.

Would you push the down button?

Yes/No

Scenario 2

An empty boxcar is running out of control down a track. In its path are five people standing on the track; these people are not aware of the oncoming danger. If the boxcar continues, it will kill all five people. You are standing next to a switch. If you flip the switch, it will cause the boxcar to turn off of the main track and onto a side track. On the side track there is one person who is also unaware of the boxcar. If the boxcar goes down this side track, the one person will die but the five people on the main track will survive.

Would you flip the switch?

Yes/No

Scenario 3

An empty boxcar is hurtling out of control down a track towards five people. If the boxcar continues, it will kill all five people. You are on a bridge over the tracks. The boxcar will pass under the bridge before it reaches the five people. You can stop the boxcar by dropping a heavy weight in front of it. Standing next to you is a man wearing a heavy backpack. If you push him over the bridge, he will land in front of the boxcar and stop it before it reaches the five people ahead. This man will, however, die.

Would you flip the switch?

Yes/No

Scenario 4

You are the operator of a lift in a gallery that shows paintings. You can see the gallery and the lift directly and you operate the lift using two buttons, the up and the down button. You are not in the lift but operating it from a small distance away. The lift itself is a platform surrounded by glass walls. There are two floors in the gallery (ground floor and upper floor) and the only access to the upper floor is by the lift. A person standing on the lift after it has reached the upper floor cannot see the area of the ground floor where visitors might be looking at the paintings.

There is 1 visitor on the upper floor and 5 on the ground floor. One other person steps on the lift and you push the button to take this person to the upper floor. When the lift arrives at the upper floor, this person takes out a gun and starts shooting at the person on the upper floor. The person on the upper floor is immediately injured, and is clearly in danger of his life. The attacker is still on the lift. If you move the lift downstairs immediately you will save the person on the upper floor. However by doing so you are putting the life of the 5 people on the ground floor in danger.

Would you push the down button?

Yes/No

Scenario 5

An empty boxcar is running out of control down a track. In its path is one person standing on the track; this person is not aware of the oncoming danger. If the boxcar continues, it will kill this person. You are standing next to a switch. If you flip the switch, it will cause the boxcar to turn off of the main track and onto a side track. On the side track there are five people who are also unaware of the boxcar. If the boxcar goes down this side track, the five people will die but the one person on the main track will survive.

Would you flip the switch?

Yes/No

EMBODIMENT QUESTIONS

Cuando miraba hacia abajo, aunque el cuerpo que veía en el mundo virtual no se parecía a mí, sentía como si pudiera ser yo (completamente en desacuerdo) -3 -2 -1 0 1 2 3 (completamente de acuerdo)

Aunque el cuerpo que veía en el mundo virtual no se parecía a mí, sentí que lo controlaba como si fuera mi propio cuerpo.

(completamente en desacuerdo) -3 -2 -1 0 1 2 3 (completamente de acuerdo)

Durante el experimento hubo momentos en los que el avatar comenzaba a parecerse a mi propio cuerpo en algunos aspectos (físicamente).

(completamente en desacuerdo) -3 -2 -1 0 1 2 3 (completamente de acuerdo)

Durante el experimento hubo momentos en los que tenía la sensación de tener más de un cuerpo

(completamente en desacuerdo) -3 -2 -1 0 1 2 3 (completamente de acuerdo)

Aunque el cuerpo que veía en el mundo virtual no se parecía a mí, sentí que se movía como yo.

(completamente en desacuerdo) -3 -2 -1 0 1 2 3 (completamente de acuerdo)

Avatar choice sentences

The average salary in Spain increased by 3.57% in the 50s.

The average salary in Spain increased by 5.23% in the 60s.

Subliminal Priming

Participants were subliminally primed with three different shapes, shown in front of their sight (Figure 0.1).

Figure 0.1: Participants were primed with a shape shown in front of them for a frame time every 15 seconds.

After all trials finished, participants were asked to choose between a shape that aggregated all the individual shapes shown earlier or one that displayed them separated (Figure 0.2 or Figure 0.3).

Figure 0.2: On the left a shape displaying the individual shapes shown earlier. On the right a shape aggregating them.

Figure 0.3: On the left a shape aggregating the individual shapes shown earlier. On the right a shape that displays them separated.

PRESENCE QUESTIONS

He tenido la sensación de estar dentro de la sala

(En ningún momento) -3 ○ -2 ○ -1 ○ 0 ○ 1 ○ 2 ○ 3 ○ (Casi todo el tiempo)

Ha habido veces durante la experiencia en que la sala ha sido real para mi

(Ninguna vez) -3 ○ -2 ○ -1 ○ 0 ○ 1 ○ 2 ○ 3 ○ (Casi todo el tiempo)

La sala virtual parece más como...

(Una imagen que he visto) -3 ○ -2 ○ -1 ○ 0 ○ 1 ○ 2 ○ 3 ○ (Un lugar que he visitado)

He tenido una fuerte sensación de…

(Estar en el laboratorio) -3 ○ -2 ○ -1 ○ 0 ○ 1 ○ 2 ○ 3 ○ (Estar en la sala)

Durante la experiencia he pensado que estaba realmente en el laboratorio...

(La mayoría del tiempo) -3 ○ -2 ○ -1 ○ 0 ○ 1 ○ 2 ○ 3 ○ (Raramente)

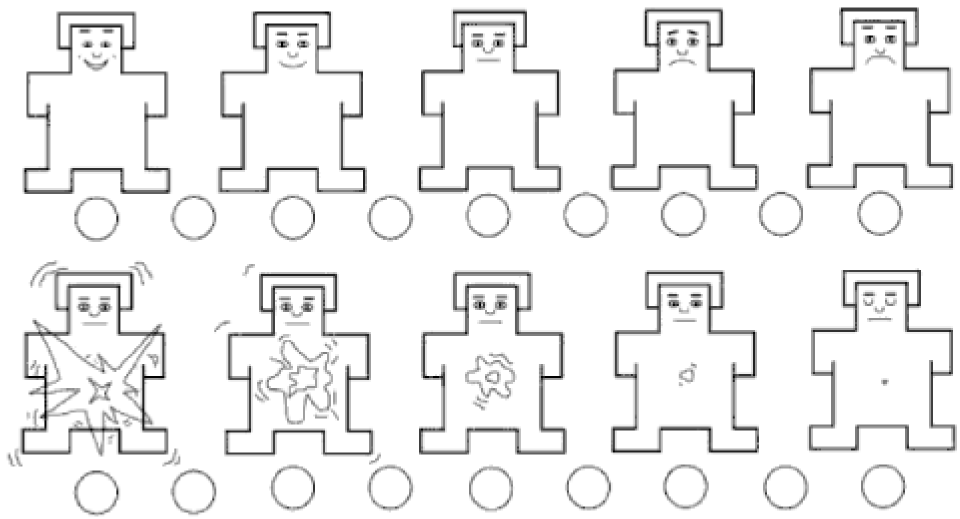
PROFILE OF MOOD STATES (POMS)

Más abajo hay una lista de palabras que describen sensaciones que tiene la gente. Por favor, lee cada una cuidadosamente. Después rodea con un círculo UNO de los números que hay al lado, rodea el que mejor describa como te has sentido durante la semana pasada, incluyendo el día de hoy.

	Nada	Un poco	Moderadamente	Bastante	Muchísimo
Tenso					
Enfadado					
Agotado					
Infeliz					
Animado					
Confundido					
Dolido por actos pasados					
Agitado					
Apático					
Enojado					
Triste					
Activo					
A punto de estallar					
Irritable					
Abatido					
Enérgico					
Descontrolado					
Desesperanzado					
Relajado					
Torpe					
Rencoroso					
Intranquilo					
Inquieto					
Incapaz de concentrarse					
Fatigado					
Molesto					

Desanimado					
Resentido					
Nervioso					
Solo					
Desdichado					
Aturdido					
Alegre					
Amargado					
Exhausto					
Ansioso					
Luchador					
Deprimido					
Desesperado					
Espeso					
Rebelde					
Desamparado					
Sin fuerzas					
Desorientado					
Alerta					
Decepcionado					
Furioso					
Eficiente					
Lleno de energía					
De mal genio					
Inútil					
Olvidadizo					
Despreocupado					
Aterrorizado					
Culpable					
Vigoroso					
Inseguro					
Cansado					

Self Assessment Manikin (SAM)



Subjective Units of Distress Scale (SUDS)

10 = Feels unbearably bad, beside yourself, out of control as in a nervous breakdown, overwhelmed, at the end of your rope. You may feel so upset that you don't want to talk because you can't imagine how anyone could possibly understand your agitation.

9 = Feeling desperate. What most people call a 10 is actually a 9. Feeling extremely freaked out to the point that it almost feels unbearable and you are getting scared of what you might do. Feeling very, very bad, losing control of your emotions.

8 = Freaking out. The beginning of alienation.

7 = Starting to freak out, on the edge of some definitely bad feelings. You can maintain control with difficulty.

6 = Feeling bad to the point that you begin to think something ought to be done about the way you feel.

5 = Moderately upset, uncomfortable. Unpleasant feelings are still manageable with some effort.

4 = Somewhat upset to the point that you cannot easily ignore an unpleasant thought. You can handle it OK but don't feel good.

3 = Mildly upset. Worried, bothered to the point that you notice it.

2 = A little bit upset, but not noticeable unless you took care to pay attention to your feelings and then realize, "yes" there is something bothering me.

1 = No acute distress and feeling basically good. If you took special effort you might feel something unpleasant but not much.

0 = Peace, serenity, total relief. No more anxiety of any kind about any particular issue.

IATs

Moral IAT

Moral categories: honesty, humility, altruism, modesty, sincerity, ethical

Immoral categories: deceptive, arrogant, cheater, egoism, vanity, corrupt

Me/Others categories: I, Me, Myself, Mine, Theirs, Others, They, Them

Guilt IAT

Guilt categories: Innocent, Irreprochable, Blameless, Clean, Legal, Legitimate

Not guilt categories: Blameworthy, Accusable, Criminal, Culpable, Remorseful, Guilty, Evil

Me/Others categories: I, Me, Myself, Mine, Theirs, Others, They, Them


18:48:30
glass wall
visitors
1st floor
ground floor
mirror
elevator
elevator entrance
time machine
user
console
entrance
DOWN
UP