The Impact of Virtual Embodiment on Perception, Attitudes, and Behaviour

Domna Banakou

Department of Clinical Psychology and Psychobiology

A thesis submitted for the degree of

Doctor of Philosophy

Barcelona, 2017

The Impact of Virtual Embodiment on Perception, Attitudes, and Behaviour

Author: **Domna Banakou**

Submitted to the **Doctorate Program in Clinical and Health Psychology, Facultat de Psicologia, Univesitat de Barcelona**

Director: **Prof. Mel Slater**
Tutor: **Prof. José Gutiérrez Maldonado**

Barcelona,
April 7, 2017

Στην αγαπημένη μου οικογένεια...

Acknowledgements

First and foremost, I would like to express my special appreciation to my supervisor Professor Dr Mel Slater for giving me the opportunity to be part of his research group. His work, on the science of virtual reality, inspired me over the years to follow this career path, which eventually led me to working with him. His encouragement, advice, and immense knowledge have allowed me to grow as a research scientist. He has taught me the best research practices, how to develop and experiment with new ideas, and how to be passionate and open-minded about my work. I thank him most sincerely for being a tremendous mentor.

I would also like to convey my heartfelt gratitude to the people of the EventLab, former and present, for all the support they offered me in order to successfully conduct my research, for the stimulating discussions and for sharing their knowledge with me, for guiding me through my work in times of uncertainty, but mostly, for being good friends.

Last, but not the least, I thank my dear friends and family: Especially to my loving parents, sister, and partner, I thank them for all the spiritual support they have given me throughout my doctoral studies, and especially, my life as a whole.

I'm more than grateful to all of you!
Domna Banakou
Barcelona, April 7, 2017

My work was funded under the European FP7 Integrated Project BEAMING: "Being in Augmented Multimodal Naturally Networked Gatherings", grant number 248620, and the European FP7 Integrated Project, Future and Emerging Technologies, VERE: "Virtual Embodiment and Robotic Re-Embodiment", grant number 257695. Additional support was provided by the FI-DGR2014 pre-doctoral grant offered by the Agència de Gestió d'Ajuts Universitaris i de Recerca of the Generalitat de Catalunya (AGAUR-Gencat).

Abstract

Over the past two decades extensive research in experimental psychology, cognitive neuroscience, and virtual reality has provided evidence for the malleability of our brain's body representation. It has been shown that, under appropriate multisensory integration, a person's body can be substituted by a life-sized artificial one, resulting in a perceptual illusion of body ownership over the fake body. More importantly, several studies in virtual reality have shown that when people are virtually represented with a body different to their own, they exhibit behaviours associated with attributes pertaining to that body.

In the research described in this thesis we exploited Immersive Virtual Reality to induce body ownership illusions over distinct virtual bodies. By combining the knowledge gained from previous studies in the field, we aimed to study the extent to which people can accept as their own, a virtual body that differs significantly from their real body. Additionally, we examined how an altered self-representation can influence one's self-perception, perception of the environment, and implicit biases. To this end, we carried out two experimental studies to investigate embodiment of healthy adults in a child virtual body, and a different race virtual body. Moreover, by exploiting the basic concepts of action perception and agency, we tested whether it is possible to induce illusory agency over specific actions that are not carried out by the participants themselves.

In the **Virtual Child Body** study, we examined the boundaries of body ownership illusions by embodying adults both as a 4-year-old child, and as an adult scaled-down to the same height as the child.

The results showed a strong ownership illusion equally for both conditions. However, embodiment in the child body led to a significant overestimation of object sizes, which was approximately double the overestimation of those embodied in the scaled-down adult body. Moreover, embodiment in the child resulted in changes in implicit attitudes about the self towards being child-like. These findings were diminished under asynchronous visuomotor correlations, providing further proof for the importance of visuomotor contingencies in producing body ownership illusions. Overall, our findings extend and enrich previous research, yielding additional evidence of the malleability of our body representation. Through our experimental work, we show that there are perceptual and behavioural correlates of body ownership illusions, which are dependent on the type of body in which embodiment occurs.

In the **Racial Bias** study, we aimed to explore how the type of body can influence racial discrimination, by embodying white people in a black virtual body. Previous research has already shown that this type of embodiment can lead to a reduction of implicit racial bias, but its long-term effects were unknown. Here we tested whether this reduction in implicit bias can (a) be replicated, (b) it can last for at least one week, and (c) it is enhanced by multiple exposures. Participants were immersed in a virtual scenario between one and three times, each separated by two days, and implicit bias was measured one week before their first exposure, and one week after their last. The results showed that implicit bias decreased more for those with the black virtual body than the white, even a week after their virtual exposure, and irrespective of the number of exposures. There was also some evidence of a general decrease in bias independent of body type, for which we discuss possible explanations.

In the **Illusory Speaking** study, we took the role of body ownership a step further, by exploring the possibility of inducing illusory agency in participants over an action they did not carry out themselves. We describe a set of experiments, where under appropriate sensorimotor contingencies, we induce a subjective illusion of agency over the participants' speaking virtual body, as if they had been themselves speaking. Moreover, when participants were asked to speak after this exposure, they shifted the fundamental frequency of their utterances towards that of the stimulus voice of the virtual body. We argue that these findings can be reconciled with current theories of agency, provided that the critical role of both ownership and actual agency over the virtual body are taken into account.

Overall, our studies expand previous evidence for the malleability of our body representation, demonstrating how it is possible to induce ownership illusions over a child body, a different race body, or even a speaking body. Notably, we provide evidence of how body ownership and agency over the virtual body result in powerful, lasting changes in perceptual and cognitive processing, having the potential of compelling applications in psychology and neuroscience.

Resumen

Durante las dos últimas décadas se ha llevado a cabo una amplia investigación en psicología experimental, neurociencia cognitiva y realidad virtual que ha permitido descubrir la maleabilidad de la representación corporal que tenemos en nuestro cerebro. Se ha demostrado que, bajo condiciones de integración multisensorial adecuadas, el cuerpo de una persona puede ser sustituido por uno artificial de tamaño real, dando lugar a una ilusión perceptual de posesión de un cuerpo falso (Body Ownership). Y lo que es más importante: varios estudios de realidad virtual han demostrado que cuando una persona se ve representada de forma virtual con un cuerpo diferente al suyo, muestra comportamientos asociados a las características de ese cuerpo.

En la investigación descrita en esta tesis hemos empleado Realidad Virtual Inmersiva con el fin de inducir ilusiones de Body Ownership sobre cuerpos muy diversos. Mediante la combinación del conocimiento adquirido en estudios anteriores en este campo, nos hemos centrado en estudiar hasta qué punto las personas son capaces de aceptar como propio un cuerpo virtual que difiere significativamente de su cuerpo real. Además, hemos estudiado cómo la alteración de la propia representación corporal puede influir en la percepción de uno mismo, la percepción del entorno y los sesgos implícitos. Con este fin, llevamos a cabo dos estudios experimentales para investigar la ilusión de Body Ownership en adultos sanos sobre el cuerpo virtual de un niño y un cuerpo virtual de otra raza. Asimismo, a partir de los conceptos básicos sobre percepción de la acción y agencia, evaluamos si era posible inducir una sensación ilusoria de agencia sobre acciones específicas que no habían sido realizadas por los participantes.

En el estudio del **Niño Virtual**, examinamos los límites de las ilusiones de Body Ownership poniendo a adultos en el cuerpo de un niño de cuatro años, o bien en el de un adulto re-escalado para tener la misma altura que el niño. Los resultados evidencian una fuerte ilusión de Body Ownership equiparable en ambas condiciones. No obstante, la ilusión en el cuerpo del niño conllevó una sobreestimación significativa del tamaño de los objetos, la cual era aproximadamente el doble de la estimación dada en el caso del cuerpo del adulto re-escalado a la misma altura que el del niño. Además, en el caso del niño virtual la ilusión de Body Ownership dio lugar a cambios en la actitud implícita propia/personal hacia un carácter más infantil. Estos resultados se redujeron en el caso de correlaciones visuomotoras asíncronas, lo cual proporcionó más pruebas de la importancia de la contingencia visuomotora con el fin de inducir ilusiones de Body Ownership. En general, nuestros resultados amplían y enriquecen lo descubierto hasta el momento, otorgando más pruebas de la maleabilidad de nuestra representación corporal. A partir de nuestro trabajo experimental, hemos demostrado que existen correlaciones entre las ilusiones de Body Ownership de carácter perceptual y de comportamiento, las cuales dependen del tipo de cuerpo con el que se produce la ilusión.

En el estudio de la **Discriminación Racial,** nos centramos en explorar el modo en que el tipo de cuerpo puede influir en la discriminación racial, poniendo a gente de piel de color blanca en un cuerpo de piel de color negra. En estudios anteriores se ha demostrado que este tipo de ilusión corporal puede conllevar una reducción del sesgo racial implícito, aunque los efectos a largo plazo son aún desconocidos. Con este estudio evaluamos si tal reducción en el sesgo implícito puede a) ser replicada, b) puede durar al menos una semana, y c) se ve incrementada después de múltiples exposiciones. Los participantes entraron en el escenario virtual entre una y tres veces, cada una separada por dos días de la anterior, y el sesgo implícito fue tomado una semana antes de la primera exposición, y una semana después de la última exposición. Los resultados muestran que el sesgo implícito disminuyó más en el caso de aquellos participantes que tenían el cuerpo virtual de piel negra en comparación con los que tuvieron el cuerpo de piel blanca incluso una semana después de la exposición virtual, independientemente del número de exposiciones. También se dieron indicios de una reducción general en el sesgo independientemente del tipo de cuerpo, para lo cual damos posibles explicaciones.

En el estudio de la **Ilusión de Hablar**, llevamos el papel de Body Ownership un paso más allá, explorando la posibilidad de inducir en los participantes una ilusión de agencia sobre una acción que ellos no llevaron a cabo. Describimos una serie de experimentos donde, bajo las contingencias sensorimotoras adecuadas, logramos una ilusión subjetiva de agencia sobre el habla del cuerpo virtual del participante, tal y como si ellos hubieran estado hablando. Además, cuando pedimos a los participantes que hablaran después de la exposición, modularon la frecuencia fundamental de su tono de voz en la dirección de la voz del cuerpo virtual. Argumentamos cómo se pueden reconciliar nuestros resultados con las teorías actuales de agencia, teniendo en cuenta el papel crucial que juegan tanto la ilusión de Body Ownership como el control sobre los movimientos del cuerpo virtual.

En general, nuestros estudios amplían los indicios previos sobre la maleabilidad de nuestra representación corporal, mostrando que es posible inducir ilusiones de Body Ownership sobre el cuerpo de un niño, un cuerpo de una raza distinta, o incluso un cuerpo que habla. Notablemente, hemos contribuido aportando evidencia sobre cómo la ilusión de Body Ownership del cuerpo virtual y agencia sobre un cuerpo virtual resultan en cambios importantes y perdurables en el procesamiento perceptual y cognitivo, lo cual puede dar lugar a potenciales e interesantes aplicaciones en psicología y neurociencia.

Contents

List of Figures

List of Tables

List of Abbreviations

The following table describes the significance of various abbreviations and acronyms used throughout the thesis. The page on which each one is defined or first used is also given.

1PP—First Person Perspective, p.6
3PP—Third Person Perspective, p.11
3D—Three-Dimensional, p.11
CNS—Central Nervous System, p.124
ECG—Electrocardiogram, p.14
FF—Fundamental Frequency, p.101
FoV—Field of View, p.36
HMD—Head-Mounted Display, p.4
HRD—Heart Rate Deceleration, p,.14
IAT—Implicit Association Test, p.24
IVR—Immersive Virtual Reality, p.1
OBE—Out-of-Body Experience, p.11
RHI—Rubber Hand Illusion, p.8
SCR—Skin Conductance Response, p.11
Vb—Vibrations. p.103
VHI—Virtual Hand Illusion, p.15
VM—Visuomotor, p.105
VT—Visuotactile, p.106
XVR—Extreme Virtual Reality Software, p.37

List of Publications

The following is a list of works published by the author during the course of the doctorate.

Journal Papers

- **Banakou, D.**, Groten, R. & Slater, M. (2013). Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. *Proc. Natl. Acad. Sci.* 110(31):12846-12851.
- **Banakou, D.**, & Slater, M. (2014). Body ownership causes illusory self-attribution of speaking and influences subsequent real speaking. *Proc. Natl. Acad. Sci.*, 111(49):17678-17683.
- **Banakou, D.**, & Hanumanthu, P. D., & Slater, M. (2016). Virtual Embodiment of White People in a Black Virtual Body Leads to a Sustained Reduction in Their Implicit Racial Bias. *Front. Hum. Neurosci.*, 10(601).
- Hamilton-Giachritsis, C., **Banakou, D.**, Giachritsis, C., & Slater, M. (2017). Improving maternal empathy and perspective-taking with virtual embodiment. *J Child Psychol Psychiatry.(Submitted)*
- Tajadura-Jimnez, A., **Banakou, D.**, Bianchi-Berthouze, N., Slater, M. (2017). Embodiment in a Child-Like Talking Virtual Body Influences Object Size Perception, Self-Indentification, and Subsequent Real Speaking. *Sci Rep. (Submitted)*

Chapter 1

Introduction

Since the dawn of modern civilisation, philosophers and scientists have attempted to understand the processes leading to the experience of perceiving a body as belonging to us, essential for creating a sense of self-identity. Ever since, the concepts of body and mind, and the perceptual and neural mechanisms of self-awareness, have been extensively and repeatedly re-conceived and refined. A relatively new and widely accepted approach to explain these theories is that of embodied cognition or embodiment (Merleau-Ponty, 2013). On the basis of this contemporary paradigm, science has aimed to explore how our body and our interaction with the environment through it can influence and shape the human mind.

In cognitive neuroscience and psychology for instance, experimental studies over the past two decades have demonstrated that healthy subjects can experience a surrogate body (or body part) as belonging to themselves, a concept widely known as a *Body Ownership Illusion* (Botvinick and Cohen, 1998; Dummer et al., 2009; Petkova and Ehrsson, 2008; Ramachandran and Hirstein, 1998; Tsakiris and Haggard, 2005). Immersive Virtual reality (IVR) has also been used to introduce such illusory experiences with respect to one's body representation with bodily manipulations in terms of structure, size and morphology. A plethora of studies have successfully induced body ownership illusions in IVR over virtual bodies, even when these differ significantly than the real body (Slater et al., 2009; Normand et al., 2011; Peck et al., 2013; Osimo et al., 2015). This research has paved the way for the investigation of more intricate correlates of body ownership illusions, such as in social cognition and perception. Overall, IVR technologies, as a more efficient and operable way of manipulating our body image, have contributed to overcome the limitations of the physical presence of our real body, and explore aspects of it that would otherwise be impossible to study in physical reality.

1.1 Research Problem

Experimental research has considerably contributed to the investigation of all the parameters and conditions necessary for the incorporation of artificial objects as part of our body representation. Nevertheless, the extent to which people can accept a body that differs significantly from their real bodies is not fully addressed. Moreover, experimental evidence regarding the existence of behavioural, perceptual and other attitudinal consequences of such body transformations is limited. This thesis explores to what extent healthy adults can experience and accept an altered body representation. By employing embodiment techniques in IVR we induced perceptual illusions of owning a virtual body that differs from the real one in terms of shape, body proportions, racial and age characteristics. We sought to investigate how embodiment of adults in a virtual body might influence implicit attitudes about the self, others, and perception of the environment.

Furthermore, it has been suggested that embodied experiences can alter the way we perceive actions as our own. Under normal circumstances we tend to believe that we are in control of our body and its actions (*sense of agency*). Nonetheless, literature is challenging this view as it has been shown that people can unconsciously alter their body actions under specific circumstances. Action perception and action manipulation in IVR however, has yet to be extensively addressed. This concept will be discussed further in this thesis, where it will be argued how body ownership illusions can induce more intricate correlates of one's body representation and associated actions, through illusory agency.

1.2 Research Questions

In order to study the aforementioned research problems we formed and tested the following three hypotheses:

1. **Hypothesis 1:** *Healthy adults can experience ownership over a child body when congruent multimodal information is provided. Such illusory experiences result in changes in self-perception, and also affect size perception of the surrounding environment.* To test this hypothesis, we created a first scenario (*A Virtual Child Body* study), where adults were embodied in either a 4-year-old child body or that of an adult, which was scaled-down to match the height of the child. We investigated to what extent people reported ownership over the two bodies, and whether there are any behavioural correlates of body ownership illusions that arise as a function of the type of body in which embodiment occurs.

2. **Hypothesis 2:** *Illusory ownership over a body of different race can lead to a sustained reduction in implicit racial bias.* This hypothesis was tested by embodying "White" people in a "Black" virtual body (*Racial Bias* study), and examining whether a reduction in implicit bias for those embodied in the "Black" body lasted for at least one week after the exposure. We also tested whether multiple exposures can further enhance the effect.

3. **Hypothesis 3:** *Healthy adults can experience illusory agency over speaking through embodiment in a talking virtual body.* To test this hypothesis we created a scenario (*Illusory Speaking* study) where we provided participants with body ownership over a virtual body that spoke. Given that they experienced the virtual body as their own, they would misattribute the speaking of their virtual body to themselves and also shift the fundamental frequency of their later utterances toward the stimulus voice.

1.3 Overview of the Thesis

In the rest of this thesis, we present how we tested our hypotheses, and discuss the results in relation to the existing literature. Specifically, in Chapter 2, we present detailed background work on body ownership illusions in physical and virtual reality, and the required mechanisms for their induction. We also assess various perceptual and behavioural consequences of these illusions, and finally, we discuss the sense of agency and its relation to body ownership. In Chapter 3, we summarise the methods used to carry out the experimental work; these include details of the immersive technologies used, the procedures that were followed and ethical considerations that were taken into account throughout the research. In Chapters 4, 5 and 6 we present the *Virtual Child Body*, the *Racial Bias*, and the *Illusory Speaking* studies respectively, in an attempt to answer Hypothesis 1, 2, and 3 of this thesis. We describe the methods and results of each study, and we discuss our findings in comparison to existing studies. Finally, in Chapter 7 we summarise the conclusions of our research, and we argue the contributions and impact of our experimental studies in neuroscience, psychology, and IVR, suggesting possible directions for future work.

1.4 Scope of the Thesis

This thesis is an attempt to study body perception, and the limitations of body ownership illusions over an altered body representation in IVR. We investigated the perceptual, behavioural and attitudinal correlates of such illusory experiences, and took the research one step further, by exploiting the basic concepts of action perception and agency. Nonetheless, approaching body and action perception on a neurological and philosophical basis was out of the scope of this thesis.

All three experimental studies used the appropriate visuomotor, visuoproprioceptive, and visuotactile information in order to induce the corresponding illusions. We acknowledge that there are additional cross-modal stimuli (e.g. vestibular, auditory, interceptive inputs etc.) that influence the induction of body ownership illusions under specific circumstances. However, the induction and exploration of such information was beyond the scope of this thesis. Furthermore, changes in space perception as presented in Chapter 4 can be due to multiple sources, such as tool use or motor adaptation etc. Here, we focus solely on changes due to the perceived body form, with all relative body and environment proportions unaffected. Also, in Chapter 6, we conduct a study of illusory agency on speaking, and we do not consider other types of illusory body movements. Finally, regarding the technology used, all three studies were conducted in a Head Mounted Display (HMD)-based IVR system.

1.5 Contributions

This research exploited the novel capabilities of IVR systems in order to study the concepts of body ownership and agency, and to investigate specific aspects and consequences of body ownership illusions. The knowledge from three different fields of research— virtual reality, embodiment and self-representation, and action control and perception—is combined to create ecologically valid setups for investigation that could be useful for future studies in cognitive sciences and psychology, while enriching the theoretical knowledge and understanding of body ownership illusions and embodiment techniques.

More concretely, we expand on previous literature, showing that people can experience an artificial body as their own, even when the latter has undergone extreme changes. First, we present a setup where one's body representation is modified in terms of age, suggesting a child body form (Chapter 4). Previous studies have shown that when people are virtually embodied or represented online with a virtual body different to their own, then they exhibit behaviours concomitant with attributes of that body. Nonetheless, the effect of embodiment regarding perception of age and how that can influence subsequent behaviour has not yet been widely addressed in literature. Furthermore, we extend previous results on spatial perception, showing that IVR supports global scaling of sizes, where the brain automatically adjusts for the overall size of one's virtual representation. Most importantly, we show that our system can reproduce the experience of the world "as a child experiences it", and not only as a simple linear transformation of size.

Second,we test the potential of virtual setups in studying racial discrimination, and notably, its effectiveness in eliminating implicit biases. Past research has already provided proof of how virtual embodiment can have an effect on reducing stereotypical behaviour. However, these results have not been investigated in the long term and the effectiveness of repeated exposures has yet to be addressed.

Here we are tackling these issues by showing that reduction in implicit bias though virtual embodiment can last at least 1 week after the exposure, and that the desired effects can be attained though a single exposure.

Finally, we consider the possibility of experiencing illusory agency over an action that is not caused by the participants themselves. According to the literature, the sense of agency can be elicited when the brain's prediction about the outcome of an action matches the actual outcome perceived from the sensory system. Nonetheless, this view has been challenged and more modalities have been suggested to contribute to the feeling of agency. Here we extended this evidence, assessing the importance of embodiment techniques for eliciting illusory agency. In particular, we address this in the context of "speaking" through a talking virtual body seen from a first-person perspective (1PP) as self-produced, when in reality the participant has not spoken (Chapter 6).

Chapter 2

Background

In this Chapter, we first present the basic concepts of both body ownership illusions and action perception, and findings from experimental studies. We give an overview of indicative examples of bodily illusions, both in physical and virtual reality, which formed the basis of our research. We also go through the perceptual mechanisms that contribute to the induction of body ownership illusions, by presenting different types of multisensory and sensorimotor stimulation. Next, we look at various physiological, behavioural and attitudinal correlates of such illusions, and we identify the limitations of the current state-of-the-art. Finally, we discuss the relationship between the concepts of ownership and agency in experimentally induced body ownership illusions, and specifically turn our attention to voice illusions.

2.1 Body Ownership

The understanding of how the human brain represents the body and the connection between physical appearance and mental models of oneself has been extensively approached in philosophy (de Vignemont, 2011; Blanke and Metzinger, 2009; Metzinger, 2008), cognitive neuroscience and psychology (Tsakiris, 2016; Blanke et al., 2015; Ehrsson, 2007; Graziano and Botvinick, 2002; Berlucchi and Aglioti, 1997), robotics (Holz et al., 2009; Foster, 2007; Wainer et al., 2006), and virtual reality (Slater et al., 2009; Slater, 2009; Petkova et al., 2011;

Biocca, 1997). Studies on body self-consciousness (brain mechanisms that process bodily signals) have examined different aspects of (a) self-identification with the body (body ownership), (b) self-localisation (the experience of where one is in space) and (c) the visual perspective (the experience from where one perceives the world). With respect to this, body change illusions have been at the center of attention, demonstrating that it is not complicated to induce the experience to healthy people that their body has changed (Blanke and Metzinger, 2009; Costantini and Haggard, 2007; Ehrsson, 2007; Lenggenhager et al., 2007; Petkova and Ehrsson, 2008). Such approaches can be traced back to findings in patients with somatoparaphrenia, a condition where subjects either misattribute one of their limbs as belonging to another person, or self-attribute body parts of other people as belonging to themselves. In healthy subjects, body illusions have been examined in the context of manipulating the identity of specific body parts in terms of size, shape, appearance etc. A distinct class of such illusions refers to body ownership illusions, which describe the feeling of owning a body that is regarded as the source of all associated sensations. For example, scientists have induced illusory ownership of a very long nose, known as the *Pinocchio Illusion*, or a fake, dummy rubber hand, the *Rubber Hand Illusion* (RHI). In the following Section we present an overview of such bodily manipulations, by specifically focusing on the induction of body ownership illusions in healthy subjects. We refer to body ownership illusions as the illusory experiences of attributing non-bodily objects (e.g. artificial limbs) to one's body representation.

2.1.1 Bodily Illusions

One of the first body ownership illusions was described by Tastevin in 1937 [as cited in Holmes and Spence (2006)]. He demonstrated how the sensed position of a limb can be transferred to another limb, and how participants can perceive a fake, realistically appearing finger protruding from a cloth, as their own finger. Six decades later, a similar illusion was reported—the *Rubber Hand Illusion* (Botvinick and Cohen, 1998)—now one of the most archetypal studies of experimental bodily manipulations in healthy subjects. In the original version of the study, the participant is seated at a table with the left hand resting on its surface. A left rubber hand is then put on a table aligned with the real one in close distance. An occluding object is also used to prevent the sight of the real left hand and arm. Next both left rubber and real hands receive simultaneous tactile stimulation from two paintbrushes, always at the same relative positions. A few seconds after this synchronous stimulation the participant experiences the left rubber hand as if it were the real hand. Additionally, when the participant is asked to close the eyes and indicate where the real hand is located, the latter is typically mislocalised closer the rubber hand after the stimulation than before—a phenomenon referred to as *proprioceptive drift*. On the contrary, when asynchronous stimulation of the real and rubber hand is employed, both illusory ownership and mislocalisation of the hand are diminished. These findings have been replicated by a plethora of researchers in later studies (Crea et al., 2015; Armel and Ramachandran, 2003; Braun et al., 2014; Costantini and Haggard, 2007; Ehrsson et al., 2004; Lewis and Lloyd, 2010; Riemer et al., 2014; Tsakiris and Haggard, 2005; Zhang and Hommel, 2015).

Moreover, various parameters of the illusion, such as alignment or distance of the fake arm from the participant's own arm (Ehrsson et al., 2004; Lloyd, 2007; Maselli and Slater, 2013; Zopf et al., 2010), or the employment of objects, rather than anthropomorphic fake limbs etc. (Haans et al., 2008; Hohwy and Paton, 2010; Tsakiris and Haggard, 2005), have also been examined, and will be further discussed in Section 2.1.5. Similar to the RHI, in a more recent paradigm, participants reported ownership over a mirrored dummy tongue—the *Butcher Tongue Illusion*—when this was synchronously simulated with their own real tongues (Michel et al., 2014). Analogous techniques have been used to generate the subjective illusory experience of ownership of others faces, and the attribution of others' facial features to one's own face (*the Enfacement Illusion*). Here synchronous visuotactile correlations on the faces of participants and an unfamiliar (Bufalari et al., 2014; Tajadura-Jiménez et al., 2012a; Tsakiris et al., 2011) or morphed (Tsakiris, 2008) face, have been shown to induce biases in participants' performance in self-face recognition tasks before and after the stimulation. Moreover, it has been shown the the self-other face distinction decreases with higher levels of illusory ownership over a fake body (Dobricki and Mohler, 2015).

Analogous to body ownership illusions, a broader class of body illusions focuses on experiences of body deformation, where people perceive that the posture or the size of their body part(s) has been drastically distorted. A well-known example is the *Pinocchio Illusion* (Ramachandran and Hirstein, 1998), where blindfolded people reported the experience of having a very long nose. In this setup, an experimenter moves the finger of a blindfolded subject in order to touch the nose of another subject sitting in front and facing away from the first one. While the experimenter taps simultaneously the nose of the first subject, the temporal registration between the finger's passive movement and the received tactile feedback on the real nose creates the illusion to the first person of having a very long nose. Similar illusions have been reported to occur for different body parts. The method to achieve distortion illusions relies on *kinesthetic illusions*, where mechanical vibrations are applied to muscle spindles (e.g. biceps or triceps) of blindfolded subjects in order to generate proprioceptive misinformation about limb position. These vibrations automatically cause the muscles to contract, which then generate the illusory perception that the corresponding body parts are moving, by extending away or towards the body (Lackner et al., 1988). It has been demonstrated that if the stationary body part is in direct contact with another body part, e.g. the nose or the waist, then the subject will not only feel that the vibrated body part is deforming, but also experience the other non-movable body part changing in size (e.g. expanding or shrinking) as described above (de Vignemont, 2011; Ehrsson et al., 2005; Longo et al., 2009; Naito et al., 1999; Naito and Ehrsson, 2001).

The combined knowledge from the studies described above has been successfully used to demonstrate that body ownership illusions are not restricted to specific body parts, but rather extend towards entire artificial bodies—*Full-Body Ownership Illusions*. In the following sections we provide an overview of the work showing that it is possible to generate ownership illusions over an entire artificial or virtual body, along with the factors known to affect such illusory experiences, and the techniques used to measure the extent of induction.

2.1.2 Full Body Ownership Illusions

Similar to body ownership illusions, full body ownership illusions are described as the experience arising from visuotactile and visuovestibular conflicts in which a person sees the fake body in the same spatial location as the physical body, thus accepting it as the own body. In a representative experimental approach to study full body ownership illusions (Petkova and Ehrsson, 2008), participants looking down towards the physical bodies were fitted with a Head Mounted Display (HMD) that was coupled to a video camera oriented to look at the body of either a plastic mannequin or another person's real body. The manipulation of the visual perspective (the participants were looking down the substituted body from a 1PP), and the receipt of incoming multisensory information from the body (the experimenter applied synchronous or asynchronous strokes on the participants and the mannequin's abdomen) were sufficient to trigger the illusion that the artificial body (or that of someone else) was the own body. A threat towards the mannequin's body tested the objective evidence of the illusion, revealing higher magnitude of Skin Conductance Response (SCR) when the illusion was induced. Researchers have explored the importance of visual perspective in the induction of full body ownership illusions (Petkova et al., 2011; Guterstam et al., 2011), suggesting that participants affirm the illusion only when a 1PP is employed as opposed to a third person perspective (3PP)—a perspective from the outside of the mannequin—even under synchronous stimulation. Moreover, it has been shown that a threat towards the plastic mannequin's body elicits significantly higher SCRs only when 1PP and synchronous stimulation are combined compared to asynchronous stimulation or the use of a 3PP.

Nonetheless, studies do report full body ownership illusions towards an artificial body as seen from a 3PP. This set of illusions fits in a different class of experimentally induced full body ownership illusions, known as *Out-of-Body Experiences* (OBE). Similar to clinical cases, subjects have the feeling of being located outside their physical body, and/or looking at it from a distance (Ehrsson, 2007), reporting sensations of floating and lightness (Blanke et al., 2004; Blanke and Mohr, 2005; Brugger, 2002). Researchers have demonstrated the possibility of making healthy people artificially experience themselves outside their bodies.

For example, the study of Lenggenhager et al. (2007) involved viewing a three-dimensional (3D) video image on a HMD that was linked to a video camera that was itself placed behind the participant, filming their back (3PP). While they saw the image of their body, an experimenter stroked their back with a stick. The stroking was seen on the back of the virtual body and was also felt by the participants on their own back. The HMD displayed the stroking of the body either in real-time or not, generating synchronous or asynchronous visuotactile stimulation. The results revealed that participants in the synchronous stimulation felt as if the body seen in front of them in the HMD was their own body. They also mislocalised themselves towards that body when prompt to walk blindfolded to the position that they felt they were located during the experiment. In a different study, seated subjects wearing a HMD viewed a video of their own body, which was being filmed by cameras placed behind them (Ehrsson, 2007). The experimenter stroked the subject's physical chest with a plastic rod, and moved a similar rod just below the cameras, where the "illusory chest" was located. The stroking was felt by the subject and was also seen though the cameras, without however the participant being able to see any part of the illusory body. Participants reported the experience of sitting behind their physical bodies and looking at themselves from that location. In another experimental approach (Lenggenhager et al., 2009), subjects were seated in a supine position while their bodies were being filmed by a camera placed above them so that the body seen on a HMD appeared to be located below the physical body. Participants received both back and chest stroking, and saw the body in the image receiving the same stimulus. The results confirmed the notion that the self is located to where touch is seen, reporting sensation of floating. Finally, another example of OBE was reported by Altschuler and Ramachandran (2007). Participants standing between two mirrors that faced each other watched their body being reflected while stroking their cheek. The visual exposure to this reflection induced the sensation of standing outside one's body, watching themselves from afar.

It could be argued that the key different between full body ownership illusions and OBE is found in the underlying mechanisms of the experimentally induced body ownership illusions, and specifically that of body recognition. Although various studies have reported positive scores towards the illusion when using 3PP (in the cases of OBE), it has been shown that when the projected body is not the participant's one, then the ratings are weak (Pfeiffer et al., 2013). Compelling evidence was provided by the study of Ramachandran et al. (2011), where participants reported feeling stronger the simulation from the body they saw in front of them when they imagined themselves being there. However, according to a recent experimental approach in virtual reality, an OBE can arise under multisensory stimulation even when the seen body is not a virtual representation of the participant's own body (Bourdin et al., 2017). In general, whereas full body ownership illusions seem unaffected by the likeness to the real body, OBE seem to be more controversial. The appearance of the artificial or virtual body, the visual perspective mentioned above, and other factors that have been shown to affect the induction of the illusion are discussed further in Section 2.1.5. Next we see how body ownership illusions have been addressed in virtual reality through the unique capabilities it offers in manipulating visual appearance and in inducing extreme scenarios that are practically and ethically challenging or impossible to develop with traditional methods.

2.1.3 Body Ownership Illusions in Immersive Virtual Reality

Immersive virtual reality, as a compelling way of easily manipulating people's sense of bodily representation in terms of structure, size, and morphology, has been used for stimulating body ownership illusions in a very operable way. People are able to change their self-representation to any type or form of body, sex, ethnicity etc., thus experiencing the virtual world through a body representation entirely different from the physical one. Experimental studies on the equivalent of the RHI in IVR for instance, showed that the illusion can be produced when a virtual hand either receives the same stimulation as the real hand (Slater et al., 2008), or moves synchronously with it—a virtual hand illusion (VHI) (Padilla-Castañeda et al., 2014; Sanchez-Vives et al., 2010). In the paradigm of Slater et al. (2008), participants saw a virtual arm (instead of a rubber arm) projected on a screen. This setup combined with head-tracking gave the illusion that the arm was attached to the shoulder, while the real hand remained hidden behind a screen. The experimenter touched the real hand of the subject with a Wand (a VR interface device composed of buttons, knobs, joy sticks etc.), and the subject saw a virtual ball touching the virtual hand in the same place, thus creating synchronous visuotactile stimulation. Similar to the classic RHI, there was greater proprioceptive drift in the synchronous visuotactile condition. Other studies found similar results when active movements of the virtual fingers and hand were employed instead of visuotactile synchrony (Sanchez-Vives et al., 2010; Yuan and Steed, 2010). Here only when those movements were synchronous with the participant's real hand movements was the ownership illusion induced.

Ownership illusions in IVR, similar to physical experimental settings, are not restricted to the manipulation of specific body parts, but can also be induced to the entire virtual body. Most importantly, however, it has been shown that ownership illusions have been elicited even when the virtual counterpart has undergone extreme changes or deformations. The first virtual reality study on full body ownership illusions as described in Slater et al. (2010), reported an ownership illusion when male participants experienced their body substituted by a life-sized virtual female body. The findings were supported through questionnaire and physiological responses, such as heart-rate deceleration (HRD) measured by electrocardiogram (ECG), in response to a threat towards the virtual body from another virtual character present in the scene. In the study of Kilteni et al. (2012), participants reported experiencing ownership over a virtual body with a very long virtual arm. Specifically, subjects experienced a virtual body substituting their real body through a head-tracked stereo HMD, with visuomotor congruence between the real and virtual dominant arms. Visuotactile congruence or incongruence was also applied, and the length of the virtual arm was either equal to the real one or double, triple or quadruples the size of the real one. Results based on questionnaire responses and withdrawal movements in response to a threat verified the high level of ownership over the virtual body in the congruent conditions. Interestingly, participants reported an illusion of ownership over the virtual body when the arm was up to three times the length of the real one. The illusion diminished, however, the longer the virtual arm was, which also affected proprioceptive drift. The authors argued that the contributing factors to this diminishing effect could be the poor visual information one gets at big distances, the fact that the hand was way too far from the rest of the body, or that the flexibility of the limp representation is limited by length. A different experimental approach showed that normal sized men had the illusion of ownership over a very fat virtual body (Normand et al., 2011). Here participants saw a virtual body with an inflated belly substituting their own, while they repeatedly poked their real belly with a rod that also had a virtual equivalent. The stimulating movements were either synchronous with what they felt and saw or asynchronous. Responses based on comparisons of before and after self-estimations of belly size verified the hypothesis of temporarily produced changes in body representation towards the larger belly size. In other experimental examples, ownership has been experienced over a whole virtual body that appeared to be smaller (underweight) or larger (overweight) than the physical body (Piryankova et al., 2014), or even an alien purple-skinned virtual body (Peck et al., 2013). **In line with the above experimental research, in Chapters 4 and 5 we introduce two studies to examine full body ownership illusions towards different virtual bodies, including a child virtual body, and a different race virtual body**.

2.1.4 Measuring Body Ownership Illusions

In this section we present some response measurements of body ownership illusions that have been developed to address both the subjective and objective extent of an ownership illusion in physical and virtual settings. One of the most basic responses in measuring the degree to which a participant has felt or not a body ownership illusions is the collection of subjective responses. This is typically based on the administration of a body ownership questionnaire, which was first developed by Botvinick and Cohen (1998) and used in the original RHI study. The questionnaire usually includes questions such as “I felt as if the rubber hand were my hand” or “I felt as if the virtual body was my body”, which participants have to respond to on a Likert scale. The body ownership questionnaire has since then been refined, extended, and re-adapted in order to meet the requirements of each individual study.

As mentioned in Section 2.1.1, proprioceptive drift is observed in synchronous stimulations and consequently, only when the illusion is induced. It is therefore considered by many studies an objective correlate of body ownership illusions, and it's commonly included in most as an objective measurement. The basis of this assumption has to do with the fact that ownership of the artificial body counterpart would bias proprioceptive estimations for the felt position of the real body part towards the seen position of the former when differences between visual and proprioceptive information occurred. As the brain attempts to resolve the contradiction of somatic feelings over a distant body part, it generates drifting illusions in order to make the real and fake bodies parts coincide. However, other reports are challenging the idea of proprioceptive drift as an objective evidence of the illusion, stating that it is observed even in asynchronous stimulation conditions (Riemer et al., 2015; Rohde et al., 2011; Tsakiris et al., 2006). In this direction, and in quest of alternative objective responses of the illusion, researchers have investigated participants' responses to threatening events towards the artificial body part, as introduced earlier. Here the argument is that, if the artificial body part is indeed perceived as part of the real body, then any harmful event on it would evoke physiological arousal, anxiety, as well activation of the defensive mechanisms for withdrawal. A number of studies on the RHI have validated this assumption by showing how Skin Conductance Response (SCR) significantly increases when the finger of the rubber hand is bended in a harmful position (only for synchronous stimulations) (Armel and Ramachandran, 2003), or when the rubber hand is stubbed with a needle or knife (Ehrsson, 2009; Petkova and Ehrsson, 2008; Zhang and Hommel, 2015). Additional support arises from the observation of activated brain areas that are associated with anxiety (e.g. insula and anterior cingulate cortex) when experiencing a threatening event towards the rubber hand (Ehrsson et al., 2007; González-Franco et al., 2013).

Moreover, it has been demonstrated that ownership illusions can even result in significant changes to how the real body is perceived at physiological level, which has formed for many studies an objective measurement of the illusion. For instance, when participants feel a somatic sense of ownership over a rubber hand, it has been shown to lead to changes to the homoeostatic regulation of the real hand. Particularly, Moseley et al. (2008) demonstrated that skin temperature of the real hand decreased when participants experienced the RHI, whilst the magnitude of the decrease was correlated to the strength of the illusion. A decrease of skin temperature across different points on the body has also been reported during full body ownership illusions from 3PP (Salomon et al., 2013), while there has also been evidence for changes in temperature sensitivity for full body ownership illusions from 1PP in IVR (Llobera et al., 2013). In a different paradigm, researches reported an increase in histamine reactivity of the real hand for those participants who felt the RHI, implying that they started to disown and "reject" their real limb in favour of the artificial one (Barnsley et al., 2011).

Intriguingly, research has shown that embodiment in a different type of body can even result in significant changes to how the real body is perceived, and also affect higher-level behaviours, attitudes, even cognitive processing (Maister et al., 2015). Although such effects are considered an objective measurement of the extent of body ownership illusions, this body of work is addressed separately in Section 2.1.6, along with some constraints that arise, and which we aim to address through the experimental work presented in this thesis. First however, since our objective is to study full body ownership illusions over distinct virtual bodies, it is essential to understand at this point the factors that contribute to the induction of the aforementioned ownership illusions. In the following section we present these key factors, the understanding of which derives from experimental studies in both physical and virtual reality, and some of which play a crucial role in designing the studies of this thesis.

2.1.5 Perceptual Mechanisms of Body Ownership Illusions

In general, it has been proposed that a number of factors are prerequisite for the induction of body ownership illusions (Tsakiris et al., 2005), and that the degree to which the illusion is experienced derives from the combination of top-down and bottom-up information processes (Tsakiris and Haggard, 2005). These refer to the delivery of multisensory and/or sensorimotor stimulation with the same spatiotemporal pattern on the real and fake body (or body part) as described earlier (Botvinick and Cohen, 1998; Costantini and Haggard, 2007), as well as the appearance of the artificial body (part), which should obey various morphological and anatomical constraints (Tsakiris, 2010).

According to various studies, also described in Section 2.1.1, the delivery of visuotactile stimulation—whether manual or with the help of computer-generated techniques—has to be synchronous in order to evoke the illusion. Nonetheless, research has shown that positive scores of ownership can also be reported under asynchronous visuotactile stimulation, given that the artificial body (part) is quite realistic and overlaps in space with the real body counterpart (Longo et al., 2008; Maselli and Slater, 2013; Kilteni, 2015). However, given that there is temporal synchrony, but which is applied on different locations (e.g. palm vs. forearm, index vs. little finger, arm vs. leg etc.), then the illusion can be abolished (Kammers et al., 2009; Limanowski et al., 2013; Riemer et al., 2014). Hence, temporal matching is not sufficient to produce an ownership illusion, nor are visuotactile correlations a prerequisite for the illusion. Visuotactile stimulation can be substituted for instance, by other modalities, such as sensorimotor contingencies in active or passive movements (Kalckert and Ehrsson, 2012; Padilla-Castañeda et al., 2014; Tsakiris et al., 2010b). Active movements refer to self-generated voluntary movements from the participant, whereas passive movements refer to involuntary movements caused by an external factor onto the participant's body (e.g. experimenter moving the participant's finger). In general, when real and fake body counterparts move analogously (including fingers, arms, hands, legs, upper or full bodies etc.), and when the temporal delays are 500 ms or less, an ownership illusion can be easily evoked (Dummer et al., 2009; Kalckert and Ehrsson, 2012; Kilteni et al., 2012; Kokkinara and Slater, 2014; Llobera et al., 2013). When comparing the influence of visuotactile and visuomotor synchronous stimulation on ownership over a virtual body, it has been found that it is the visuomotor synchrony that contributes the greatest to the achievement of the illusion (Kokkinara and Slater, 2014). **In Chapters 4 and 6 we consider two studies that support the enhancing effects of visuomotor synchrony on full body ownership illusions when compared to control asynchronous conditions or visuotactile stimulation only**.

Furthermore, the spatial configuration of the artificial body (part) with respect to the participants' real body has been found to significantly affect the induction and strength of the illusion. Overall, spatial configuration is defined by visuoproprioceptive information in which spatial location encoded by vision is compared with that encoded by proprioception. Visual and proprioceptive information is characterised (a) by the position and orientation of the fake and real bodily parts when these are motionless (or static), and (b) the congruency between the seen movements of the artificial body (part) and the felt movements the participant performs. The illusion does not arise when anatomical constraints are violated, such as when the artificial body part is in implausible postures, or does not represent the main topological features of the body (Ehrsson et al., 2004; Tsakiris and Haggard, 2005). Neither does the illusion arise when the artificial counterpart is located outside the participant's peripersonal space (Lloyd, 2007). Most studies follow the same protocol and place the fake and real body (part) at the same positions, including depth, horizontal and vertical alignment, or a combination of those (Armel and Ramachandran, 2003; Austen et al., 2004; Costantini and Haggard, 2007; Pavani and Zampini, 2007; Preston, 2013). Studies on the RHI have suggested that the between hand distance on the horizontal plane is not a crucial factor for the strength of the illusion (e.g 15 cm 45 cm) (Zopf et al., 2010). Whereas others have reported different results when the fake hand is placed further away from the participant's body mid-line (Preston, 2013). The same results hold in the vertical plane for distances of 12 cm to 27.5 cm, with the illusion being significantly attenuated for vertical distances of 43 cm (Kalckert and Ehrsson, 2014b). Similarly, studies on full body ownership illusions have showed that the experience cannot be induced when seeing the body in extrapersonal space (Petkova et al., 2011), or seeing the body in peripersonal space but located to the side (Maselli and Slater, 2013, 2014). However, when the virtual body overlaps only partially with the real one, and upon congruent visuotactile stimulation, a full body ownership illusions can still be experienced. Regarding rotational discrepancies, evidence suggests that when a synchronously stimulated artificial body is viewed from 1PP but is rotated by approximately 15-20^o, the illusion can still be evoked (Petkova et al., 2011). Meanwhile, rotation of the fake hand by 44^o clockwise does not prevent participants from experiencing the illusion, but additionally leads to a recalibration of their perceived elbow joint (Butz et al., 2014). The RHI has also been induced when a fake hand was placed palm-up whereas the real counterpart was facing palm-down (Ionta et al., 2012).

The body of experimental studies described in this thesis report ownership illusions that arise when the participant's virtual body is collocated with their real one and viewed from a 1PP. However, the visual appearance of the virtual body is extremely manipulated. Various studies on ownership illusions over plastic or virtual hands have shown that the artificial body counterpart does not need to be realistic for the illusion to take place (Kilteni et al., 2012; Preston and Newport, 2012; Schaefer et al., 2007). Rather, differences in skin tone, shape, size, skin complexion and other variables in the RHI and full body ownership illusions have been found to not hinder the illusion (Hohwy and Paton, 2010; Peck et al., 2013). **In line with this, in Chapters 4 and 5 we consider two studies where the appearance of the virtual body has been manipulated in terms of age characteristics and human skin tone**. Although the illusion is easily elicited with plastic mannequins, low resolution virtual characters or even robots (Spanlang et al., 2013; Pan and Steed, 2016; Sameer et al., 2014), it has been shown that it is enhanced when higher levels of realism of the artificial part or whole body, in terms of texture and structure, are employed (Haans et al., 2008; Maselli and Slater, 2013; Peck et al., 2013). For example, an unnatural purple skin virtual body produced negligible differences in strength of ownership compared to when a realistic skin texture was used (Peck et al., 2013). This is not the case whatsoever for abstract objects, as previous studies have shown that ownership illusions are shape-sensitive, and that non-humanoid shaped objects fail to be integrated into one's own body. The RHI does not work for example when a wooden no-hand-shaped object is stroked synchronously with the real hand (Tsakiris and Haggard, 2005; Tsakiris et al., 2005), even when sculpted with a wrist and fingers (Tsakiris et al., 2010a), or when a check board (Zopf et al., 2010), a cardboard (Hohwy and Paton, 2010), or a flat sheet (even with a skin texture) (Haans et al., 2008) are stroked instead of a rubber hand. Analogously, full body ownership illusions do not arise when the body is substituted with a wooden block, even when the latter might have the same dimensions as the real body (Lenggenhager et al., 2007; Petkova and Ehrsson, 2008).

Likewise, with respect to body proportions, studies have shown that it is possible to induce the illusion of ownership of abnormally large or small entire bodies (van der Hoort et al., 2011). In this experimental setup, artificial mannequin bodies of different sizes were used. The investigators employed synchronous visuotactile stimulation on the visible dummy body as seen from 1PP through cameras, and the unseen real body. The results revealed a subjective experience of ownership over the different artificial bodies, and also demonstrated that the visual perception of distance and object sizes are affected by one's own multisensory body representation. A later study, where participants' virtual hands, rather than the entire virtual body, were manipulated in terms of size, also demonstrated how one's body is used as a metric in perceiving sizes and distances (Linkenauger et al., 2013). Concretely, the authors reported participants perceiving object sizes larger, the smaller their virtual hand was. **This hypothesis on perception of object sizes in the environment as a function on the body was considered in Chapter 4 of this thesis.** Ownership illusions have also been induced towards artificial hands of reduced (e.g. hand size of a primary school child) or exaggerated volume (e.g. hand size of a tall man) (Heed et al., 2011; Pavani and Zampini, 2007), and exaggerated length (Kilteni et al., 2012; Preston and Newport, 2012). Similar findings have been demonstrated even when manipulating the total number of artificial body parts. For example, it has been shown that synchronously stimulating two rubber hands that are placed side by side, and the participant's real occluded hand, induces the illusions of having two limbs (Ehrsson, 2009; Guterstam et al., 2011). The same was revealed in a study where participants moved their hand while seeing two video replicas moving accordingly (Newport et al., 2010).

Nonetheless, it's not only exteroceptive sources of information about the body, such as tactile stimulation or vision, structure etc. as described above, that have been studied in the induction of body ownership illusions. Rather, the combination of other interoceptive, vestibular and auditory inputs have also been examined to contribute significantly (Aspell et al., 2013; Seth, 2013; Suzuki et al., 2013; Tajadura-Jiménez et al., 2012a,b; Tsakiris et al., 2011; van Stralen et al., 2014). In a recent experimental setup, it was investigated how conflicts between exteroceptive (e.g. visual) and interoceptive (e.g. heartbeat) signals modulated bodily self-consciousness, and how this "cardio-visual" conflict altered tactile perception (exteroception) (Adler et al., 2014). Specifically, participants were presented with a real-time video image of an occasionally flashing silhouette outlining their projected bodies. The silhouette was illuminated temporally either synchronously or asynchronously with respect to the participant's heartbeat. Results showed that synchronous "cardio-visual" signals increased self-identification with and self-location towards the virtual body. Those signals altered the perception of tactile stimuli applied to participants' backs, so that touch was mislocalised towards the virtual body.

Overall, the combination of sensory inputs deriving from vision, touch, motor control and proprioception is the key to the induction of body ownership illusions (for a review, see (Ehrsson, 2012)). Although experimental studies have confirmed the importance of congruent multisensory integration, recent evidence, as mentioned above, suggests that incongruent cues can also experienced as correct when the illusion is strong. In Chapters 4 and 6 we present additional evidence supporting the different propositions. In the next Section we take the understanding of body ownership beyond the current state-of-the-art, and address experimental research that aims to understand how an altered self-representation can lead to behavioural and cognitive changes.

2.1.6 Higher-Level Correlates of Body Ownership Illusions

In Section 2.1.4 we saw how body ownership illusions can induce perceptual and physiological changes to the real body, as a way of measuring the extent of the illusion. Most interestingly though, research has provided evidence for higher-level correlates of experiencing a different self-representation. These go beyond changes to the introspective and physiological levels, but rather changes to behaviours, attitudes, and even cognitive processing. Yee and Bailenson (2007) approached this topic by examining how manipulating one's self-representation can affect people's behaviour in online 3D worlds and virtual environments. They referred to this effect as the *Proteus effect*, which describes an intrapersonal behavioural process that explains how people evaluate and respond to a virtual self-representation. It is argued that people may conform to the expectations and stereotypes of the identity of their virtual self regardless of whether their virtual body is an accurate representation of their "real" selves (Yee and Bailenson, 2009). For example, in a reported experiment in IVR, participants were assigned to virtual bodies with either an attractive or unattractive face of the same gender, and were then instructured to interact with a confederate (Yee and Bailenson, 2007). It was shown that those embodied in more attractive representations behaved more intimately with the confederate and disclosed more information about themselves, compared to those who were embodied in less attractive virtual bodies. Similarly, when the participant's height was manipulated, it was demonstrated that those in taller virtual bodies negotiated more aggressively with a confederate of the opposite gender in a decision making task, compared to those who were given shorter or same height virtual bodies as the confederate (Yee and Bailenson, 2009). In a different study described in Fox et al. (2009), the experimenters measured individuals' responses to their ideal body images. Participants viewed through a head-tracked HMD their virtual bodies from 3PP (the bodies were rendered based on a photograph of each participant and therefore bore a resemblance to themselves) eating either healthy or fattening food, and respectively becoming slimmer or fatter. Although there were no differences in behavioural outcomes, female participants believed that they could perform significantly more push-ups after having being exposed to the system. A similar setup was used to manipulate participants' virtual weight while playing a virtual exercise game (Peña and Kim, 2014). The results showed that those in normal weight self-alike virtual bodies were more physically active relative to those using an obese virtual body.

Hershfield et al. (2011) exposed participants to their future "aged" selves in order to study behaviours and saving tendencies. The results suggested that participants interacting with their future selves focused on long-term implications of their choices. They exhibited, for instance, increased preferences for larger rewards further on in life when prompted to complete money allocation tasks. On the contrary, no effects were found for those who were virtually represented with their normal selves.

Participants' altered self-representation has also been used to address stereotyping and pre-existing prejudices. For example, Yee and Bailenson (2006), aimed to investigate stereotyping of the elderly in a virtual reality system. Participants were assigned to have either a virtual body of an elderly person or a body of a young adult, while interacting with a confederate of the same gender. The results showed that negative stereotyping of the elderly was significantly reduced when participants were embodied in the virtual body of old people compared with those participants embodied in younger ones. In a more recent experimental work, it was examined how having an elderly or young virtual body affected purchasing behaviours, revealing virtual age-related shopping tendencies (Yoo et al., 2015). In addition, those participants in the elderly bodies appeared to be more willing to donate to and volunteer for non-profit organisations supporting the elderly. In the study of Peña et al. (2009), participants who saw themselves in virtual bodies with negative associations, such as wearing Ku Klux Klan uniforms, were biased towards negative attitudes, compared to participants in a doctor's uniform or a control transparent body. Kilteni et al. (2013) described an experiment where participants were embodied in a dark-skinned casual looking virtual body (Jimi Hendrix-like) or a light-skinned formally dressed one, and performed a drumming task with real-time visuomotor and visuotactile feedback. The results led to the conclusion that participants in the casual looking body performed the drumming task more expressively (i.e. significantly greater body movement) than those embodied in the formal looking body. The degree of objective difference in their drumming movement correlated with their level of subjective body ownership over the virtual body. The higher the body ownership, the greater was the difference in body movements between the two distinct bodies while drum playing. According to the authors, the results can be explained in terms of stereotype theories, as people who looked more like Jimi Hendrix would be expected to be more expressive. Similarly, in the study of Rosenberg et al. (2013), participants were given either the power of flight (their arm movements akin to Superman's flying ability) or rode as a passenger in a helicopter. They were then assigned to either help find a missing diabetic child in need or to tour a virtual city. The results showed that those assigned to the "superheroes" condition later helped the experimenter pick up spilled pens significantly more times than those who were virtual passengers, thus leading to greater assisting behaviour. According to the researchers a possible mechanism for this result is that the power of flight is priming concepts and prototypes associated with superheroes (e.g. Superman).

Groom et al. (2009) reported a study where they embodied "White" or "Black" people in a "White" or "Black" virtual body that could be seen through a head-tracked HMD as reflected in a virtual mirror. The scenario was one where participants applied for hypothetical job interview. The results as measured by a racial

Implicit Association test (IAT) (Greenwald et al., 1998) revealed an increase in racial bias for those embodied in the "Black" body. In a later setup to study racial bias as described in Peck et al. (2013), the authors embodied participants in a "White", "Black", "Purple" body, or no body at all, which was seen from 1PP and as reflected in a virtual mirror, and that moved synchronously with the participants' real body movements. A racial IAT showed that embodiment resulted in a reduction of implicit racial bias only for those participants in the "Black" body. The authors argued that unlike the study of (Groom et al., 2009), where participants were exposed to a situation known for racial discrimination, their results were based on the embodiment technique itself thought multisensory integration, the longer exposure times, and the fact that no social task was involved. Similar results were also reported by a different study, where it was shown that the RHI over a black rubber hand leads to a reduction of implicit racial bias in "White" people (Maister et al., 2013b). **In Chapter 5 we present a study where we provide a replication of earlier results on racial bias described above, and more importantly, extend those results by considering whether the reduction of bias is sustained, and whether there is any effect of multiple exposures**.

The aforementioned studies, and according to the *Proteus Effect*, are premised on Self-Perception Theory, which argues that people infer their attitudes and behaviours by observing and interpreting their own behaviours in a given context and on what they themselves do in that situation (Bam, 1972). It has also been argued that stereotyping plays a role in this. As Yee and Bailenson (2007, p. 286) are pointing out, behaviours can be influenced by assumptions about how one would believe others would expect them to behave with that type of body. As they state "the false self-concept (i.e. self-stereotyping) may override behavioural confirmation", discussing the possibility of a feedback effect playing role in their findings. This phenomenon has been discussed in early research on behavioural confirmation (Snyder et al., 1977). Snyder and colleagues stated that an individual's behaviour can be shaped by the beliefs and stereotypes of the people with whom the individual interacts. For example, it was found that when a male believed he was speaking to an attractive female, this belief affected the female's engagement in the conversation. She was then led to exhibit a behaviour which made naive observers rate her more positively. The male's pre-existing evaluation about the female led him to treat her differently, and as a result the female acted in a way that confirmed his pre-existing (and experimentally imposed) belief. Similar early findings in a computer-mediated environment showed that individuals projected characteristics of their ideal friend, depending on the extent to which they liked their conversation partner (Bargh et al., 2002). The concept of the feedback loop, as described in Walther's hyper personal model (Walther, 1996), suggests that one's behaviour can be influenced in on-line interactive conversations by behavioural expectations of the conversation partner; this in turn can also influence the behaviour of this partner. Moreover, the studies discussed earlier look at how identity cues may lead to changes in behaviour, and that negative cues, situations, and events have stronger effects than more positive situations. However, this approach cannot explain how there can be perceptual and implicit attitude changes when participants are embodied in a virtual body in a neutral situation - i.e. where there is no social context and behaviour is only associated with one's altered body representation. **In Chapter 4 we present a study, where we concentrated on manipulating solely one's bodily self-representation and on the consequences of this in subsequent perception and attitudes. No external factors, such as social interaction, were present, and participants were alone rather than in social settings.**

In this Section we presented how various characteristics of the artificial body (part) can moderate participants' behaviours and attitudes during illusory experiences. Overall, the type of body appears to carry with it physiological, perceptual and even deep-seated attitudinal correlates. However, as presented above, there seem to be some limitations in the way that experimental studies have addressed this theory so far, which we aim to tackle in Chapter 4. Nonetheless, a fundamental question that remains unanswered is whether the factors that lead to a strong illusion of body ownership and its related behavioural consequences, could also lead to further illusory correlates, such as agency over a specific action that is not caused by the user—*Illusory Agency*. In the next Section we set the basis for understanding the research problems related to our Hypothesis 3 on illusory agency. We discuss the literature on basic concepts of agency in order to provide the insights on how to experimentally test it, and further distinguish between the senses of agency and ownership in the process of self-recognition.

2.2 The Sense of Agency

Normally humans are able to distinguish their own motor actions from those of other people. We are aware of our own volitional motor actions and take responsibility for the effects, thus implying a sense of agency. Studies with people with lesions have identified specific brain regions implicated in agency (Blakemore et al., 2002), and although there is a significant intersection between brain activity in motor areas when observing someone else do an action and when carrying it out ourselves, there are also additional processes that distinguish self-movement from others'-movement (Rizzolatti et al., 2001). This sense of agency has been the subject of significant study in recent years, and self-attribution of actions has been explained by a combination of modalities. Amongst these are feed-forward processing, that is when we predict that we are to do an action and then observe the consequences of having done it (Blakemore et al., 2002; Frith et al., 2000). A first formulation of this model was presented by Wolpert et al. (1995), originally expressed to describe motor control. The forward model concept is defined as a comparator model, which takes as an input the intention for an action, and through an efference copy of the execution command, it produces a prediction of the outcome. The model continuously compares the actual outcome to the prediction, monitoring whether the action occurred as anticipated. Although the comparator model has been widely used to explain the sense of agency, it has raised substantial controversy. It has been proposed that not all the cases of action attribution can be efficiently explained with the comparator model (Synofzik et al., 2008), and that the sense of agency may be a post-detective or reconstructive process generated from both implicit perceptual processes and explicit high-level cognitive processes (Haggard and Cole, 2007; Haggard, 2005; Wen et al., 2015). The sense of agency and the attribution of actions to the self have also been explained via other modalities. It's been proposed that cause precedes the effect, there is no other explanation for the result that is readily available (Wegner, 2002), and there is a requirement for tight temporal binding between the intention to carry out the action and the resulting sensory consequences–the *intentional binding effect* (Haggard et al., 2002).

2.2.1 The mechanisms of Agency

It is important to distinguish at this point between an intention to act, and the attribution to the self as the cause of an act (sense of agency) (Haggard, 2005). Evidence suggests that conscious awareness of the intention to act occurs subsequent to observable brain activity. This is measured for example, by the Readiness Potential, the preconscious activity in the motor cortex that occurs before an action is made, as reported in the work of Libet et al. (1983). Although empirical evidence shows that the awareness of action and the sense of agency over that action usually go hand by hand, the opposite is also plausible, as for instance in schizophrenic patients with delusions of alien control. The delusion of control is an example of experience in which a patient feels that his actions are created by an external agent, rather than himself. However, experiments show that dissociation between awareness of action and sense of agency can also occur in non-pathological conditions. For instance, delusions of control in normal subjects arise when one experiences a sense of agency for actions someone else is doing. In the experiment of Wegner (2002), participants watched themselves in a mirror, while the experimenter standing behind them, and hidden from view, extended his hands forward where the participant's hand would normally be. The experimenter's hands performed a series of movements. Meanwhile, participants heard either congruent, incongruent or no instructions of those movements before they were executed. Although participants did not perform any movement themselves, they reported stronger feeling of agency when the instructions where congruent, compared to incongruent or nonexistent instructions. Such misattributions of perceptual events to the self can occur when one expecting those events to happen as a consequence of one's own actions, are produced instead by someone else. In such cases, providing participants with a preview that allowed them to create an anticipation of the action could have been the reason of the action attribution. In other words, intention prior to action might play an important role in action attribution (Chambon and Haggard, 2012).

In action recognition studies based on hand movements fed back to participants visually with spatial or temporal distortions, subjects also self-attribute actions, which are presented with a rather strong deviation from their real actions (Daprati et al., 1997; Farrer et al., 2003). Similarly, participants have reported a sense of agency towards a moving rubber hand, even though they did not actually move their limbs (Tsakiris et al., 2010a). In another experiment, where the outcomes of participants' action choices were surreptitiously changed, participants reported having an intention corresponding to the actual outcome, rather than their original choice (Johansson et al., 2005). Moreover, it has been proposed that in cases of continuous actions, where the comparison between the action and feedback is difficult, people may heavily rely on external factors, such as task performance (Metcalfe and Greene, 2007). In one example, results showed that participants' sense of agency increased with better performance in an assisted relative to a self-control condition, even though a large proportion of their commands were not executed (Wen et al., 2015). In a more recent experimental paradigm in VR it was shown that visual information regarding visually incongruent finger movements (both active and passive) strongly affected motor perception judgement (Salomon et al., 2016). The authors suggest that awareness of one's bodily movements can be modulated by sensorimotor conflicts causing the illusion that someone else's movements can be felt as one's own. Other researchers (Kokkinara et al., 2016) used IVR to give participants the illusion of walking when they saw their virtual body walking even though they themselves were seated.

Overall, the sense of agency can be modulated by various mechanisms, with studies indicating that it might occur even without actual action execution. Wegner and Wheatley (1999) argued that the attribution of an act to the self is based on the same mechanisms as the perception of causality in general—that a specific act carries the sense of agency when it satisfies the general conditions for attribution of causality. They identified three necessary conditions for an agentic relationship between the thought prior to an action and the act itself: (a) Priority: "The thought should precede the action at a proper interval"; (b) Consistency: "The thought should be compatible with the action"; and (c) Exclusivity: "The thought should be the only apparent cause of action". **Based on these mechanisms on action attribution, we carried out a study to test whether it is possible to generate an illusion of agency—*a Vir-***

***tual Voice Illusion*—when (i) there is no possibility of there having been feed-forward prediction (ii) there is no thought or cause preceding the effect and (iii) there is an obvious alternative explanation for the observed action. This will be tested and discussed in Chapter 6.**

2.2.2 Agency versus Ownership

According to Jeannerod (2003), self-consciousness relies on two components: (a) the experience of oneself as the owner of one's body (ownership), and (b) the experience of oneself as the agent of one's actions (agency). Literature has further distinguished the sense of agency from the sense of ownership in that the former refers to the sense of authorship of an action whereas the second refers to the sensation of experiencing that the action is being done (e.g., authorship of moving the body compared to the sensation that it is my body that is moving) (Gallagher, 2000, 2012). The relationship between the two however, has occupied science for a while, and still remains unclear. Whereas earlier studies tended to consider ownership and agency as separate components of the self, there is increasing evidence that these two factors interact in producing illusions of ownership. Some studies show greater sense of ownership with greater sense of agency; others support the opposite relation between the two, whilst some reveal no correlation at all. Supportive evidence for the dissociation between the two phenomena comes from the Alien Hand syndrome. In this condition, the affected patient's hand does not obey their will and instead "appears to have a mind of its own" (Goldberg et al., 1981; Della Sala, 2005; Schaefer et al., 2010). Nevertheless, despite of the autonomous behaviour of the affected hand, and the inability of the patient to control its movement, the sense of ownership is retained (Marcel, 2003). In a more recent setup, researchers showed that patients with left upper limb hemiplegia exhibited stronger illusory effects than healthy subjects when the affected hand was stimulated, but no effects when the unaffected hand was stimulated (Burin et al., 2015). They concluded that active movement plays an important role in maintaining ownership.

In healthy subjects, Sato and Yasuda (2005) provided evidence demonstrating that ownership and agency are independent—that attribution of an action to the self is independent of recognition that it is the self that experienced the action, and vice versa. Similarly, Kalckert and Ehrsson (2012) found a "double dissociation" between ownership and agency in the RHI. Agency could be diminished for example, by varying the time between a finger movement and the observation of the movement, but without reducing ownership. Similarly, ownership could be reduced by rotating the rubber arm to an implausible position but without reducing agency. Nevertheless, agency and ownership were correlated precisely in the condition where there was also the illusion of ownership over the rubber hand. Analogous findings were reported by other studies, with the authors finding some associations, and some double dissociations between the two senses (Braun et al., 2014; Jenkinson and Preston, 2015). In IVR settings, Kokkinara and Slater (2014) observed higher ownership over a virtual leg in active movement, reporting a positive correlation between ownership and agency ratings. Likewise, Ma and Hommel (2015) suggested synchrony-induced ownership illusions were strongly affected by agency.

It's been argued before that the relation between agency and ownership is additive (Tsakiris and Haggard, 2005). According to this additive model, agency entails ownership. Evidence for this comes from behavioural studies, where voluntary action and passive movement conditions are compared. According to this approach, if the sense of body ownership is present both during active and passive movements it is the sense of agency that plays the critical role. Based on the classic RHI paradigm, one has both a sense of agency and body ownership during an active voluntary movement, whereas during passive movement, only the sense of body ownership is present (Botvinick and Cohen, 1998). On the other hand, and according to an "independence model", the two senses rely on completely different brain mechanisms, which do not share any common components, thus predicting agency- and ownership-specific brain areas. Support for this model arises from neuroimaging studies, where for instance, activity in premotor areas is associated with the sense of agency. The sense of body ownership on the contrary is associated with activity arising in midline cortical structures (Farrer et al., 2003, 2008; Leube et al., 2003). According to the framework proposed by Tsakiris et al. (2007), it is argued (based on earlier findings in the context of the RHI) that when ownership is caused by passive stimulation it does not generalise beyond the point being stimulated (e.g. a specific finger). On the contrary, when it is based on active movement it generalises to the whole body part (e.g. hand). This is explained by noting that the primary somatosensory cortex is segmented so that stimulation of one specific point on the body surface normally does not affect any other point (e.g. a point on one finger only affects that finger). Nonetheless, in the primary motor cortex different movements can overlap in their activations (so moving one finger has shared activation with many other possible movements). **This hypothesis was considered when carrying out the study on the *Virtual Voice Illusion* discussed in Chapter 6. It is argued that the resulting motor area activations during speaking might have overlapped with earlier activations, providing a unified experience with all of the actions attributed to the self.** Since our hypothesis directly relates to speaking, in the next section, we briefly introduce some experimentally induced voice illusions, which the methods of our study were based on.

2.2.3 Vocal Production and Voice Illusions

Action control and action perception are important cues for embodied cognition and for the interaction of the self with the environment. Taking advantage of the fact that motor control contributes significantly to the self-recognition process, in this Section, we discuss the perception of vocal production. This relates to Hypothesis 3, which is concerned with the experience of talking through a virtual body in IVR, and relies heavily on the level of ownership over a virtual body, as discussed later on in Chapter 6.

Studies on voice illusions are usually concerned with the temporal and phonetic congruence between auditory and somatosensory feedback from the articulator (Blakemore et al., 2002; Burnett et al., 1998; Frith et al., 2000; Houde and Jordan, 1998; Jones and Munhall, 2000; Zheng et al., 2011). Vocal production provides rich auditory and somatosensory feedback that can contribute to the recognition of one's own voice. Research based on on-line feedback perturbation has provided proof, in both behavioural and neuroimaging level, for the role of auditory feedback in vocal motor control through a self-mirroring system, and for the recognition of one's own voice. This perception of the identity of an external voice has been shown to fail in the case of an impaired self-monitoring system, as for example in psychotic patients with symptoms of auditory hallucinations and delusions (Blakemore et al., 2000; Connie Cahill, 1996; Johns et al., 2006). Studies with patients on distorted feedback of their own voices have shown that the hallucinators tend to misattribute their voices to an alien source (Johns et al., 2001, 2006), or also misidentify the source of someone else's undistorted speech (Johns et al., 2006). In one example, an early study using distorted auditory feedback of one's own voice showed that participants easily attributed the heard voice to themselves, even though the pitch of the voice was distorted to a large degree (Connie Cahill, 1996).

In healthy people, a more recent study (Zheng et al., 2011) explored how individuals in whom the self-monitoring system is intact, perceive the identity of an external voice, referring to it as the *"Rubber Voice Illusion"*. More specifically, participants talked into a microphone while receiving auditory feedback that was either their own vocalisations or someone else's voice in temporal synchrony. The results suggested a sense of ownership over a stranger voice, when participants experienced an alignment between their own vocal motor movement and the resulting sensory events. They reported the stranger's voice being a distorted version of their own voice. Such studies on vocal production perception, whether with patient or healthy populations, have explored the effects of on-line feedback perturbation during ongoing speech. **In Chapter 6 we will introduce an experimental study where we investigated whether it is possible to induce the feeling of *Illusory Speaking* without the participants having spoken themselves, and hence, where there is no associated auditory feedback of their own vocalisations.**

In this Chapter, we presented an overview of the literature work that serves as a theoretical background throughout this thesis. We went through the basic concepts of body ownership illusions, and the requirements, in terms of multisensory integration, for inducing so in both physical reality and IVR. We also explored how the type of body can affect behaviours and implicit attitudes of the embodied participant. Various issues have been raised throughout the various sections, regarding the gaps in the literature that we aimed to address though our research. In the following sections we present our work to explore the boundaries of accepting an altered virtual self-representation. More interestingly though, we concentrate on how changing the body can lead to attitudinal and perceptual changes for the embodied individual, in the absence of any important social aspect. Also, we offer proof for the first time that these effects can be lasting, while exploring the role of multiple exposures. Finally, we consider how body ownership over a virtual body can lead to additional changes to the real body, such as illusory agency over an action not initiated by the participants themselves. In Chapters 4, 5, and 6 we will attempt to tackle these issues, with the help of controlled experimental studies. Before that, however, in the following Chapter, we present the methods and materials used in order to elicit full body ownership illusions in our setups.

Chapter 3

Methodology

In this Chapter, we present the materials and methods employed in the experiments described in this thesis. Details are further discussed in Chapters 4, 5, and 6, respectively. We provide the specifics of the available hardware and software in immersive technologies, as well as the techniques and multimodal information of an IVR setup in order to induce body ownership illusions. We address these both in our concrete setup but also in a broader view. We also present the methods for data acquisition and analysis when collecting participants' physiological responses. Last, we consider ethical issues and how they were addressed.

3.1 IVR Setup, Tracking and Interaction

One of the most powerful aspects of an IVR system for the induction of body ownership illusions is the dynamic and continuous reconstruction of the body representation based on multisensory information. In this Section, we present the details of how such information is provided. We describe the basic equipment of an IVR system, and demonstrate how to achieve multisensory and sensorimotor integration, including visuotactile, proprioceptive, and motor stimuli. The technical infrastructure in order to achieve embodiment in IVR was described in a recently presented framework (Spanlang et al., 2014), the context of which was assumed in our studies.

3.1.1 Basic Equipment and IVR Setup

The basic equipment of an IVR setup consists of a computer with a 3D graphics engine and a display device, such as an HMD. The computer runs various VR scripts that operate on a database, and display all VR content stereoscopically in the HMD. The HMD used in all studies was a stereo NVIS nVisor SX111[1] (Figure 3.1 A). This has dual SXGA displays with 76^oH$\times$$64^o$V degrees field of view (FoV) per eye, totalling a wide field-of-view (FoV) 111^o horizontal with 50^o (66%) overlap and 64^o vertical, with a resolution of 1280$\times$1024 pixels per eye displayed at 60Hz. It weighs 1.3 Kg.

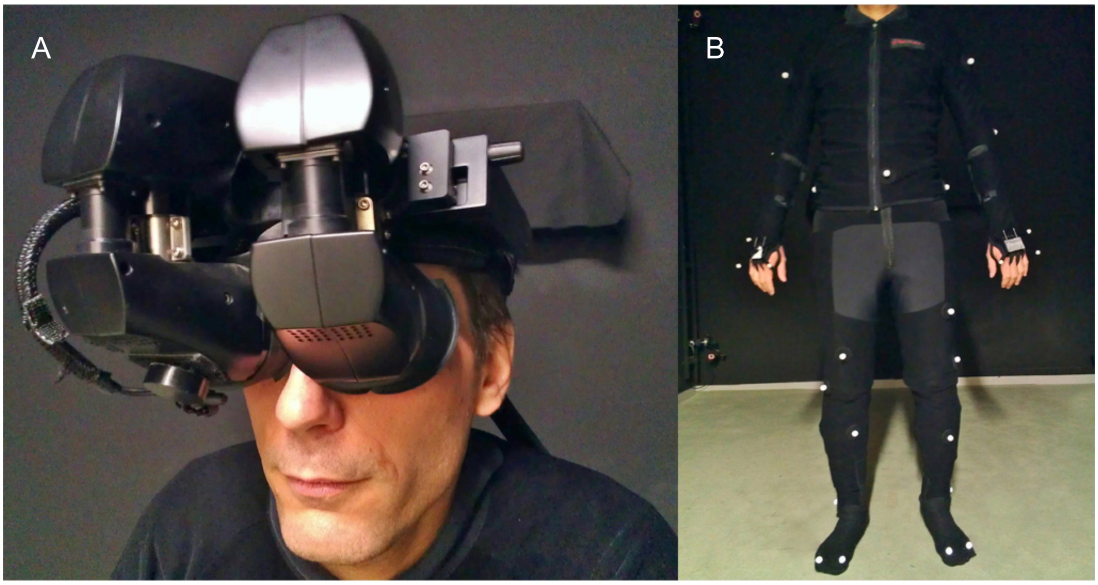

Figure 3.1: (A) The Head-Mounted Display NVIS nVisor SX111. (B) The full-body motion capture suit from OptiTrack.

The VR content includes the background 3D scene and its objects, such as lighting, material properties, and virtual models, ranging from simple cubes and spheres to more complex agents like humanoid avatars, animals, and other. In order to model the 3D content of all experimental studies, various 3D software tools were used. All virtual models were designed and modified in Autodesk 3D

[1] http://www.nvisinc.com

Studio Max 2010 and 2013[2] (educational version), Autodesk Motion Builder 2012 and 2013[3] (educational version), Autodesk Maya 2013[4] (educational version), Autodesk Character Generator[5], and DAZ Studio V3[6]. The virtual bodies were gender-matched in all studies. For the *Virtual Child Body* study, avatars of a 4-year-old body were used. Also, for the *Virtual Child* study, the adult-like avatar was scaled down to match the height of the child avatar, but with no other body proportions modified (see Figures in Chapters 4, 5 and 6). The virtual scenes and scenarios were implemented using the eXtreme Virtual Reality (XVR) software platform (Tecchia et al., 2010) for the *Virtual Child Body*, and *Illusory Speaking* studies, and the Unity 3D[7] engine for the *Racial Bias* study.

3.1.2 Sensorimotor Contingencies

One of the basic components of a VR setup in order to elicit body ownership illusions is to provide the participant with a 1PP viewpoint of the world (see Sections 2.1.2 and 2.1.4). In order to achieve this, the virtual eyes need to be placed where the participant's real eyes are so as to look directly at the virtual body when looking down (Figure 3.2). The virtual eyes are implemented using a VR camera that the VR script places approximately at the midpoint of the avatar's eyes.

Additionally, the HMD needs to update the displayed image appropriately when participants move their head around in order to provide them with accurate sensorimotor contingencies. To attain this, the participant's head position and orientation is tracked, and the VR system processing unit updates the viewpoint of the participant and the displayed images in the HMD analogously. Then, as the participant looks up and down, left and right, the view shifts, and whenever the participant's head tilts, the angle of gaze changes. Head tracking can be implemented using mechanical, electromagnetic, optical, acoustic, or inertial and hybrid methods. In the studies described here, a hybrid acoustic-inertial method

[2] http://www.autodesk.es/products/3ds-max/overview
[3] http://www.autodesk.com/products/motionbuilder/overview
[4] http://www.autodesk.es/products/maya/overview
[5] http://charactergenerator.autodesk.com/
[6] http://www.daz3d.com
[7] http://unity3d.com/unity

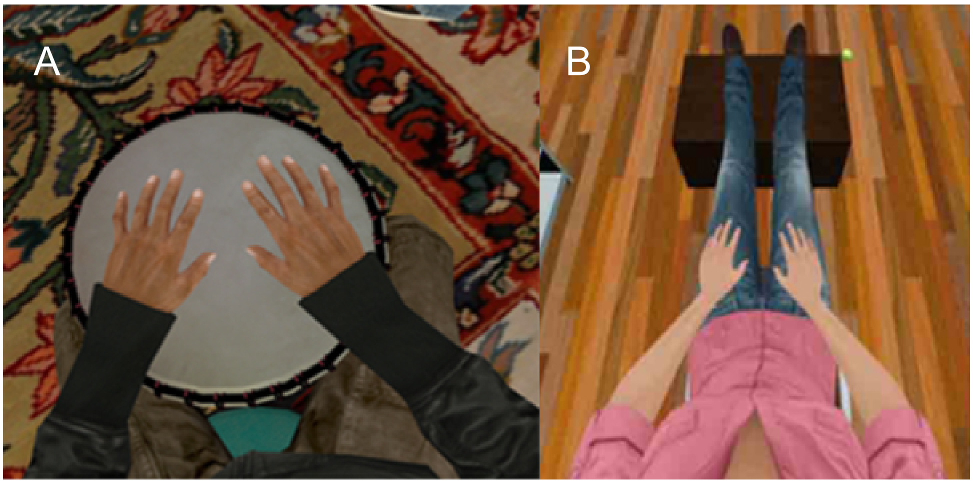

Figure 3.2: Participants wearing the HMD see a virtual body that represents themselves from a 1PP, and when looking down toward their own body they see a virtual body co-located with their own. Images retrieved from (A) Kilteni et al. (2013), and (B) Maselli and Slater (2013).

was employed using a 6-DOF Intersense (ISENSE) IS-900 device, which provides a precision of 0.75mm and 0.05^o, with a latency of 4ms.

3.1.3 Visuomotor Stimuli

In order to provide visuomotor stimuli the participant's movements must be captured and mapped onto the virtual limbs or whole body. Capturing the movements can be implemented using dedicated hardware and software that follow various methods such as optical, magnetic, acoustic, inertial or mechanical. For the studies described in this thesis, a marker-based optical motion tracking system was used. The Natural Point OptiTrack ARENA[1] and MOTIVE[2] systems work with sub-millimetre precision, and require a number of reflective markers to be attached on the participant's body (Figure 3.1 B), and a set of cameras in the physical space. Participants are required to wear a suit, which the reflective markers are attached onto at specific positions with respect to their body (following the manufacturer's instructions). Then, the software constructs the virtual

[1] https://www.naturalpoint.com/optitrack/products/arena/
[2] https://www.naturalpoint.com/optitrack/products/motive/

skeleton where the real skeleton is inferred by the data of the camera-detected markers. The created skeleton contains information for each bone with respect to the neighbour bones in terms of lengths and spatial configuration (positions and rotations), which is then streamed to the main VR script. Once the body movements are captured, the virtual limb(s) or whole body are animated based on the received 3D data. For animating the virtual characters a hardware accelerated library (HALCA) (Gillies and Spanlang, 2010) was used in the studies in Chapters 4 and 5, while for the study in Chapter 6 we used a character animation-library for avatar mapping described in Spanlang et al. (2013, 2014).

Following the method described above, congruent visuomotor information can be provided between the participant's real movements and those generated virtually and mapped onto the virtual body. Nonetheless, such correlations can break when features of the stimuli such as timing and other effectors including speed, frequency, and trajectories are manipulated. For example, the seen movements can be displayed with a delay or applied onto a different body part that the one the participant is moving. Alternatively, the virtual body movements can be generated from a pre-recorded animation and be independent of those of the participant. The last method was used in the experimental studies described here in order to diminish the illusion of ownership and agency over the virtual body (See Chapters 4 and 5).

3.1.4 Visuotactile Stimuli

When providing visuotactile stimuli in IVR, a tactile stimulation on the real body is coupled with a visual event involving something touching the virtual body. The two tactile events can be either congruent or incongruent, depending on the experimental condition, and features such as location, timing, and pattern can be adjustable. In order to visualise a tactile stimulus, a virtual object is seen to intersect the participant's virtual representation as if touching it. This correlation can be achieved using different methods, one of which is the manual delivery of the stimulation by the experimenter onto the participant's body. The experimenter uses a device (e.g. VR Wand) to stimulate the different body parts, the position of which is tracked such as to animate a virtual object that is shown to touch the virtual body (Figure 3.3). For example, as the experimenter moves the device up and down touching the participant's limbs, a virtual ball can be seen to go up and down touching the corresponding virtual limb.

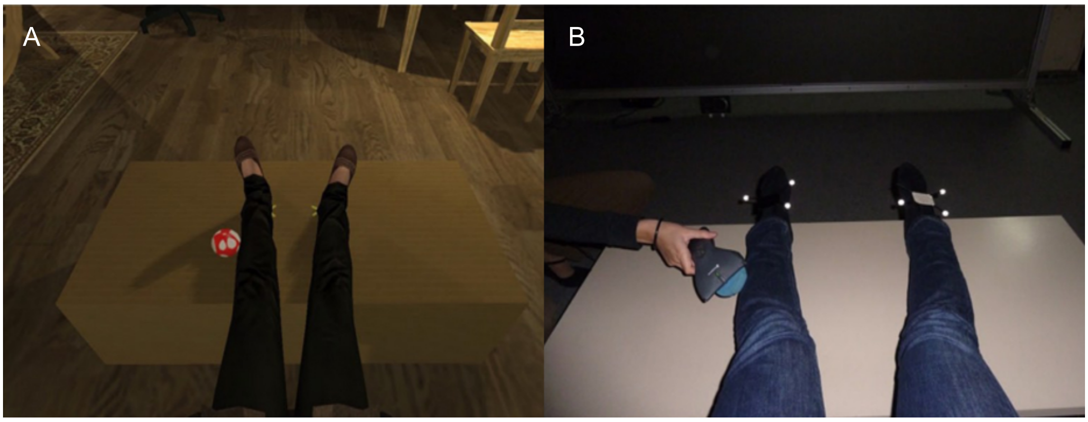

Figure 3.3: Example of visuotactile stimulation on the virtual body through a hand-held wand. Tactile stimulation delivered through the soft ball attached to the device (B) is seen by the participant as feedback from a virtual ball. Images retrieved from Kokkinara and Slater (2014).

In order to provide a more automatic stimulation using the methods described above, the tactile stimulation can be delivered using vibrators that are attached to the participant's body, on the exact limbs that are to be stimulated. Next the VR script sends the command to the vibrator micro-controller in order to fire them; at the same time the virtual object is animated appropriately, so as to come in contact with the virtual body (Figure 3.4). This method was used in the Illusory Speaking study for providing visuotactile correlations.

Alternatively, visuotactile stimulation can be delivered with the method of self-delivery. Here, the virtual object is placed at the same location as the real object in the physical world, and with respect to the participant's point of view. Collocating the two objects allows the participant to experience the contact with the physical object while seeing the virtual object in contact with his virtual representation. Breaking this collocation causes the tactile feedback to fail to agree with the visual one. A break occurs when the virtual and real objects are located at different positions, or when the virtual arm does not follow the real arm movements while exploring. To enhance such tactile correlations, the participant can explore the physical object while seeing his virtual counterpart exploring the virtual one. This is achieved by providing visuomotor correlations between real and virtual bodies as discussed in Section 3.1.3.

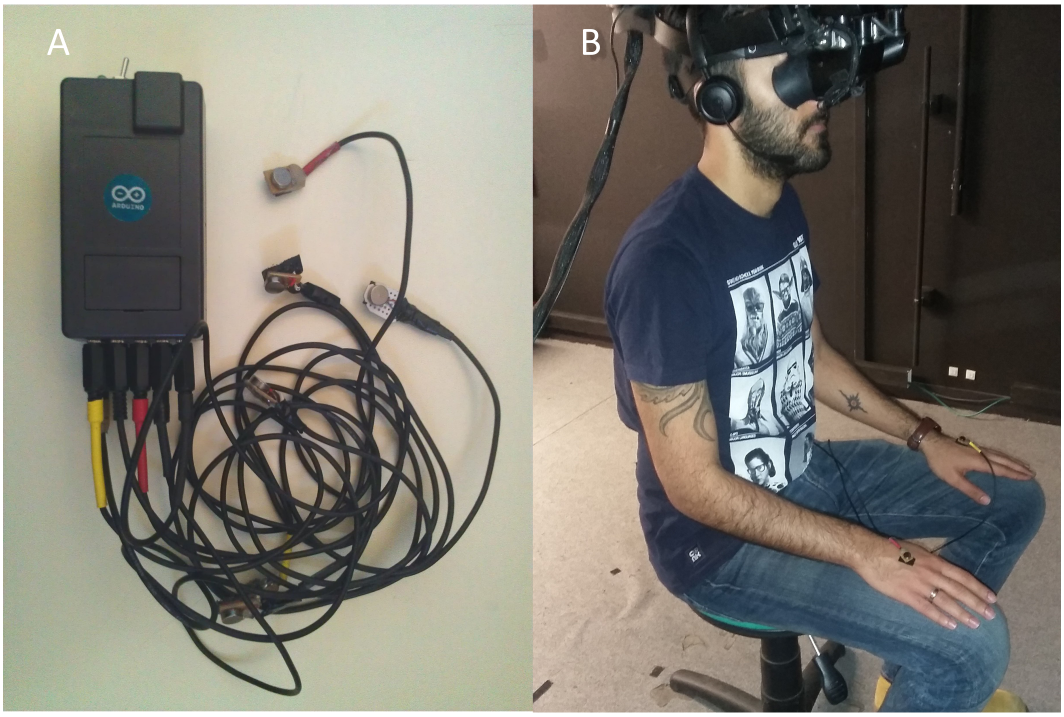

Figure 3.4: (A) The vibrator micro-controller Arduino and a set of vibrators that are placed on the participant's body, on the exact location that is to be stimulated. (B) Example of placing the vibrators on the participant's hands.

3.1.5 Visuoproprioceptive Stimuli and Semantic Congruence

Similar to visuotactile and visuomotor stimuli, visuoproprioceptive information–congruent or incongruent–can also be provided in an IVR setup. Here, the body (or body part) has to match the displayed virtual counterpart not only in terms of visual perspective, but also postural configuration, including position and orientation. In order to break the illusion, the body can be shown from a different perspective than 1PP (usually achieved by placing the virtual body away from the participant's point of view–3PP), or be placed in an anatomically impossible spatial configuration (see Sections 2.1.2 and 2.1.4). The latter is achieved by setting the position and rotation of the virtual body to violate the human anatomy, showing body parts to be disconnected from the rest of the body (Kokkinara and Slater, 2014; Llobera et al., 2013; Maselli and Slater, 2013; Perez-Marcos et al., 2012), elongated or shrunk (Kilteni et al., 2012), or by presenting additional limbs to be attached to the virtual body.

Furthermore, regarding semantic congruence, objects far from the human body shape can be easily designed and imported into the virtual scene and be compared to human-shaped virtual bodies (avatars); parameters such as textures and scale can then be manipulated and tested (Blom et al., 2014). When using avatars, there is the possibility of customisation so that they resemble the participant in terms of body, facial and clothing likeness—*Own Body Likeness*. Concerning demographic characteristics, these can also be easily manipulated, by displaying a virtual body of different gender, age, or colour than the participant's real body. Here, avatars of a different age were used in the studies described in Chapters 4 and 6.

3.1.6 Comparing IVR to Traditional Techniques

In this Section, we present the advantages of using IVR technology against traditional methods to study body ownership illusions, in terms of the aforementioned information, i.e visuotactile, visuomotor etc.

The greatest advantage of an IVR system is the supply of visuomotor information, as IVR can provide sensorimotor contingencies otherwise difficult or impossible to reproduce with classic video technologies. IVR offers the possibility to visually explore details of both the virtual body and surrounding environment with a dynamic visual perspective, which is constantly updated based on the participant's real head movements. On the contrary, the visual outcome of a video-based technology is a fixed static perspective. Although physical reality techniques do provide visuomotor information, they are rather restricted. They can only be implemented through video, mirrors, or special devices constructed to mechanically link the fake and real body parts (Dummer et al., 2009; Kalckert and Ehrsson, 2012). Meanwhile, manipulation of effectors other than timings is impossible in physical reality setups. In terms of visuoproprioceptive information, the fact that the virtual body can be implemented to take various spatial configurations, exploring difficult or impossible to implement in reality scenarios, distinguishes the advantage of IVR. Although regarding visuotactile stimulation IVR may not offer any innovative contributions, it can whatsoever, provide all manipulations available in physical reality, and with less effort. Further, IVR is very flexible in manipulating the semantic congruence described above, whereas physical reality requires the construction of the desirable physical objects and their semantic characteristics, a usually expensive and time consuming process.

3.1.7 Technical and software information of studies

Tables 3.1 and 3.2 below list the software and hardware used to implement all three studies of this thesis.

Table 3.1: The equipment used in all experimental studies

Equipment	Company	Specifics	Website	Study
Head-mounted display	NVIS	nVisor SX111	http://www.nvisinc.com	All
Head tracking	Intersense	IS-900 SimTracker	http://www.intersense.com	All
Motion capture hardware	Natural Point	Optitrack V100:R2 12-Cameras	https://www.naturalpoint.com	All
Video capture	Sony			All
Sound reproduction and recording	Yamaha	YSP-4000 Digital Sound Bar	http://usa.yamaha.com	Virtual Child Body,Racial Bias
	Asus	HS 1000 W	http://www.asus.com/Multimedia/	Illusory Speaking

3.2 Recruitment and Procedures

Participants were recruited through posters, e-mail and word of mouth around the city of Barcelona, as well as the campus of University of Barcelona.

3.2.1 Consent and Data Protection

The following documentation was given to participants in all three experiments:

- A pre-questionnaire to record basic information about the participant such as age, status, prior experience of virtual reality, criteria that could possibly lead to exclusion from the study later on etc. (see Appendix A).
- An information sheet describing the procedures of each experiment (see Appendix A, Appendix B and Appendix C).
- A consent form (see Appendix A).

Participants were informed both verbally and in writing that they were free to withdraw from the study at any time without having to provide any explanation. All data was made anonymous by assigning a unique identifier to each participant at the time of arrival at the experiment. No computer records tied up the name of the participant to the results gathered. A paper record that tied together the identification number of the participant and the contact details was kept by the principal investigator only during data analysis, and was destroyed soon after. No personal information was or will ever be published except in anonymous form. Participants always received monetary compensation for their participation at a prefixed rate in € (Euros). All written documentation, including consent forms, questionnaires etc., was available in Castellano (Spanish), Catalan and English, according to participants' preferences. The actual experiments were conducted in Spanish.

3.2.2 Ethical Consideration

All studies were approved by Comissió Bioètica of Universitat de Barcelona. For the *Virtual Child Body*, we manipulated the body of adult participants in terms of age, so as to virtually represent themselves in the body of a 4 year-old child. For the *Racial Bias* study, we manipulated the ethnographic characteristics, by embodying Caucasian race participants in a Negroid race virtual body. For the *Illusory Speaking* study, we did not manipulate demographic, or ethnographic characteristics, or proportions of the avatars. In order to consider any ethical concerns that may have risen from the execution of these studies, we followed a post-experiment monitoring of the participants regarding negative feelings or thoughts with respect to the context presented to them. The follow-up was implemented as a questionnaire that all participants received to complete through e-mail three weeks after the end of each study. Those who did not reply to the e-mail were contacted by telephone. The questionnaire is shown in Table 3.3. None of the participants reported any negative feelings, thoughts or carry-over effects.

3.2.3 Procedures

Once participants read the instructions and signed the consent form, they entered the laboratory where the experiment took place. All required equipment was then attached to them (trackers, physio devices etc.), while they were verbally reminded of the instructions of the experiment. The HMD was placed on their heads last, and a calibration procedure was followed in order to assure that the HMD screens were correctly placed in front of each eye (Grechkin et al., 2010).

One or more experimenters were present throughout the whole experiment, and assigned each participant to a specific experimental condition. The experiments always began with a familiarisation phase, where participants were asked to describe the virtual environment by turning their heads and look around in all directions. They were also always instructed to look down toward the virtual body, and then into a virtual mirror, in order to establish (or diminish) the ownership illusion. Thereof, each experiment continued following different procedures (for details see Chapters 4, 5 and 6). Typically, a post-questionnaire adapted for each study was given to them at the end of each experiment in order to assess their experience. Participants were then briefly interviewed; they were debriefed about the purposes of each study they took part in, and were finally compensated for their participation.

Table 3.2: The software used in the experimental studies

Software	Company	Website	Study
Motion capture software	Natural Point Optitrack ARENA	https://www.naturalpoint.com/optitrack/products/arena/	Virtual Child Body, Illusory Speaking
	Natural Point Optitrack MOTIVE	http://www.naturalpoint.com/optitrack/products/motive/	Racial Bias
	Faceshift	http://www.faceshift.com/	Virtual Child Body, Illusory Speaking
VR Toolkit	eXtreme Virtual Reality - XVR	http://www.vrmedia.it/	Virtual Child Body, Illusory Speaking
	3D Unity	http://unity3d.com	Racial Bias
3D Character Animation (online)	HALCA	http://www.lsi.upc.edu/~bspanlang/animationHuman/avatarslib/doc/	Virtual Child Body, Illusory Speaking
	HUMAN	(Spanlang et al., 2014)	Racial Bias
3D Character Animation (offline)	Autodesk Motion Builder 2012, 2013	http://www.autodesk.com/products/motionbuilder/overview	Racial Bias, Illusory speaking
	Autodesk Maya 2013	http://www.autodesk.es/products/maya/overview	
3D Modelling Software	Autodesk 3D Studio Max 2010, 2013	http://www.autodesk.es/products/3ds-max/overview	All
	Autodesk Character Generator	http://charactergenerator.autodesk.com/	Racial Bias
	DAZ Studio V.3	http://www.daz3d.com	Virtual Child Body

Table 3.3: Post experiment monitoring questionnaire

	Please answer the following questions:
Q1	Did you think about the experiment since your experience? If so, what types of things did you think about?
Q2	Did you have any negative thoughts regarding the experiment?
Q3	Did you have any positive thoughts regarding the experiment?
Q4	Did you have any strange feeling, thoughts or behaviour related to the experiment?
Q5	Would you do a similar type of experiment again?
Q6	In case you want us to call you for further discussion, please let us know.

Chapter 4

Illusory Ownership of a Virtual Child Body

In this Chapter we present the study related to our first hypothesis: *Healthy adults can experience ownership over a child body when congruent multimodal information is provided. Such illusory experiences result in changes in self-perception, and also affect size perception of the surrounding environment.* In Chapter 2 we discussed how IVR has been used manipulate our body representation in terms of structure, size, and morphology, and introduce ownership illusions under specific types of multisensory and sensorimotor stimulation (Sanchez-Vives et al., 2010; Yuan and Steed, 2010; Slater et al., 2010; González-Franco et al., 2013; Normand et al., 2011; van der Hoort et al., 2011; Kilteni et al., 2012; Kokkinara and Slater, 2014; Maselli and Slater, 2013). Although previous work has focused on the phenomena of body ownership and explanations for it, here we show that the form of the body, in terms of the relative proportions of head size, trunk, and limbs, can impact size-perceptions of the external world and reaction-time behaviours in the selection of categories that compare the self with others. This study was published in the journal *Proceedings of the National Academy of Sciences* (Banakou et al., 2013).

4.1 Introduction

How would it be to have the body of a child again, and how would this change perception of the world and your attitudes toward yourself and others? In this study we address this question in the context of body ownership illusions. As introduced in Chapter 2, it has been demonstrated that it is straightforward to generate the illusion in people that their body has changed. Immersive virtual reality has been used as a compelling way to manipulate and introduce illusions with respect to the body representation of people in terms of structure, size, and morphology. In other words, there have been significant demonstrations that perceptual ownership of a body that may be quite different to your own is possible through particular types of multisensory stimulation. Here we show that the form of the body, in terms of the relative proportions of head size, trunk, and limbs, can impact size-perceptions of the external world and implicit behaviours regarding categorisation of the self.

To this this end, we carried out two experiments. In the first, we embodied adults in the virtual body of a toddler (about 4-y-old) and as a control in a virtual body of the same size but representing a scaled-down adult body. The virtual body moved in real-time determined by the actual movements of the participant. The second experiment was carried out as a further control with the same child or scaled-down adult body, but where the virtual bodies moved asynchronously with respect to the real movements of the participants. This control was to examine what would happen when participants did not have the ownership illusion over their virtual body. The results reveal that an illusion of ownership over the child body has different perceptual and behavioural consequences than ownership over the scaled-down adult body form.

The effect of embodiment regarding perception of age and how that can influence subsequent behaviour has yet to be extensively addressed in literature. Hershfield et al. (2011) used IVR to expose participants to their future-aged selves to study the impact on attitudes toward monetary saving for the future. The results suggested that those interacting with their future selves focused on long-term implications of choices and exhibited increased preferences for larger rewards later in life. Yee and Bailenson (2006) found that negative stereotyping of the elderly was significantly reduced when participants were placed in avatars of old people compared with those participants placed in avatars of young people.

What is the link, however, between an altered representation of oneself and the perception of the surrounding environment? It has been suggested that body size serves a fundamental reference in visual perception of object size (Merleau-Ponty, 2013), but also, that the combination of information from different visual and oculomotor cues also affects this perception (Goldstein, 2010). Previous studies have shown, for example, that hand size affects the perceived sizes of external objects (Linkenauger et al., 2010; Marino et al., 2010). Besides the size of specific body parts in perceiving the external world, the role of whole-body scaling has also been recently studied. van der Hoort et al. (2011) studied the sense of body ownership and the effect of the body as a relative cue on object size and distance estimation. For this purpose, manikin bodies of different sizes were used, and participants experienced ownership of abnormally large and small bodies. The results demonstrated that the visual perception of distance and object sizes is affected by one's own multisensory body representation. Is size, however, the only factor influencing perception of the surrounding environment, or do additional bottom-up and top-down influences play a role in spatial awareness?

All of us can recall childhood memories and the environment in which they were set. We often find it surprising how objects that we found gigantic back then now seem considerably smaller, for example, when revisiting our childhood school. The experiment reported here addresses the question as to how embodiment of adults in a body of a child might influence size-perception of the environment and categorisations of self compared with others. We compare embodiment in a child (or "toddler" body) with embodiment in that of a scaled-down adult body of the same size. We consider three issues: First, whether there is evidence of an illusion of body ownership with respect to these two virtual bodies, and in particular whether the strength of the illusion differs between the two body types. Second, whether perception of size of the surrounding environment is influenced by the virtual body form. Third, whether there is a difference in reaction times in attributing child-like or adult-like attributes to the self.

4.2 Materials and Methods

4.2.1 Materials

The experiment was conducted in a virtual reality laboratory [width: 2.96 m, length: 3.4 m (back wall to curtain), height: 2.87 m]. Participants were fitted with a stereo NVIS nVisor SX111 HMD (Figure 4.1 C, 4.2 A). Head tracking was performed by a 6-DOF Intersense IS-900 device. Participants were also required to wear an Optitrack full-body motion-capture suit to track their movements (Figure 4.1 C). A virtual reality wand was also presented to them to complete the Implicit Association Test (IAT) (Figure 4.2 B). Virtual models were modelled in 3D Studio Max 2010 and DAZ Studio V.3. The virtual environment was implemented on the XVR platform (Tecchia et al., 2010), and the virtual body was displayed using a hardware accelerated avatar library (HALCA) (Gillies and Spanlang, 2010) (see Chapter 3 for full equipment details).

4.2.2 Experimental Design

Thirty-two (Experiment 1) and 16 (Experiment 2) adult male and female healthy participants with correct or corrected vision were recruited by advertisement and e-mail around the campus of University of Barcelona. Almost all of them were students, researchers, or employees of the University with no prior knowledge of the experiment; most of them had no prior experience of our virtual reality system. All participants filled in a demographic questionnaire before the experiment. Each one received the amount of 15 € (Euros) for participating (5 € at the end of the first phase and the remaining 10 € after the second phase was complete for Experiment 1).

The experiment was conducted as a within-groups counterbalanced design with a single binary factor, referred to as "Body Form". The first factor level represented the body of a visually realistic 4-year-old child (condition C) and the second level (condition A) (Figure 4.1 A,B) represented the body as an adult but with the same height as the child body (91.5 cm) by scaling down the adult body to match the height of the child body. Both virtual bodies were dressed in a similar way. The size of the virtual environment and proportions of the content

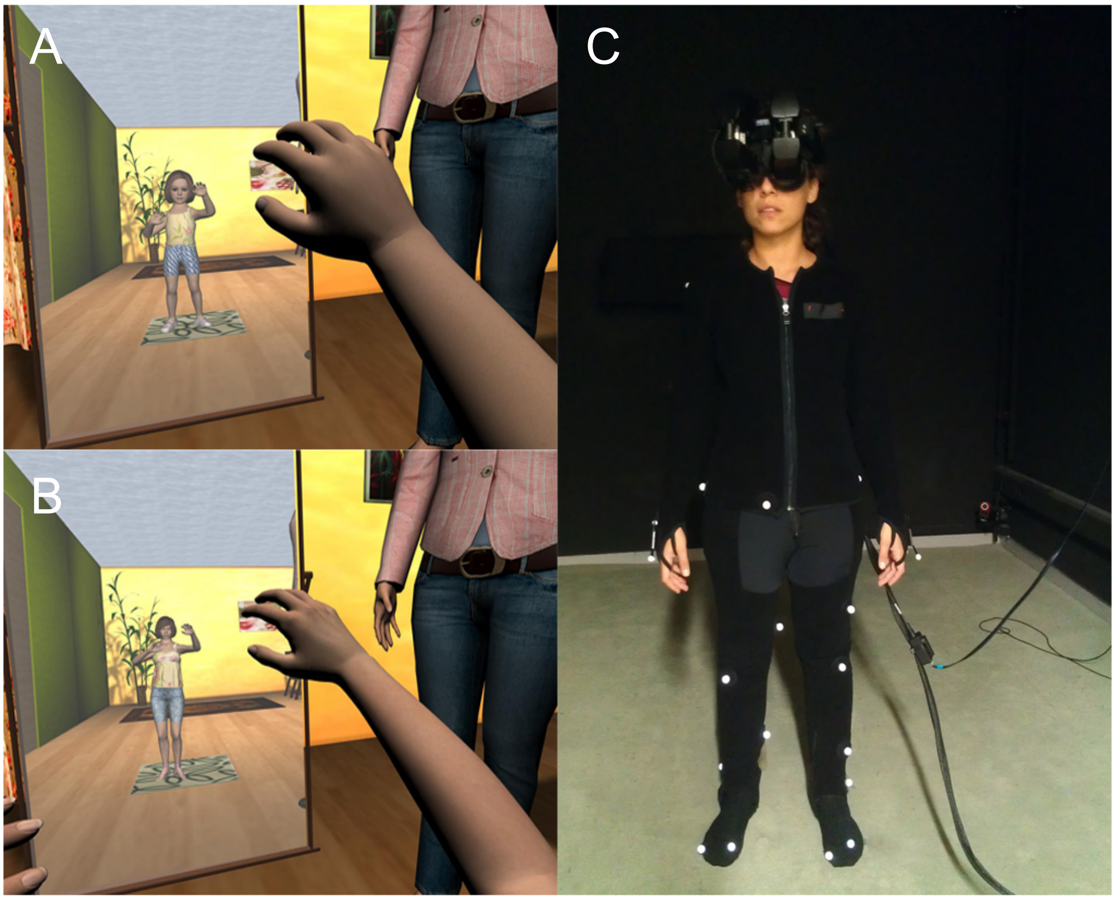

Figure 4.1: Experimental setup. The body of the participant was substituted by a sex-matched virtual body, viewed from first-person perspective, onto which body and head movements were mapped in real time. The body could also be seen as reflected in a virtual mirror as shown. The body each participant viewed depended on the condition C (for child) or A (for adult) to which each one was assigned. (A) A female participant in a child's body. (B) A female participant in a scaled-down adult's body. (C) Participants' body movements were tracked by 34 Optitrack markers.

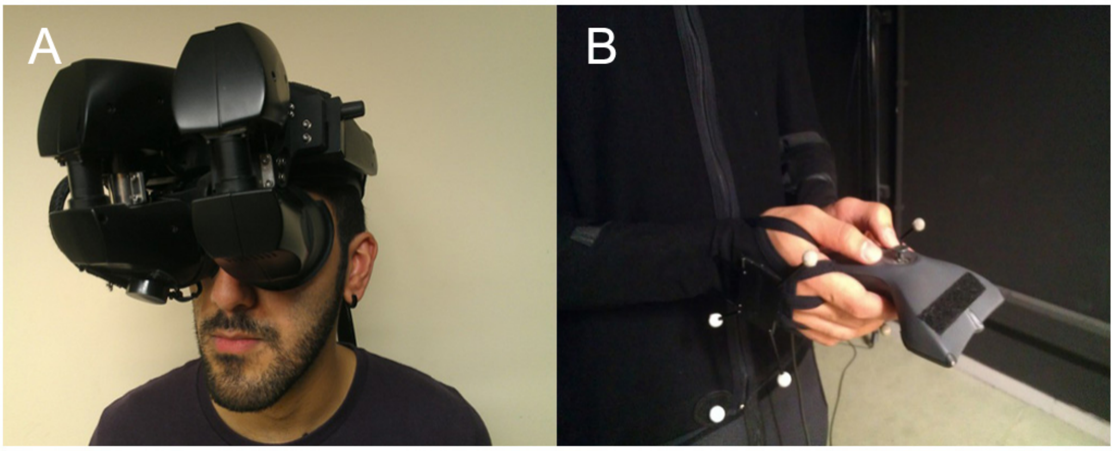

Figure 4.2: The HMD and tracking equipment. (A) Participants experienced the virtual environment through a nVisor SX111 HMD. (B) A virtual reality wand was used for the completion of the IAT.

were equivalent to reality and identical in both conditions.

Participants were randomly allocated to one of the two designed groups, regarding whether they first experienced a child virtual body and then an adult body (C) or an adult body first and then a child body (A). Their two trials were separated by 1 week. The experimental design can be seen in Table 4.1.

Table 4.1: Experimental design: The final number of participants distributed by group and experiment.

Group	n	No. of males	Mean±SE age (y)	Median code previous VR experience (IQR)	Median code hrs playing video games (IQR)
Experiment 1, synchronous					
AC	15	7	25 ± 1.2	2 (2)	2 (1)
CA	15	6	24 ± 1.0	2 (3)	1 (2)
Experiment 2, asynchronous					
AC	8	5	23 ± 1.7	2 (3.5)	2 (1.5)
CA	8	3	22 ± 1.1	2 (1.5)	1 (1)

4.2.3 Procedures

Participants attended the experiment at prearranged times. Upon arriving, they were given an information sheet to read (see Appendix A), and after they agreed to continue with the experiment, they were given a consent form to sign. Before the experiment started, participants were fitted with the HMD and the body-tracking suit. The view seen through the HMD was calibrated for each one of them.

The position of all participants was controlled through Velcro strips on the floor, which were used to mark where they should stand during the experiment. These positions corresponded to the center of the physical and virtual room. Participants were instructed to turn and move their heads and bodies but not walk away from that area unless requested otherwise by the experimenter. That area was represented in the virtual environment by a virtual carpet, on which participants were asked to stand.

During the first part of the experiment, participants entered a virtual outdoor scene where they trained their object-size estimation capability, thereby also familiarising themselves with the task of estimating sizes of objects in virtual reality. In this setup they had no virtual body. During this task the participants were presented in random order with six virtual red color cubes of different sizes (15, 25, 30, 45, 60, and 75 cm) in front of them over a period of 5 min. All cubes were shown in the same position and at 0.6 m with the same orientation. The position from which participants looked at the objects was from a height of about 90 cm, equal to the height of the child and scaled adult avatars. The participants were instructed to indicate the width of each cube by raising their hands and hold them straight in front of them, as if they would like to grasp it, and the size was measured as the distance between the palms. The distance was calculated using the tracking devices on their hands and was automatically recorded for each object separately. An offset corresponding to the distance between the tracking device and the participant's palms individually was also taken into account when estimating the final results (the average among all participants was 8 cm) (Figure 4.3 A). After each size estimation, participants were given visual feedback in the form of words on the screen regarding their measurements that categorised their estimations as “Too Big”, “Too Small”, or “Correct”. In cases where measurements were other than “Correct”, participants were instructed to relax their arms and try again, until they achieved a “Correct” feedback. Only then was the next virtual object presented to them. Each measurement was classified with a ±4-cm tolerance (e.g., for 15-cm virtual objects, “Correct” estimation varied from 11 to 19 cm).

Next, participants removed the HMD and were asked to complete a personal traits questionnaire, the information from which was used later during the IAT test. For example, participants had to provide their age, sex, profession, and other such individual information. Immediately after completing the questionnaire they put on the HMD again, and the second and main part of the experiment started. Participants entered the same training virtual scene, still with no virtual body; they were asked to repeat the object-size estimation task. Red-coloured cubes of 15 cm, 30 cm, and 45 cm were each presented three times in random order. Each virtual object remained visible in front of participants at a constant distance (of 0.6 cm) for 5 s. After each cube disappeared, they were asked to indicate their estimate by the distance between their hands, and the measurements were recorded with the same procedure as described before, but without any feedback as to the correctness of the size estimations. This process provided the baseline size estimations.

While participants wore the HMD they were asked to close their eyes, during which time a new scene was loaded. This scene portrayed a virtual living room decorated with everyday furniture, including a virtual mirror. The body of the participant was substituted by a sex-matched virtual body, seen from a first-person perspective. The participant’s head and body movements were mapped in real time to the virtual body; they could see this body both by looking toward directly toward their real body and also in the virtual mirror. The body seen by each participant depended on the condition A or C. A series of tasks were then assigned to the participants. First, they were asked to perform a simple set of stretching exercises that had previously been demonstrated to them by the experimenter, in order that they should explore the capabilities and real-time motion of the virtual body, including movements of their arms, legs, and feet. Participants were asked to continue performing these exercises by themselves and also look around the virtual room in all directions. During this visual exploration, participants were asked to state and describe what they saw, to be sure that they were paying attention. After the exploration period (5 min), the participants were asked to repeat the size-estimation task, with no virtual body present. Each object was measured three times in random order at three different locations, all at the same distance from the participant equal to that of the control measurements and with the same orientation (Figure 4.3 B–D). The heights at which each object was placed were always the same, and were the same as in the control condition.

Then participants were instructed to locate two virtual doors in the room and face toward these. One door was to a room that looked like a child's playroom, and the second more like an adult sitting room (Figure 4.4). We asked participants to choose between these two virtual doors. The location of the rooms in the environment was randomised across participants to avoid choice based on adaptation. Participants were told that they would be given only 4 s to make their choice before the doors closed. They were told that any delay could result in failing the experiment.

Finally, participants completed the IAT (from within the HMD) and after removing the HMD they were asked to complete the post-experimental questionnaire. Next, the participants were paid and debriefed. The whole procedure lasted between 45 and 60 min. The experimental operator (female) was present throughout the whole experiment. All participants attended the second trial of the experiment 1 week after the first phase and the procedures were identical to the ones presented above, except that the avatar body used was the other one.

Experiment 2 was identical to Experiment 1, except that the virtual body moved independently of the movements of the participant and the second trial was carried out on completion of the first.

IAT Procedure. As described by Schnabel et al. (2008), the "IAT measures are designed to assess automatic associations between a contrasted pair of target...and attribute...concepts through a series of discrimination tasks that require fast responding." The target category in the IAT design adapted for the current study refers to "Children versus Adults" images; the attribute category to "Me versus Others" has personal attributes in the form of words or short sentences.

The IAT was applied immediately after the exposure in the virtual environ-

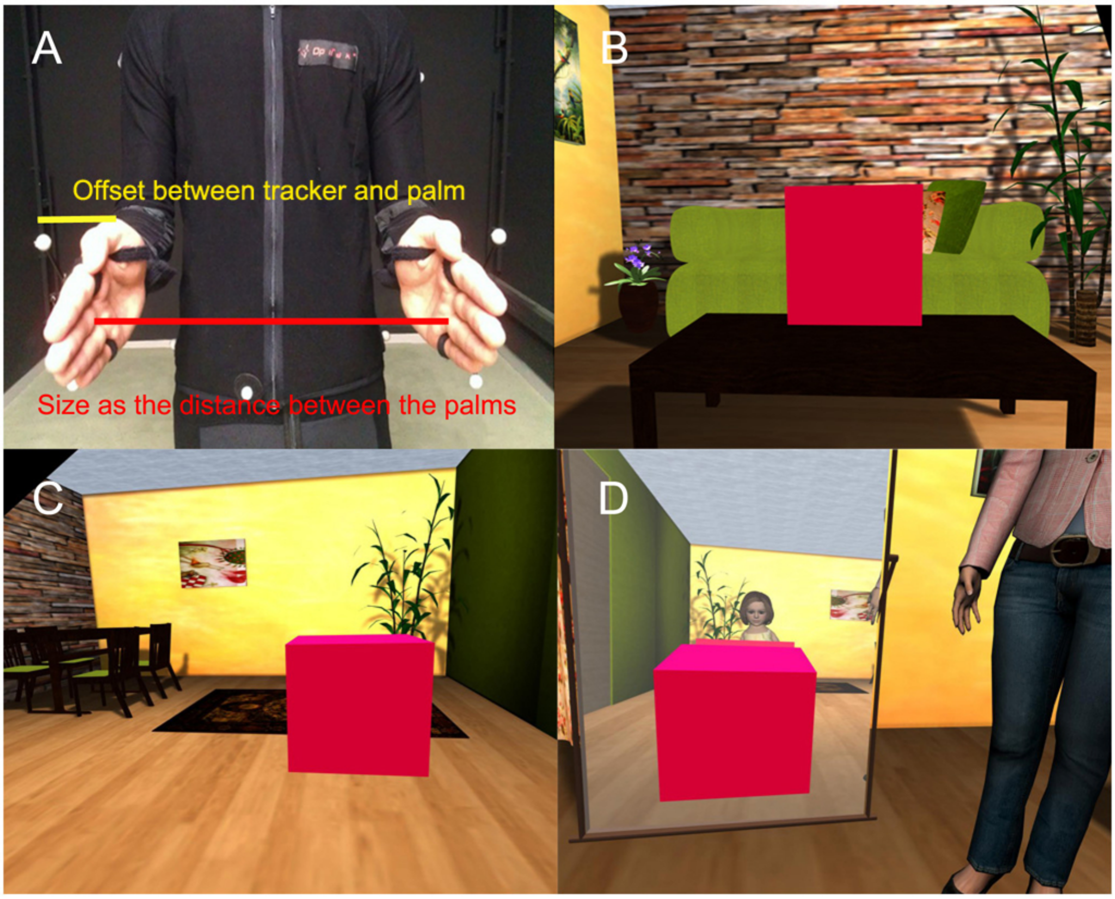

Figure 4.3: Object size estimation measurements.(A) The sizes of virtual objects were measured as the distance between the participants' palms, using the tracking devices on the hands and recorded for each object separately. An offset corresponding to the distance between the tracking device and the participant's palms (average 8 cm) was deducted from the recorded results. (B–D) A cube at three different locations in the virtual reality set-up, all at the same distance from the participant and with the same orientation.

Figure 4.4: Experimental setup: Room choice. The two rooms: (Left) child room and (Right) adult room that participants were prompted to select, by indicating the desired location "right" or "left".The location of the rooms was randomised across conditions and among participants.

ment and while participants were still wearing the HMD through which the test was displayed. A virtual reality wand was used by the participants to make their selections by putting their left and right thumbs on the left and right buttons, respectively (Figure 4.2 B). During the first IAT block, the participant was asked to categorise visual stimuli into the two target categories, namely "Children" and "Adults" (Table 4.2). The stimuli were pictures of adult and child faces appearing in the middle of the screen for the participant to sort into the appropriate category. In the second block, the participant was trained to press one button for "Me" attributes and the other button for "Others" attributes. These attributes were presented as written words. The attributes were personalised for each participant and corresponded to preferences and personal data, such as their names, ages, occupation, food/music, or other likes, life status, and so on. These personal data and preferences had been obtained for each individual from the questionnaire administered before they started the experiment. The third and fourth blocks combined the target and the attribute discrimination that were subdivided into two blocks of 40 trials each. The subsequent fifth block reversed the target discrimination and the sixth and seventh blocks combined again the attribute and the previously reversed target discrimination. As has been shown, mean IAT scores tend to show slightly stronger associations corresponding to the pairings of the combined block that is completed first (Nosek et al., 2005). To control for this effect, the order of combined blocks was counterbalanced between participants as proposed by Nosek et al. (2007).

4.2.4 Response Variables

In this experimental design we use four different types of response variables to measure participants' level of embodiment in a child's body, perceptual, and behavioural responses, with the resulting awareness of their body, age, and the surrounding environment. We specifically use a post-experimental questionnaire, participants' size estimations of virtual objects, an IAT, and a behavioural measurement as to participants' preferences. Before the experiment, a personality pre-questionnaire was also used to record basic information about the participant such as age, sex, and status. A personal traits questionnaire was completed by

Table 4.2: Task sequence and stimuli of the IAT

Block	Trial	Task	Response key assignment: Left key	Right key
0	20	Target discrimination	Children	Adults
1	20	Attribute discrimination	Me	Others
2	40	First block of first combined task (practice block)	Me,Children	Others, Adults
3	40	Second block of first combined task (test block)	Me, Children	Others, Adults
4	20	Reversed target discrimination	Adults Children	
5	40	First block of second combined task (practice block)	Me, Others	Adults, Children
6	40	Second block of second combined (test block)	task Me, Adults	Others, Children

each individual that was used in the IAT. More specifically the questionnaires included:

- A pre-questionnaire to record basic information about the participant, such as age, sex, status, and prior experience of virtual reality and computer games. We had to make sure that dyslexic volunteers would not be included in the study, as this could possibly cause problems in the IAT procedure (see Appendix A).

- A personal traits questionnaire to record more basic information about the participant, personal characteristics, and preferences, all to be used for the implementation of the IAT (see Appendix A).

- A 17-statement post-questionnaire to assess participants' subjective experience (Table 4.3). A 7-point scale was used ranging from "-3" to "+3", with "0" indicating a neutral response, always with regard to what each question measured individually (i.e., the scale varying from Not at All/Very Much, Smaller/Larger, and so forth). More specifically, these questions were related to the strength of body ownership (Q1, Q2)- here we require that the level of body ownership to the same between the two conditions C and A in Experiment 1 - specific effects as to the sizes of the virtual world compared with the body and surrounding attributes (Q5–Q9), miscellaneous questions relating to the experience of being a child (Q11–Q17); other questions served as control questions (Q3, Q4). The age-related questions were asked at the very end of the experiment, and there was no other reference to age before the end of the experimental process.

All questionnaires were available in English, Spanish, and Catalan and used according to the preference of each participant. Size estimations were based on tracking data during the experiment by recording the positions of the participants' hands for each of the presented objects. Here, we were interested in examining whether, and if so to what extent, the experimental conditions could differentially affect the object size estimation. Our hypothesis was that participants in a child's body would estimate sizes and the surrounding environment as being larger than participants in shrunken-down adult bodies.

The IAT explored the relationship between self and child/adult categories. For the calculation of the IAT scores, the algorithm of Greenwald et al. (2003) was implemented, which produces an interrelated set of D measures. Trials with latencies over 10,000 ms and data from participants with more than 10% of trials showing latencies of less than 300 ms were excluded. All error latencies were recoded based on the mean of correct latencies for each trial block plus an error penalty of 600 ms. All analyses presented here involved the 30 participants. A comparison of the reaction times in the task in which one category (i.e., child images) was paired with self attributes with the times obtained in the task in which the other category was paired with strangers' attributes, provides a measure of implicit preferences for the two categories. That is, faster responses to a category when it was paired with self attributes than when it was paired with a stranger's attributes indicate a stronger preference for that category than for the alternative.

The IAT followed the standard IAT procedure (Greenwald et al., 2003). Participants were instructed to "respond rapidly, while occasional errors are acceptable"; categorisation errors were identified with a red "X" below the stimulus item and participants had to correct the response before continuing to the next trial. All category labels, which assigned to the right or left response key, were displayed in the right or left upper screen corner throughout all tasks. To emphasize the distinction of the labels and stimuli of the target concept, "Children/Adult" labels appeared in light blue font, and "Me/Others" labels and items in yellow font, all on a black background; instructions were presented in white. The target and attribute stimuli were alternated in the combined blocks, and 80 trials were used in the combined blocks (each divided into an initial block of 40 trials and a main block of 40 trials), 20 trials in the first two simple discrimination blocks, and 20 trials in the reversed target discrimination.

Finally, the behavioural measurement adopted here refers to the selection of a room in the virtual environment to evaluate participants' preferences and change of attitudes and subsequent behaviour in the virtual environment. The participants were instructed to report their choice both verbally, by saying to the experimenter "right" or "left", and by indicating with their hand the preferred room. Their answers were recorded by the experimenter based on the location of the two rooms at each time.

4.3 Results

Experiment 1 had a single factor (body form) with two conditions. In condition C, participants were embodied in the body of a child (Figure 4.1 A). In condition A, they were embodied in a scaled-down adult body of the same height as that in C (Figure 4.1 B). The height (of 91.5 cm) represented a child of about 4-y-old. Embodiment was through first-person viewpoint from the eyes of the virtual body that substituted the own body with synchronous visuomotor feedback, so that as the person moved their virtual body moved in real-time and synchronously (see also Supplementary Movie). The eye heights were identical in both conditions.

The experiment was conducted as a within-group counter- balanced design originally with 32 participants (n = 16 in each condition). Two participants were excluded from the analysis because of the lack of data during the second condition of the experiment (final, n = 15 in each condition). Participants were randomly allocated to one of the two groups, regarding whether they first experienced a child virtual body and then an adult body or an adult body first and then a child body. Their two trials were separated by 1 week.

Table 4.3: Post-experiment questionnaire about virtual experience

Question ID	Variable name	Question	Scoring scale
Q1	VRBody	How much did you feel that the virtual body you saw when you looked down at yourself was your own body?	Not at all/Very Much (-3...3)
Q2	Mirror	How much did you feel that the virtual body you saw when you looked at yourself in the mirror was your own body?	Not at all/Very Much (-3...3)
Q3	Features	How much did you feel that your virtual body resembled your own (real) body in terms of shape, skin tone or other visual features?	Not at all/Very Much (-3...3)
Q4	TwoBodies	How much did you feel as if you had two bodies?	Not at all/Very Much (-3...3)
Q5	RoomSize	Did the room that you saw seem bigger, smaller or about the same as what you would expect from your everyday experience?	Smaller/Larger (-3...3)
Q6	VBSize	Did the virtual body you owned seem bigger, smaller or about the same as what you would expect from your everyday experience?	Smaller/Larger (-3...3)
Q7	RBSize	While being in the virtual room, did you feel your unseen real body being:	Small/Large (-3...3)
Q8	WomanVB	Did you feel that the virtual woman you saw compared with your virtual body was:	Smaller/Larger (-3...3)
Q9	WomanRB	Did you feel that the virtual woman you saw compared with your real felt body was:	Smaller/Larger (-3...3)
Q10	WomanPresence	How much did you feel that the woman you saw was aware of your presence?	Not at all/Very Much (-3...3)
Q11	WomanAge	Of what was the age of the virtual woman you saw?	<20 y old/21–30 y old/ 31–40 y old/ 41–50 y old/ >50 y old
Q12	VBAge	Of what age was your virtual body?	1–4 y old/ 5–8 y old/ 9–12 y old/ 13–16 y old/ 17–20 y old/ 21–24 y old/ >25 y old
Q13	Younger	How much younger did you feel?	Not at all/Very Much (-3...3)
Q14	Older	How much older did you feel?	Not at all/Very Much (-3...3)
Q15	FeltAge	What age did you feel yourself to be?	1–4 y old/ 5–8 y old/ 9–12 y old/ 13–16 y old/ 17–20 y old/ 21–24 y old/ >25 y old
Q16	FeltBody	During the experiment you felt:	Child/Adult
Q17	FeltChild	How much did you feel like a child?	Not at all/Very Much (-3...3)
Comments		Please write down any other comment or feeling you had regarding your experience?	

4.3.1 Body Representation Questionnaire

First, we examine the extent of body ownership with respect to the two virtual bodies of conditions C and A. Participants completed a questionnaire after each experimental condition (Table 4.3). The box plot (Figure 4.5 A) of questionnaire responses for the ownership illusion questions Q1 (VRBody) and Q2 (Mirror) shows that participants tended to affirm the illusion of ownership with respect to the child and the adult body, and that there was no significant difference between the two conditions. To test these hypotheses, we used the Friedman non-parametric test for two-way layouts, with the trial number as the blocking factor (for VRBody $\chi_1^2 = 0.05$, P = 0.82, for Mirror $\chi_1^2 = 0.16$, P = 0.69). The median scores for Q4 (TwoBodies) are each 0, with no difference between the conditions ($\chi_1^2 = 0.12$, P = 0.73). The median score for Q3 (Features) is significantly lower in the Child condition (median = -2) than the Adult condition (median = -1) (χ_1^2 = 5.32, P = 0.02), which is consistent with participants recognising the difference between the two bodies, although it should be noted that both scores are very low.

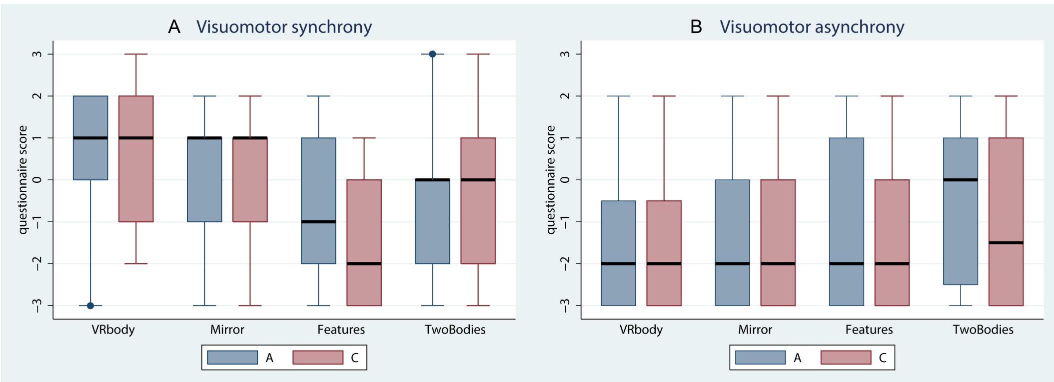

Figure 4.5: (A and B) Box plots for questionnaire results on body ownership (see Table 4.3) for Exps. 1 and 2, respectively, by the Adult and Child conditions. The thicker horizontal lines are the medians and the boxes the interquartile ranges.

4.3.2 Effect of Body Form on Size Estimation

A major issue of the study was to investigate the relationship between body form and the perceived sizes of objects in the environment. Our expectation was that condition C would result in greater overestimation of sizes compared with condition A, although based on previous literature, we expected overestimation in both conditions. Participants were trained to hold their hands apart with the distance between the two hands representing the estimated sizes of objects. The locations of the two hands were tracked and the distance between them recorded (Figure 4.3 A). Participants were required to carry out these estimations twice, for three differently sized cubes (15 cm, 30 cm, 45 cm); they had previously had training on this method of size estimation (see Materials and Methods). The first estimates were obtained after they had entered the virtual environment but before embodiment in a virtual body, where they made three estimates for each object. Then, after some experience of being in the virtual body, the participants were required to make the estimations again. We took the mean of nine estimates as their final estimate for each size estimation, as each object was measured three times in random order at three different locations, all at the same distance from the participant (0.6 cm) and with the same orientation (Figure 4.3 B–D). The differences between the mean size estimates during the embodiment phase and the pre-embodiment mean estimates are denoted by *dmean15*, *dmean30*, and *dmean45*. One extreme outlier was detected, which was removed from all analyses involving these means (Figure 4.6).

The results (Figure 4.7) show that there is a significantly greater overestimation of size in condition C compared with condition A. This finding is confirmed by a within-groups ANOVA: *dmean15*: $F(1, 28) = 11.37$, $P = 0.002$; *dmean30*: $F(1, 28) = 16.43$, $P = 0.0004$; *dmean45*: $F(1, 28) = 8.92$, $P = 0.006$. The Shapiro-Wilk test shows compatibility of the residual errors of the fit with normality for *dmean15* and *dmean30* (both $P > 0.89$) but not so for *dmean45* ($P = 0.03$, although the distribution of residual errors is clearly symmetric about 0 and bell-shaped). It should be noted that in the adult condition the differences are significantly greater than 0, consistent with earlier results (van der Hoort et al., 2011) that the scaled-down body does result in object size overestimation.

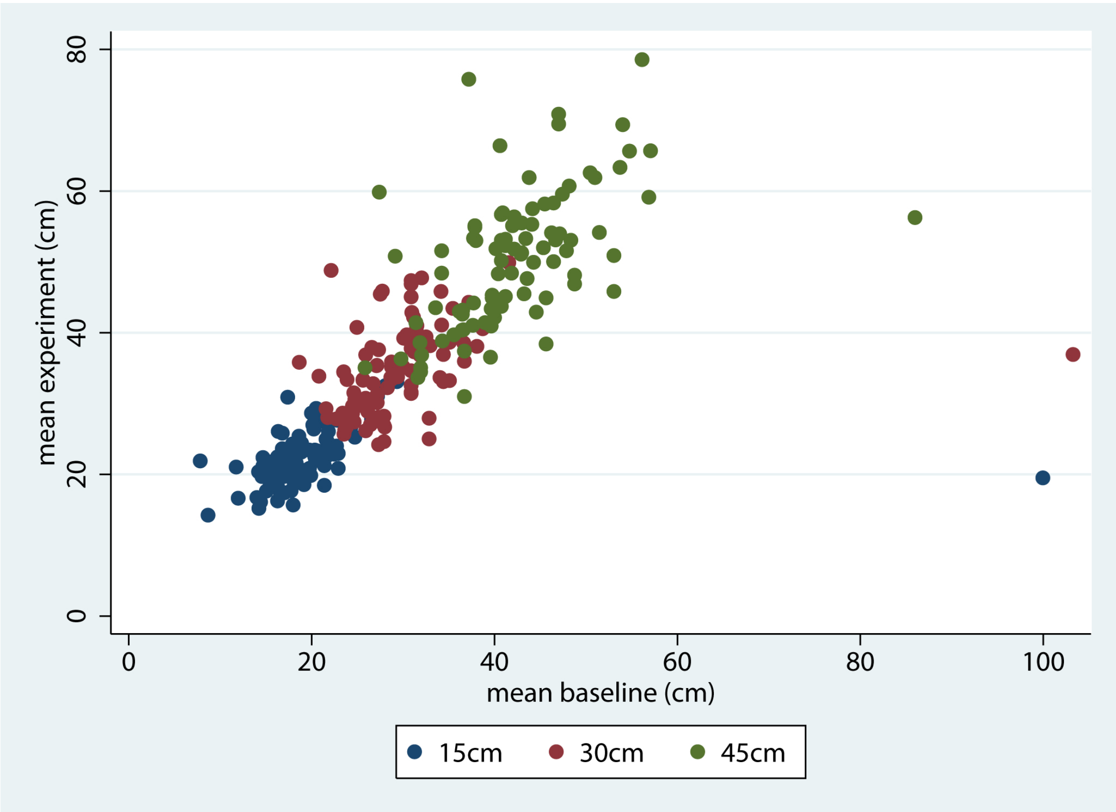

Figure 4.6: Scatter diagram of the mean experiment size estimates by the mean baseline size estimates for each of the three box sizes (15 cm, 30 cm, 45 cm). This is for Experiment 1 only. The diagram clearly shows an outlier in each case–the same actual participant–which only occurs in the adult condition. The data for this participant was excluded for all analysis involving these means.

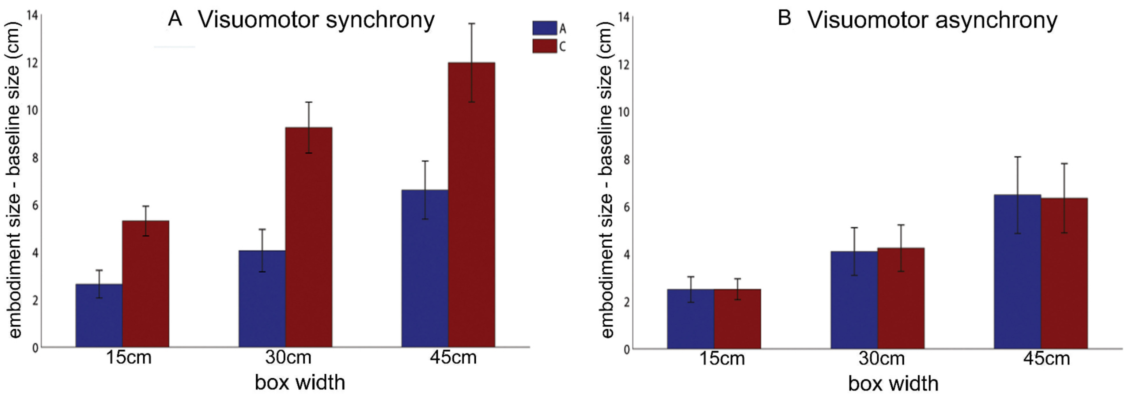

Figure 4.7: (A and B) Bar chart size-estimation results for Exps. 1 and 2, respectively. The heights are means and the bars SEMs. The variable *dmean15*, *dmean30*, and *dmean45* are the differences between the post-embodiment size estimations and pre-embodiment (baseline) size estimations, for the boxes of the three different sizes.

4.3.3 Implicit Association Test Scores

Participants completed an IAT Schnabel et al. (2008) at the end of both conditions and while still in the virtual environment. This IAT paired child or adult with self and other categories. The results show that participants in the child condition C responded faster when the self was paired with child images (Me-C) than when the self was paired with adult images (Me-A). On the other hand, participants in the adult condition A had faster response times for Me-A pairs than for Me-C pairs. In the interpretation of the IAT scores, positive scores reflect stronger associations for Me-C relatively to Me-A. Figure 4.8 shows that the IAT C scores are greater than the A scores. The within-groups ANOVA shows that the difference in means between the conditions is significant [$F(1, 29) = 22.12$, $P = 0.0001$, and Shapiro-Wilk test for normality $P = 0.49$].

4.3.4 Experiment 2: The Influence of Body Ownership

The analysis above shows that there is a significant effect of the type of body; that is, the child body leads to higher IAT scores and overestimation of object sizes compared with the adult body. However, we are interested in whether it

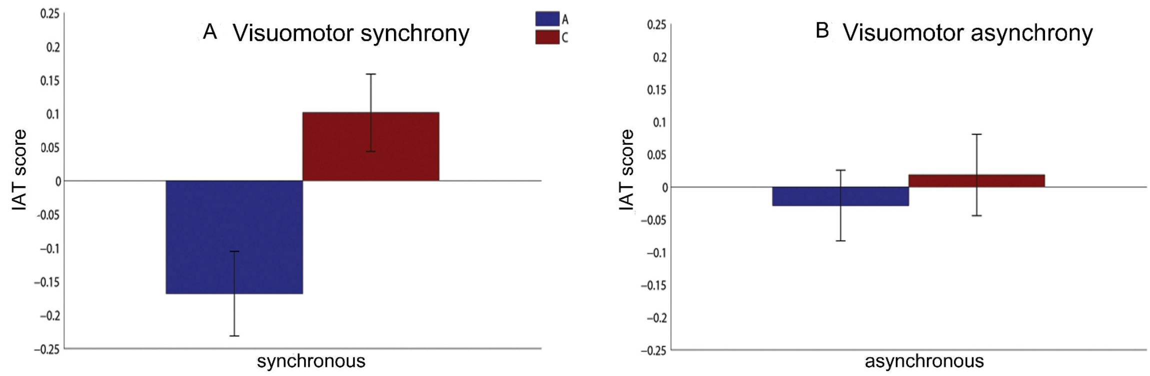

Figure 4.8: (A and B) Bar charts for the IAT results for Exps. 1 and 2, respectively. A higher IAT score represents faster response times for self compared with child categories. Significance levels are given in the text.

was the illusion of body ownership that contributed to these effects. To this end, Experiment 2 was designed to diminish the degree of body ownership by using visuomotor incongruence. Another 16 people were recruited from the same population as Experiment 1. These participants completed the full experiment in the same session, with counterbalanced order (either child embodiment first or adult embodiment first). However, whereas in Experiment 1 there was real-time synchrony between the movements of the participant and the movements of the virtual body, in this case the virtual body moved asynchronously with respect to the movements of the participant, although seen from exactly the same perspective condition as in Experiment 1. In other words, in Experiment 2 participants saw the virtual body from a first-person perspective and in the mirror as before, but its movements were not those of the participant. Based on previous research (Sanchez-Vives et al., 2010; González-franco et al., 2010; Noe, 2004; Proffitt, 2006; Lanier, 2010), we expected this aspect to reduce the degree of body ownership.

Indeed, this result is what happened, as can be seen in Figure 4.5 B. For example, for Q1 (VRBody) and Q2 (Mirror), the medians are both -2 in all asynchronous conditions, compared with 1 in all synchronous conditions. (Using the Wilcoxon rank-sum test comparing VRBody between synchronous and asynchronous conditions $P < 0.00005$, and for Mirror $P = 0.0001$. There are no significant differences for Features or TwoBodies).

If it is the case that only the level of body ownership is responsible for the overestimation of sizes in the child condition compared with the adult, but that there would be a general overestimation in both conditions because of the low height in both, then we would predict that in Experiment 2 the C condition should give the same results as the adult condition in Experiment 1. In fact, in Experiment 2, we ran both child and adult conditions. However, to be rigorous and conservative we should only consider results from the first trial in both experiments, thus treating this as a pure between-groups experiment. Table 4.4 shows that this prediction is warranted. (As occurred in the other analyses, the residual errors are compatible with normality for *dmean15* and *dmean30* but not for *dmean45*).

Figure 4.7 B shows the bar charts for *dmean15*, *dmean30*, and *dmean45* in the asynchronous condition. It is evident that there are no differences between the child and adult conditions. The within-group ANOVAs have all $P > 0.80$ for the difference between C and A in this asynchronous setup (and all satisfy normality using the Shapiro-Wilk test all $P > 0.68$). Similarly, Figure 4.8 B shows the IAT results, with no difference between C and A (within-groups ANOVA $P = 0.65$, Shapiro-Wilk $P = 0.10$).

Taking both experiments together, "synchronous" is a between-group factor and condition (A or C) is a within-group factor. As can be seen from Figure 4.7 A and B, for *dmean15* the within-groups main effect difference between A and C is significant [$F(1,43) = 5.67$, $P = 0.02$], with a significant interaction between condition and synchronous [$F(1,43) = 5.50$, $P = 0.02$]. The residual errors satisfy normality (Shapiro-Wilk $P = 0.26$). The findings are similar for *dmean30*: the within-groups condition main effect $F(1,43) = 8.73$, $P = 0.005$, interaction $F(1,43) = 7.68$, $P = 0.008$, Shapiro-Wilk $P = 0.97$. For *dmean45*: the within-groups main effect is $P = 0.05$, and interaction effect $P = 0.04$. This time normality is not satisfied (Shapiro-Wilk $P = 0.001$) but the residual error distribution is highly symmetric. As before, each of *dmean15*, *dmean30*, and *dmean45* are significantly greater than 0 (t tests, all $P < 0.0001$), showing that there was an overestimation of size.

For IAT (Figure 4.8 A and B), the within-groups main effect for condition has F(1,44) = 9.01, P = 0.004, with interaction effect F (1,44) = 4.72, P = 0.035 (Shapiro-Wilk P = 0.86). The significant interaction effects are all critical in demonstrating that the relationship between responses in the adult and child conditions were different, depending on whether there was asynchronous or synchronous visuomotor feedback. The former is associated with a low level of body ownership and the latter with a high level.

Table 4.4: Means and SEs of size estimations comparing asynchronous and synchronous conditions in the child condition

Group	***dmean15***	***dmean30***	***dmean45***	***n***
Asynchronous Child condition (Experiment 2)	2.20(0.5)	3.08(1.5)	4.48(1.80)	8
Synchronous Child condition (Experiment 1)	5.98(1.03)	9.17(1.76)	10.91(2.34)	15
P (two-tailed *t* test) comparing Experiment 1 and Experiment 2	0.02	0.03	0.09	

Note that the *n* in Experiment 1 is 15 rather than 14 because the outlier mentioned in the main text only occurs in the adult condition.

4.3.5 Room Chosen

Participants were asked to quickly choose between one of two rooms, each shown through an open door. One room was decorated in a child-like way and the other in an adult way (Figure 4.4). Adopting this measurement helped us understand how participants felt while being embodied in the two different type bodies, and whether that body form and consequently feeling of the virtual age had any impact on their behavioural choices. In Experiment 1, participants in condition C chose the child room in 13 of the 30 trials, whereas in condition A this was 1 of 30. In Experiment 2, in condition C the child room was chosen 4 of 16 times, whereas in condition A it was 2 of 16.

4.4 Discussion

Our first result is that it is possible to generate a subjective illusion of ownership with respect to a virtual body that represents a child and a scaled-down adult of the same size when there is real-time synchronous movement between the real and virtual body. The illusion is extinguished when the virtual body moves asynchronously compared with the real body. It was found that there were no significant differences with respect to body ownership between the child and adult condition. This result is not surprising and is in line with earlier results that it is possible to generate such illusions with different body forms (Petkova and Ehrsson, 2008; Slater et al., 2010; Normand et al., 2011; Kilteni et al., 2012), including very small or large bodies (van der Hoort et al., 2011). This result serves mainly as a reference point, to show that there is no difference in the extent of the illusion of ownership over the adult and child body forms in Experiment 1 that could account for the other findings.

Our second result concerned object size estimation in the different body forms. It has been argued that body size serves a reference for the external world, and earlier studies using IVR have examined how the perception of one's body size influences the perception of spatial layouts (van der Hoort et al., 2011). Other studies (e.g. refs. (Noe, 2004) and (Proffitt, 2006)), show that scaling one's body size up or down proportionally results in perceiving the world as smaller or larger respectively. The results of our study go one step beyond this. We have shown that although there was an overestimation by the A group, as would be expected, there was an even greater overestimation by the C group compared with the A group (Figure 4.7 A). Hence, as well as body size influencing the estimation of the sizes of objects in the environment, there must be an additional underlying mechanism relating to perception of the form of the own body. The findings support the notion that higher-level cognitive processes (i.e., the implications of the form of the body in terms of how it represents age) can influence our perceptual interpretation of sizes of objects in the external world other than body size alone.

Our third result shows an impact of body form on self- and other-categorisation (measured by reaction times) with respect to classification of the self as a child or as an adult, where those in the C body responded significantly faster to self-categorization with child-like attributes compared with those in the A body. In the late 1980s, Jaron Lanier was the first to realize that IVR could be used to virtually transform one's body [discussed in Lanier (2010)] and previous research has focused on demonstrating how an avatar's visual appearance can influence participants. Yee and Bailenson (2007) examined how manipulating the on-line self-representation can cause changes in the behaviour of people embodied in avatars (their notion of the *Proteus effect*). However, this earlier work does not provide evidence that body ownership can affect attitudes and behaviour intrapersonally. First, there was no notion of or attempt to measure the degree of body ownership; and second, their theoretical framework describes how an external perceiver can possibly influence the user of an avatar through interpersonal communication behaviour (i.e., when interacting or communicating with others). According to Yee and Bailenson, as discussed in Chapter 2, behaviours can be influenced by assumptions about how one would believe others would expect them to behave (Yee and Bailenson, 2007). In a different study, it was examined how an avatar's appearance can affect the behaviour and cognition of the participant (Peña et al., 2009) by making the user more or less confident, friendly, aggressive, negative, or intimate. In that study however, the hypothesis was based on how the manipulation of outer appearance and clothing contribute to the argued effect. Therefore, no direct manipulation of the bodily self-representation and type of body was engaged.

Here we concentrated on manipulating solely the bodily self-representation and on the consequences of this in subsequent perception and attitudes. No external factors, such as social interaction, were present, and participants were alone rather than in social settings. Furthermore, this study is innovative in the way that takes into account the virtual representation in a body of a different age–a child–and on the consequences of such a transformation on behaviour and attitudes. To our knowledge, no previous studies have examined the effect of owning a body of a child in an experimental setup. The results of the present study support the hypothesis that not only did participants feel ownership of the child body, but that this body transformation also affected their identification by modifying their IAT responses.

Our fourth finding is that the size estimation and IAT results were influenced by the extent of the illusion of body ownership. Importantly, the size estimation and IAT responses compared between high (synchronous) and low (asynchronous) ownership-illusion conditions show that the difference in responses between the C and A conditions only occur for the group with the higher level of body-ownership illusion. This finding suggests that a correlate of a body-ownership illusion is that the type of body carries with it a set of temporary changes in perception and behaviours that are appropriate to that type of body. Here it relates to age, and everyone will have experiences of being 4-y-old, possibly with first-hand memories that may be triggered by being embodied in and having strong agency over an apparent 4-y-old body. As noted by Vogeley and Fink (2003) in their review of the neural correlates of first-person perspective: "*emotional traces* of past experiences trigger our actual decisions based upon experiences similar to the actual experience." The authors also argue that our core self is reconstituted on a moment-to-moment basis in the relationship between ourselves and the external world, and that this is a "necessary component for the so-called autobiographical self, that integrates particular states of the core self over one's personal life history". In our experiment we radically changed not only the relationship of the self to the external world through the manipulation of size but also with respect to body type representing a profoundly different age. Therefore, we would predict a triggering of past first- person perspective experiences associated with being that younger age that then influenced present-day perceptual and attitudinal processing.

However, if the body type was not one that had been coded in memory through previous experience, participants might be influenced by socially and culturally derived expectations of what it would be like to have a specific type of body. The recently introduced framework of a cortical "body matrix" might explain this. The body matrix is a multisensory representation of peripersonal space and the space immediately around the body, in a body-centered reference frame (Moseley et al., 2012). According to this, and a further interpretation in Llobera et al. (2013), when multisensory data generates an illusion of change in the body structure, then the body matrix maintains the homeostatic and psychological integrity of the body to conform with the changed body. Our current results suggest the intriguing possibility that this even extends to perceptual processing and implicit attitudes and behaviours (Kilteni et al., 2013). There is further evidence for this in recent experiments where light-skinned people were induced to experience the illusion of ownership over a black rubber arm (Maister et al., 2013b) and over a dark-skinned virtual body (Peck et al., 2013). In both cases, there was a reduction in implicit racial bias associated only with the illusion of ownership of a dark-skinned body. These experiments provide evidence supporting the idea that it is not only prior experience of a body type that influences the extent of perceptual, attitudinal, and behavioural correlates of the body ownership illusion. However, more work is required in this regard, including brain-imaging studies, to help to understand the extent of cortical reorganization under body illusions that result in such changes.

The experiments presented in this report confirm that altered bodily self-representation can have a spontaneous and significant influence on aspects of perception and behaviour. It has been shown that IVR supports global scaling of sizes, where the brain automatically adjusts for the overall size of one's avatar, which is in line with past studies (van der Hoort et al., 2011). Most importantly, our system can reproduce the experience of the world "as a child experiences it," and not only as a simple linear transformation of size. Furthermore, a demonstration that avatars can change perception of our selves has great potential in various applications and for the interaction between participants. Finally, and importantly, it is worth pointing out that as we choose our self-representations in virtual reality settings, our behaviours may be shaped accordingly (Yee and Bailenson, 2007); it is therefore not only the influence that users exert on avatars, but essentially the impact of avatars on their users and how they can shape their attitudes.

Chapter 5

Virtual Embodiment in a Black Body Leads to a Sustained Reduction in Implicit Racial Bias

In Chapter 4 we showed how changing the type of body through multisensory integration, in the absence of any important social aspect, can lead to attitudinal and perceptual changes for the embodied individual. Specifically, we showed how embodiment in a virtual child body leads to overestimation of object sizes, and implicit associations of the self with child-like attributes. In this Chapter we introduce an additional example of embodiment over a different type of body, and we present how illusory body ownership can lead to lasting changes in implicit biases. This addresses the second hypothesis of this thesis: *Illusory ownership over a body of different race can lead to a sustained reduction in implicit racial bias.* This study was published in the journal *Frontiers in Human Neuroscience* (Banakou et al., 2016).

5.1 Introduction

There are many interventions discussed in the literature designed to have the effect of reducing implicit racial bias of "White" people toward "Black" people. Seventeen interventions were described and evaluated by Lai et al. (2014) of which the most successful were those that involved examples that ran against stereotypical behaviour, and the least effective involved perspective taking or invoking egalitarian values. However, in a subsequent study, it was found that no intervention was successful in inducing a sustained reduction of racial bias whether for hours or days (Lai et al., 2016). In this study we show how the technique of virtual embodiment, where a light-skinned person's body is visually substituted in IVR by a life-sized spatially coincident dark-skinned virtual body, results in a reduction in implicit bias that lasts at least one week. The results provide a replication of earlier results described by Peck et al. (2013), and extend those results by considering whether the reduction of bias is sustained, and whether there is any effect of multiple exposures.

In Chapter 2 we discussed how when people are virtually embodied or represented online with a virtual body different to their own then they exhibit behaviours associated with attributes pertaining to that body. Although, as we saw earlier, the majority of these studies are based on Self-Perception Theory (Bam, 1972), and stereotyping (Yee and Bailenson, 2007), in Chapter 4 we showed that perceptual and implicit attitude changes occur even when participants are embodied in a virtual body in a neutral situation—i.e., where there is no social context. This was in a context where the only task of participants was to look at themselves (seeing their virtual body) both directly looking down toward their real body, and in the virtual mirror.

As discussed in Chapter 4, it is possible that in the case of child embodiment the brain relies on autobiographical memory—since all the adults of course had once been children. In order to test this we turned to another example of embodiment where it would not be possible for autobiographical memory to be a factor. Peck et al. (2013) embodied White participants in a Black body. This was a between groups experiment (n = 15 per group), where White (female) participants were embodied in a Black body, a White body, a Purple body, or No Body. Participants saw their virtual body either directly by looking down toward themselves and in a virtual mirror. In the case of the "No body" condition participants saw a reflected Black body at the correct place geometrically in the mirror, but it moved asynchronously with their movements. In all other cases there was visuomotor synchrony. The scenario was neutral—participants spent altogether 12 min embodied in this way, in an empty room, and eventually 12 virtual characters walked by them (6 White characters and 6 Black). The characters entered their personal space as they walked by. Unlike the study of Groom et al. (2009) there was no social meaning to this that had anything in itself to do with racial bias. A racial IAT was used as the main response variable. It was administered approximately 3 days before the virtual reality exposure (preIAT) and then immediately after (postIAT). The variable of interest was dIAT = postIAT preIAT.

The levels of body ownership were equivalent for the three embodied conditions and lower for the "No body" condition. Those with the Black body showed significantly less implicit racial bias after the experiment compared to before. The inclusion of the purple body as a control showed that this was probably a racial effect rather than only being a difference or strangeness effect. This result seemed to be stunning in the sense that it was hard to believe that 12 minutes of exposure to being embodied in a Black virtual body might alter something that is as apparently ingrained as implicit racial bias. However, similar results were reported by Maister et al. (2013b) where the RHI with a black arm or white arm (control) was used.

Here we describe an experiment that takes these results further. We tested whether embodiment of White people in dark-skinned virtual body would lead to a reduction in negative implicit racial bias toward Black people, as described earlier except that we were specifically interested in whether the illusion would last at least one week after the final exposure. We were also interested in whether multiple exposures might further strengthen the reduction in racial bias. We carried out two conceptually distinct experiments that we refer to as Experiment 1 and Experiment 2 in order to address these questions.

5.2 Materials and Methods

5.2.1 Materials

The experiment was conducted in a virtual reality lab, and participants were fitted with a stereo NVIS nVisor SX111 HMD, and were also required to wear an

Optitrack full body motion capture suit to track their movements (Figure 5.1 D). Virtual models created with 3D StudioMax 2010 and Autodesk Character Generator, and the virtual environment was implemented on the Unity 3D platform (see Chapter 3 for full equipment details).

The Tai Chi animation was based on a motion captured Tai Chi animation[1], which was used as a reference to manually build the animation clips. As Tai Chimovements are challenging for beginners to perform, the continuous form of the original clip was broken down into shorter animation clips. These were triggered by the experimenter throughout the experiment. Nine short clips were used in total.

5.2.2 Experimental Design

Sixty (Experiment 1) and 30 (Experiment 2) female participants aged 18—44 years (mean age 21.9, SD = 4.45, SE = 0.47) with normal or corrected vision took part in this study. They had no prior knowledge of the experiment, and little or no prior experience of VR. Participants were recruited through posters, e-mail and word of mouth around the campus of the University of Barcelona. Preliminary checks established whether participants fitted the inclusion criteria (Caucasian only, no psychoactive medication, no mental-health disorders, no epilepsy). Participants were provided with an information sheet regarding issues such as the limits of confidentiality, right to withdraw (either during the experiment or later) etc. Written informed consent was obtained. The experimental groups were comparable across a number of variables. The age distribution of participants is shown per condition in Table 5.1. Almost all the participants were novices in computer programming. In Experiment 1 43/60 played computer video games to a moderate extent (47/60 less than twice a year) with little variation between the experimental groups. In Experiment 2, 24/30 played less than twice a year. On a scale of 1 (no experience) to 7 (extensive) previous experience of VR, the medians are at most 4 across all experimental groups, with the maximum IQR of 4. Participants were paid between 15€ and 25€ (Euros) for participating, according to the number of exposures to which they were assigned, or a pro-rata

[1] http://abranimations.com/new-mocap-tai-chi-animation/

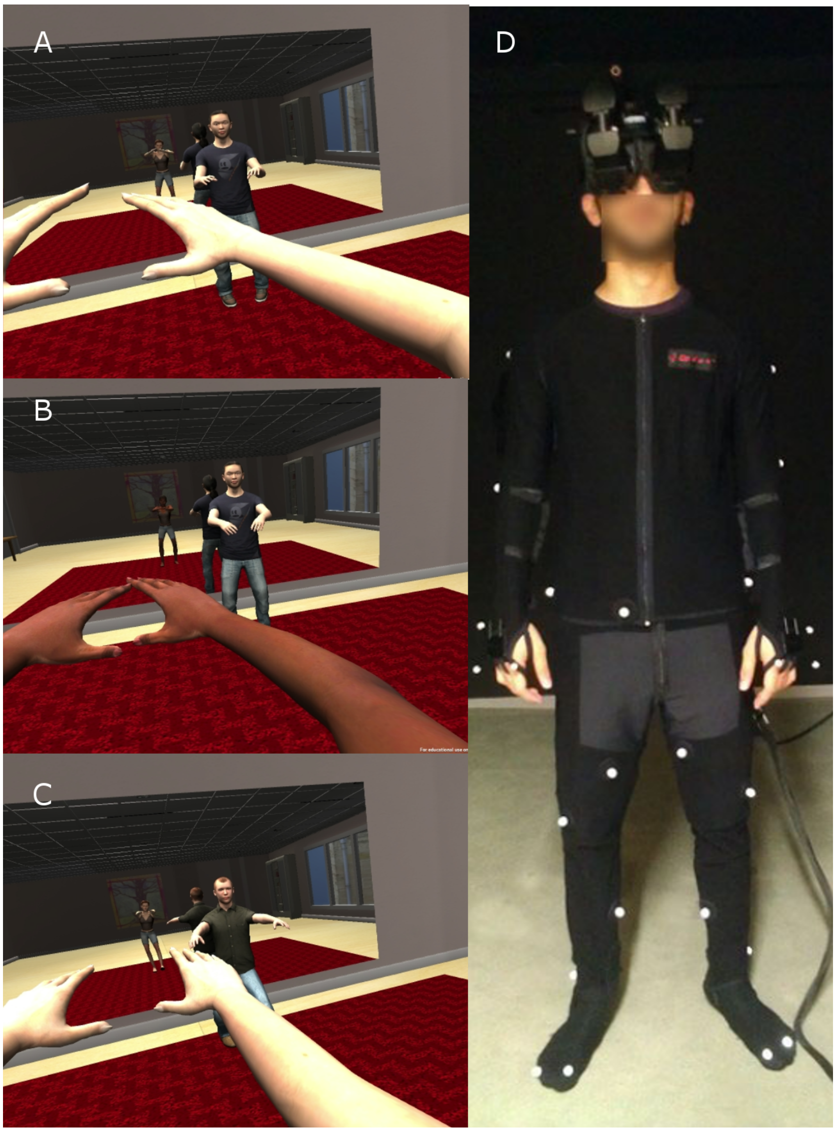

Figure 5.1: The experimental scenario, with variations in the virtual body of the participant and the teacher. (A) The participant is embodied in a White virtual body and the Teacher is Asian. (B) The participant is in a Black virtual body and the Teacher is Asian. (C) The participant is in a White virtual body and the teacher is European (Experiment 2). (D) The physical apparatus worn by participants—the HMD and the motion capture suit.

rate if they chose to withdraw (5 € at the end of the first session and the rest after the end of the last session).

The scenario was one where participants were encouraged to follow the movements of a (virtual) Tai Chi teacher. Each participant was embodied in either a Black or White body (Figures 5.1 A, B). The participants had either 1, 2, or 3 exposures, each separate by two days. In Experiment 1 the Tai Chi teacher was of Asian appearance (Figures 5.1 A, B). There was visuomotor synchrony so that through real-time motion capture the virtual body moved in synchrony and correspondence with real body movements. Each exposure consisted of a 5-minute orientation period, and then the Embodiment condition for 10 minutes.

In all conditions the participants were administered a racial IAT test one week before their first (or only) exposure (preIAT). They were administered a second IAT always one week after their final exposure (postIAT). Hence for each participant, no matter how many exposures they had, they were administered the IAT only twice—one week before their first exposure and one week after their last exposure. The response variable of interest is dIAT = postIATpreIAT.

Experiment 1 therefore followed a single factor between groups design and an independent variable. The factor was Embodiment (White, Black) indicating the type of body in which participants were embodied. The independent variable was Exposure (the number of exposures to the scenario, 1, 2, or 3). There were 10 participants per group, thus 60 in all, females.

Experiment 2 was carried out under the same conditions as the first and with another group of 30 participants. The difference was that the Teacher was of European appearance (Figure 5.1 C), and the participants (10 per cell) were always embodied as White. Hence the experimental independent variable was Exposures (1, 2, or 3 as before). The reason for this second experiment is explained in the Results section.

5.2.3 Procedures

On a first visit, participants were given the study information sheet to read and after they agreed to participate they were given a consent form to sign. Next they completed a short demographics questionnaire (i.e., age, occupation, VR,

Table 5.1: Mean±Standard Deviation of Age by experimental conditions.

Teacher Asian	**Exposures**		
Embodiment	1	2	3
Black	21.5 ± 3.54	20.3 ± 1.41	22.4 ± 2.80
White	19.9 ± 1.73	20.8 ± 2.74	21.7 ± 2.36
Teacher European	26.9 ± 9.78	21.9 ± 3.25	22.0 ± 3.80

and games experience etc.) and then completed a racial bias Implicit Association Test (IAT) (Greenwald et al., 1998, 2003) on a desktop computer, and the results were recorded (preIAT). After a period of one week they returned for their first (or only) exposure in the main experiment.

The position of all participants was controlled through Velcro strips on the floor that were used to mark where they should stand during the experiment. These positions corresponded to the centres of the physical and virtual room. Participants were instructed to turn and move their heads and bodies and walk a maximum two steps away from that area, to prevent them from hitting the walls due to the restricted laboratory space.

During the orientation phase of the experiment, participants entered a virtual room decorated with everyday furniture and a virtual mirror. The body of the participant was substituted by the Black or White virtual body, seen from 1PP (Figure 5.1). The participant's head and body movements were mapped in real time to the virtual body. They could see this body both by looking directly toward their real body, and also in the virtual mirror. A series of instructions were then given to the participants from a pre-recorded audio. First, they were instructed to perform a simple set of stretching exercises in order to explore the capabilities and real time motion of the virtual body, including movements of their arms, legs and feet. They were asked to continue performing these exercises by themselves and also look around the virtual room in all directions, where they were asked to state and describe what they saw. After this 5-minute orientation period, participants were instructed that the second virtual character they would see in the room in front of them would be a Tai Chi teacher who would perform different movements that they should follow. They They were free to choose whether they performed each movement simultaneously with the teacher or after the movement was completed. The Tai Chi training went on for 10 minutes, the same for all conditions and exposure repetitions. The reason of choosing such a setup was to engage participants for the total time required in the virtual environment, and to constantly reinforce visuomotor synchrony. The whole procedure lasted approximately 35 minutes. Finally, the HMD was removed, and they completed a questionnaire about their experience, including questions about the level of subjective body ownership (Table 5.2). Those in the multiple exposure groups returned to the laboratory for their second and third sessions two days and four days later. One week after completion of the final exposure, all participants returned to the lab in order to perform the IAT again (postIAT). Two experimental operators (females) were present throughout the whole experiment.

5.2.4 Response Variables

Racial Implicit Association Test (IAT). Implicit racial bias was calculated by administering participants an IAT (Greenwald et al., 1998), one week before their first virtual exposure, and one week after their last (or unique) virtual exposure. The IAT was completed on the same desktop computer screen both times. The racial IAT followed the standard IAT procedure (Nosek et al., 2005), where participants are required to rapidly categorise faces (White or Black) and words (positive or negative) into groups. Implicit bias is calculated from the differences in accuracy and speed between categorisations (e.g., white faces, positive words and black faces, negative words compared to the opposite groups). Higher IAT scores are interpreted as the greater implicit racial bias, as this signifies longer reaction times and greater inaccuracies in categorising black faces with positive

Table 5.2: Post Exposure Questionnaire—set of statements each on a -3 to 3 scale with -3 being strong disagreement and 3 being complete agreement.

Variable Name	**Statement**
MyBody	I felt that the virtual body I saw when looking down at myself was my own body
TwoBodies	I felt as if I had two bodies
Mirror	I felt that the virtual body I saw when looking at myself in the mirror was my own body
Features	I felt that my virtual body resembled my own (real) body in terms of shape, skin tone, or other visual features
Agency	I felt that the movements of the virtual body were caused by my own movements

words, and white faces with negative words. It has been shown that mean IAT scores tend to show slightly stronger associations corresponding to the pairings of the combined block that is completed first (Nosek et al., 2005). To control for this effect, the order of the combined blocks was counterbalanced between participants as proposed by Nosek et al. (2007).

Post-experience Questionnaire. After each exposure a 5-statement post-questionnaire was administered to assess subjective experience of participants (Table 5.2). A 7-point scale was used ranging from -3 to +3, with "0" indicating a neutral response on each question (with the scale varying from Strongly Disagree to Strongly Agree). More specifically, these questions were related to the strength of body ownership (*MyBody, Mirror*) and agency (*Agency*)—here we require that the levels of body ownership and agency are the same between the two conditions—while others served as control questions (*Features, TwoBodies*).

5.3 Results

5.3.1 Experiment 1

First we consider the questionnaire responses on body ownership and agency (Table 5.2). Figure 5.2 shows the scores on body ownership. The variable *MyBody* refers to the degree to which participants felt as if the body they saw when looking toward themselves was their body, *TwoBodies* refers to the extent to which they felt they had two bodies. *Mirror* refers to the body they saw in the mirror, and *Features* refers to the extent to which participants affirmed that the virtual body had physical features in common with themselves. *TwoBodies* is considered as a control question for *MyBody* and *Mirror*. All are on a scale from -3 to 3, where -3 means strongly disagree and+3 strongly agree. It is clear that participants tended to affirm the virtual body as their own, irrespective of skin color and irrespective of the number of exposures. On the other hand, they tended to disagree with the feeling of having two bodies. Comparing *TwoBodies* with *MyBody* and *Mirror* it can be seen that even the interquartile ranges of *TwoBodies* do not intersect those of *MyBody* and *Mirror*. *Features* is the lowest for the Black Embodiment and somewhat higher for the White Embodiment, in line with the fact that the White virtual body would have more in common with the bodies of the participants than the Black body. To test whether there is a difference in scores on *Features* between the Black and White body we carried out a mixed effects ordered logistic regression of *Features* on Embodiment×Exposure. Neither the interaction term ($P > 0.38$) nor Exposure as a main effect ($P > 0.79$) are significant, whereas eliminating Exposure we find that Embodiment has $z = 2.86$, $P = 0.004$. Hence the appearance in Figure 5.2 B that *Features* in the White Embodiment is greater than in the Black Embodiment is supported.

Agency, referring to the extent to which participants affirmed that the virtual body's movements were their own (Table 5.2), had a median of 3 in all conditions with the interquartile range, and in most cases the range, no more than 1. This reflects that the real-time motion capture system worked well, since it was in fact the case that the virtual body was programmed to move in synchrony and correlation with real body movements.

Figure 5.3 shows the plot of postIAT by preIAT across participants in both experiments. It is clear that there is one outlier (id 38), corresponding to a participant in Experiment 1 (Asian teacher) who had 2 exposures. This data point was excluded from subsequent analysis.

Recall that the racial bias IAT was measured for each person 1 week prior to their first virtual reality exposure. Lower values of IAT indicate less implicit bias against Black. For Experiment 1 preIAT has mean 0.59±0.037 (SE) (n = 59). For those in the White embodied group the postIAT mean±SE is 0.60±0.055 (n=30), and for those in the Black embodied group 0.36 ± 0.059 (n = 29). In line with previous results the Black embodiment appears to have reduced the degree of bias but not changed bias to non-bias. Figure 5.4 provides a more complete picture showing the means and standard errors of dIAT by the two factors. Recalling that the postIAT was measured one week after the final exposure what is interesting is that the results are quite similar to the single exposure experiment of Peck et al. (2013), where the postIAT was measured immediately after the exposure. In that earlier experiment we also found that the mean IAT increased for the White embodied group and decreased for the Black embodied group. We see the same here for those who had only 1 exposure. The number of exposures may have an influence, and at each exposure level the decrease in IAT appears to be greater in the Black embodied group than the White.

ANCOVA of postIAT on Embodiment × Exposures with preIAT as the covariate reveals no interaction ($P > 4$ 0.58). Removing the interaction term we find that Embodiment has $F_{(1,55)} = 9.02$, $P = 0.004$ (Partial $\eta^2 = 0.14$), Exposures has $F_{(1,55)} = 1.96$, $P = 0.17$ (Partial $\eta^2 = 0.03$). The Overall $R^2 = 0.26$. If we therefore remove Exposure then Embodiment has $F_{(1,56)} = 7.81$, $P = 0.004$ ($\eta^2 = 0.14$). The covariate preIAT of course always makes a major contribution in each of the models. For example, in the last model preIAT has $F_{(1,56)} = 7.81$, $P = 0.007$, (Partial $\eta^2 = 0.12$). Overall $R^2 = 0.24$. The Shapiro-Wilk test for normality of the residuals results in $z = 1.34$, $P = 0.09$.

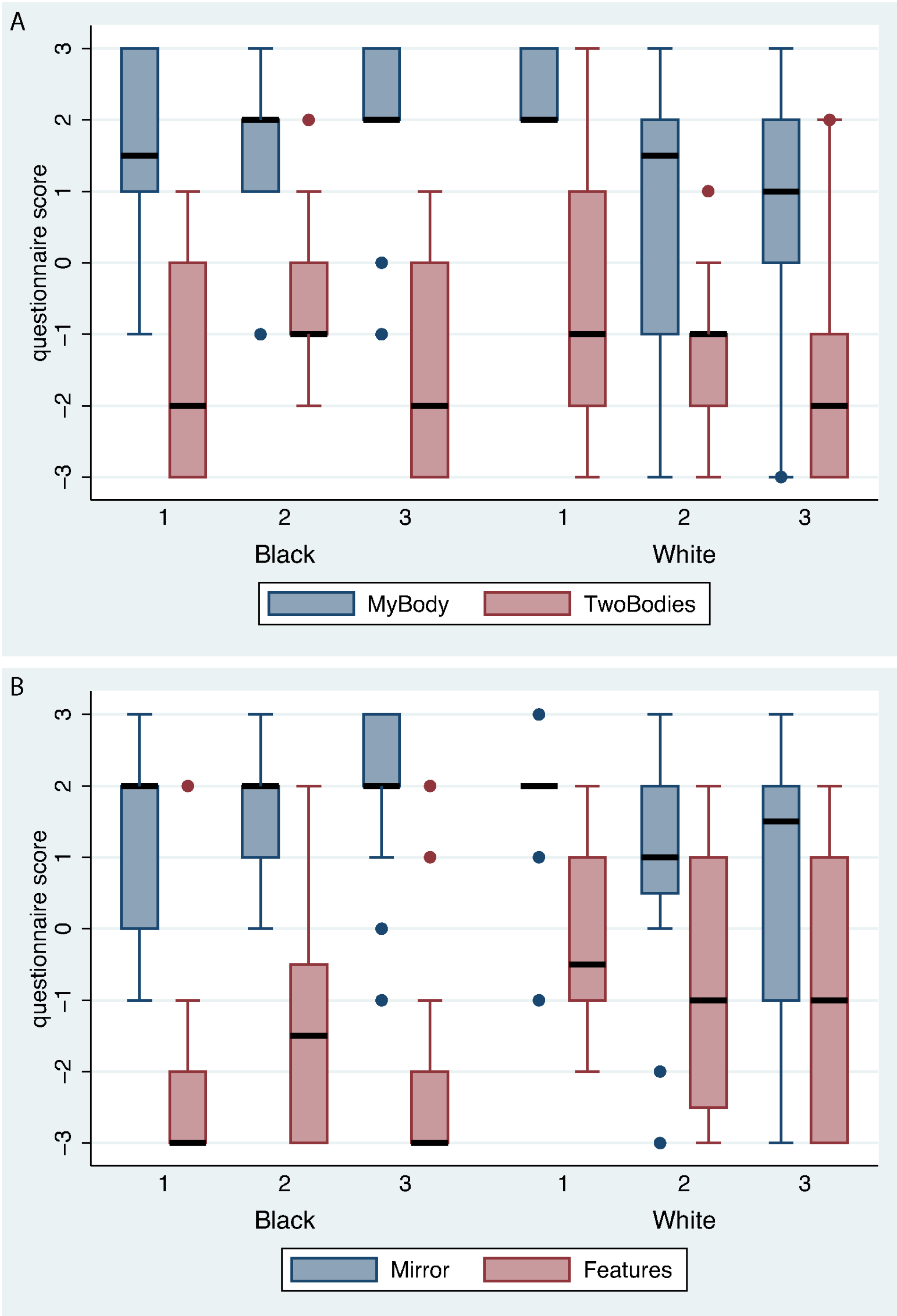

Figure 5.2: Box plots of body ownership questions by Embodiment and Exposure (A) for *MyBody* and *TwoBodies* (B) for *Mirror* and *Features*. The thick black horizontal lines are the medians, the boxes are the interquartile ranges, and the whiskers extend to ±1.5× IQR, or the range. Individual points are outliers.

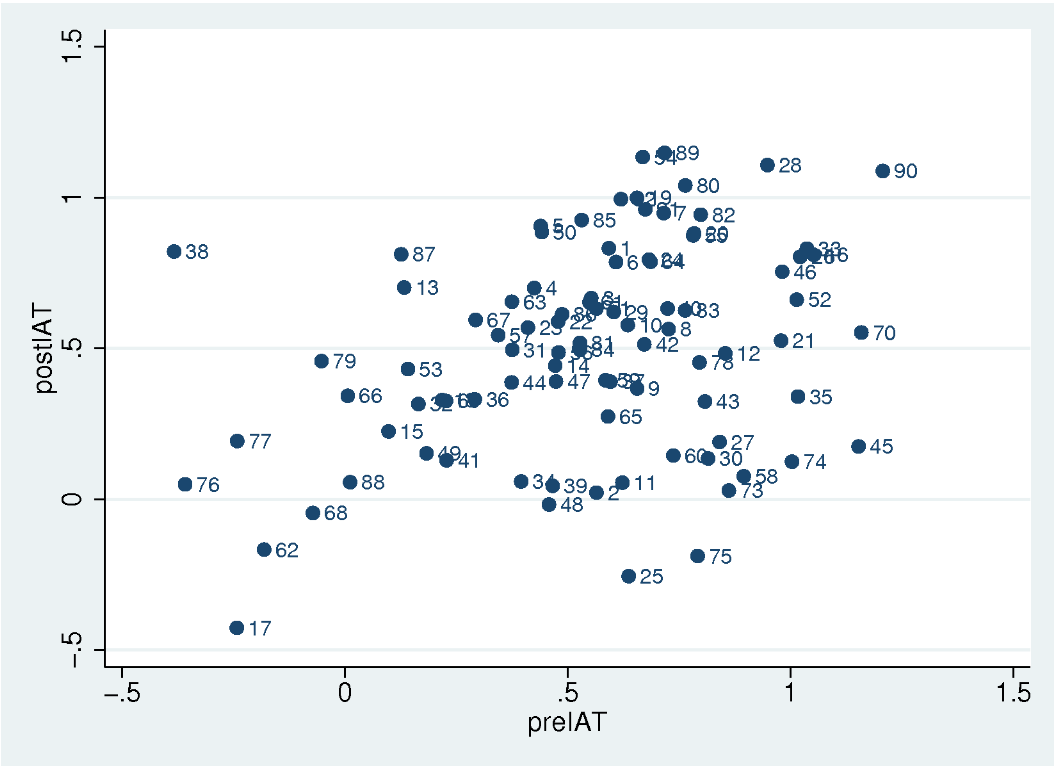

Figure 5.3: Scatter diagram of postIAT by preIAT for all participants in Experiments 1 and 2.

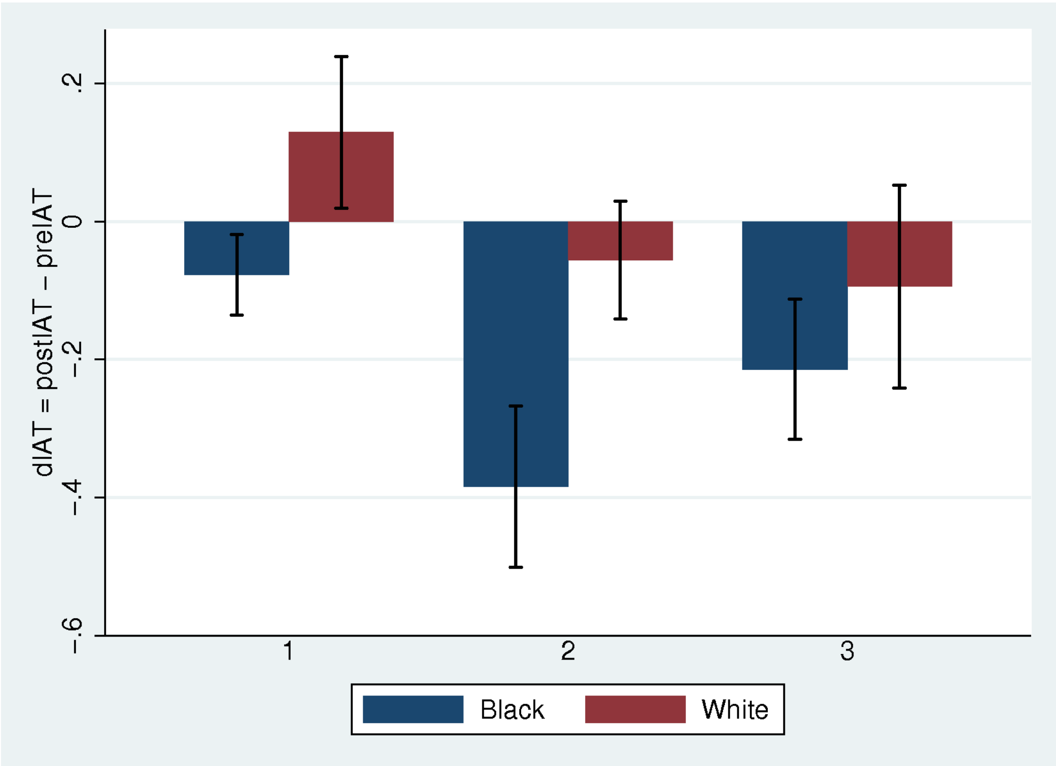

Figure 5.4: Bar chart (means and standard errors) of dIAT by Embodiment (Black,White) and Exposures (1,2,3), Experiment 1.

5.3.2 Experiment 2

We were interested in why dIAT might decrease with increasing exposures, even if slightly, also for those in the White body. This could have occurred simply because prior experience with IAT tends to diminish the likelihood of biased responses (Greenwald and Nosek, 2001) and in this experiment each participant was administered the IAT twice. However, if this were the case then we would have expected those with only one exposure to show a decreased IAT, but in fact for those in the White Embodiment group it increases. Alternatively, the effect might occur because of the contact hypothesis (Pettigrew and Tropp, 2006; Van Bavel and Cunningham, 2008), which states that positive contact with non-involved other out-group members can generalise to reduction in bias to other groups. In our case the other out-group member was the Teacher, who was of Asian appearance.

Therefore, we carried out a second experiment under the same conditions as the first and with a different group of 30 participants, except that the Teacher was of European appearance, and the participants (10 per cell) were always embodied as White. If the contact hypothesis were operating, we would expect a reduction in IAT after exposure.

The body ownership results are similar to those of Experiment 1. Figure 5.5 shows the body ownership and control questions, equivalent to Figure 5.2. Agency had a median of 3 with interquartile range 1 for all three Exposures. Figure 5.6 shows the results for dIAT combining the Embodied White with the Asian Teacher from Experiment 1 and the new results from Experiment 2. We find again that the IAT increases after the first exposure with White Embodiment, repeating the result found by (Peck et al., 2013) and in Experiment 1 above. There is a hint that indeed the Asian teacher might reduce the IAT more than the European if there is more than one exposure. However, ANCOVA of postIAT on Teacher × Exposures with preIAT as the covariate shows no interaction effect ($P > 0.68$) and no main effect of Teacher ($P > 0.86$). Eliminating the interaction term the main effect of Teacher is still not significant ($P > 0.59$) but Exposures has $P = 0.037$. Eliminating Teacher results in Exposures having significance level $P = 0.036$, $F_{(1,57)} = 4.60$, $R^2 = 0.20$. (Shapiro-Wilk test for normality of the residual errors results in z = 0.379, P = 0.35).

Since Teacher has no effect we can pool all results of both experiments together and test amongst all n = 89 participants (recall that there is one deleted observation) for the effect of Embodiment and Exposures on postIAT with preIAT as a covariate. This is shown in Figure 5.7. ANCOVA of postIAT on Embodiment $\times$ Exposures with preIAT as covariate shows no interaction effect ($P > 0.43$). Eliminating the interaction term we find that Embodiment results in $F_{(1,85)} = 9.34$, P = 0.003, Partial $\eta^2 = 0.10$. For Exposures $F_{(1,85)} = 4.51$, P = 0.036, Partial $\eta^2 = 0.05$. (The Shapiro-Wilk test for normality results in z = 1.68, P = 0.046).

5.3.3 Summary of findings

The evidence from Experiment 1 suggests that Embodiment in the Black body results in a reduction of implicit racial bias, even one week after the end of the experiment. However, the evidence for the influence of multiple exposures is more ambiguous. Figure 5.4 indicates that there may be some effect even if not statistically significant. The results from Experiment 2 support the conclusion that the Embodied Black condition does reduce implicit bias irrespective of the number of exposures. However, there is also evidence that bias also decreases with the number of exposures independently of the Embodiment factor (White or Black body). The evidence suggests that the Teacher (Asian, Caucasian) had no influence on bias.

5.4 Discussion

The study has several findings in relation to implicit racial bias. The first is that the earlier results reported by Peck et al. (2013) have been reproduced taking into account those who had only one exposure. After one exposure for those embodied in the Black virtual body the mean implicit bias against Black decreases compared to those embodied in the White body. Second, the reduction is sustained for at least one week. Third, the number of exposures may have an effect independently of type of body, a point we will return to below.

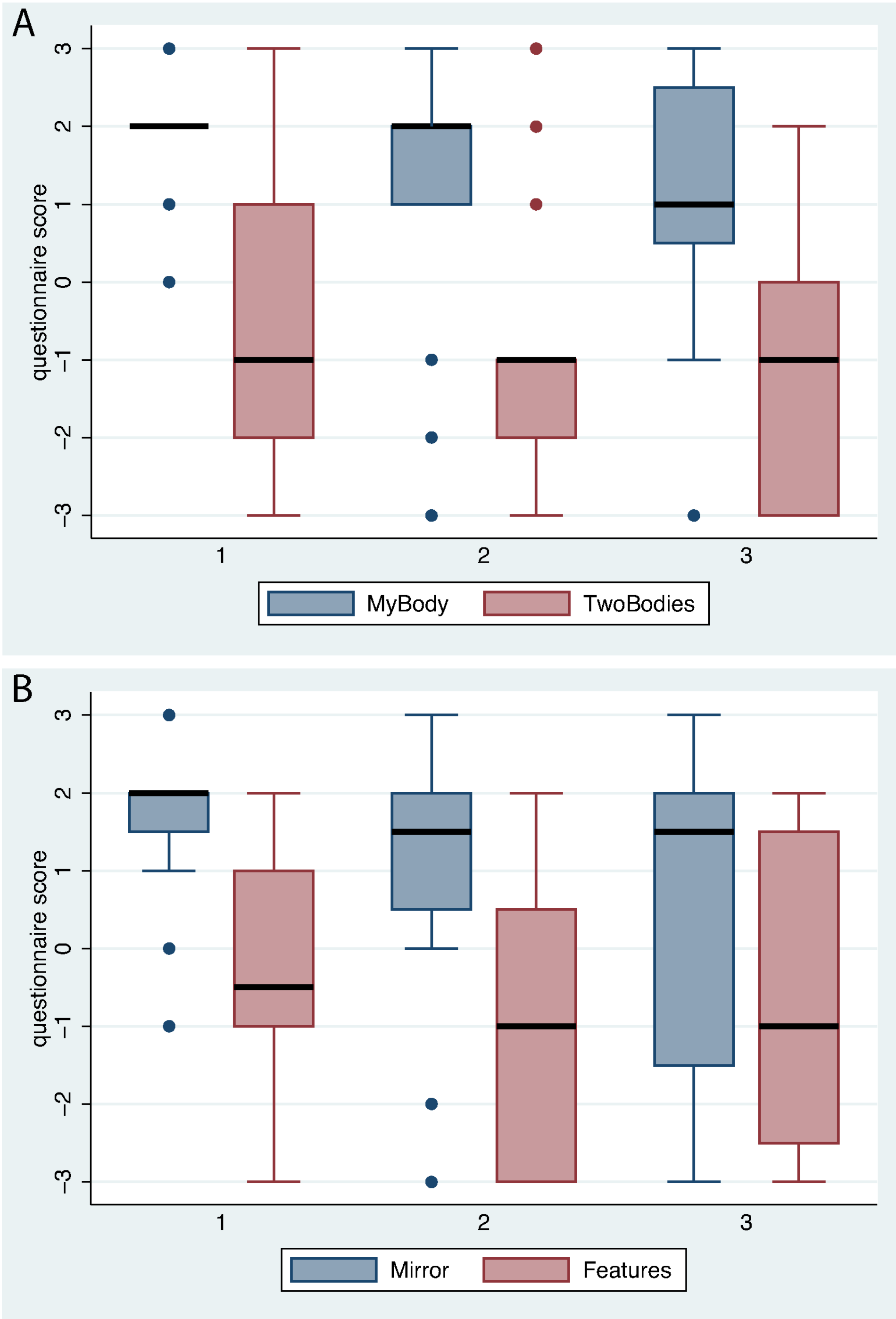

Figure 5.5: Box plots of body ownership questions by Exposure in Experiment 2 (European Caucasian Teacher) (A) for *MyBody* and *TwoBodies* (B) for *Mirror* and *Features*. The thick black horizontal lines are the medians, the boxes are the interquartile ranges, and the whiskers extend to $\pm 1.5 \times$ IQR. Individual points are outliers.

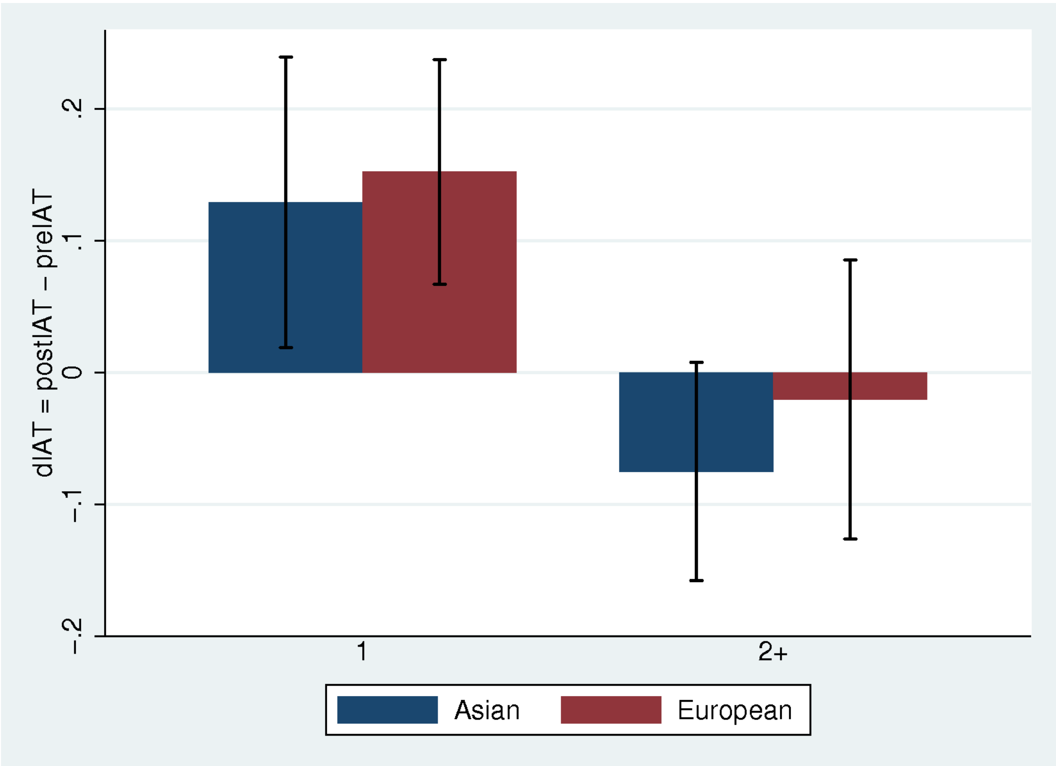

Figure 5.6: Bar chart showing means and SEs of dIAT by Teacher and Exposures.

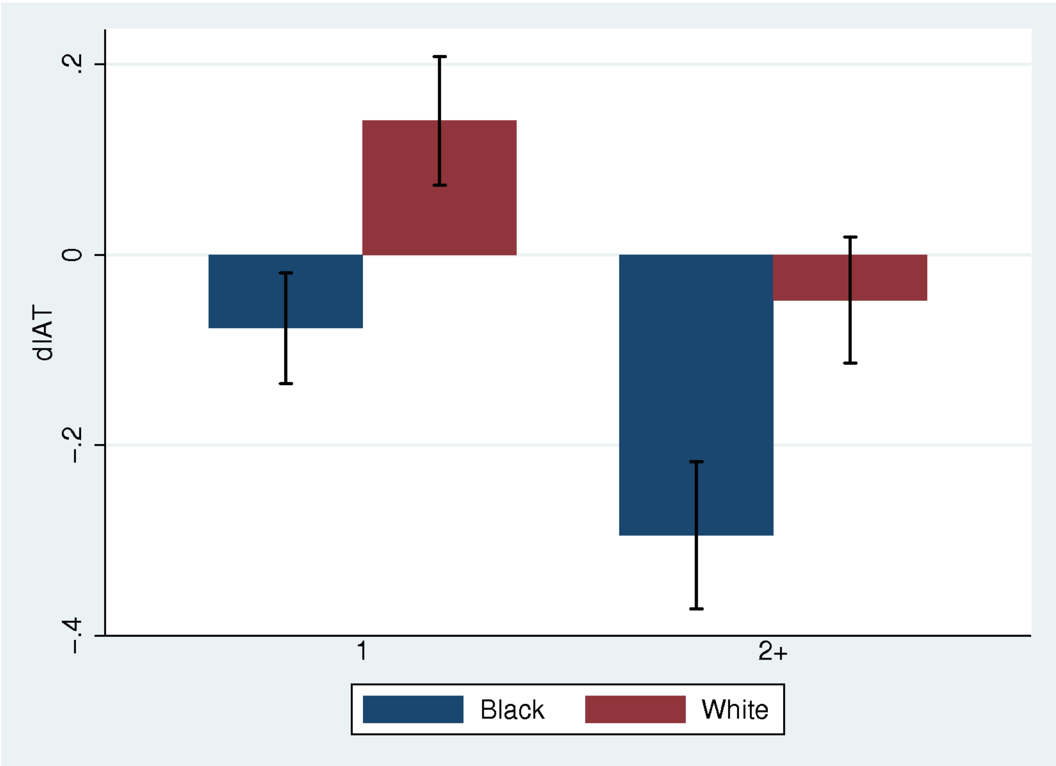

Figure 5.7: Bar chart showing means and SEs of dIAT for all observations (n = 89) by Embodiment and Exposures.

It is important to note that the setting of the experiment was a benign one—a Teacher showing the participants various Tai Chi movements. In contrast, the finding of Groom et al. (2009) stands out as the one case where embodiment of White participants in a Black virtual body resulted in an increase in implicit racial bias. Although there are many technical differences between the setup in that experiment and ours, as detailed by Peck et al. (2013), and there was no notion of body ownership, the fundamental difference is that the Groom study included a negative social setting (a job interview) that in itself was related to racial bias. In the present study, unlike that of Peck et al. (2013) there was also a social setting, but it was one unrelated to the issue of racial bias.

Amongst the least successful interventions for the reduction of bias discussed by Lai et al. (2014) were those that employed perspective taking. Superficially perspective taking is, amongst the methods considered, the closest to the technique of embodiment. Participants were required to imagine that they were the person shown in a picture and describe how they might experience an event as that person, their emotions, thoughts and feelings, based on the method described by Ames et al. (2008). Thus, with the subject of the experiment being White and the person shown in the picture being Black, this would be like an imaginal equivalent of embodiment. However, the critical point is that it is imaginal, whereas virtual embodiment is direct, leading to a perceptual illusion of body ownership. Moreover, in the case of virtual embodiment participants are not required to imagine anything or think about how it would be to be that person, they simply see the virtual body that moves in correspondence with their own movements, both by looking toward it and in a mirror. Therefore, participants only have to experience, rather than just imagine. Moreover, unlike the studies reported by Lai et al. (2016), the evidence suggests that the embodiment intervention results in a sustained reduction of implicit bias that lasts at least one week. Next we discuss this finding and give some possible explanations.

One way to think about an IAT is that it samples for any individual their statistical associations between categories. If over a long period a person has been subject to information that X is associated with Y but not Z and they are given X with two cues Y and Z there is a higher probability that they will choose Y at a greater speed than they would choose Z in a forced choice. A racial bias

IAT ultimately tests the strength of such associations. We contend that in most Western countries there has been a greater preponderance in the media of negative associations with the concept of "Black" people compared to "White", and the racial IAT reflects this in spite of the explicit attitudes of people, so that there is a dissociation between the implicit and explicit bias (Greenwald, 2006). Indeed in the explicit racial attitudes test in Peck et al. (2013) there was no evidence of racial bias, even though the pre-experiment IAT showed implicit bias. However, when it comes to discriminatory behaviour the IAT results have better predictive power for social interaction than explicit measures (Greenwald et al., 2009)—for example, with respect to eye contact, proxemics, and hiring practice (Ziegert and Hanges, 2005; Rooth, 2010). Even though the use and interpretation of the IAT may be controversial there is significant evidence of its explanatory and predictive power (Jost et al., 2009).

Now based on this model of how the IAT may work we consider how it can be possible that relatively short exposures of embodiment in a Black virtual body can impact and reduce implicit bias. One answer may be that body ownership and agency over a virtual body is more than a superficial illusion, that it goes beyond the perceptual to influence cognitive processing. In Chapter 4 we argued that a fundamental mechanism may be through the postulated "cortical body matrix" (Moseley et al., 2012), that maintains a multi-sensory representation of the space immediately around the body in a body-centred reference frame. The system is responsible for homeostatic regulation of the body, and for dynamically reconstructing the body representation moment to moment based on current multisensory information. Moreover, we propose that it also maintains an overall consistency between the multifaceted aspects of self (personality, attitudes, behaviours) and the body representation. In other words, our suggestion is that when the body changes not only are there updates to the multisensory representation of peripersonal space but also there are corresponding psychological updates. For example, as we presented earlier, when adults are embodied in a child body not only do they overestimate object sizes but they self-identify more with child-like attributes in an IAT classifying self with adult or child-like attributes. We can view IAT changes as direct evidence of this idea, that changing the body apparently leads to changes in implicit attitudes. This is not a process whereby participants in any way believe that their body has changed, nor might they explicitly say that their attitude is now different, but it is a process that occurs below the threshold of consciousness. We can say that as well as body ownership over a different body leading to changes in implicit attitudes, the documented changes in implicit attitudes are a very strong signal that in fact there has been a change in body ownership.

As we argued the IAT is simply a statistical measure of association between categories for any individual, for example, based on a lifetime of statistical associations from the social environment. We can think of this as there being a current joint probability distribution over the sets of categories, and the IAT is based on sampling this distribution. Now thinking of this in Bayesian terms the process of embodiment, where e.g., the White person now has a Black body, provides a strongly weighted piece of new evidence that leads to an update of this probability distribution. The vast amount of statistical evidence that made up the probability distribution is for most people based on impersonal evidence. It is just picked up from everyday commentary, for example, in the media. Now though there is a new piece of "evidence" of critical importance—"I" have a Black skin, and "I" in turn carries with it a whole set of associations with the positively/negatively valenced categories that are likely to be very different from the associations with the out-group. This leads to a new probability distribution—as if the new embodiment information disrupts the previous associations between categories. The one piece of new evidence is a critical one—since it is about the self. Hence it could be argued that the changes in IAT are produced by a disruption of the standard associations between "Black" and "negative"-based on the new observation that "I can be Black". In the terminology of the opening paragraph of this section X(Black) is typically associated with Y (a set of negative attributes) but not Z (a set of positive attributes), so that in rapid sampling of associations with X there is higher probability of choosing elements from Y instead of Z. However, the embodiment of Self as Black can change the associations with X because X has now been identified with Self, which in turn will have its own distribution of probabilities over elements in Y and Z. Hence sampling the associations with X after embodiment is, in this explanation, likely to lead to a different outcome than prior to embodiment. However, this argument relies on the participant being more likely to have positive (Z) than negative (Y) associations with Self. This leads to the testable hypothesis that the reduction in IAT should be more likely to occur for individuals with higher self-esteem than those with lower self-esteem. We do not have such data in this experimental study, but this is left as further work as a way to test this model.

From our current results it seems that just one exposure is already sufficient to disrupt the probability distribution in this model. This argument is similar to that of Maister et al. (2015): that similarity between appearance of the self (as transformed during body ownership) and the out-group results in the disruption of associations between the out-group and negative valence items, and substituted by positive associations with the self.

Treating the IAT as measuring associations though is only one way (even if the dominant one) for understanding how this measure works. Rothermund and Wentura (2004) introduced an alternate figure-ground explanation, where the most salient aspects of the target tend to be associated with the most salient attributes, independently of whether there are psychological associations between the two categories. For example, suppose the target categories are the musical instruments sitars and pianos, and the attributes are words with positive and negative valence. The explanation supposes that sitars are more salient, being the more unusual in most countries, appearing as a figure against the background of the more common pianos. Similarly, unpleasant words stand out more against the background of pleasant or neutral words. Hence subjects find it easier to quickly associate two salient categories together, even though there may be no intrinsic psychological association between sitars and negative words. In a series of experiments Rothermund and Wentura (2004) provided strong evidence that this explanation is viable—although the two different explanations, associative and figure-ground, are not mutually exclusive.

In our experiment it could be argued that the racial categorisation “Black” is more salient than “White”, and therefore is more likely to be associated with salient negative attributes compared to positive. In this explanation embodiment of a White person as Black changes the ground, so that Black is no longer salient. However, this seems unlikely as an explanation for these particular results. Participants had short embodiment exposures and otherwise during the time of the experimental period of course lived their normal lives in society where “Black” would be more salient than “White”. Also we would expect that more exposures as Black might make “Black” less salient, but the number of exposures operated independently of the type of embodiment. However, in the associations based explanation a single embodiment exposure as “Black” in itself provides evidence “I can be Black” and thus disrupt associations between positively/negatively valenced attributes (since these are now confounded with associations that apply to the self).

The results suggest that the number of exposures may be associated with a decrease in implicit bias irrespective of the type of embodiment. The explanation that this may be due to the contact hypothesis was not borne out by Experiment 2. Apart from simply being in VR the only other invariant across the two embodiment groups was that all practised Tai Chi movements as part of the experiment. Tai Chi has been shown to have positive psychological benefits including a reduction of stress and anxiety, and more generally a number of positive health advantages—see the meta studies by Sandlund and Norlander (2000) and Jahnke et al. (2010). As noted by Sandlund and Norlander (2000) Tai Chi has elements in common with mindfulness meditation. Moreover, as reported by Lueke and Gibson (2015) mindfulness meditation reduces implicit racial and age bias. In that study participants listened to a 10 min mindfulness or a control recording. Those in the mindfulness group showed statistically significant but moderately less implicit bias than the control group. Similarly, and with more striking results Lueke and Gibson (2016) showed that a group that received a brief mindfulness meditation exposure exhibited less behavioural racial bias than control groups. Also in the context of prejudice against persons with disabilities, Schimchowitsch and Ohmer (2016) also showed moderate effects in the reduction of bias in a group that practised yoga and mediation compared to a control group that did not. In our study the greater the number of exposures that participants had the greater their exposure to Tai Chi, with each TaiChi session lasting for 10 minutes. Of course we cannot know whether or how much they entered any kind of meditative state, or whether they thought any more about their experience outside of the experimental sessions. It remains an intriguing possibility though that simply their exposure to TaiChi may have influence their level of implicit bias. We leave this as an open question for further research.

Overall our findings are that: first, body ownership over a differently raced body has again been shown to occur, suggesting that ownership is not contingent on the appearance of the virtual body. Second, there is further evidence that embodiment of White people in a dark-skinned virtual body does diminish their implicit racial bias. Third, this diminution lasts at least one week after the end of the exposure. Finally, one exposure is sufficient to observe this effect. Further replication studies would be needed to further support the last point. Moreover, it is important to note that the experiment involved only female participants. While there is some evidence that there is greater implicit racial bias amongst females compared to males (but greater explicit bias of males compared to females) (Ekehammar et al., 2003), further replication studies should address this issue.

Chapter 6

Illusory self-attribution of Speaking

In Chapter 2 we discussed how the sense of agency can be modulated by various mechanisms, and that action attribution to the self can occur even without actual action execution. In this chapter we extend this research by providing evidence that it is possible to attribute illusory agency with respect to a speaking action that was carried out by the participants' virtual body, but not themselves. This set of experiments addresses Hypothesis 3: *Healthy adults can experience illusory agency over speaking through embodiment in a talking virtual body.* We present our findings in terms of current theories of agency, and we discuss the importance of embodiment techniques in eliciting illusory agency experiences.

6.1 Introduction

It has been demonstrated that in spite of the seeming constancy of our body that normally changes slowly through time, nevertheless the brain is extremely plastic in its body representation. We have shown that the illusion of body ownership can be obtained over a whole virtual body, even over that of a different age–a child–as discussed in Chapter 4. There also seems that 1PP and synchronous visuomotor correlations between the real and seen body movements play a critical role in the induction of the illusion, something that has been replicated by many studies.

Furthermore, we presented evidence suggesting that such illusions and the type of body appears to carry with it physiological, perceptual, and even deep-seated attitudinal correlates.

Following on from these findings the fundamental question in the present work is whether the factors that lead to a strong illusion of body ownership with respect to a virtual body would also lead to illusory agency over a specific action that was definitely not caused by participants, and where current explanations of agency apparently do not apply. As discussed in Chapter 2, "Agency" refers to the sensation of authorship of actions. Under normal circumstances humans are able to trivially distinguish their own motor actions from those of other people; we know when we are the cause of our own volitional motor actions and take responsibility for the effects. As we saw earlier, this sensation of agency has been the subject of significant study, and self-attribution of actions has been explained by a combination of feed-forward processing (Blakemore and Frith, 2003), no other explanation for the result that is readily available (Wegner, 2002), and a requirement for tight temporal binding between the intention to carry out the action and the resulting sensory consequences (Haggard et al., 2002). Here we show that it is possible to generate an illusion of agency when apparently *(i)* there is no possibility of there having been feed-forward prediction, *(ii)* there is no thought or cause preceding the effect, and *(iii)* there is an obvious alternative explanation for the observed action.

Our general hypothesis was that a strong illusion of ownership over a virtual body would map over to illusory agency with respect to an action—speaking—not executed by the participant, but only carried out by that virtual body. To study this, we exploited an IVR system using a wide FoV stereo head-tracked HMD with headphones, and full-body motion-capture suit (Figure 6.1 A). Participants experienced a life-sized virtual body from a 1PP that was spatially coincident with and therefore substituted their own body. They saw the virtual body (or avatar) in a virtual mirror and when directly looking toward themselves (Figure 6.1 B and C). During their experience, the avatar uttered a set of pre-recorded words. The voice that each participant heard had a higher fundamental frequency (FF) than his or her real voice. Our specific hypothesis was that the factors that would lead to a high level of body ownership would also result in the participants affirming that they had said the words, thus demonstrating illusory agency. Further evidence for such agency would be whether they would exhibit a shift in the FF of their voice toward that of the stimulus voice in their subsequent real utterances of the same words (Zheng et al., 2011; Burnett et al., 1998). In order to study whether illusory agency can simply be a result of body ownership or is due to body ownership plus a generalisation of agency over the body, we carried out a further experiment. We induced body ownership over a virtual body seen as before but where there was no body movement except for head movement. Instead there was visuotactile synchrony—i.e., the body was seen to be tapped while the participant felt corresponding tactile sensations (synchronously or asynchronously). The hypothesis was that if the experience of illusory agency were obtained as a result of a generalisation of actual agency (visuomotor synchrony), then the change in FF should not occur here, even if there might still be strong body ownership over the virtual body. We describe two distinct experiments that we refer to as Experiment 1 and Experiment 2 in order to address these hypotheses.

6.2 Materials and Methods

6.2.1 Materials

The experiments were conducted in a VR laboratory, where participants were fitted with a stereo NVIS nVisor SX111 HMD (Figure 6.1 A). For Experiment 1 participants were also required to wear an OptiTrack full-body motion-capture suit to track their movements (Figure 6.1 A). For Experiment 2 vibrotactile stimulation was delivered via mechanical vibrators connected to a wired Arduino micro-controller, which was attached to participants' hands and abdomen respectively (Figure 6.2 B). The location of the vibrators was adjusted for each participant in order to match the contact points of the virtual ball's trajectory with the virtual body counterparts. The tapping and vibrations alternated among the different locations on the real and virtual bodies in random order, varying in frequency, intensity and time intervals. An additional vibrator used to simulate vocal motor control in both experiments, and was adjusted for each one of them

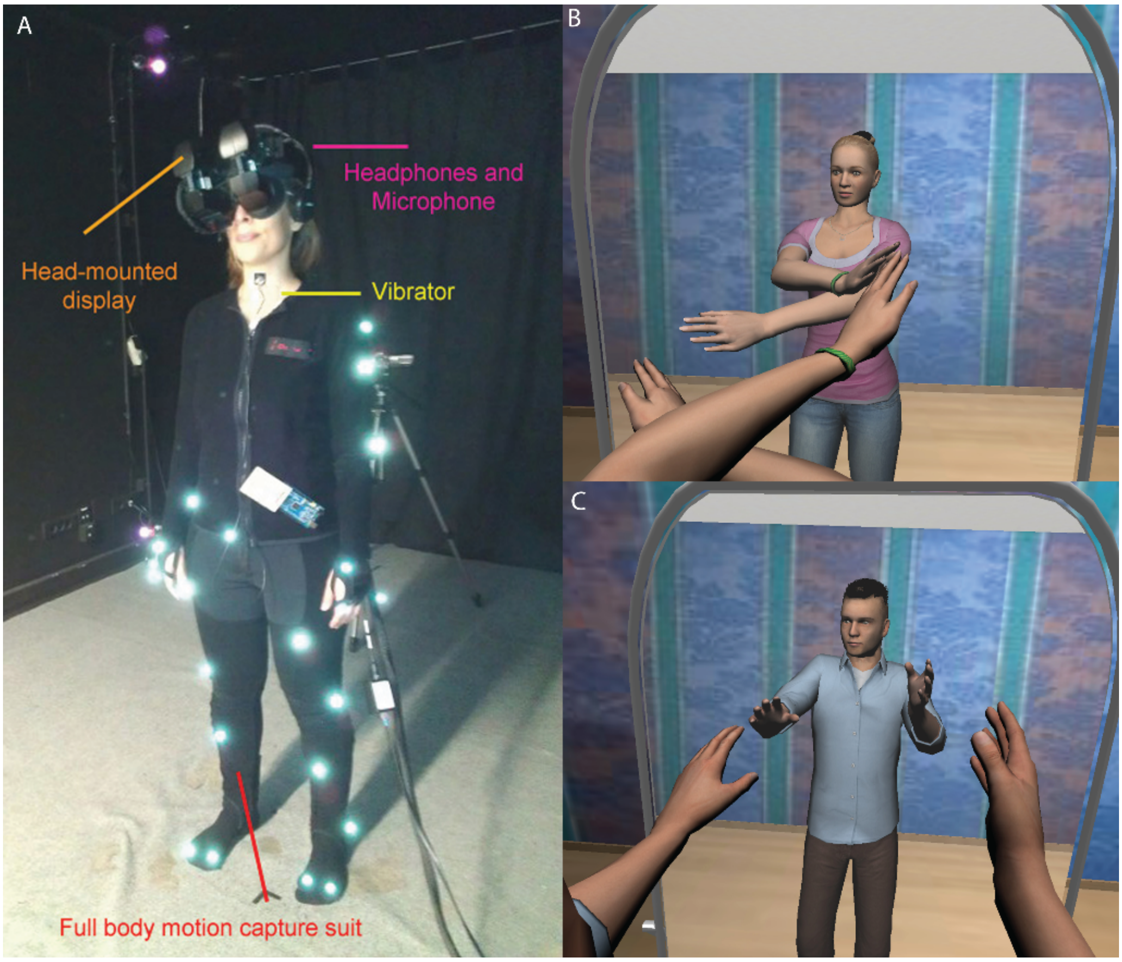

Figure 6.1: The experimental setup for Experiment 1. The body of the participant was substituted by a gender-matched virtual body, viewed from 1PP, onto which body and head movements were mapped in real time for the sync condition. The body could also be seen as reflected in a virtual mirror. (A) Participants wore an HMD with earphones, a full-body motion-capture suit, and a vibrotactile device. (B) The female virtual body. (C) The male virtual body. B and C illustrate that the virtual body (here, the arms) could be seen directly when looking toward their own body, and also in the virtual mirror.

Figure 6.2: The experimental setup for Experiment 2. The body of the participant was substituted by a gender-matched virtual body, viewed from 1PP, onto which visuotactile stimulation was applied with the help of mechanical vibrators. The body could also be seen as reflected in a virtual mirror. (A) The collocated male VB showing in red lines the contact points of the virtual ball's trajectory with the virtual body counterparts. The tapping alternated among the three locations in random order. (B) Participant wore an HMD with a headset equipped with headphones and a microphone, and a set of mechanical vibrators attached to their hands and abdomen. (C) The male VB seen through the HMD from 1PP directly when looking toward it, and also in the virtual mirror when the virtual ball collided with the abdomen, and (D) with the left hand.

on the thyroid cartilage. It was activated for a short time interval (in milliseconds), depending on the length of each syllable, with a maximum intensity of 9,600 rpm. The time delay of the vibrator activation corresponds to the communication time between the machine running the IVR software and is negligible (¡10 ms). To assure that all participants felt the vibrational feedback correctly, we asked them to describe it before they were debriefed. They were also fitted with a wireless headset including speakers and a noise-cancellation microphone (Asus; HS-1000W). See Chapter 3 for full equipment details.

Virtual models were created in 3D Studio Max 2010 and Motion Builder 2012 using RocketBox avatar Library. The virtual environment was implemented using the XVR software platform (Tecchia et al., 2010) and the virtual body was rendered using the HALCA hardware accelerated avatar library (Gillies and Spanlang, 2010). When participants looked at their avatar's eyes in the virtual mirror but turned their head, the virtual eyes were programmed to always be looking back toward the eyes of the participants, as in a real mirror, rather than remaining fixed, using the method described in Borland et al. (2013).

6.2.2 Experimental Design

Fourty-four (Experiment 1) and 36 (Experiment 2) adult male and female healthy participants with correct or corrected vision who were recruited by advertising and email around the campus of University of Barcelona. Almost all of them were students, researchers or employees of the university with no prior knowledge of the experiment; most of them had no prior experience of our virtual reality system. They were all native Spanish speakers from Spain. All participants completed a demographic questionnaire before the experiment. Each one received 5 € for participating. Three other participants had been excluded from the study, two due to glottal fry and one due to audio failure. All participants gave their written informed consent before participating in the experiment. The study was performed according to institutional ethics and national standards for the protection of human participants.

Experiment 1 was conducted as a between-groups design, with two binary factors referred to as visuomotor (VM) (async and sync) and vibrations (Voff and Von). In the sync condition the movements of the avatar were synchronised in real time with the actual body movements of the participant. In the async condition the avatar movements were generated from a pre-recorded animation and independent of those of the participant. Experiment 2 followed a between-groups design, with a single binary factor referred to as visuotactile (VT) (async, sync). Synchronous or asynchronous passive vibrotactile feedback was applied on the hands and abdomen of the participants with the help of mechanical vibrators. For the synchronous visuotactile stimulation, the time delay of the vibrator activation with respect to the virtual collision corresponds to the communication time between the machine running the IVR software and the mechanical vibrators (<10ms). For the asynchronous visuotactile stimulation, the vibrators were implemented to be randomly activated so that during the visualisation of the virtual tapping, touch and collisions were not correlated.

Based on past results, and also presented in Chapter 4, we expected that both VM and VT sync conditions would result in a substantially greater illusion of body ownership over the virtual body than the async conditions (Peck et al., 2013; Banakou et al., 2013; Kalckert and Ehrsson, 2012; Sanchez-Vives et al., 2010; Kokkinara and Slater, 2014). The hypothesis was the same in terms of agency over the virtual body for the visuomotor synchronous condition, but not necessarily the case for the visuotactile synchronous condition (Kalckert and Ehrsson, 2014a). The vibrations factor (Experiment 1) was designed to enhance the sense of speaking by applying vibratory feedback on the thyroid cartilage (Figure 6.1 A) to coincide with the period that the embodied avatar was speaking (Von) or no vibratory feedback (Voff). The vibrations were synchronised with avatar lip movements that were themselves synchronised with the word being said. Participants were sequentially allocated to one of the cells of the factorial design in order of attendance to the experiment, with the final numbers as shown in Table 6.1. There was approximately equal distribution of participants in the cells of the experimental design and gender balance.

Table 6.1: Mean and Standard Deviation of Age by experimental conditions.

	Vibrations	
Visuomotor (VM)	**Off**	**On**
	Async	
Male (n)	6	5
Mean ± SD Age	22±2.6	21±2.9
Female (n)	4	7
Mean ± SD Age	22±1.7	27±8.3
	Sync	
Male (n)	5	5
Mean ± SD Age	23±3.7	20±2.2
Female (n)	6	6
Mean ± SD Age	23±7.1	23±4.0
Visuotactile (VT)		
	Async	
Male (n)	9	
Mean ± SD Age	22.4±3.17	
Female (n)	9	
Mean ± SD Age	21.2±3.19	
	Sync	
Male	9	
Mean ± SD Age	22.6±4.9	
Female	9	
Mean ± SD Age	22.3±3	

6.2.3 Procedures

Before the experiment, utterances of the nine target words (casa, mes, sopa, vela, paz, voz, vaso, mesa, and copa) were recorded from two native Spanish speakers, one male and one female. The target words were randomly selected as one– and two–syllable Spanish words of consonant–vowel–consonant form. The individuals recruited for their stimulus voices were chosen because the FF of their voices was higher than that of the average male and female speaker of Spanish (in Spain). It is reported that the FF of an average Spanish-speaking female is approximately between 175 and 200 Hz and that of a male around 110 Hz (García et al., 2000).

For the utterances used in this study the FF of each recorded word for both the female and male voices was further pitch modulated by applying a +10% change in the pitch, resulting in the following frequencies: for the female voice, casa = 236 Hz, mes = 231 Hz, sopa = 256 Hz, vela = 220 Hz, paz = 221 Hz, voz = 218 Hz, vaso = 236 Hz, mesa = 231 Hz, and copa = 234 Hz; and for the male voice, casa = 128 Hz, mes = 128 Hz, sopa = 124 Hz, vela = 124 Hz, paz = 118 Hz, voz = 117 Hz, vaso = 122 Hz, mesa = 123 Hz, and copa = 124 Hz. The pitch modulation of the stimulus voice was implemented using the audio editing software Audacity[1] (Version 2.0.3 for Windows 7).

Participants attended the experiment at prearranged times. Upon arriving, they were given an information sheet to read (see Appendix C), and after they agreed to continue with the experiment, they were given a consent form to sign. The experiment was approved by the Comissió Bioètica of Universitat de Barcelona. Before the experiment started, participants were seated in front of a laptop computer (Dell Inspiron Q15r) wearing a wireless headset fitted with speakers and a noise–cancellation microphone (Asus HS1000-W). They were instructed to read out in a clear voice nine target words displayed in sequence. Each word was recorded five times, in random order, using audio editing software, and used as baseline data (BaseF0) for later analysis. The same headset was used during the experimental conditions to both stream the auditory stimulus and record the post-experiment F0 of the participant. The stimulus voice was recorded using the same recording device (Asus HS1000-W microphone) and was played back during the experiment in stereo.

Next participants were fitted with an HMD, a body–tracking suit, a pair of headphones, and a microphone. The view seen through the HMD was calibrated using the method described in Grechkin et al. (2010). When the experiment started, participants were in a virtual room that included a virtual mirror. The body of the participant was substituted by a gender–matched virtual body, seen from the 1PP. In Experiment , the participant's head and body movements were mapped in real time to the virtual body in the sync condition, but were based on a pre-recorded animation for the async condition. However, participants always saw the scene based on correct head tracking. Participants could see the body both by

[1] http://audacityteam.org/

looking directly toward their real body and also in the virtual mirror (Figure 6.1 B and C). They were asked to perform a simple set of stretching exercises that had previously been demonstrated to them by the experimenter (thus experiencing either sync or async). They were asked to continue performing these exercises by themselves and also look around the virtual room in all directions. During this visual exploration participants were asked to state and describe what they saw, to make sure they were paying attention and that the system was working properly. After the exploration period (5 min), participants were asked to focus on their virtual body and face in the mirror and avoid looking away in other directions, while still occasionally performing exercises with their bodies. During the following 5 min 21 sec, the pre-recorded stimulus voice was played through the headphones while the avatar's lips moved synchronously with the spoken words. Each word was played 14 times. During this period participants assigned to the Von condition also experienced vibrational feedback on the thyroid cartilage that was synchronised to the syllables of the words.

Experiment 2 followed the same procedures, with the only difference that visuomotor correlations were replaced with visuotactile ones. Participants were seated on a stool in the physical laboratory, and they could also see a collocated virtual avatar seated on a virtual stool (Figure 6.2 A, C, D). They were instructed to stay still during the whole experimental procedure, and that they could only move their heads to look around the virtual room in all directions during the exploration phase. After the exploration period (2 minutes), they were asked to focus on their virtual body (both hands and abdomen) in the mirror and by looking down, and to avoid looking away in other directions. For the following 5 minutes they saw a virtual ball bouncing on their virtual body along a pre-recorded path (Figure 6.2 A, C, D). Physical touch was delivered via mechanical vibrators attached to their hands and abdomen respectively. It was essential to make sure that participants paid attention, and that the view through the mirror would not confuse them as to what part of the body was being stroked. Hence, they were instructed to alternate their gaze between looking down towards their bodies and in the virtual mirror every time they heard a beeping sound (approximately every 1 min). Next the pre-recorded stimulus voice and lip-sync animation started, and participants were requested to focus their attention to their face reflected in the mirror.

After the speaking stimulus period, a black background was displayed in the HMD with written instructions to read out loud the nine target words that then appeared in front of them in random order. Each word was recorded five times. After removing the HMD, participants were asked to complete the post-experimental questionnaire. Next they were paid and debriefed. The whole procedure lasted between 20 and 30 min. The experimental operator (female) was present throughout the entire experiment.

6.2.4 Response Variables

Immediately after the experiment, participants answered a 10–statement post-questionnaire to assess their subjective experience (Table 6.2). A seven-point scale was used, ranging from −3 to +3, (with −3 indicating "strongly disagree" and +3 indicating "strongly agree"). The statements were concerned with the strength of body ownership *MyBody* (the illusion of body ownership), *Mirror* (the illusion of ownership of the body in the mirror), and *Agency* (being the agent of movements of the VB), questions relating to the experience of owning the stimulus voice *VoiceSourceRoom*, *VoiceSourceHead*, *OwnVoice*, *ModifiedVoice*, and *Speaking*, while others served as control questions: *Features*(resemblance of the virtual body to the own body) and *TwoBodies*(the illusion of having two bodies). The *OwnVoice* and *ModifiedVoice* questions were adapted from the rubber voice illusion questionnaire (Zheng et al., 2011): "It felt as if the voice I heard was my voice" and "It felt as if the voice I heard was a modified version of my voice". The voice-related questions were asked at the very end of the experiment, and there was no prior reference to the issue of voice before the end of the experimental process.

Vocal Production Analysis. During the vocal production analysis we extracted the FF across the 90 trials for each participant before (BaseF0) and after (F0) the exposure to the virtual environment to track the changes in the acoustics of the produced words (45 trials before the stimulus baseline, and 45 trials after the stimulus voice). The computer software Praat (Boersma, 2001) was used for analysis of the speech and was also for reviewing trials from each participant for

Table 6.2: Post-experiment questionnaire items

Variable name	Questionnaire statements
MyBody	I felt that the virtual body I saw when looking down at myself was my own body
Mirror	I felt that the virtual body I saw when looking at myself in the mirror was my own body
Features	I felt that my virtual body resembled my own (real) body in terms of shape, skin tone, or other visual features
TwoBodies	I felt as if I had two bodies
Agency	I felt that the movements of the virtual body were caused by my own movements
VoiceSourceRoom	It felt as if the voice I heard was coming from somewhere in the room
VoiceSourceHead	It felt as if the voice I heard was coming from inside my head
OwnVoice	It felt as if the voice I heard was my own voice
ModifiedVoice	It felt as if the voice I heard was a modified version of my own voice
Speaking	It felt as if I was speaking out the words I heard

discontinuities caused by glottal fry. Participants with glottal fry were excluded.

6.3 Results

6.3.1 Experiment 1

Questionnaire Responses

Participants completed a questionnaire immediately after the experiment (Table 6.2), derived from the original RHI questionnaire (Botvinick and Cohen, 1998). Each question was scored on a −3 to +3 Likert scale, where −3 represented least agreement with the statement and +3 most agreement. Two questions were concerned with body ownership (*MyBody* and *Mirror*) with two related control questions (*Features* and *TwoBodies*). Figure 6.3 shows that the variables *MyBody* and *Mirror* are positively influenced by sync with median scores of 1 or 2, whereas the two control questions *Features* and *TwoBodies* have median scores of 0 or less. The results that are evident in Figure 6.3 are supported by ordered logistic regression of each of the questionnaire scores on the factors visuomotor and vibrations. (The rationale for the statistical methods used is given in Materials and Methods.) For *MyBody* and *Mirror* there is no significant interaction effect between the two factors and only the main effect of visuomotor is significant (P < 0.0005 in each case). There is nothing significant for *Features*.For *TwoBodies* there is a significant effect of vibrations (P = 0.009) with Von resulting in lower scores than Voff, but overall the median scores for Von are very low.

Figure 6.4 shows the scores relating to the questions on agency, the voice, and speaking. For *Agency* there is no interaction effect, and the main effects of visuomotor and vibrations are significant (P < 0.0005 and P = 0.024 respectively, ordered logistic regression). It is evident that the sound is interpreted more as originating from the room (*VoiceSourceRoom*) in the async condition, and the scores are substantially lower in the sync condition (P = 0.033, ordered logistic regression). Correspondingly *VoiceSourceHead* goes in the opposite direction (P = 0.004). The voice tends to be interpreted more as their own by participants (P = 0.011) and as the self-speaking (P < 0.0005) in the sync condition. However, the idea that the voice was a modified version of the own voice is not significantly different between the conditions. It is clear from the box plot and also the logistic regression that the major contributor of the extent to which participants experienced illusory speaking is the visuomotor factor.

Vocal Production Analysis

The FF of the stimulus voice of the virtual body was designed to well exceed the average FF of Spanish speakers (Spain) (separately for males and females) (see Materials and Methods). The FFs of the voices of the participants uttering the same words used in the stimulus were recorded immediately before the experiment (BaseF0). They were recorded again immediately after the stimulation period of the experiment (F0) while still wearing the HMD. The variable of interest is dF = F0 - BaseF0. Each participant carried out 45 utterances before and after the stimulation. This is therefore a mixed-effects design, with fixed-effects visuomotor and vibrations, and random effects "individual subject" and "word", and is appropriately analysed by a mixed-effects ANOVA. The means and SEs of dF over the full set of data are shown in Figure 6.5. The main effect of VM is significant (z = 8.13, P < 0.0005), similarly for vibrations (z = 2.51, P = 0.012),

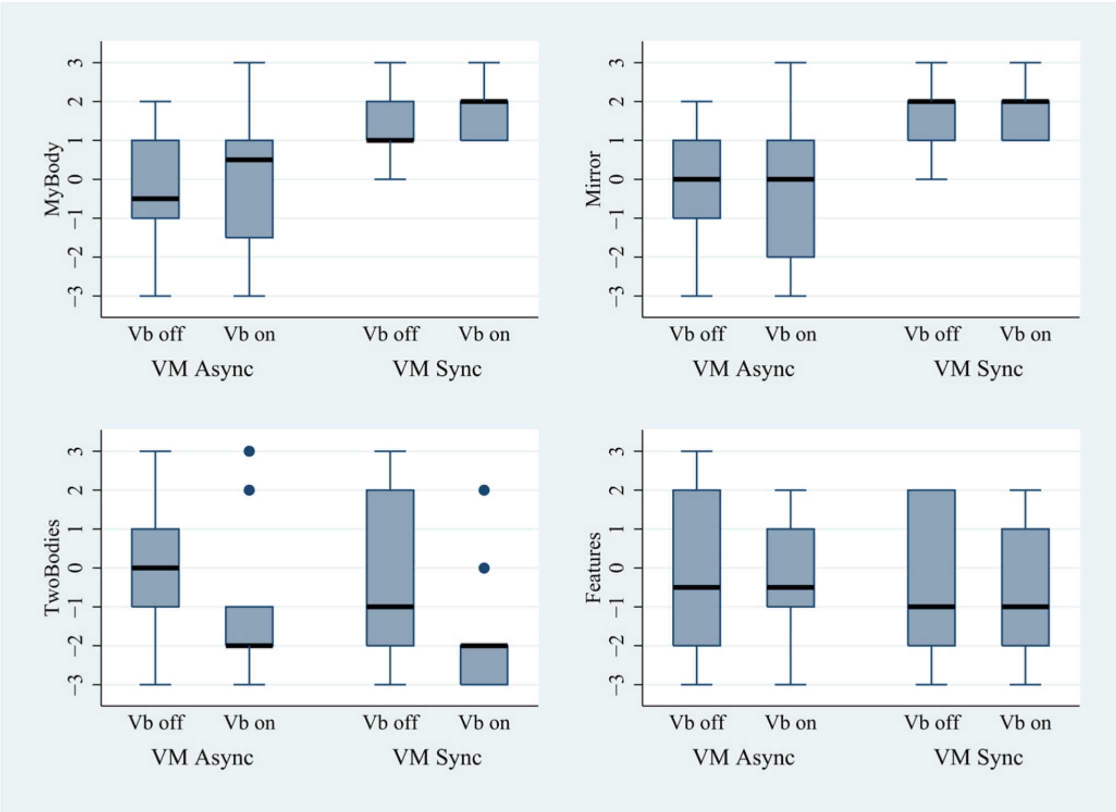

Figure 6.3: Boxplots for scores on body ownership. The horizontal black bars are the medians, and the boxes the interquartile ranges (IQRs). The whiskers stretch to the data points that are within the median ±1.5 IQR, with outliers beyond this shown as single points. *MyBody* and *Mirror* are significantly different between async and sync ($P < 0.0005$, ordered logistic regression) (Table 6.2).

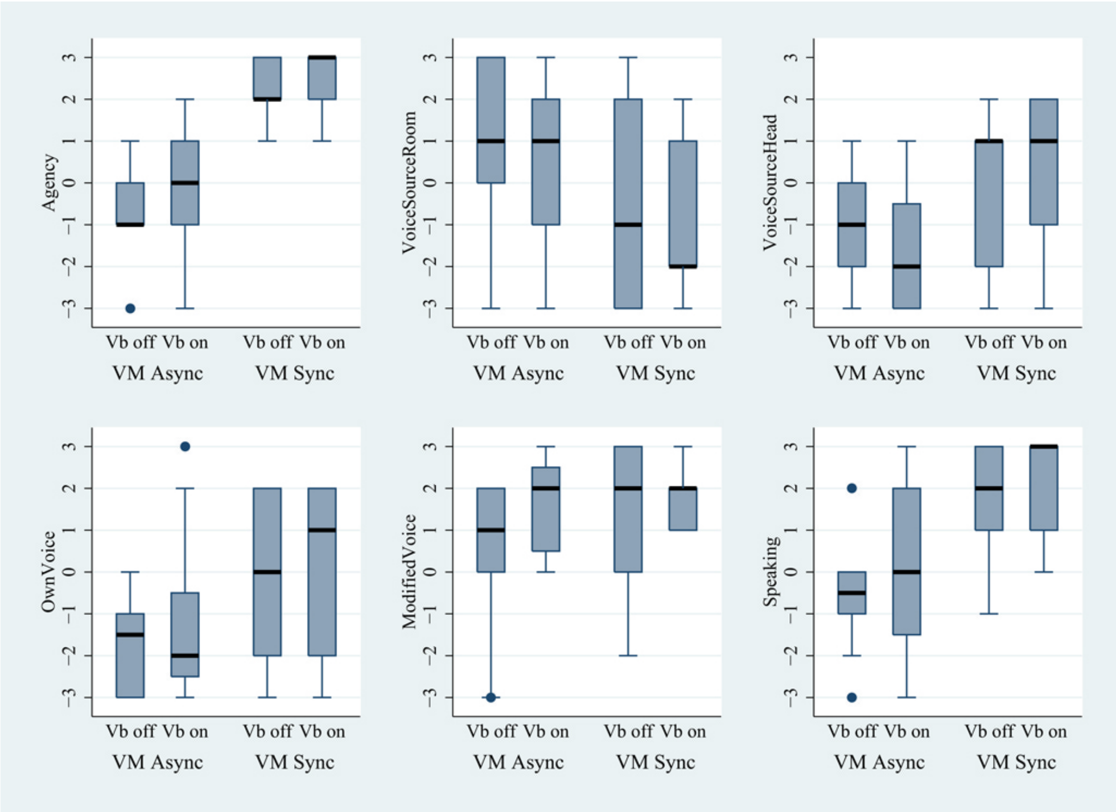

Figure 6.4: Boxplots for scores on agency and speaking. Agency is significantly different between the VM conditions (P < 0.0005) and the vibrations (Vb) conditions (P < 0.024). The differences between the VM conditions are significant for *VoiceSourceRoom* (P = 0.033), *VoiceSourceHead* (P = 0.004), *OwnVoice* (P = 0.011), and *Speaking* (P < 0.0005). There are no other significant differences. All significance levels are with respect to ordered logistic regression (Table 6.2).

and there is a significant and positive interaction effect ($z = 3.55$, $P < 0.0005$). Although the distribution of residual errors is highly symmetric and bell shaped, the distribution is not normal. A plot of residual errors clearly shows three outliers. Removal of these improves the situation somewhat but does not result in normal errors, although the histogram of residual errors is a highly symmetric and bell shaped.

In these fits (with or without the outliers) the coefficient for the main effect of VM (sync = 1, async = 0) is more than double that of vibrations (Von = 1, Voff = 0), and their respective 95% confidence intervals do not overlap. The magnitudes of the coefficients ($\pm$SE) are (with outliers removed) VM: 9.7 ± 1.17, vibrations: 2.6 ± 1.15, and interaction: 5.8 ± 1.62. It is also clear that in the condition (async, Voff) the difference in FF is negative (i.e., it is less after the stimulation than before) which is taken up at the end of Discussion.

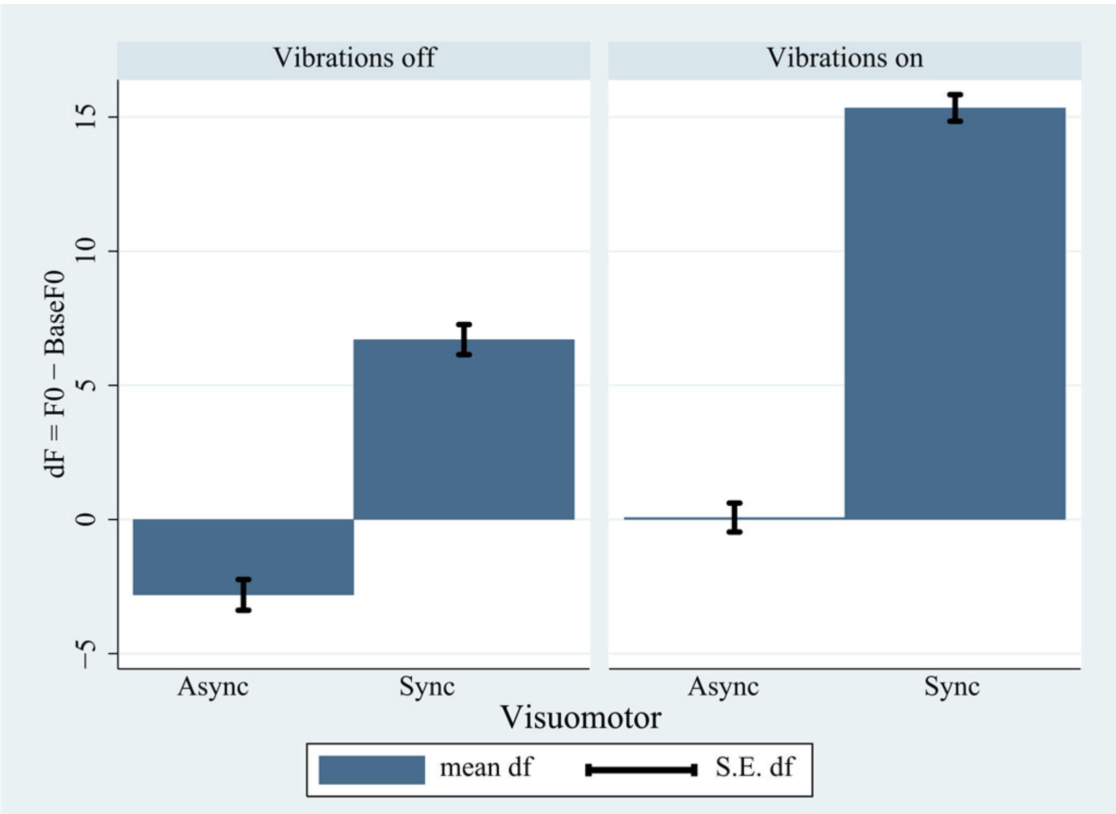

Figure 6.5: Bar chart for dF by VM and vibrations.

Further Analysis of Change in FF

Here we provide an alternative analysis where the means of dF within each cell are treated in a fixed–effects only analysis (Table 6.3). Let mdF be the mean of dF over all 45 utterances spoken by the participant (i.e., the mean of the difference between the post- and pre- stimulus frequencies; Materials and Methods). Table 6.3 shows the means of mdF and the ANOVA, indicating the highly significant impact of sync and Von. This is a remarkable result considering that 55% of the variation in mdF is accounted for by just two binary factors. More specifically, considering Table 6.3, two-way ANOVA shows significant main effects for both VM and vibrations but no interaction effect (P = 0.13). The results are after the non–significant interaction term was eliminated. Viewing the ANOVA as a (equivalent) regression, the coefficient for sync (12.5) is more than double that of Von (5.8) (both with an SE 1.91). The residual errors of the fit are just compatible with normality (Shapiro-Wilk P = 0.09).

However, a residual error plot suggests three outliers. When these are removed, the interaction effect is positive and significant [F(1,37)= 5.76, P = 0.02, $\eta^2 = 0.13$] and the main effect for VM is significant [F(1,37) = 42.54, P < 0.00005, $\eta^2 = 0.18$]and as is vibrations [F(1,37) = 14.71, P = 0.0005, $\eta^2 = 0.03$]. Overall, $R^2 = 0.64$. (The residual errors are compatible with normality, Shapiro-Wilk P = 0.27.) This is almost the same qualitative result as above, but the interaction effect is more in accord with what can be observed in Table 6.3. However, in any case the major conclusion is that VM has the dominant effect on mdF nevertheless with a clear contribution of vibrations. It should be noted that there was no significant effect of sex in either case.

Table 6.3: Means and SEs of mdF by condition, with ANOVA tests

	Vibrations		
VM	**Off**	**On**	**Difference between vibration means**
VM async	-2.81 ± 2.42 $(n = 10)$	0.07 ± 1.54 $(n = 12)$	
VM sync	6.71 ± 2.25 $(n = 11)$	15.34 ± 1.20 $(n = 11)$	$F(1,41) = 9.10$, $P = 0.0044$, partial $\eta^2 = 0.18$
Difference between VM means		$F(1,41) = 42.93$ $P < 0.00005$, Partial $\eta^2 = 0.51$	Overall $R^2 = 0.55$

The results show that participants in the VM sync condition tended to have a strong subjective illusion of body ownership and agency with respect to the virtual body, and to attribute to themselves authorship of the vocalisation. Additionally, the participants in this group subsequently tended to exhibit a higher FF in their vocal productions toward the frequency of the avatar voice. There is a significant contribution of the vibrations (Von) to these effects, but the dominant factor is sync. Moreover, the FF was lower than baseline in the (async, Voff) condition. Agency with respect to the specific event of the avatar vocalisation was scored highly in the sync condition. In the (sync, Von) condition more than half of the participants gave the maximum score of $+3$ on a -3 to $+3$ scale in agreement with the statement, "It felt as if I was speaking out the words I heard" (Figure 6.3).

6.3.2 Experiment 2 in relation to Experiment 1

In this section we present the results of Experiments 1 and 2 together—the VT (async and sync) and the previous VM (async and sync)—for better visualisation and comparison. We refer to VT and VM as condition *Mode*.

Figure 6.6 shows the median and interquartile ranges of the the body ownership questionnaire, which was the same as in Experiment 1. It is clear that body ownership is high in both VT conditions (sync and async), whereas the control questions *TwoBodies* and *Features* have comparatively low scores. Hence in spite of the asynchronous visuotactile stimulation the level of body ownership was high in the VT async condition. Ordered logistic regression of each of the questionnaire scores on the factors VT and VM reveals that for *VRBody* there is a significant interaction term indicating that *VRBody* in the VM async condition gives the lowest score (z = -2.46, P = 0.014). Likewise, for *Mirror* there is a significant interaction term (z = -2.45, P = 0.014) with the same meaning as above. There is nothing significant for *TwoBodies*, or *Features*.

Similarly, Figure 6.7 shows the box plots for agency over the body *Agency*, and the extent to which participants felt that it was they who were speaking *Speaking*. Again we find no difference between sync and async in the VT case, suggesting that indeed the conditions that lead to strong body ownership can also result in

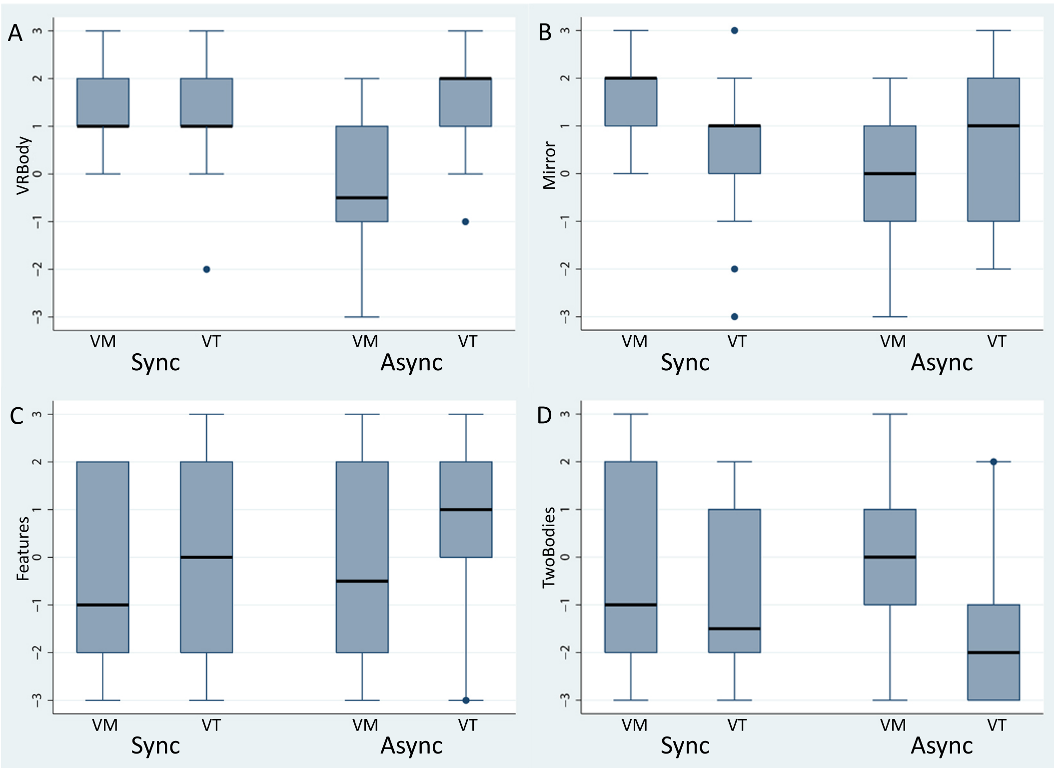

Figure 6.6: Box plots of body ownership questions. The thick black horizontal lines are the medians, the boxes are the interquartile ranges, and the whiskers extend to ±1.5×IQR, or the range. Individual points are outliers. (A) *VRBody* refers to the illusion of ownership over the virtual body seen directly, (B) *Mirror* refers to ownership over the body seen in the mirror, (C) *Features* refers to the extent to which the virtual body looked like the participant, and (D) *TwoBodies* refers to the illusion of having two bodies.

subjective illusory agency. There was of course some actual agency since the head movements of the participants were reflected in head movements of the virtual body, as seen in the mirror. Since participants were instructed not to move their body or limbs, they may not have realised that had they moved that the virtual body would not have moved. However, participants, as in Experiment 1, did not talk, so that the "Speaking" response reflects an entirely illusory sense of agency over the speaking. On the contrary, in the VM case the asynchronous condition gives low scores for both *Agency* and *Speaking*. Ordered logistic regression for *Agency* shows a significant interaction term, indicating the lowest scores for VM async ($z = -4.50$, $P < 0.0005$). Similarly, for *Speaking* the interaction term has ($z = -2.58$, $P = 0.01$). Amongst other values there are no significant interaction terms or main effects of *Mode*. Note also that for *Agency* and *Speaking* there are not great differences between VT and VM sync, meaning that relatively high scores for these can be obtained simply from 1PP—so that subjective sense of agency follows from subjective body ownership (or vice versa).

Regarding the vocal production analysis, Figure 6.8 shows the means and standard errors of dF—differences in FF before and after the stimulation—for both experiments. The VT async values of Experiment 2 are almost the same and negative as those in Experiment 1, and the VT sync value is close to zero. It can be noted that among all conditions the completely dominant value is VM sync. Figure 6.8, however, does not take into account the effect of Vibrations in the Experiment 1. Taking this into account, and restricting the attention to only all observations where there are no vibrations, a mixed effects regression gives the greatest impact of Sync×Mode (VM) ($z = 4$, $P < 0.0005$). We carry out an analysis of all possible pairwise differences all at an overall level of 5% using Scheffé's method. This reveals that there are no significant differences between (async, VM) and (async, VT), (sync, VT) and (async, VT), or (sync, VT) and (async, VM). Table 6.4 shows all significant differences at the overall 5% level, where dF(α,b) means the change dF = F0 - BaseF0 with α being sync or async, and b being the *Mode*.

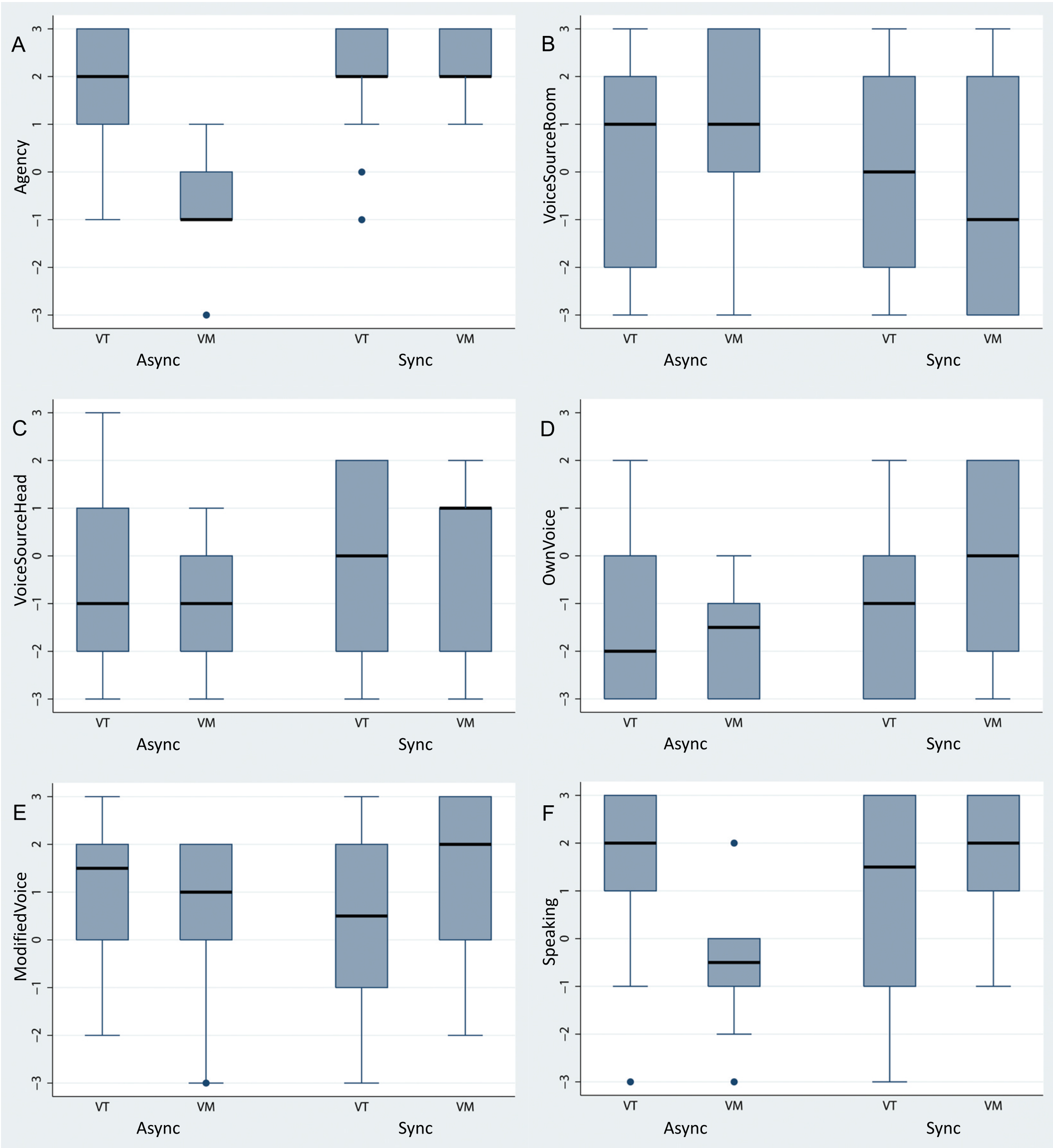

Figure 6.7: Box plots of agency and speaking. The thick black horizontal lines are the medians, the boxes are the interquartile ranges, and the whiskers extend to ±1.5×IQR, or the range. Individual points are outliers. (A) *Agency* is the sense of agency over the movements of the virtual body, (B) *VoiceSourceRoom* identifies the origin of the voice-higher values mean from the room, (C) *VoiceSourceHead* identifies the origin of the voice as from inside the head of the participant, (D) *OwnVoice* is the extent to which the voice appeared to be the participants' own, (E) *ModifiedVoice* the extent to which it appeared to be a modified version of their own voices, and (F) *Speaking* the extent of agency over the virtual body speaking.

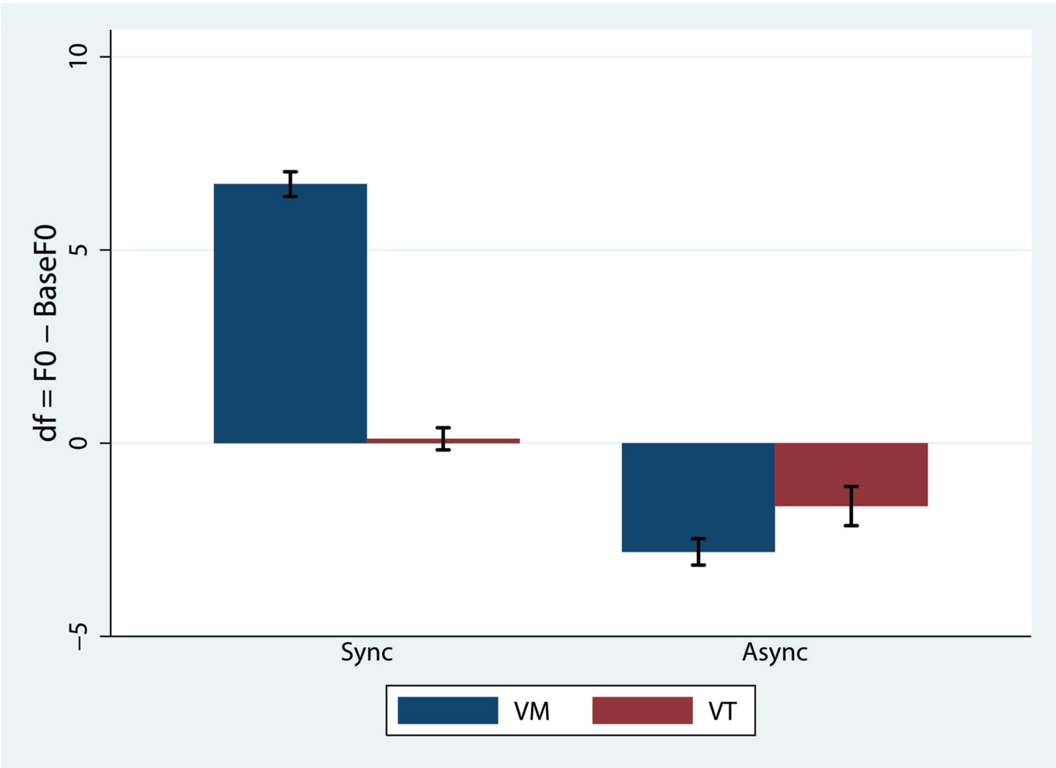

Figure 6.8: Bar chart showing means and standard errors of dF by the VT and VM conditions, Sync and Async.

Table 6.4: Summary of comparisons in vocal production analyses (the 95% confidence intervals of left hand expression-right hand expression do not include 0).

	95% CI for left hand side expression - right hand side expression	
dF(VT) < dF(VM)	-4.95	-.89
dF(async) < dF(sync)	-6.61	-2.68
df(async, VM) < dF(sync, VM)	-14.14	-4.93
df(sync, VT) < dF(sync, VM)	-10.8	-2.72
df(async, VT) < dF(sync, VM)	-12.51	-4.43

6.4 Discussion

The findings presented here may be considered puzzling because they apparently do not fit with the major theories concerning explanations for the sensation of agency. In what follows we argue that the results can nevertheless be reconciled with current theories, provided that we take into account the issue of body ownership. We also consider an alternative explanation that the results may have been caused by mimicry (the chameleon effect), as studied in the social psychology literature.

Before addressing these explanations, we first regard participants' subjective experience of ownership and agency over the virtual body. We found that both VM and VT synchronous conditions contribute to the effect, which in turn gives rise to the subjective illusory agency over the speaking. Nonetheless, although VM asynchrony seems to be the most effective in diminishing both subjective ownership and agency over the virtual body, and subsequently illusory agency over speaking, the results are rather contradictory for the VT asynchronous condition. This finding is not surprising, but provides further support to previous studies suggesting that an ownership illusion can be sustained despite asynchronous visuotactile stimulation, given that congruent visual sensorimotor contingencies are available (Maselli and Slater, 2013; Kilteni, 2015; Maselli et al., 2016). In our experimental design, although participants were asked not to move their bodies, they were able to move their heads and look around. In fact, they were asked to first look around and describe the virtual scene, and later on, during the VT stimulation, they were asked to change their gaze between looking directly down to their body or their reflection in the mirror (see 6.2.3 for details). This level of agency over the head movements, combined with 1PP and collocation of participants' real and virtual bodies, appeared to be sufficient to create an ownership illusion under which visuotactile spatiotemporal asynchronies failed to be noticed. In turn, this discrepancy led participants to also report a subjective illusion of agency over the whole body, and also illusory agency over the speaking, in both VT sync and async conditions. Nonetheless, the behavioural measures regarding participants' shifting of their voice frequency, suggested changes only for the VM sync condition which we approach next.

As discussed in Section 2.2.2, the sense of agency refers to the sense of one's authorship of an action whereas the sense of body ownership refers to the sensation of experiencing that the action is with respect to one's own body (Gallagher, 2012, 2000). We also considered the relationship between agency and ownership. We saw that on one hand the subjective experience of ownership has been found to include agency as a component (Longo et al., 2008), whereas other experimental work has provided evidence demonstrating their independence (Kalckert and Ehrsson, 2012; Sato and Yasuda, 2005). In our own work, including all experiments described in this thesis, we have used synchrony between real and virtual body movements to induce a strong ownership illusion and agency (critically always in the context of 1PP of a virtual body spatially coincident with the real body). This allows us to make use of the framework of Tsakiris et al. (2007) introduced earlier, who argue that when ownership is caused by passive tactile stimulation, it does not generalise beyond the point being stimulated (e.g., a specific finger), whereas when it is based on active movement, it generalises to the whole hand. They explain this by noting that the primary somatosensory cortex is segmented, so that stimulation of one specific point on the body surface normally does not affect any other point. However, in the primary motor cortex different movements can overlap in their activations (so moving one finger has shared activation with many other possible movements). In our VM setup, participants spent 5 minutes moving with visuomotor synchrony (in the sync condition)—thus, of course, continuously activating multiple areas in the motor cortex—and continued moving for more than another 5 minutes during the talking phase. Because it is known that seeing and hearing a talking face activates many cortical motor areas (Skipper et al., 2005), it is possible that when the avatar spoke, the resulting motor area activations overlapped with earlier and ongoing activations, providing a unified experience with all of the actions attributed to the self. On the contrary, in the VT setup, and during the speaking stimulus, participants were asked to remain still and focus on their faces in the mirror. Therefore, this explanation, similar to the VM async condition, could not have applied here.

The participants in our experiment observed an event (the avatar speaking), and those in the VM sync condition—and especially those who additionally experienced Von—tended to retrospectively attribute authorship of that event to themselves. Our explanation suggests that this was due to the 1PP body-ownership illusion, and the agency caused by the synchrony between real and virtual body movements. We propose that under these circumstances specific acts that are carried out by the virtual body but not by the participant are also attributed to by the participant to him– or herself, generalised from the agency associated with the body movement. Put simply, the inference may be, "This is my body, I am moving it—it spoke, so I must have been the one that did the speaking. Indeed, these findings diminished in the second experiment, where visuomotor correlations were replaced with visuotactile, and participants did not experience agency of the whole virtual body movements.

This explanation is compatible with the widely accepted internal motor control models of agency, and we argue that the critical evidence for this is the drift of FF of participants' own later utterances toward that of the avatar in the (sync, Von) condition. In the forward model of motor control, an efference copy of a motor command to achieve a goal is used by the Central Nervous System (CNS) to predict the sensory consequences of motor action, and before the act has been realised, the predicted outcome is compared with the goal. Then after the act the actual sensory feedback is compared with the predicted, and the extent to which these cohere contributes to agency. However, an inverse model computes the detailed sequence of the motor commands necessary to achieve the goal. It is argued that this inverse model is not available to consciousness (Blakemore et al., 2002). In the case of our experiment the forward model apparently cannot apply, there is no preparation for action, and there can be no comparison between the sensory outcome and goal because there was no goal, only the observation of an act. However, this only applies to the first utterances by the virtual body. We propose that once the avatar starts speaking, the body ownership results in a retrospective intention to act that then mobilises the same brain areas as in a prospective intention to act.

Normally, preparation for action results in a conscious intention to act. We propose that in this case there is an additional feedback circuit where the observation of apparent self-action results in an activation of preparation for action circuits which then give rise to the sensation of agency with respect to the specific act. We suggest that the inverse model is fully mobilised. If the act is ascribed to the self, then after the first few words are spoken the retrospective intention to act would require the CNS to compute how to actually reproduce the vocalisation that was ascribed to the self, especially if there were an expectation of subsequent speech. When the participant is later asked to vocalise those same words, the CNS has already prepared the motor commands to make this possible–and indeed the vocalisations were carried out with the higher frequency associated with the heard voice. Essentially, therefore, we can say that the body ownership that resulted from the sync condition generalises to retrospectively produce the same CNS computations as if the person had really spoken. The fact that the production of the vocalisation was clearly influenced by the heard voice in the (sync, Von) condition suggests that there must have been some preparation of the motor system for action, and therefore there must have been an influence via the internal model as suggested.

We saw earlier that according to Wegner and Wheatley (1999) a specific act carries the sensation of agency under three necessary conditions: *(i)* priority, "the thought should precede the action at a proper interval"; *(ii)* consistency, "the thought should be compatible with the action"; and *(iii)* exclusivity, "the thought should be the only apparent cause of action". These principles seemingly do not apply to our experiment because, given the unexpected nature of the avatar speaking, there was no thought intentionally related to this before its occurrence. However, as argued above, this only applies to the first word spoken by the avatar, and that this first word or at least the first few words spoken established prior thoughts in participants in the form of expectations for the subsequent speaking. In this case the priority and consistency requirements might have been met. However, the exclusivity requirement would still not be satisfied because there was an entirely plausible, obvious (and true) alternative explanation that the avatar was talking by itself.

A similar consideration applies to priming, the idea that "Authorship is likely to be inferred when the agent has action-relevant thoughts that occur prior to the action" (Wegner et al., 2004, p.839). In particular Wegner et al. describe an experiment that has some similarity to our own but where their participants looked at themselves in a mirror in which the substitute rubber arms they saw moving (arranged so that it could seem as if they were the arms of the participants) were actually moved by a confederate. Participants tended to attribute authorship to themselves in the condition when there was a prior instruction to carry out the movement. In the case of our study we suggest that the initial utterances acted as primes for the subsequent ones. Moreover, the vibrations experienced in the Von condition would also eventually have acted as primes in the sense that this particular stimulus was always associated with the speaking in that condition. However, it remains to be explained how the exclusivity requirement could be satisfied in our experiment. We turn to this next.

Wegner et al. (2004) provided a set of authorship indicators as conditions for the judgement of agency. Here we mention only those that could be relevant to our setup. The indicator referred to as "body and environment orientation cues" is concerned with knowing about the body and its affordances and those of the environment. In our case, in the VM sync condition, there was a strong illusion of body ownership over the virtual body that could be seen directly and in the mirror (Figure 6.3). A further relevant authorship indicator is "direct bodily feedback", referring to feedback "from body to brain...proprioceptive and kinesthetic sensations from muscles, skin, joints, and tendons as well as from the vestibular system". This occurred throughout the experience for those in the VM sync condition because the virtual body moved synchronously with their own movements. Moreover, for the specific event of speaking, those in the Von condition had the associated vibrotactile feedback which further positively influenced the illusion of authorship over the speaking. Additionally, this, combined with the visible lip sync (which occurred in all experimental conditions), would fall under the "visual and other indirect sensory feedback" indicator, and could have contributed further to agency.

Putting these together, the experience of participants in the VM (sync, Von) condition is that they would have had a full-body-ownership illusion with respect to a body that was seen and heard talking, and where the seen visual movement of the lips and the sound of speaking were synchronised with vibrotactile stimulation just at that point on the body associated with the act of speaking. The exclusivity requirement could therefore be moderated by a degree of uncertainty caused by the body-ownership illusion. In other words, the alternative explanation for the cause of the talking ("it is the virtual character doing the talking not me") ceases to be effective when the virtual character seen in the mirror could indeed be me.

In this context it is worth noting that the type of illusory agency that we have found is similar to mirror-touch synaesthesia except in motor activity rather than touch [see (Banissy and Ward, 2013) for a review]. An individual with MTS will actually experience the tactile sensation of seeing someone else touched. We would predict that were such individuals embodied in a virtual body using our method, they would directly feel the tactile stimulation associated with a visually presented tactile stimulation on the avatar's body. It was reported in Maister et al. (2013a) that mirror-touch synesthetes have an enhanced sense that another's face is their own simply as a result of observing the other face stroked, indicating a change in mental representation of self. It was argued in Banissy and Ward (2013) that this confusion between self and other may be at the root of an explanation for MTS at the neural level. We suggest that similarly the confusion of ownership between the avatar body and the participants' own bodies plays an important role in explaining our results.

A quite different explanation for the vocal production effect concerns mimicry, referred to in the social science literature as the chameleon effect (Chartrand and Bargh, 1999), where people tend to unwittingly mimic the behaviour of others with whom they interact, which in turn leads to more positive attitudes toward the other and enhanced social interaction. In the neuroscience literature it has been observed that observation of others' actions leads to internal motor representations of the actions, which in turn may facilitate mimicry—in other words, a shared motor representation between perception of others' action and self-action. For example, van Ulzen et al. (2013) showed that the motor system resonates with unobtrusive non-verbal behaviour of another person, specifically face touching that has nothing to do with the purpose of the action being observed. Regarding the implications for mimicry, they suggest that "there is a tendency to immediately mimic the inconspicuous FT but that the emission of this tendency into observable mimicry behaviour is controlled by an inhibitory mechanism that is susceptible to the social context" (van Ulzen et al., 2013, p. 352). Hogeveen and Obhi (2012) found that motor resonance as the result of action observation in another person was more likely to occur if there had been prior social interaction with the other, although this did not apply when the other was a robot rather than human. In any case, it is clear that for human-human interaction, there is a shared representation between action observation and self-action (Rizzolatti et al., 2001).

It could be argued that the (almost exact) mimicry in our experiment between self-movements and the movements of the avatar resulted in a chameleon effect which then generalised to the specific event of talking. In other words, because the avatar reproduced the global body movements of the participants (in the sync condition), there would be a high degree of empathy toward the avatar and reciprocally the participants would find themselves unwittingly mimicking the avatar's voice production. However, in terms of motor resonance, the situation is more complex—because the participants were themselves actually making the movements that were synchronously reflected back to them in the movements of the avatar. Hence, more than there being just some shared representation between observation and action, these coincided because the movements of the avatar were those of the self. The interesting question then arises as to how the generalisation to vocal production occurred. This could be due to the mechanism discussed earlier of the nonspecificity of motor production, so that activation in one area is associated with activation in other areas. So although the social mimicry explanation cannot be ruled out, it is unlikely because unobtrusive and unconscious mimicry between the participant and avatar did not take place: The avatar moved almost exactly the same as the person (except for the act of talking).

Having discussed the issue of agency above, we now turn to the remaining issues of ownership over the avatar voice, and a possible explanation for the reduction of frequency compared with baseline in the (async, Voff) VM and VT conditions. In Chapter 2 we introduced the "Rubber Voice Illusion", which suggests a sense of ownership over a stranger's voice when participants experienced an alignment between their own vocal motor movement and the resulting sensory events, reporting the stranger's voice being a distorted version of one's own voice (Zheng et al., 2011). In our study, we explored how the alignment between motor feedback from a substituted virtual body that then subsequently vocalised words associated with visible lip sync and vibrotactile stimulation resulted in participants perceptually experiencing themselves as talking and categorising a stranger's voice as their own. Research involving online voice perturbation and FF shifting has shown that people tend to compensate for a change of FF in the real-time auditory feedback during vocal production, either by shifting their FF in the direction of the feedback signal (Zheng et al., 2011; Burnett et al., 1998) or in the opposite direction (Burnett et al., 1998; Larson et al., 2000; Jones and Munhall, 2000). The participants in our experiment in the VM sync condition tended to follow the stimulus rather than compensate for it in the opposite direction. It is argued in (Burnett et al., 1998; Larson et al., 2000; Jones and Munhall, 2000) that following the stimulus voice can serve to bring the participant's voice to agree with that of the external source, whereas compensating works as an error-correction mechanism to return the signal closer to that intended by the speaker. In our study the change was therefore not an error correction but rather signifying ownership over the voice in the VM (sync, Von) condition, and it was likely to be error correction in the VM (async, Voff) and VT async conditions. This also accords with the questionnaire responses (Figure 6.7, *OwnVoice*). Nonetheless, in the VT sync condition, participants seemed to keep their voice frequency un-altered (6.8). It could be argued that they did feel some illusory agency over the speaking, in accordance with their subjective responses, but which was not high enough so as to lead to a behavioural change. Since the overall level of actual agency over their body movements was low, the generalisation of agency over the speaking, as discussed earlier, could not have occurred. This speculation needs to be further tested in future studies.

Overall, we can draw the following conclusions by summarising the findings from the two experiments: First, synchronous multisensory stimulation (whether VT or VM) over a virtual body seen from 1PP can lead to both a subjective illusory body ownership over the speaking virtual body as well as subjective illusory agency over the speaking act. Second, asynchronous VT stimulation can still lead to a subjective illusion of ownership and agency under ambiguous situations. This is in line with previous research suggesting that asynchronous stimulation can be disregarded when synchronous visuomotor cues are provided (Kokkinara and Slater, 2014; Maselli and Slater, 2013), such as participants' head movements in our experiment. Interestingly, Maselli and Slater (2013) showed that when head movements are allowed and the FoV is not static, asynchronous visuotactile stimulation is not perceived as completely wrong. Third, the behavioural change of shifting the voice frequency towards that of the virtual body only occurs when there is visuomotor synchrony. In other words the veridical agency over the entire virtual body transforms into a new motor plan for speaking in the way that the virtual body spoke. Thus, synchronous visuomotor stimulation is both subjectively and observationally more powerful than visuotactile stimulation. Fourth, in both VM and VT async conditions we see a decrease in dF, which we explain as participants attempting to "error correct", that is shift their voice away from the one with greater FF more towards their own voice leading to a compensation effect.

Increasingly surrogates will represent people through online avatars and in robotic form where the robot actions may even be caused by interpretations of a person's brain activations (Grechkin et al., 2010). One corollary of this trend toward surrogate representation is that the concept of agency will come increasingly to the fore in ethical, legal, and societal arenas. If my representation in a remote location carries out some act, I may claim or deny agency over that act, which has consequences for my personal, legal, and social responsibility. If, as we have shown in this paper, a person may attribute agency over an act to themselves, even though they had no intention to act and played no part in its production, it becomes essential to understand this scientifically. From a societal, legal, and ethical point of view, unravelling the truth between "I caused an action but attributed it to another agent", "I thought I caused the action but did not", and "I correctly attributed the action to myself", will become vital.

Chapter 7

Conclusions

7.1 General Discussion

Throughout this thesis we demonstrated how we can exploit embodiment techniques with the help of IVR in order to study body perception. We specifically focused on the concepts of illusory body ownership and agency over a virtual body, and investigated the perceptual, behavioural and attitudinal correlates of such illusory experiences.

In Chapters 4, 5, and 6, we presented three experimental studies we conducted with human adult participants, and on account of our results, we hereunder defend our research hypotheses:

- **Hypothesis 1:** *Healthy adults can experience ownership over a child body when congruent multimodal information is provided. Such illusory experiences result in implicit changes in self-perception, and also affect size perception in the surrounding environment.*

  Previous studies have examined how we can induce an illusory sensation of ownership over a surrogate limb or whole body through specific forms of multisensory stimulation, such as synchronous visuomotor and visuotactile stimulation. Such methods have been used to induce ownership over a manikin and a virtual body that substitute the real body, as seen from 1PP, through an HMD.

In our experimental study, we sought to investigate the perceptual and behavioural consequences of such ownership illusions. In a first experiment, IVR was used to embody 30 adults as a 4-y-old child, or as an adult body scaled down to the same height as the child. The two bodies were experienced from 1PP, and with synchronised virtual and real body movements. The second experiment conducted with an additional 16 participants extinguished the ownership illusion by using visuomotor asynchrony between virtual and real body movements, with all else equal.

The results suggested a strong body ownership illusion equally for the child and scaled-down adult avatars. This is in line with previous research, as discussed in Chapter 2, and an additional demonstration that body ownership illusions can occur irrespective of the body type. Moreover, we showed that the illusion of body ownership over a small body leads to overestimation of object sizes as previosuly demostrated by (van der Hoort et al., 2011). However, when the type of the body represented that of a 4-year-old child, the size overestimation was approximately double that compared to when the type of the body was an adult body but shrunk down to the same size as the child. Also, an IAT revealed that embodying the child results in changes in implicit attitudes about the classification of one's self with child-like attributes significantly beyond the changes induced with the adult body. Nonetheless, both size-estimation and IAT differences between child and adult embodiment diminished under asynchronous visuomotor correlations, showing that the effects are influenced by the extent of the illusion of body ownership. We conclude that there are temporary perceptual and behavioural correlates of body ownership illusions related to age, which occur as a function of the type of body in which embodiment occurs (child-like compared to adult-like).

- **Hypothesis 2:** *Illusory ownership over a body of different race can lead to a sustained reduction in implicit racial bias.*

As seen in previous chapters, embodying White participants in a Black body in IVR (Peck et al., 2013), or inducing the RHI with a black rubber hand (Maister et al., 2013b) can lead to a significant reduction of implicit racial bias right after the exposure of participants to the illusion. Here we aimed to examine whether this effect is sustained for at least one week after participants have experienced owning a Black virtual body, and whether the number of exposures to the illusion can further strengthen the results. To this end, we carried two experimental studies where we embodied in total 90 Caucasian female participants in a White or Black virtual body, and tested their implicit racial attitudes a week after the experiment. As part of their experience, participants were instructed to follow a series of Tai Chi movements demonstrated by a virtual Teacher who was either Asian (experiment 1) or Caucasian (experiment 2).

Our results suggested that, similar to previous studies, one exposure of embodiment in the Black virtual body is sufficient to decrease implicit bias against Black compared to those embodied in the White body. Here, however, it was shown that this reduction can be retained for at least one week. Additionally, the results revealed that the number of exposures do have an effect independently of the type of body, leading to a decrease in implicit bias for both White and Black embodiment conditions. We aimed to address this point through the second experiment, however, our hypothesis that this may be due to a contact hypothesis theory (Asian Teacher) was not borne out. Overall, our findings demonstrated that changes in implicit attitudes that arise based on the type of the embodied virtual body–here that of a different race–are not temporary but are rather preserved in the longer term.

- **Hypothesis 3:** *Healthy adults can experience illusory agency over speaking through embodiment in a speaking avatar.*

  In this study, we explored the role of embodiment further, by investigating the possibility of inducing to participants illusory agency over an action they did not carry out themselves. When we carry out an act, we typically attribute the action to ourselves, the sense of agency. As discussed in Chapter 2 the literature has identified various explanations for agency including conscious prior intention to act, followed by observation of the sensory consequences; brain activity that involves the feed-forward prediction of the consequences combined with rapid inverse motor prediction to fine-tune the action in real time; priming where there is, e.g., a prior command to perform the act; a cause (the intention to act) preceding the effect (the results of the action); and common-sense rules of attribution of physical causality satisfied. We described an experiment where participants falsely attribute a speaking act to themselves under conditions that apparently cannot be explained by current theories of agency.

In our setup, a life-sized virtual body seen from 1PP as if substituting the real body, was used to induce the illusion of ownership over the virtual body. For experiment 1, half of the 44 participants, both male and female, experienced body movements that were synchronous with their own movements, and the other half asynchronous. The virtual body, which was also seen in a mirror, spoke with corresponding lip movements, and for half of the participants this was accompanied by synchronous vibrotactile stimulation on the thyroid cartilage. In order to examine whether the effect was a result of illusory body ownership over the virtual body, or a generalisation of actual agency over the body that mapped to illusory agency, we carried out a second study with additional 36 participants. The setup was identical to the first study, only there was no body movement except for head movement, and body ownership was induced through visuotactile synchrony, where the body was seen to be tapped while the participant felt corresponding tactile sensations. Other than the use of visuotactile stimulation instead of visuomotor, the only difference was that we did not apply the vibrations on the throat.

The results of the first study suggested that participants who experienced synchronous movements falsely misattributed the speaking to themselves, and also shifted the fundamental frequency of their later utterances toward the stimulus voice. Stimulation on the thyroid cartilage also contributed to these results, although the dominant factor was visuomotor. This was not the case, whatsoever, for those experiencing asynchronous visuomotor stimulation, as supported by subjective questionnaires and insignificant changes to their fundamental frequencies. The findings from the second study revealed that although participants reported subjective illusory agency over the speaking, the behavioural change of shifting the voice frequency towards that of the stimulus voice did not occur. Additionally, we saw a decrease in the fundamental frequency for all asynchronous conditions in both studies, which was explained as participants attempting to "error correct"; that is shift their voice away from the one with greater frequency more towards their own voice, thus leading to a compensation effect. Overall, our findings suggest that illusory agency over the speaking is driven by the same factors that lead to body ownership—synchronous multisensory stimulation (whether visuotactile or visuomotor) over a virtual body seen from 1PP—but behavioural changes occur only when there is visuomotor synchrony. In other words, actual agency over the virtual body transforms into a new motor plan for speaking in the way that the virtual body spoke.

In conclusion, we suggest that congruent visuomotor information between a virtual body and its real counterpart is a key factor in inducing illusory body ownership and agency, even in the absence or actual motor execution. More interestingly, there appears to be evidence that such experiences entail long-term changes for the individual, which manifest in a perpetual, behavioural, and cognitive level.

7.2 Main Contributions and Future Work

The contributions of the research presented in this thesis can be summarised in two main points. First, we extended previous research on the malleability of our body representation. We demonstrated that it is possible to accept an altered body form with respect to age—that of a child, and also with respect to demographic characteristics—that of different race. We also showed that altering one's body representation can bring changes to perception, behaviours, and implicit attitudes. More importantly, we argued that these changes are not necessarily influenced by socially and culturally derived expectations of having a specific type of body, but are rather a sheer effect of illusory ownership over a different type of body. Additionally, we provided evidence that such behavioural and attitudinal changes are not temporary, but can be sustained for at least one week after being exposed to a virtual scenario, and that a single exposure is sufficient to elicit the desired effect. Second, our studies expanded previous work on the field of agency and action perception, and specifically, the significance of visuomotor congruency for inducing both a subjective and objective sense of ownership and agency over a virtual body. Throughout the various studies we argued that the induction of body ownership and agency is both qualitatively and observationally more powerful when induced by 1PP and visuomotor synchrony, in line with previous research (Kokkinara and Slater, 2014). Furthermore, we demonstrated the possibility of experiencing illusory agency over an action—speaking, and we concluded that veridical agency over the virtual body can transform to a new motor plan for action similar to that of the virtual body. Novel findings from these studies can provide valuable contribution to the fields of action perception and IVR technologies.

Our studies, however, do present some limitations, which we discuss next. Specifically, in the *Virtual Child* study, we induced illusory ownership and agency over a 4-y-old child body, and showed that by manipulating the relationship between one's body representation and the external world, we can alter perception of sizes. We did not, however, examine changes regarding other affordances, such as distances, or objects' perceived weight, something to be taken into consideration for future exploration. Furthermore, along with the type of the body, other cues, such as speech and auditory feedback, can also be examined for their influence on ownership illusions towards a child avatar body. Additionally, we demonstrated that body type transformations can affect perception about one's self. A next step would be to test how body semantics can result in changes beyond perceptual, attitudinal and behavioural, but towards higher cognitive processing, namely intelligence, gratification, decision making etc. More work is required in this regard, ideally with brain-imaging studies to help us understand the extent of cortical reorganisation under bodily illusions that result in such changes.

In the *Racial Bias* study, we demonstrated that embodying White participants in a Black virtual body not only does it result in a reduction of implicit racial bias, but this is sustained for at least one week after participants' exposure to the virtual scenario. Also, we showed that this effect is observed even after a single exposure. However, as discussed in Chapter 5, further studies are needed to replicate this result, both with female and male participants, as implicit racial bias differs by gender. Ideally, control conditions should be employed to strengthen the validity of the results, such as asynchronous visuomotor stimulation, which has been shown to diminish behavioural, perceptual and other changes. Also, it was observed that multiple exposures lead to a reduction of implicit racial bias irrespective of the type of embodiment (Black or White). Although we aimed to explain this effect in terms of the contact hypothesis, the second experiment did not validate this theory. Our suggestion that the Tai Chi movements could have helped participants enter some kind of meditative state, which it turn influences racial bias, is only a speculation and further research is needed to address this issue. Last, replication studies should aim to study these effects targeting different racial groups, as well as other forms of implicit biases.

In the *Illusory Speaking* study, we showed that body ownership illusions can lead to illusory agency towards a speaking act. It is the first time that such evidence has been provided and future research should investigate this further, with neuroimaging studies aiming to understand the underlying neural mechanisms of illusory agency. Moreover, research from a societal, legal, and ethical point of view is needed in this direction; attributing agency over an act to oneself, even though themselves play no part in its production, becomes very critical to understand scientifically. This will have great implications in a world where surrogate representation through online virtual characters or in a robotic form increasingly come to the forefront and become part of the everyday life.

The demonstration that one's altered body representation can lead to long-term changes in self-perception and implicit attitudes has great potential in various applications in learning, education, training, psychotherapy and rehabilitation, and for the interaction between participants. Following the results from the *Virtual Child* study, we designed an application to explore the possibilities in this direction. Specifically, we studied the role of illusory body ownership in improving empathy and perspective-taking through a parenting scenario with low-risk, control groups (Hamilton-Giachritsis et al., 2017). Past research has extensively focused on and examined how parental negative attributions and unrealistic expectations increase the likelihood of childhood maltreatment (Dixon et al., 2005; Dadds et al., 2003), with psychologists emphasising the ability to perspective-take and empathise as important characteristics for positive parenting (Rodriguez et al., 2012). However, one difficulty with working with families where abuse and/or neglect are occurring is how to achieve the aims in a safe, constructive environment. In our study, IVR was used to place parents in the position of a child, in order to assess impact on development of understanding, perspective-taking and empathy. We reported a study that was conducted with 21 non-high risk (control groups) mothers, who were embodied as a 4-y-old child, experienced from 1PP and with virtual and real body movements synchronised. They interacted with a "mother" virtual character, who responded either appropriately, by being loving and caring, or inappropriately by giving a negative reaction, and being abrupt. Overall, the results revealed that it is possible to use IVR to enable mothers to take the perspective of a child, and to create temporarily feelings of empathy. The evidence was supported by responses to both subjective and physiological measurements. We argued that, although further research is required to assess the effectiveness of such methods, and that it is essential to first consider a number of factors before exploring this avenue further, any improvement in empathy that leads to a change in parenting behaviour has the potential to impact on the quality of life of families and the society overall. Furthermore, this application has the potential to aid not only current but also prospective parents, including child, elderly, mental-health and other carers to better understand one's needs, and develop feelings of empathy.

In an additional study, following the results from the *Virtual Child* and *Illusory Speaking* experiments, we aimed to explore what happens when an adult embodied in a child body speaks, but they hear their own voice transformed into that of a child (Tajadura-Jiménez et al., 2017). Previous studies suggest that the sounds that are produced by one's body are used to update the represented body appearance, and that these changes may lead to alterations in behaviour and emotional state. For example, it has been shown that modifying the sounds produced by one's body while walking or when interacting with different objects, results in changes in one's perceived body size, weight, and arm length or strength (Tajadura-jiménez et al., 2015; Tajadura-Jiménez et al., 2012b). In our study, we explored the extent to which auditory feedback of one's own vocal production—real or child-like—in combination with the type of body self-representation experienced from 1PP—child or adult—can influence perception and implicit attitudes. We conducted a mixed-groups counterbalanced experiment following the methods and procedures described in the *Virtual Child* study in Chapter 4. An additional condition "Voice" was designed as a between-groups factor, and referred to whether participants received real-time feedback of their own voice while speaking, or a modified version of their voice that matched that of a child in terms of frequency. The results first replicated the findings reported in Banakou et al. (2013), showing that embodying the virtual child body made participants estimate the objects as being larger, while associating themselves with child-like attributes. Although there was no effect of the voice on any of the subjective (questionnaire) responses, there was an effect on the vocal reproduction, which is in line with the findings of Banakou and Slater (2014). It was also found that the direction of the adaptation depended on whether the heard child voice was congruent or incongruent with the age of the virtual body. Additionally, the results revealed a positive impact of the illusion of having a child body on feeling younger and happier, with previous studies having already argued the impact of body-representation on emotional state and self-esteem (Tajadura-jiménez et al., 2015; Carruthers, 2008). This finding opens up possibilities for applications in health and rehabilitation seeking to increase the confidence about one's body, while providing alternatives to medication treatments in clinical cases.

To conclude, we have demonstrated through our experimental work the great potential of illusory body ownership using embodiment in virtual reality for the study of body and action perception, and for its impact on behaviours and higher-level cognitive processing. The flexibility and ease-of-use of immersive virtual reality systems render them compelling tools to explore new body features but also people's behaviours and responses to situations that would otherwise be difficult or impossible to investigate in physical reality. Although many aspects of our research still remain to be taken forward, and more work is needed in order to extend and strengthen the knowledge in the relative fields, this research can contribute to tackle pending questions, and serve a guide for future research.

References

Adler, D., Herbelin, B., Similowski, T., and Blanke, O. (2014). Breathing and sense of self: Visuorespiratory conflicts alter body self-consciousness. *Respiratory Physiology & Neurobiology*, pages 1–7. 21

Altschuler, E. L. and Ramachandran, V. S. (2007). A simple method to stand outside oneself. *Perception*, 36(4):632–634. 12

Ames, D. L., Jenkins, A. C., Banaji, M. R., and Mitchell, J. P. (2008). Taking another person's perspective increases self-referential neural processing. *Psychological science*, 19(7):642–4. 94

Armel, K. C. and Ramachandran, V. S. (2003). Projecting sensations to external objects: evidence from skin conductance response. In *Proceedings of the Royal Society of London Series B-Biological Sciences*, volume 270, pages 1499–1506. 9, 16, 19

Aspell, J. E., Heydrich, L., Marillier, G., Lavanchy, T., Herbelin, B., and Blanke, O. (2013). Turning Body and Self Inside Out: Visualized Heartbeats Alter Bodily Self-Consciousness and Tactile Perception. *Psychological Science*. 21

Austen, E. L., Soto-Faraco, S., Enns, J. T., and Kingstone, A. (2004). Mislocalizations of touch to a fake hand. *Cognitive, affective & behavioral neuroscience*, 4(2):170–81. 19

Bam, D. J. (1972). Self-perception theory. *Advances in Experimental Social Psychology*, 6:1–62. 25, 82

Banakou, D., Groten, R., and Slater, M. (2013). Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. *Proceedings of the National Academy of Sciences*, 110(31):12846–12851. 51, 106, 135

Banakou, D., Hanumanthu, P. D., and Slater, M. (2016). Virtual Embodiment of White People in a Black Virtual Body Leads to a Sustained Reduction in their Implicit Racial Bias. *Frontiers in Human Neuroscience*, 10(601). 81

Banakou, D. and Slater, M. (2014). Body ownership causes illusory self-attribution of speaking and influences subsequent real speaking. *Proceedings of the National Academy of Sciences of the United States of America*, 111(49):17678–17683. 135

Banissy, M. J. and Ward, J. (2013). Mechanisms of self-other representations and vicarious experiences of touch in mirror-touch synesthesia. *Frontiers in human neuroscience*, 7(April):112. 122, 123

Bargh, J. a., McKenna, K. Y. a., and Fitzsimons, G. M. (2002). Can You See the Real Me? Activation and Expression of the "True Self" on the Internet. *Journal of Social Issues*, 58(1):33–48. 26

Barnsley, N., McAuley, J. H., Mohan, R., Dey, A., Thomas, P., and Moseley, G. L. (2011). The rubber hand illusion increases histamine reactivity in the real arm. *Current Biology*, 23(6):R945–R946. 17

Berlucchi, G. and Aglioti, S. M. (1997). The body in the brain: neural bases of corporeal awareness. *Trends in neurosciences*, 20(12):560–4. 7

Biocca, F. (1997). The cyborg's dilemma: embodiment in virtual environments. *Proceedings Second International Conference on Cognitive Technology Humanizing the Information Age*, pages 12–26. 8

Blakemore, S.-J. and Frith, C. (2003). Self-awareness and action. *Current Opinion in Neurobiology*, 13(2):219–224. 102

Blakemore, S. J., Smith, J., Steel, R., Johnstone, C. E., and Frith, C. D. (2000). The perception of self-produced sensory stimuli in patients with auditory hallucinations and passivity experiences: evidence for a breakdown in self-monitoring. *Psychological medicine*, 30(5):1131–9. 33

Blakemore, S. J., Wolpert, D. M., and Frith, C. D. (2002). Abnormalities in the awareness of action. *Trends in cognitive sciences*, 6(6):237–242. 27, 32, 120

Blanke, O., Landis, T., Spinelli, L., and Seeck, M. (2004). Out-of-body experience and autoscopy of neurological origin. *Brain : a journal of neurology*, 127(Pt 2):243–58. 11

Blanke, O. and Metzinger, T. (2009). Full-body illusions and minimal phenomenal selfhood. *Trends in cognitive sciences*, 13(1):7–13. 7, 8

Blanke, O. and Mohr, C. (2005). Out-of-body experience, heautoscopy, and autoscopic hallucination of neurological origin: Implications for neurocognitive mechanisms of corporeal awareness and self-consciousness. *Brain Research Reviews*, 50(1):184–199. 11

Blanke, O., Slater, M., and Serino, A. (2015). Behavioral, Neural, and Computational Principles of Bodily Self-Consciousness. *Neuron*, 88(1):145–166. 7

Blom, K. J., Arroyo-Palacios, J., and Slater, M. (2014). The effects of rotating the self out of the body in the full virtual body ownership illusion. *Perception*, 43(4):275–294. 44

Boersma, P. (2001). Praat, a system for doing phonetics by computer. *Glot International*, 5(9/10):341–345. 111

Borland, D., Peck, T., and Slater, M. (2013). An evaluation of self-avatar eye movement for virtual embodiment. *IEEE transactions on visualization and computer graphics*, 19(4):591–6. 105

Botvinick, M. M. and Cohen, J. (1998). Rubber hands 'feel' touch that eyes see. *Nature*, 391(6669):756. 1, 8, 15, 17, 31, 111

Bourdin, P., Barberia, I., Oliva, R., and Slater, M. (2017). A Virtual Out-of-Body Experience Reduces Fear of Death. *Plos One*, 12(1):e0169343. 13

Braun, N., Thorne, J. D., Hildebrandt, H., and Debener, S. (2014). Interplay of Agency and Ownership: The Intentional Binding and Rubber Hand Illusion Paradigm Combined. *Plos One*, 9(11):e111967. 9, 31

Brugger, P. (2002). Reflective mirrors: perspective-taking in autoscopic phenomena. *Cognitive neuropsychiatry*, 7(3):179–194. 11

Bufalari, I., Lenggenhager, B., Porciello, G., Serra Holmes, B., and Aglioti, S. M. (2014). Enfacing others but only if they are nice to you. *Frontiers in behavioral neuroscience*, 8(March):102. 9

Burin, D., Livelli, A., Garbarini, F., Fossataro, C., Folegatti, A., Gindri, P., and Pia, L. (2015). Are Movements Necessary for the Sense of Body Ownership? Evidence from the Rubber Hand Illusion in Pure Hemiplegic Patients. *Plos One*, 10(3):e0117155. 30

Burnett, T. A., Freedland, M. B., Larson, C. R., and Hain, T. i. C. (1998). Voice F0 responses to manipulations in pitch feedback. *The Journal of the Acoustical Society of America*, 103(6):3153–61. 32, 103, 124, 125

Butz, M. V., Kutter, E. F., and Lorenz, C. (2014). Rubber hand illusion affects joint angle perception. *Plos One*, 9(3). 19

Carruthers, G. (2008). Types of body representation and the sense of embodiment. *Consciousness and cognition*, 17(4):1302–16. 135

Chambon, V. and Haggard, P. (2012). Sense of control depends on fluency of action selection, not motor performance. *Cognition*, 125(3):441–451. 28

Chartrand, T. L. and Bargh, J. A. (1999). Chartrand-chameleon effect.pdf. *Journal of personality and social psychology*, 76(6):893–910. 123

Connie Cahill (1996). Psychotic Experiences Induced in Deluded Patients Using Distorted Auditory Feedback. *Cognitive Neuropsychiatry*, 1(3):201–211. 33

Costantini, M. and Haggard, P. (2007). The rubber hand illusion: sensitivity and reference frame for body ownership. *Consciousness and cognition*, 16(2):229–40. 8, 9, 17, 19

Crea, S., DAlonzo, M., Vitiello, N., and Cipriani, C. (2015). The rubber foot illusion. *Journal of NeuroEngineering and Rehabilitation*, 12(1):77. 9

Dadds, M. R., Mullins, M. J., McAllister, R. a., and Atkinson, E. (2003). Attributions, affect, and behavior in abuse-risk mothers: a laboratory study. *Child abuse & neglect*, 27(1):21–45. 134

Daprati, E., Franck, N., Georgieff, N., Proust, J., Pacherie, E., Dalery, J., and Jeannerod, M. (1997). Looking for the agent: an investigation into consciousness of action and self-consciousness in schizophrenic patients. *Cognition*, 65(1):71–86. 29

de Vignemont, F. (2011). Embodiment, ownership and disownership. *Consciousness and cognition*, 20(1):82–93. 7, 10

Della Sala, S. (2005). The Anarchic Hand. *October*, 18(10):606–609. 30

Dixon, L., Browne, K., and Hamilton-Giachritsis, C. (2005). Risk factors of parents abused as children: a mediational analysis of the intergenerational continuity of child maltreatment (Part I). *Journal of Child Psychology and Psychiatry*, 46(1):47–57. 133

Dobricki, M. and Mohler, B. J. (2015). Self-identification with another's body alters self-other face distinction. *Perception*, 44(7):814–820. 9

Dummer, T., Picot-Annand, A., Neal, T., and Moore, C. (2009). Movement and the rubber hand illusion. *Perception*, 38(2):271–280. 1, 18, 45

Ehrsson, H. (2012). The Concept of Body Ownership and Its Relation to Multisensory Integration. In E, S. B., editor, *The New Handbook of Multisensory Processes*, pages 775–792. Cambridge,MA:MIT Press. 22

Ehrsson, H. H. (2007). The experimental induction of out-of-body experiences. *Science (New York, N.Y.)*, 317(5841):1048. 7, 8, 11, 12

Ehrsson, H. H. (2009). How many arms make a pair? Perceptual illusion of having an additional limb. *Perception*, 38(2):310–312. 16, 21

Ehrsson, H. H., Kito, T., Sadato, N., Passingham, R. E., and Naito, E. (2005). Neural substrate of body size: illusory feeling of shrinking of the waist. *Plos biology*, 3(12):e412. 10

Ehrsson, H. H., Spence, C., and Passingham, R. E. (2004). That's my hand! Activity in premotor cortex reflects feeling of ownership of a limb. *Science (New York, N.Y.)*, 305(5685):875–7. 9, 19

Ehrsson, H. H., Wiech, K., Weiskopf, N., Dolan, R. J., and Passingham, R. E. (2007). Threatening a rubber hand that you feel is yours elicits a cortical anxiety response. *Proceedings of the National Academy of Sciences of the United States of America*, 104(23):9828–33. 16

Ekehammar, B., Akrami, N., and Araya, T. (2003). Gender differences in implicit prejudice. *Personality and Individual Differences*, 34(8):1509–1523. 99

Farrer, C., Franck, N., Georgieff, N., Frith, C. D., Decety, J., and Jeannerod, M. (2003). Modulating the experience of agency: A positron emission tomography study. *NeuroImage*, 18(2):324–333. 29, 31

Farrer, C., Frey, S. H., Van Horn, J. D., Tunik, E., Turk, D., Inati, S., and Grafton, S. T. (2008). The angular gyrus computes action awareness representations. *Cerebral Cortex*, 18(2):254–261. 31

Foster, M. E. (2007). Enhancing Human-Computer Interaction with Embodied Conversational Agents. In *Proceedings of the 4th international conference on Universal access in human-computer interaction: ambient interaction*, pages 828–837. Springer-Verlag Berlin, Heidelberg. 7

Fox, J., Bailenson, J. N., and Binney, J. (2009). Virtual Experiences, Physical Behaviors: The Effect of Presence on Imitation of an Eating Avatar. *Presence: Teleoperators and Virtual Environments*, 18(4):294–303. 23

Frith, C. D., Blakemore, S. J., and Wolpert, D. M. (2000). Abnormalities in the awareness and control of action. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 355(1404):1771–88. 27, 32

Gallagher, S. (2000). Philosophical conceptions of the self: Implications for cognitive science. *Trends in Cogn. Sci*, 4:14–21. 30, 118

Gallagher, S. (2012). Multiple aspects in the sense of agency. *New Ideas in Psychology*, 30(1):15–31. 30, 118

García, C., Tapias, D., and Vargas, C. E. (2000). La frecuencia fundamental de la voz y sus efectos en el reconocimiento de habla continua. *Procesamiento del lenguaje natural*, 26:163–168. 106

Gillies, M. and Spanlang, B. (2010). Comparing and Evaluating Real Time Character Engines for Virtual Environments. *Presence: Teleoperators and Virtual Environments*, 19(2):95–117. 40, 54, 104

Goldberg, G., Mayer, N. H., and Toglia, J. U. (1981). Medial frontal cortex infarction and the alien hand sign. *Archives of neurology*, 38(11):683–686. 30

Goldstein, B. E. (2010). *Sensation and Perception*. Cengage Learning, CA, USA, 8th edition. 53

González-Franco, M., Peck, T. C., Rodríguez-Fornells, A., and Slater, M. (2013). A threat to a virtual hand elicits motor cortex activation. *Experimental Brain Research*. 16, 51

González-franco, M., Pérez-marcos, D., Spanlang, B., and Slater, M. (2010). The Contribution of Real-Time Mirror Reflections of Motor Actions on Virtual Body Ownership in an Immersive Virtual Environment. *Virtual Reality Conference (VR), 2010 IEEE*, pages 111–114. 69

Graziano, M. S. A. and Botvinick, M. M. (2002). How the brain represents the body: insights from neurophysiology and psychology. In Prinz, W. and Hommel, B., editors, *Common Mechanisms in Perception and Action: Attention and Performance*, volume 19, pages 136–157. Oxford University Press, Oxford, xix edition. 7

Grechkin, T. Y., Nguyen, T. D., Plumert, J. M., Cremer, J. F., and Kearney, J. K. (2010). How does presentation method and measurement protocol affect distance estimation in real and virtual environments? *ACM Transactions on Applied Perception*, 7(4):26. 47, 108, 126

Greenwald, A., Poehlman, T. A., Uhlmann, E., and Banaji, M. R. (2009). Understanding and using the Implicit Association Test: III.\nMeta-analysis of predictive validity. *Journal of Personality and Social Psychology*, 97(1):17–41. 95

Greenwald, A. G. (2006). Implicit Bias : Scientific Foundations Implicit Bias : Scientific Foundations. *California Law Review*, 94(4):945–967. 95

Greenwald, A. G., McGhee, D. E., and Schwartz, J. L. (1998). Measuring individual differences in implicit cognition: the implicit association test. *Journal of personality and social psychology*, 74(6):1464–1480. 25, 86, 87

Greenwald, A. G. and Nosek, B. A. (2001). Health of the implicit association test at age 3. *Zeitschrift Fur Experimentelle Psychologie*, 48(2):85–93. 91

Greenwald, A. G., Nosek, B. A., and Banaji, M. R. (2003). Understanding and using the Implicit Association Test: I. An improved scoring algorithm. *Journal of Personality and Social Psychology*, 85(2):197–216. 64, 86

Groom, V., Bailenson, J. N., and Nass, C. (2009). The influence of racial embodiment on racial bias in immersive virtual environments. *Social Influence*, 4(3):231–248. 24, 25, 83, 94

Guterstam, A., Petkova, V. I., and Ehrsson, H. H. (2011). The illusion of owning a third arm. *Plos One*, 6(2):e17208. 11, 21

Haans, A., Ijsselsteijn, W. a., and de Kort, Y. a. W. (2008). The effect of similarities in skin texture and hand shape on perceived ownership of a fake limb. *Body image*, 5(4):389–94. 9, 20

Haggard, P. (2005). Conscious intention and motor cognition. *Trends in cognitive sciences*, 9(6):290–5. 27, 28

Haggard, P., Clark, S., and Kalogeras, J. (2002). Voluntary action and conscious awareness. *Nature neuroscience*, 5(4):382–5. 28, 102

Haggard, P. and Cole, J. (2007). Intention, attention and the temporal experience of action. *Consciousness and Cognition*, 16(2):211–220. 27

Hamilton-Giachritsis, C., Banakou, D., Giachritsis, C., and Slater, M. (2017). Improving maternal empathy and perspective-taking with virtual embodiment. *(Submitted)*. 133

Heed, T., Gründler, M., Rinkleib, J., Rudzik, F. H., Collins, T., Cooke, E., and O'regan, J. K. (2011). Visual information and rubber hand embodiment differentially affect reach-to-grasp actions. *Acta Psychologica*, 138(1):263–271. 21

Hershfield, H. E., Goldstein, D. G., Sharpe, W. F., Fox, J., Yeykelis, L., Carstensen, L. L., and Bailenson, J. N. (2011). Increasing Saving Behavior Through Age-Progressed Renderings of the Future Self. *Journal of Marketing Research (JMR)*, 48(Special Issue 2011). 23, 52

Hogeveen, J. and Obhi, S. S. (2012). Social Interaction Enhances Motor Resonance for Observed Human Actions. *Journal of Neuroscience*, 32(17):5984–5989. 123

Hohwy, J. and Paton, B. (2010). Explaining away the body: experiences of supernaturally caused touch and touch on non-hand objects within the rubber hand illusion. *Plos One*, 5(2):e9416. 9, 20

Holmes, N. P. and Spence, C. (2006). Beyond the body schema: Visual, prosthetic, and technological contributions to bodily perception and awareness. In Knoblich, G., Thornton, I., Grosjean, M., and Shiffrar, M., editors, *Human body perception from the inside out*, pages 15–64. Oxford University Press, Oxford. 8

Holz, T., Dragone, M., and O' Hare, G. M. P. (2009). Where Robots and Virtual Agents Meet. *International Journal of Social Robotics*, 1(1):83–93. 7

Houde, J. F. and Jordan, M. I. (1998). Sensorimotor Adaptation in Speech Production. *Science*, 279(5354):1213–1216. 32

Ionta, S., Sforza, A., Funato, M., and Blanke, O. (2012). Anatomically plausible illusory posture affects mental rotation of body parts. *Cognitive, Affective, & Behavioral Neuroscience*, pages 197–209. 19

Jahnke, R., Larkey, L., Rogers, C., Etnier, J., and Lin, F. (2010). A comprehensive review of health benefits of qigong and tai chi. *American journal of health promotion : AJHP*, 24(6). 98

Jeannerod, M. (2003). The mechanism of self-recognition in humans. *Behavioural Brain Research*, 142(1-2):1–15. 30

Jenkinson, P. M. and Preston, C. (2015). New reflections on agency and body ownership: The moving rubber hand illusion in the mirror. *Consciousness and Cognition*, 33:432–442. 31

Johansson, P., Hall, L., Sikström, S., and Olsson, A. (2005). Failure to detect mismatches between intention and outcome in a simple decision task. *Science (New York, N.Y.)*, 310(5745):116–119. 29

Johns, L. C., Gregg, L., Allen, P., and McGuire, P. K. (2006). Impaired verbal self-monitoring in psychosis: effects of state, trait and diagnosis. *Psychol Med.*, 36(4):465–474. 33

Johns, L. C., Rossell, S., Frith, C., Ahmad, F., Hemsley, D., Kuipers, E., and McGUIRE, P. K. (2001). Verbal self-monitoring and auditory verbal hallucinations in patients with schizophrenia. *Psychological Medicine*, 31(04):705–715. 33

Jones, J. A. and Munhall, K. G. (2000). Perceptual calibration of F0 production: evidence from feedback perturbation. *The Journal of the Acoustical Society of America*, 108(3 Pt 1):1246–51. 32, 124, 125

Jost, J. T., Rudman, L. A., Blair, I. V., Carney, D. R., Dasgupta, N., Glaser, J., and Hardin, C. D. (2009). The existence of implicit bias is beyond reasonable doubt: A refutation of ideological and methodological objections and executive summary of ten studies that no manager should ignore. *Research in Organizational Behavior*, 29:39–69. 95

Kalckert, A. and Ehrsson, H. H. (2012). Moving a Rubber Hand that Feels Like Your Own: A Dissociation of Ownership and Agency. *Frontiers in human neuroscience*, 6(March):40. 18, 31, 45, 106, 119

Kalckert, A. and Ehrsson, H. H. (2014a). The moving rubber hand illusion revisited: comparing movements and visuotactile stimulation to induce illusory ownership. *Consciousness and cognition*, 26:117–32. 106

Kalckert, A. and Ehrsson, H. H. (2014b). The spatial distance rule in the moving and classical rubber hand illusions. *Consciousness and cognition*, 30C:118–132. 19

Kammers, M. P. M., Longo, M. R., Tsakiris, M., Chris Dijkerman, H., and Haggard, P. (2009). Specificity and coherence of body representations. *Perception*, 38(12):1804–1820. 18

Kilteni, K. (2015). Over my fake body: body ownership illusions for studying the multisensory basis of own-body perception. *Frontiers in Human Neuroscience*, 9(March). 18, 118

Kilteni, K., Bergstrom, I., and Slater, M. (2013). Drumming in immersive virtual reality: the body shapes the way we play. *IEEE transactions on visualization and computer graphics*, 19(4):597–605. xv, 24, 39, 74

Kilteni, K., Normand, J.-M., Sanchez-Vives, M. V., and Slater, M. (2012). Extending body space in immersive virtual reality: a very long arm illusion. *Plos One*, 7(7):e40867. 14, 18, 20, 21, 44, 51, 71

Kokkinara, E., Kilteni, K., Blom, K. J., and Slater, M. (2016). First Person Perspective of Seated Participants Over a Walking Virtual Body Leads to Illusory Agency Over the Walking. *Scientific Reports*, 6(July 2015):28879. 29

Kokkinara, E. and Slater, M. (2014). Measuring the effects through time of the influence of visuomotor and visuotactile synchronous stimulation on a virtual body ownership illusion. *Perception*, 43(1):43–58. xv, 18, 31, 42, 44, 51, 106, 125, 132

Lackner, J. R., Graybiel, A., and Orientation, S. (1988). Some proprioceptive influences on the perceptual representation of body shape and orientation. *Brain*, 111(2):281–297. 10

Lai, C. K., Marini, M., Lehr, S. A., Cerruti, C., Shin, J.-E. L., Joy-Gaba, J. A., Ho, A. K., Teachman, B. A., Wojcik, S. P., Koleva, S. P., Frazier, R. S., Heiphetz, L., Chen, E. E., Turner, R. N., Haidt, J., Kesebir, S., Hawkins, C. B., Schaefer, H. S., Rubichi, S., Sartori, G., Dial, C. M., Sriram, N., Banaji, M. R., and Nosek, B. A. (2014). Reducing implicit racial preferences: I. A comparative investigation of 17 interventions. *Journal of Experimental Psychology: General*, 143(4):1765–1785. 81, 94

Lai, C. K., Skinner, A. L., Cooley, E., Murrar, S., Brauer, M., Devos, T., Calanchini, J., Xiao, Y. J., Pedram, C., Marshburn, C. K., Simon, S., Blanchar, J. C., Joy-Gaba, J. A., Conway, J., Redford, L., Klein, R. A., Roussos, G., Schellhaas, F. M. H., Burns, M., Hu, X., McLean, M. C., Axt, J. R., Asgari, S., Schmidt, K., Rubinstein, R., Marini, M., Rubichi, S., Shin, J.-E. L., and Nosek, B. A. (2016). Reducing Implicit Racial Preferences: II. Intervention Effectiveness Across Time. *Journal of Experimental Psychology: General*, 145(8):1001–1016. 82, 94

Lanier, J. (2010). *You Are Not a Gadget: A Manifesto*, volume 30. New York. 69, 72

Larson, C. R., Burnett, T. A., Kiran, S., and Hain, T. i. C. (2000). Effects of pitch-shift velocity on voice Fo responses. *The Journal of the Acoustical Society of America*, 107(1):559–64. 124, 125

Lenggenhager, B., Mouthon, M., and Blanke, O. (2009). Spatial aspects of bodily self-consciousness. *Consciousness and cognition*, 18(1):110–7. 12

Lenggenhager, B., Tadi, T., Metzinger, T., and Blanke, O. (2007). Video ergo sum: manipulating bodily self-consciousness. *Science (New York, N.Y.)*, 317(5841):1096–9. 8, 12, 20

Leube, D. T., Knoblich, G., Erb, M., Grodd, W., Bartels, M., and Kircher, T. T. J. (2003). The neural correlates of perceiving one's own movements. *NeuroImage*, 20(4):2084–2090. 31

Lewis, E. and Lloyd, D. M. (2010). Embodied experience: A first-person investigation of the rubber hand illusion. *Phenomenology and the Cognitive Sciences*, 9(3):317–339. 9

Libet, B., Gleason, C. A., Wright, E. W., and Pearl, D. K. (1983). Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential): The unconscious initiation of a freely voluntary act. *Brain*, 106(3):623. 28

Limanowski, J., Lutti, A., and Blankenburg, F. (2013). The extrastriate body area is involved in illusory limb ownership. *NeuroImage*. 18

Linkenauger, S. A., Leyrer, M., Bülthoff, H. H., and Mohler, B. J. (2013). Welcome to Wonderland: The Influence of the Size and Shape of a Virtual Hand On the Perceived Size and Shape of Virtual Objects. *Plos One*, 8(7):e68594. 21

Linkenauger, S. a., Ramenzoni, V., and Proffitt, D. R. (2010). Illusory shrinkage and growth: body-based rescaling affects the perception of size. *Psychological science*, 21(9):1318–25. 53

Llobera, J., Sanchez-Vives, M. V., and Slater, M. (2013). The relationship between virtual body ownership and temperature sensitivity. *Journal of the Royal Society, Interface / the Royal Society*, 10(85):20130300. 17, 18, 44, 74

Lloyd, D. M. (2007). Spatial limits on referred touch to an alien limb may reflect boundaries of visuo-tactile peripersonal space surrounding the hand. *Brain and cognition*, 64(1):104–9. 9, 19

Longo, M. R., Kammers, M. P. M., Gomi, H., Tsakiris, M., and Haggard, P. (2009). Contraction of body representation induced by proprioceptive conflict. *Current biology : CB*, 19(17):R727–8. 10

Longo, M. R., Schüür, F., Kammers, M. P. M., Tsakiris, M., and Haggard, P. (2008). What is embodiment? A psychometric approach. *Cognition*, 107(3):978–98. 18, 119

Lueke, A. and Gibson, B. (2015). Lueke-Mindfulness Meditation Reduces Implicit Age and Race Bias.pdf. *Social Psychological and Personality Science*, 6(3):284–291. 98

Lueke, A. and Gibson, B. (2016). Brief Mindfulness Meditation Reduces Discrimination. *Psychology of Consciousness: Theory, Research, and Practice*, 3(1):34–44. 98

Ma, K. and Hommel, B. (2015). The role of agency for perceived ownership in the virtual hand illusion. *Consciousness and Cognition*, 36:277–288. 31

Maister, L., Banissy, M. J., and Tsakiris, M. (2013a). Mirror-touch synaesthesia changes representations of self-identity. *Neuropsychologia*, 51(5):802–808. 123

Maister, L., Sebanz, N., Knoblich, G., and Tsakiris, M. (2013b). Experiencing ownership over a dark-skinned body reduces implicit racial bias. *Cognition*, 128(2):170–178. 25, 74, 83, 128

Maister, L., Slater, M., Sanchez-Vives, M. V., and Tsakiris, M. (2015). Changing bodies changes minds: owning another body affects social cognition. *Trends in Cognitive Sciences*, 19(1):6–12. 17, 97

Marcel, A. J. (2003). The sense of agency: Awareness and ownership of actions and intentions. In Roessler, J. and Eilan, N., editors, *Agency and Self-Awareness: Issues in Philosophy and Psychology*, pages 48–93. Oxford University Press, Oxford. 30

Marino, B. F. M., Stucchi, N., Nava, E., Haggard, P., and Maravita, A. (2010). Distorting the visual size of the hand affects hand pre-shaping during grasping. *Experimental Brain Research*, 202(2):499–505. 53

Maselli, A., Kilteni, K., López-moliner, J., and Slater, M. (2016). The sense of body ownership relaxes temporal constraints for multisensory integration. *Scientific Reports*, 6(30628):1–9. 118

Maselli, A. and Slater, M. (2013). The building blocks of the full body ownership illusion. *Frontiers in human neuroscience*, 7(March):83. xv, 9, 18, 19, 20, 39, 44, 51, 118, 125

Maselli, A. and Slater, M. (2014). Sliding perspectives: dissociating ownership from self-location during full body illusions in virtual reality. *Frontiers in Human Neuroscience*, 8(September):1–19. 19

Merleau-Ponty, M. (2013). *Phenomenology of Perception*. Routledge Classics. 1, 53

Metcalfe, J. and Greene, M. J. (2007). Metacognition of agency. *Journal of experimental psychology. General*, 136(2):184–199. 29

Metzinger, T. (2008). Empirical perspectives from the self-model theory of subjectivity: a brief summary with examples. *Progress in brain research*, 168(07):215–45. 7

Michel, C., Velasco, C., Salgado-Montejo, A., and Spence, C. (2014). The Butchers Tongue Illusion. *Perception*, 43(8):818–824. 9

Moseley, G. L., Gallace, A., and Spence, C. (2012). Bodily illusions in health and disease: physiological and clinical perspectives and the concept of a cortical 'body matrix'. *Neuroscience and biobehavioral reviews*, 36(1):34–46. 74, 95

Moseley, G. L., Olthof, N., Venema, A., Don, S., Wijers, M., Gallace, A., and Spence, C. (2008). Psychologically induced cooling of a specific body part caused by the illusory ownership of an artificial counterpart. *Proceedings of the National Academy of Sciences of the United States of America*, 105(35):13169–73. 16

Naito, E. and Ehrsson, H. H. (2001). Kinesthetic illusion of wrist movement activates motor-related areas. *Neuroreport*, 12(17):3805–9. 10

Naito, E., Ehrsson, H. H., Geyer, S., Zilles, K., and Roland, P. E. (1999). Illusory arm movements activate cortical motor areas: a positron emission tomography study. *The Journal of neuroscience : the official journal of the Society for Neuroscience*, 19(14):6134–44. 10

Newport, R., Pearce, R., and Preston, C. (2010). Fake hands in action: Embodiment and control of supernumerary limbs. *Experimental Brain Research*, 204(3):385–395. 21

Noe, A. (2004). *Action in Perception*. MIT Press, London, UK. 69, 71

Normand, J.-M., Giannopoulos, E., Spanlang, B., and Slater, M. (2011). Multisensory stimulation can induce an illusion of larger belly size in immersive virtual reality. *Plos One*, 6(1):e16128. 1, 15, 51, 71

Nosek, B. A., Greenwald, A. G., and Banaji, M. R. (2005). Understanding and using the Implicit Association Test: II. Method variables and construct validity. *Personality & social psychology bulletin*, 31(2):166–80. 62, 88

Nosek, B. A., Greenwald, A. G., and Banaji, M. R. (2007). The Implicit Association Test at Age 7: a Methodological and Conceptual Review. In Bargh, J. A., editor, *Social Psychology and the Unconscious: The Automaticity of Higher Mental Processes*, page 265. Psychology Press, New York. 62, 88

Osimo, S. A., Pizarro, R., Spanlang, B., and Slater, M. (2015). Conversations between self and self as Sigmund FreudA virtual body ownership paradigm for self counselling. *Scientific Reports*, 5(July):13899. 1

Padilla-Castañeda, M., Frisoli, A., Pabon, S., and Bergamasco, M. (2014). The Modulation of Ownership and Agency in the Virtual Hand Illusion under Visuotactile and Visuomotor Sensory Feedback. *presence*, 23(2):1–17. 13, 18

Pan, Y. and Steed, A. (2016). A Comparison of Avatar-, Video-, and Robot-Mediated Interaction on Users' Trust in Expertise. *Frontiers in Robotics and AI*, 3(March):1–12. 20

Pavani, F. and Zampini, M. (2007). The role of hand size in the fake-hand illusion paradigm. *Perception*, 36(10):1547–1554. 19, 21

Peña, J., Hancock, J. T., and Merola, N. A. (2009). The Priming Effects of Avatars in Virtual Settings. *Communication Research*, 36(6):838–856. 24, 72

Peña, J. and Kim, E. (2014). Increasing exergame physical activity through self and opponent avatar appearance. *Computers in Human Behavior*, 41:262–267. 23

Peck, T. C., Seinfeld, S., Aglioti, S. M., and Slater, M. (2013). Putting yourself in the skin of a black avatar reduces implicit racial bias. *Consciousness and cognition*, 22(3):779–787. 1, 15, 20, 25, 74, 82, 90, 92, 93, 94, 95, 106, 128

Perez-Marcos, D., Sanchez-Vives, M. V., and Slater, M. (2012). Is my hand connected to my body? The impact of body continuity and arm alignment on the virtual hand illusion. *Cognitive Neurodynamics*, 6(4):295–305. 44

Petkova, V. I. and Ehrsson, H. H. (2008). If I were you: perceptual illusion of body swapping. *Plos One*, 3(12):e3832. 1, 8, 11, 16, 20, 71

Petkova, V. I., Khoshnevis, M., and Ehrsson, H. H. (2011). The perspective matters! Multisensory integration in ego-centric reference frames determines full-body ownership. *Frontiers in psychology*, 2(March):35. 7, 11, 19

Pettigrew, T. F. and Tropp, L. R. (2006). A meta-analytic test of intergroup contact theory. *Journal of personality and social psychology*, 90(5):751–783. 91

Pfeiffer, C., Lopez, C., Schmutz, V., Duenas, J. A., Martuzzi, R., and Blanke, O. (2013). Multisensory origin of the subjective first-person perspective: visual, tactile, and vestibular mechanisms. *Plos One*, 8(4):e61751. 13

Piryankova, I. V., Wong, H. Y., Linkenauger, S. a., Stinson, C., Longo, M. R., Bülthoff, H. H., and Mohler, B. J. (2014). Owning an overweight or underweight body: distinguishing the physical, experienced and virtual body. *Plos One*, 9(8):e103428. 15

Preston, C. (2013). The role of distance from the body and distance from the real hand in ownership and disownership during the rubber hand illusion. *Acta psychologica*, 142(2):177–83. 19

Preston, C. and Newport, R. (2012). How long is your arm? Using multisensory illusions to modify body image from the third person perspective. *Perception*, 41(2):247–249. 20, 21

Proffitt, D. R. (2006). Embodied Perception and the Economy of Action. *Perspectives on Psychological Science*, 1(2):110–122. 69, 71

Ramachandran, V. S. and Hirstein, W. (1998). The perception of phantom limbs. The D. O. Hebb lecture. *Brain*, 121:1603–1630. 1, 10

Ramachandran, V. S., Krause, B., and Case, L. K. (2011). The phantom head. *Perception*, 40(3):367–370. 13

Riemer, M., Bublatzky, F., Trojan, J., and Alpers, G. W. (2015). Defensive activation during the rubber hand illusion: Ownership versus proprioceptive drift. *Biological Psychology*, 109:86–92. 16

Riemer, M., Fuchs, X., Bublatzky, F., Kleinböhl, D., Hölzl, R., and Trojan, J. (2014). The rubber hand illusion depends on a congruent mapping between real and artificial fingers. *Acta psychologica*, 152C:34–41. 9, 18

Rizzolatti, G., Fogassi, L., and Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience*, 2(September):1–10. 27, 123

Rodriguez, C. M., Cook, A. E., and Jedrziewski, C. T. (2012). Reading between the lines: implicit assessment of the association of parental attributions and empathy with abuse risk. *Child abuse & neglect*, 36(7-8):564–71. 134

Rohde, M., Luca, M., and Ernst, M. O. (2011). The rubber hand illusion: Feeling of ownership and proprioceptive drift Do not go hand in hand. *Plos One*, 6(6). 16

Rooth, D.-O. (2010). Automatic associations and discrimination in hiring: Real world evidence. *Labour Economics*, 17(3):523–534. 95

Rosenberg, R. S., Baughman, S. L., and Bailenson, J. N. (2013). Virtual superheroes: using superpowers in virtual reality to encourage prosocial behavior. *Plos One*, 8(1):e55003. 24

Rothermund, K. and Wentura, D. (2004). Underlying processes in the implicit association test: dissociating salience from associations. *Journal of experimental psychology. General*, 133(2):139–165. 97

Salomon, R., Fernandez, N. B., van Elk, M., Vachicouras, N., Sabatier, F., Tychinskaya, A., Llobera, J., and Blanke, O. (2016). Changing motor perception by sensorimotor conflicts and body ownership. *Scientific Reports*, 6(April):25847. 29

Salomon, R., Lim, M., Pfeiffer, C., Gassert, R., and Blanke, O. (2013). Full body illusion is associated with widespread skin temperature reduction. *Frontiers in behavioral neuroscience*, 7(July):65. 17

Sameer, K., González-Franco, M., Hintemüller, C., Kapeller, C., Guger, C., Slater, M., and Blom, K. J. (2014). Comparison of SSVEP BCI and Eye Tracking for Controlling a Humanoid Robot in a Social Environment. *Presence: Teleoperators & Virtual Environments*, 23(3):242–252. 20

Sanchez-Vives, M. V., Spanlang, B., Frisoli, A., Bergamasco, M., and Slater, M. (2010). Virtual hand illusion induced by visuomotor correlations. *Plos One*, 5(4):e10381. 13, 14, 51, 69, 106

Sandlund, E. S. and Norlander, T. (2000). The effects of Tai Chi Chuan relaxation and exercise on stress responses and well-being: An overview of research. *International Journal of Stress Management*, 7(2):139–149. 98

Sato, A. and Yasuda, A. (2005). Illusion of sense of self-agency: discrepancy between the predicted and actual sensory consequences of actions modulates the sense of self-agency, but not the sense of self-ownership. *Cognition*, 94(3):241–55. 30, 119

Schaefer, M., Flor, H., Heinze, H.-J., and Rotte, M. (2007). Morphing the body: illusory feeling of an elongated arm affects somatosensory homunculus. *NeuroImage*, 36(3):700–5. 20

Schaefer, M., Heinze, H. J., and Galazky, I. (2010). Alien hand syndrome: Neural correlates of movements without conscious will. *Plos One*, 5(12). 30

Schimchowitsch, S. and Ohmer, O. (2016). Can we reduce our implicit prejudice toward persons with disability? the challenge of meditation. *International Journal of Disability, Development and Education*, 63(6):641–650. 98

Schnabel, K., Asendorpf, J. B., and Greenwald, A. G. (2008). Using Implicit Association Tests for the Assessment of Implicit Personality Self-concept. In Boyle, G. J., Matthews, G., and Saklofske, D. H., editors, *The SAGE Handbook of Personality Theory and Assessment: Volume 2 Personality Measurement and Testing*, pages 508–528. SAGE Publications Ltd., London, UK. 59, 68

Seth, A. K. (2013). Interoceptive inference, emotion, and the embodied self. *Trends in Cognitive Sciences*, pages 1–9. 21

Skipper, J. I., Nusbaum, H. C., and Small, S. L. (2005). Listening to talking faces: motor cortical activation during speech perception. *NeuroImage*, 25(1):76–89. 119

Slater, M. (2009). Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 364(1535):3549–57. 7

Slater, M., Perez-Marcos, D., Ehrsson, H. H., and Sanchez-Vives, M. V. (2008). Towards a digital body: the virtual arm illusion. *Frontiers in human neuroscience*, 2(August):6. 13

Slater, M., Perez-Marcos, D., Ehrsson, H. H., and Sanchez-Vives, M. V. (2009). Inducing illusory ownership of a virtual body. *Frontiers in neuroscience*, 3(2):214–20. 1, 7

Slater, M., Spanlang, B., Sanchez-Vives, M., and Blanke, O. (2010). First person experience of body transfer in virtual reality. *Plos One*, 5(5):e10564. doi:10.1371/journal.pone.0010564. 14, 51, 71

Snyder, M., Tanke, E. D., and Berscheid, E. (1977). Social perception and interpersonal behavior: On the self-fulfilling nature of social stereotypes. *Journal of Personality and Social Psychology*, 35(9):656–666. 25

Spanlang, B., Navarro, X., Normand, J.-M., Kishore, S., Pizarro, R., and Slater, M. (2013). Real time whole body motion mapping for avatars and robots. *Proceedings of the 19th ACM Symposium on Virtual Reality Software and Technology*, page 175. 20, 40

Spanlang, B., Normand, J.-M., Borland, D., Kilteni, K., Giannopoulos, E., Pomes, A., Gonzalez-Franco, M., Pérez-Marcos, D., Arroyo-Palacios, J., Navarro Muncunill, X., and Slater, M. (2014). How to Build an Embodiment Lab : Achieving Body Representation Illusions in Virtual Reality. *Frontiers in Robotics and AI. Virtual Environments.*, 1(November):1–22. 35, 40, 48

Suzuki, K., Garfinkel, S. N., Critchley, H. D., and Seth, A. K. (2013). Multisensory integration across exteroceptive and interoceptive domains modulates self-experience in the rubber-hand illusion. *Neuropsychologia*, 51(13):2909–2917. 21

Synofzik, M., Vosgerau, G., and Newen, A. (2008). Beyond the comparator model: a multifactorial two-step account of agency. *Consciousness and cognition*, 17(1):219–39. 27

Tajadura-Jiménez, A., Banakou, D., Bianchi-Berthouze, N., and Slater, M. (2017). Embodiment in a Child-Like Talking Virtual Body In uences Object Size Perception, Self-Indentification, and Subsequent Real Speaking. *(Submitted)*. 134

Tajadura-jiménez, A., Basia, M., Deroy, O., Fairhurst, M., Marquardt, N., and Bianchi-berthouze, N. (2015). As light as your footsteps: Altering walking sounds to change perceived body weight, emotional state and gait. *CHI 2015, Crossings*, pages 2943–2952. 134, 135

Tajadura-Jiménez, A., Grehl, S., and Tsakiris, M. (2012a). The other in me: interpersonal multisensory stimulation changes the mental representation of the self. *Plos One*, 7(7):e40682. 9, 21

Tajadura-Jiménez, A., Väljamäe, A., Toshima, I., Kimura, T., Tsakiris, M., and Kitagawa, N. (2012b). Action sounds recalibrate perceived tactile distance. *Current Biology*, 22(13):R516–R517. 21, 134

Tecchia, F., Carrozzino, Marcello Bacinelli, S., Rossi, F., Vercelli, D., Marino, G., Gasparello, P., and Bergamasco, M. (2010). A Flexible Framework for WideSpectrum VR Development. *Presence: Teleoperators and Virtual Environments*, 19(4):302–312. 36, 54, 104

Tsakiris, M. (2008). Looking for myself: current multisensory input alters self-face recognition. *Plos One*, 3(12):e4040. 9

Tsakiris, M. (2010). My body in the brain: a neurocognitive model of body-ownership. *Neuropsychologia*, 48(3):703–12. 17

Tsakiris, M. (2016). The multisensory basis of the self: from body to identity to others. *Quarterly journal of experimental psychology (2006)*, 0218(August):1–28. 7

Tsakiris, M., Carpenter, L., James, D., and Fotopoulou, A. (2010a). Hands only illusion: multisensory integration elicits sense of ownership for body parts but not for non-corporeal objects. *Experimental brain research. Experimentelle Hirnforschung. Expérimentation cérébrale*, 204(3):343–52. 20, 29

Tsakiris, M. and Haggard, P. (2005). The rubber hand illusion revisited: visuotactile integration and self-attribution. *Journal of experimental psychology. Human perception and performance*, 31(1):80–91. 1, 9, 17, 19, 20, 31

Tsakiris, M., Haggard, P., Franck, N., Mainy, N., and Sirigu, A. (2005). A specific role for efferent information in self-recognition. *Cognition*, 96(3):215–31. 17, 20

Tsakiris, M., Longo, M. R., and Haggard, P. (2010b). Having a body versus moving your body: Neural signatures of agency and body-ownership. *Neuropsychologia*, 48(9):2740–9. 18

Tsakiris, M., Prabhu, G., and Haggard, P. (2006). Having a body versus moving your body: How agency structures body-ownership. *Consciousness and cognition*, 15(2):423–32. 16

Tsakiris, M., Schütz-Bosbach, S., and Gallagher, S. (2007). On agency and body-ownership: phenomenological and neurocognitive reflections. *Consciousness and cognition*, 16(3):645–60. 31, 119

Tsakiris, M., Tajadura-Jiménez, A., and Costantini, M. (2011). Just a heart-beat away from one's body: interoceptive sensitivity predicts malleability of body-representations. *Proceedings. Biological sciences / The Royal Society*, 278(1717):2470–6. 9, 21

Van Bavel, J. J. and Cunningham, W. A. (2008). Self-Categorization With a Novel Mixed-Race Group Moderates Automatic Social and Racial Biases. *Personality and Social Psychology Bulletin*, 35(3):321–35. 91

van der Hoort, B., Guterstam, A., and Ehrsson, H. H. (2011). Being Barbie: the size of one's own body determines the perceived size of the world. *Plos One*, 6(5):e20195. 20, 51, 53, 68, 71, 74, 128

van Stralen, H. E., van Zandvoort, M. J. E., Hoppenbrouwers, S. S., Vissers, L. M. G., Kappelle, L. J., and Dijkerman, H. C. (2014). Affective touch modulates the rubber hand illusion. *Cognition*, 131(1):147–158. 21

van Ulzen, N. R., Fiorio, M., and Cesari, P. (2013). Motor resonance evoked by observation of subtle nonverbal behavior. *Social neuroscience*, 8(4):347–55. 123

Vogeley, K. and Fink, G. R. (2003). Neural correlates of the first-person-perspective. *Trends in cognitive sciences*, 7(1):38–42. 73

Wainer, J., Feil-seifer, D., Shell, D., and Mataric, M. (2006). The role of physical embodiment in human-robot interaction. In *ROMAN 2006 - The 15th IEEE International Symposium on Robot and Human Interactive Communication*, pages 117–122. Ieee. 7

Walther, J. B. (1996). Computer-Mediated Communication: Impersonal, Interpersonal, and Hyperpersonal Interaction. *Communication Research*, 23(1):3–43. 26

Wegner, D. M. (2002). *The illusion of conscious will.* MIT Press Books. 27, 28, 102

Wegner, D. M., Sparrow, B., and Winerman, L. (2004). Vicarious Agency: Experiencing Control Over the Movements of Others. *Journal of Personality and Social Psychology*, 86(6):838–848. 121, 122

Wegner, D. M. and Wheatley, T. (1999). Apparent mental causation: Sources of the Experience of Will. *American Psychologist*, 54(7):480–492. 29, 121

Wen, W., Yamashita, A., and Asama, H. (2015). The Sense of Agency during Continuous Action: Performance Is More Important than Action-Feedback Association. *Plos One*, 10(4):e0125226. 27, 29

Wolpert, D. M., Ghahramani, Z., and Jordan, M. I. (1995). An internal model for sensorimotor integration. *Science*, 269(5232):1880–1882. 27

Yee, N. and Bailenson, J. N. (2006). Walk A Mile in Digital Shoes : The Impact of Embodied Perspective-Taking on The Reduction of Negative Stereotyping in Immersive Virtual Environments. In *Proceedings of PRESENCE 2006: The 9th Annual International Workshop on Presence*, pages 1–9. 23, 52

Yee, N. and Bailenson, J. N. (2007). The Proteus Effect: The Effect of Transformed Self-Representation on Behavior. *Human Communication Research*, 33(3):271–290. 22, 23, 25, 72, 74, 82

Yee, N. and Bailenson, J. N. (2009). The Difference Between Being and Seeing: The Relative Contribution of Self-Perception and Priming to Behavioral Changes via Digital Self-Representation. *Media Psychology*, 12(2):195–209. 22, 23

Yoo, S.-C., Peña, J. F., and Drumwright, M. E. (2015). Virtual shopping and unconscious persuasion: The priming effects of avatar age and consumers age discrimination on purchasing and prosocial behaviors. *Computers in Human Behavior*, 48:62–71. 24

Yuan, Y. and Steed, A. (2010). Is the rubber hand illusion induced by immersive virtual reality? *2010 IEEE Virtual Reality Conference (VR)*, pages 95–102. 14, 51

Zhang, J. and Hommel, B. (2015). Body ownership and response to threat. *Psychological Reports*, pages 1–19. 9, 16

Zheng, Z. Z., Macdonald, E. N., Munhall, K. G., and Johnsrude, I. S. (2011). Perceiving a stranger's voice as being one's own: a 'rubber voice' illusion? *Plos One*, 6(4):e18655. 32, 33, 103, 110, 124

Ziegert, J. C. and Hanges, P. J. (2005). Employment discrimination: the role of implicit attitudes, motivation, and a climate for racial bias. *The Journal of applied psychology*, 90(3):553–62. 95

Zopf, R., Savage, G., and Williams, M. a. (2010). Crossmodal congruency measures of lateral distance effects on the rubber hand illusion. *Neuropsychologia*, 48(3):713–25. 9, 19, 20

Appendix A

Material for the *Virtual Child Body* Study

In this Appendix we present the material used in the *Virtual Child Body* study, described in Chapter 4. These include:

- An information sheet with a general description of the study that participants had to read and sign prior to the experiment.
- A written consent form that participants were asked to sign in order to be able to participate.
- An anonymous demographics questionnaire that recorded basic information about the participant.

All written documentation was available in Castellano (Spanish), Catalan and English and it was chosen according to participants' preferences. The forms presented here are examples in English.

UNIVERSITAT DE BARCELONA

eventLAB Neuroscience & Technology

EXPERIMENT INFORMATION

This study is part of a series of experiments where we are attempting to learn about people's responses to virtual reality experiences. This will be in two phases, the first one will be held today and next one will be arranged for a few days time.

In this study you will wear a head-mounted display (HMD) (Figure 1A) through which a virtual world will be displayed. Additionally, you will wear a full body motion suit (Figure 1B) to track your body movements.

Figure 1A

Figure 1B

In both phases you will spend approximately 15 minutes in a virtual world. In the virtual reality you will see a virtual body that will substitute your own body. At the end of the experiment you will be asked to fill out a questionnaire. Each one of the two phases will last about 40 minutes. We will pay you 15€ for your participation (5€ 1st phase - 10€ 2nd phase).

If you have any questions, please ask.

Remember that you are free to leave the experiment at any time without giving reasons.

IMPORTANT

When using a Virtual Reality System, people often report feeling nauseous. If at any moment during the study you feel uncomfortable, please report so to the investigators and you will stop.

In other studies, it has been suggested that individuals might experience a small visual disturbance right after the study. Long-term studies have not been carried out to test this effect, but few suggest that it might appear after 30 minutes of exposures.

It has also been suggested that sometimes after 30 minutes of exposure in the VR, participants report having "flashbacks", related to the virtual experience.

Finally, there is the possibility of inducing epileptic episodes, as has been reported to occur is some video games.

You are kindly requested to read, understand and sign the consent form given to you by the investigators (the consent form covers all sessions of the study). If you sign it the study will count on your participation. Remember that you are free to leave the study at any moment and without giving any explanation. In case you have any question or comment regarding the study please contact the investigator: Domna Banakou (domnaban@gmail.com).

Thank you for your participation

Name(s) and Surname(s):

Signature:

Date:

PARTICIPANT INFORMED CONSENT

To be completed by volunteers. We would like you to read the following questions carefully.

Have you read the information sheet about this study?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all your questions?	YES/NO
Have you received enough information about this study?	YES/NO

Which investigator have you spoken to about this study? ……………………………………………

Do you understand that you are free to withdraw from this study?

- At any time YES/NO
- Without giving a reason for withdrawing YES/NO

Do you understand and accept the risks associated with the use of virtual reality equipment?	YES/NO
Do you agree to take part in this study?	YES/NO
Do you agree to be videotaped?	YES/NO
Do you agree to be audio taped?	YES/NO

I certify that I do not have epilepsy.

I certify that I am not taking any psychoactive medication.

I certify that I will not be driving a car, motorcycle, bicycle, or use other types of complex machinery that could be a danger to myself or others, within 3 hours after the termination of the study.

Signed…………………………………...…………**Date**……………………………..

Name in block letters……………………………..……………………………………...

In case you have any enquiries regarding this study in the future, please contact:

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*

Information that we collect will never be reported in a way that individuals can be identified. Information will be reported in aggregate, and any verbal comments that you make, if written about in subsequent papers, will be presented anonymously.

DEMOGRAPHIC INFORMATION

1.ID *(to be filled in by the experimenter)*	
2.Age	
3.Gender	Male Female
4. Height	
5. Occupation	Undergraduate Student Master Student PhD Student Investigator University Employee Professor Administrative Stuff Other
7. Have you consumed more that 2 units of alcohol in the last 6 hours? *(2 units of alcohol = 1 beer or 2 glasses of wine)*	Yes No
8. Please indicate your level of knowledge of informatics on a scale from 1 to 7 (beginner) 1 2 3 4 5 6 7 (expert)	
9. Please indicate your level of knowledge of computer programming: (beginner) 1 2 3 4 5 6 7 (expert)	
10. Have your ever experienced virtual reality before? (no experience) 1 2 3 4 5 6 7 (wide experience)	

11. How many times have you played videogames the past year (at home, at work, at school, public or other places)?	Never ◯ 1 - 5 ◯ 6 - 10 ◯ 11 - 15 ◯ 16 - 20 ◯ 21 - 25 ◯ > 25 ◯
12. How many hours per week do you play videogames?	0 ◯ < 1 ◯ 1 - 3 ◯ 3 - 5 ◯ 5 - 7 ◯ 7 - 9 ◯ > 9 ◯

Appendix B

Material for the *Racial Bias* Study

In this Appendix we present the material used in the *Racial Bias* study, described in Chapter 5. Here we include:

- An information sheet with a general description of the study that participants had to read and sign prior to the experiment.

The signed consent form and demographic questionnaire were the same as in the Virtual Child Body (see Appendix A)

Experiment Information

This study is part of a series of projects where we are attempting to learn about people's responses to virtual reality experiences.
Please read this information sheet carefully and feel free to ask questions or solve any doubts. The investigators will answer all of your questions. However, the exact details we are investigating in this study cannot be revealed until the end of the last session.
The duration of the study varies, depending on the number of sessions you have chosen to participate in. The first and last session will last approximately 15 minutes, where you will be asked to fill in some questionnaires, as well as perform a couple of easy tests on the computer.
The rest of the sessions will be carried out in virtual reality, where you will be asked to wear a head-mounted display, equipped with sensors to detect your head movements, and through which you will experience the virtual world (Figure 1A). You will also be required to wear a full-body suit equipped with sensors in order to record your body movements (Figure 1B).
You will spend it total approximately 15 minutes in the virtual environment.
Remember that you are free to quit the study at any moment and without giving any explanation. You can also ask to delete any records of your answers to questionnaires.

Figure 1A **Figure 1B**

All information gathered during the study will be safely kept away and used in a way that participants cannot be identified. All reports regarding the study (published articles, conferences etc) will reference participants as a group and at any moment will any individual be identified. Comments and other answers can be publicly available, but only in an anonymous format.

Ways or payment for participating:

- Depends regarding the number of session:

A) 5 euros at the end of the first session and 20 euros at the end of all other sessions (5 sessions in total).
B) 5 euros at the end of the first session and 15 euros at the end of all other sessions (4 sessions in total).
C) 5 euros at the end of the first session and 10 euros at the end of all other sessions (3 sessions in total).

IMPORTANT

When using a Virtual reality System, people often report feeling nauseous. If at any moment during the study you feel uncomfortable, please report so to the investigators and you will stop.
In other studies, it has been suggested that individuals might experience a small visual disturbance right after the study. Long-term studies have not been carried out to test this effect, but few suggest that it might appear after 30 minutes of exposures.
It has also been suggested that sometimes after 30 minutes of exposure in the VR, participants report having "flashbacks", related to the virtual experience.
Finally, there is the possibility of inducing epileptic episodes, as has been reported to occur is some video games.

You are kindly requested to read, understand and sign the consent form given to you by the investigators (the consent form covers all sessions of the study). If you sign it the study will count on your participation. Remember that you are free to leave the study at any moment and without giving any explanation. In case you have any question or comment regarding the study please contact the investigators: Domna Banakou (domnaban@gmail.com), or Irene Torres (iretopa@gmail.com)

Thank you for your participation

Name and Surname:

Signature:

Date:

Appendix C

Material for the ***Illusory Speaking*** Study

In this Appendix we present the material used in the *Illusory Speaking* study, described in Chapter 6. Here we include:

- An information sheet with a general description of the study that participants had to read and sign prior to the experiment.

The signed consent form and demographic questionnaire were the same as in the Virtual Child Body (see Appendix A)

UNIVERSITAT DE BARCELONA

eventLAB Neuroscience & Technology

EXPERIMENT INFORMATION

This study is part of a series of projects where we are attempting to learn about people's responses to virtual reality experiences. Please read this information sheet carefully and feel free to ask questions or solve any doubts. The investigators will answer all of your questions. However, the exact details we are investigating in this study cannot be revealed until the end of the last session.

In this study, you will be asked to wear a head-mounted display, equipped with sensors to detect your head movements, and through which you will experience the virtual world (Figure 1A). You will also be required to wear a full-body suit equipped with sensors in order to record your body movements (Figure 1B).

Figure 1A **Figure 1B**

You will spend approximately 15 minutes in the virtual world. You will see a virtual body that will substitute your own body. At the end of the experiment you will be asked to fill out a questionnaire. The whole session will last approximately 25-30 minutes. You will be rewarded with 5€ for your participation.

Remember that you are free to leave the experiment at any time without giving reasons. You can also ask to delete any records of your answers to questionnaires.

IMPORTANT

When using a Virtual reality System, people often report feeling nauseous. If at any moment during the study you feel uncomfortable please report so to the investigators and you will stop.

In other studies, it has been suggested that individuals might experience a small visual disturbance right after the study. Long-term studies have not been carried out to test this effect, but few suggest that it might appear after 30 minutes of exposures.

It has also been suggested that sometimes after 30 minutes of exposure in the VR, participants report having "flashbacks", related to the virtual experience.

Finally, there is the possibility of inducing epileptic episodes, as has been reported to occur is some video games.

You are kindly requested to read, understand and sign the consent form given to you by the investigators (the consent form covers all sessions of the study). If you sign it the study will count on your participation. Remember that you are free to leave the study at any moment and without giving any explanation. In case you have any question or comment regarding the study please contact the investigator: Domna Banakou (domnaban@gmail.com).

Thank you for your participation

Name(s) and Surname(s):

Signature:

Date:

Declaration

I herewith declare that I have produced this work without the prohibited assistance of third parties and without making use of aids other than those specified; notions taken over directly or indirectly from other sources have been identified as such. This work has not previously been presented in identical or similar form to any examination board. The dissertation work was conducted from 2012 to 2016 under the supervision of Mel Slater at the University of Barcelona.

Barcelona, April 7, 2017