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Embodiment and the Self: using Virtual Reality and Full Body Illusion to change bodily self-representation, perception and behaviour

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Publications

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Summary

Virtual Reality (VR) is an important tool for researchers of many different fields, from cognitive neuroscience to social psychology. Here we will explore the use of VR, and in particular of immersive virtual reality (IVR), in the study of some key aspects of bodily self and body related behaviour and perception. The present work is divided in two main parts. The main section (chapter 1 to 4) reports two studies on the combined use of IVR and full body illusion (FBI) to investigate and reduce body image distortion (BID) in anorexia nervosa (AN).

Chapter 1 serves as a general introduction to AN and its prominent clinical characteristics, introducing relevant concepts such as the malleability of the bodily-self through multisensory bodily illusions. This chapter also includes a brief overview of a series of studies that applied both IVR and multisensory bodily illusions to manipulate body representation.

Chapter 2 presents the first study in which we used the embodiment illusion with differently sized and personalized avatars to characterize and reduce both the perceptual (body overestimation) and cognitive-emotional (body dissatisfaction) components of BID in AN. Synchronous and asynchronous interpersonal multisensory stimulation (IMS) were applied to three different virtual bodies (the one which most resembled the perceived size of the actual body , one +15% fatter and one -15% thinner). The different components of BID were measured by asking participants to choose the body that best resembled their real and ideal body before and after the embodiment illusion was induced. The results of this study showed a higher body dissatisfaction in AN patients, who also reported stronger negative emotions after being exposed to the largest avatar. However, the embodiment procedure did not affect BID in AN patients.

Based on the results of this study, we decided to shift our focus from somatorepresentation, i.e. the explicit representation of the body which comprises both cognitive and emotional components of body image, to somatoperception, i.e. the implicit representation of the body which comprises both body perception and body schema.

Chapter 3 thus reports a second s study in which we applied a FBI over an underweight (BMI = 15) and normal weight (BMI = 19) avatar and measured the effect of the embodiment illusion on participants' (AN and HC) body perception and body schema estimations. To measure body perception, we asked participants to estimate the width of their hips while their vision was blocked, whereas for the body schema estimation participants had to estimate the minimum door's aperture width in order to pass through it inside an IVR scenario. The results showed that AN patients reported an overestimation in both body perception and body schema estimations. Furthermore, in AN patients we saw a change in the body schema estimation accordingly to the size of the embodied avatar, thus showing a higher bodily self-plasticity compared to HC. In the fourth chapter of the present work we will go over the results of the two aforementioned studies and will briefly discuss some possible future directions.

The second part of the present work (chapter 5 and 6) introduces two research projects that utilize IVR and bodily illusions to investigate the relationship between different components of bodily self-consciousness and dishonest behaviour in digital and virtual environments (chapter 5) and the analgesic potential of virtual social touch on acute and chronic pain (chapter 6). As the COVID-19 pandemic deeply affected the work on both these studies, preventing the possibility to collect participant's data, chapter 5 and chapter 6 only report the relevant literature underlying the experimental hypotheses of the two studies and the experimental methods and technical implementations to address the experimental aims. Finally, chapter 7 will serve as short conclusion by summarising the principal finding and the most important topics discussed in the present work.

PART I

INVESTIGATING BODY IMAGE DISTORTION AND BODILY SELF-PLASTICITY IN ANOREXIA NERVOSA VIA IMMERSIVE VIRTUAL REALITY

1. General Introduction

1.1 Anorexia nervosa.

Anorexia nervosa (AN) is a serious psychiatric disorder characterized by the inability to maintain an healthy body weight. The DSM-5 indicates three main criteria for the diagnosis of Anorexia Nervosa: i) “restriction of energy intake relative to requirements, leading to a significantly low body weight in the context of age, sex, developmental trajectory, and physical health”, ii) “intense fear of gaining weight or of becoming fat, or persistent behaviour that interferes with weight gain, even though at a significantly low weight”, iii) “Disturbance in the way in which one’s body weight or shape is experienced, undue influence of body weight or shape on self-evaluation, or persistent lack of recognition of the seriousness of the current low body weight” (American Psychiatric Association, 2013). AN is also further classified into two distinctive subtypes: the restrictive type (AN – r), characterized by the lack of binge eating and purging behaviours, and the binge-eating/purging type (AN – b/p), characterized by recurring episodes of binge eating and/or purging behaviours (American Psychiatric Association, 2013).

AN has the highest mortality rate among all psychiatric disorders (Arcelus, 2011), and while it can occur in individuals of all ages and sexes, AN predominantly affects adolescent and young women (Gaudio, Brooks, & Riva, 2014), with a female-male ratio of 10:1 (Gueguen et al., 2012), although this ratio is likely to be skewed by the fact that men's eating disorder are often underdiagnosed and poorly understood even by some clinicians (Strother, Lemberg, Stanford, & Turberville, 2012). In women, eating disorders represent the most common psychiatric disorder between 14-26 years of age (Fassino, Pierò, Gramaglia, & Abbate-Daga, 2004), affecting 1% of the general women population in high-income countries (Zipfel, Giel, Bulik, Hay, & Schmidt, 2015). Despite all this, AN is still a poorly understood pathology, as its etiology is still unclear and there are no medications or treatments that have been able to cure its core symptoms (Kaye, Wierenga, Bailer, Simmons, & Bischoff-Grethe, 2013).

1.2 Body image distortion in anorexia nervosa

As pointed out earlier, one of the core clinical symptoms of AN is body image distortion (BID). Body image is generally considered a multidimensional construct comprising three different dimensions: a perceptive component, a cognitive component and an affective component (Cash & Deagle, 1997; Gaudio et al., 2014). The perceptive component mainly refers to the estimation of one's own body, which entails the individuals' accuracy in evaluating the size and shape of their own body in relation to their real body's proportions. The cognitive component mainly refers to beliefs and thoughts concerning body appearance and shape, which includes also the mental representation of one’s own body. Finally, the affective component mainly refers to the feelings regarding one’s own body appearance and the feelings of satisfaction or dissatisfaction towards it. Generally, the current literature regarding BID in AN states that anorectic patients show an overestimation of their own body size compared to neurotypical individuals, a greater body dissatisfaction towards their own body shape and size and a greater discrepancy between their own perceived body and the desired ideal body (Gardner & Brown, 2014). BID in AN can also vary based on the individual’s gender, as men’s concern are usually focused more on the muscularity of their body while women’s are more concerned about their body weight (Treasure, Duarte, & Schmidt, 2020).

It must be pointed out that the overestimation of own one’s body size in AN is not the result of a deficit in visual perception, being instead the result of both a distorted attitudinal component towards one’s own body image (Cash & Deagle, 1997; Sepúlveda, Botella, & León, 2002a) and of a distorted representation of the bodily-self due to somatosensory and proprioceptive impairments (Case, Wilson, & Ramachandran, 2012; Gaudio et al., 2014; Keizer et al., 2013; Keizer, Smeets, Dijkerman, van Elburg, & Postma, 2012). In order to better understand body image and its different components, in the next paragraph we will briefly explore the various aspects of body representation and of the bodily self-consciousness.

1.3 Body image and body schema

Our body representation is the result of the constant integration of a multitude of bodily signals coming from both outside our body, i.e. exteroceptive signals recorded through our sensory modalities (e.g. vision and hearing), and from inside our body, i.e.

proprioceptive (e.g. joints and muscles movements) and interoceptive signals (e.g. heartbeat, hunger, thirst, and bowels movements) (Berlucchi & Aglioti, 2010). The constant elaboration by the brain of this incessant stream of bodily signals is the basis of our corporal awareness, of the feeling of 'being I', experiencing a 'real me that resides in my body' which bounds all our experiences to the unitary entity of the Self (Blanke, 2012). From a predictive coding perspective, this sense of selfhood is the result of the predictive multisensory integration of self-related signals across interoceptive and exteroceptive domains that "are most likely to be me" (Apps & Tsakiris, 2014; Seth, 2013). As we collect all these data regarding our body, we build up a mental image of ourselves, developing thoughts and feelings about our body and how we appear to ourselves and other people, i.e. we form our own *body image* based on the multiple sensorial representations of our body (de Vignemont, 2010; Gallagher, 2005). Another core aspect of corporal awareness and then bodily self-consciousness is the feeling of 'being in control of our own body', of being able to interact with the outside world and having an effect on it, which forms a dynamic action-oriented representation of our body, i.e. our own body schema. The *body schema* is a dynamic sensorimotor representation of body that guides our action, and it is activated regardless if the action is executed or just imagined / anticipated (de Vignemont, 2010; Guardia et al., 2010). Thus, while both being crucial for our bodily self-consciousness, body image is more involved in the explicit and conscious representation, whereas body schema is more involved in the implicit representation of the interaction between the body and the surrounding environment (Berlucchi & Aglioti, 2010).

1.4 Manipulation of the bodily self-consciousness

As mentioned before, our bodily self-consciousness is derived by the constant processing of signals coming from both inside and outside our body. In particular, on a phenomenological level of analysis, the two key components of our bodily self-consciousness are the sense of owning one's own body, i.e. the sense of ownership (Bufalari & Aglioti, 2015), and the sense of being in control one's own body actions, i.e. the sense of agency. Furthermore, being the result of a multisensory integration of different bodily signals, our bodily self-consciousness' is an online construct that can be affected and molded by experience, as in the case of multisensory bodily illusions. Such illusions take advantage of the multisensory integrative processes at the basis of our sense of bodily self to induce the illusionary feeling of owning another person's face (enfacement illusion), body (full body illusion) or body part (rubber hand illusion).

Such illusions adopt interpersonal multisensory stimulation (IMS) paradigms. In IMS, participants typically experience a tactile stimulation on their own body synchronously with an observed touch on the corresponding body part on another individual's body (Matthew Botvinick & Cohen, 1998; Lenggenhager, Tadi, Metzinger, & Blanke, 2007; Porciello, Bufalari, Minio-Paluello, Di Pace, & Aglioti, 2018) which leads to the illusory sensation of ownership toward the latter (termed embodiment), as evidenced by subjective, behavioural, and physiological measures (Bufalari, Sforza, Di Russo, Mannetti, & Aglioti, 2019; M Fusaro, Tieri, & Aglioti, 2019; Sforza, Bufalari, Haggard, & Aglioti, 2010).

In the Rubber Hand Illusion (RHI) (M Botvinick & Cohen, 1998) participants observe a rubber hand that is placed in front of them while their real hand is hidden from their view. Both the participant' hand and the fake hand are then stroked either synchronously or asynchronously. During the synchronous stimulation, the multisensory integration between the touch observed on the fake hand and the one felt of the real hand creates the illusion of feeling the fake hand as one's own, i.e. it creates illusionary ownership over the fake hand. However, if the stroking of the fake and real hand is asynchronous this embodiment illusion is absent or greatly reduced. A measure of the strength of the embodiment illusion is the 'proprioceptive drift' (Abdulkarim & Ehrsson, 2016; M Botvinick & Cohen, 1998), i.e., the perceived position of participant's own hand shifts towards the position of the fake hand. The RHI has been extensively used to investigate different components of embodiment and the bodily-self, such as body ownership (Ehrsson, Spence, & Passingham, 2004; Manos Tsakiris, Hesse, Boy, Haggard, & Fink, 2007), body agency (Manos Tsakiris & Haggard, 2005), self-recognition (Manos Tsakiris, Haggard, Franck, Mainy, & Sirigu, 2005) and body image (Longo, Schüür, Kammers, Tsakiris, & Haggard, 2009).

In the enfacement illusion (Sforza et al., 2010), synchronous and asynchronous visuo-tactile stimulations are applied to a participant's face and to the face of another person sitting in front of him. To measure the strength of the illusion, after the embodiment procedure participants are asked to recognize their own face by discriminating between a set of morphed photos of their own face and the face of the other person that was sitting in from of them. Results have shown that after the synchronous stimulation participants attribute to themselves facial features of the other person, i.e. they include the other into the self-face representation (Bufalari, Lenggenhager, Porciello, Holmes, & Aglioti, 2014; Tajadura-Jiménez, Longo, Coleman, & Tsakiris, 2012). In the next paragraph we will discuss a third type of embodiment illusion, the full body illusion (FBI), which utilises immersive virtual reality (IVR) to create an illusionary sense of body ownership over a virtual avatar.

1.5. Immersive Virtual Reality and Full Body Illusion

While Virtual Reality (VR) has reached the general public only recently thanks to the development of powerful and cheap head-mounted displays (HMDs), as a technology VR has been around since the late 1980s (Slater, 2018) and in the past two decades it has been extensively used by researchers of many different fields, from social psychology (Pan & Hamilton, 2018) to cognitive neuroscience (Bohil, Alicea, & Biocca, 2011) and clinical research (Riva, Wiederhold, & Mantovani, 2019). VR provides a middle ground between ecological validity and experimental control by giving researcher the possibility to have immersive and naturalistic scenarios while keeping an exact degree of control over key experimental variables (Bohil et al., 2011).

One of the key characteristic of VR is its high level of immersivity, i.e. 'the technical capability of the system to deliver a surrounding and convincing environment with which the participant can interact'(Sanchez-Vives & Slater, 2005), which is a requirement for the illusion of presence, i.e. the feeling of being inside the virtual scenario rather than where the user's real body is located. More precisely, presence is defined as a psychological state in which an individual feels immersed in a mediated environment to the extent in which she/he feels physically present in the virtual environment (Tussyadiah, Wang, Jung, & Claudia, 2018). While not a requirement per se, presence in virtual reality can be further enhanced by the identification of the user with a virtual body observed from a first person perspective (Slater & Wilbur, 1997), which is achieved through the illusionary body ownership of virtual avatar, i.e. full body illusion (FBI). There are already numerous experimental evidences about the effect of FBIs on bodily self-consciousness. In a famous 2007 study (Lenggenhager et al., 2007), Lenggenhager and colleagues manipulated both body ownership and body location by applying both synchronous and asynchronous stroking on the back of participants’ body and on the back virtual body placed in front of them, i.e. observed from a third person view (3PP). During the synchronous condition, participants felt illusionary body ownership over the virtual body seen in front of them and mis localized themselves to a position outside their real body, as if participants were experiencing an out of body experience (OBE). In a similar study (Petkova & Ehrsson, 2008) researchers induced a body swapping illusion by applying synchronous and asynchronous strokes on participant’s abdomen and on a mannequin’s abdomen observed from a 1PP. The induced embodiment illusion was so strong that participants felt illusionary body ownership over the mannequin even when facing their own real body and shaking hands with it. Researchers pointed out that the factors essential for the FBI were visual-perceptive congruency between the felt and observed touch, the appearance of the fake body and the visual perspective of the fake body, i.e. 1PP. In another study (van der Hoort, Guterstam, & Ehrsson, 2011) , a synchronous multisensory stimulation was applied over a doll’s size body and a giant’s size body observed from a first person perspective (1PP), showing that not only is possible to feel body ownership over bodies significantly different from one’s own body, but also that the size of the embodied body affects perceived size and locations of external objects. Finally, in a series of three studies, Maselli & Slater (Maselli & Slater, 2013) sought out investigate the importance of the three factors that have been considered to play a key role in the induction of the FBI, i.e. visual perspective, visuo-tactile stimulation synchronicity and virtual body’s appearance. The results of these studies show that visual perspective, i.e. 1PP, was the most important factor in inducing illusionary ownership over a virtual body, as the visual proprioceptive overlap between the real body and an observed realistic virtual body is enough for inducing the FBI. However, visuo-tactile stimulation synchronicity can not only boost the strength of embodiment illusion, but it is essential for the induction of the illusion when there is a spatial mismatch between the real and the observed body and/or when the virtual body is not perceived as realistic enough (Maselli & Slater, 2013). In the next paragraph we will discuss how FBIs can affect also body image and how these bodily illusions have been used so far to study BID in AN.

1.6. Bodily-self illusions and body image plasticity

A crucially important aspect for the aim of the present work is the effect that FBIs can have on one's own body image. While neurotypical individuals have a substantially stable internal representation of themselves and their own body (Longo, 2015a), FBIs over different sized avatar have been proved capable to change one's own body image accordingly to the size of the embodied virtual avatars. In a 2011 study (Normand, Giannopoulos, Spanlang, & Slater, 2011), participants were instructed to observe a virtual avatar with an enlarged belly from a first-person perspective (1PP) and to stroke their real belly with a stick. The stroking movement was replicated in the virtual environment, with the same movements happening synchronously on both participant's real and virtual belly. The results showed that the 1PP of a virtual body coupled with synchronous visuo-tactile stimulation caused not only the illusionary ownership of the enlarged virtual body, but also the perception of an increase in participants' real belly size. FBIs can also affect the cognitive and emotional components of body image, as it was found that participants reported a decrease in their body size estimation and an increase in body satisfaction towards their own body after a illusionary body ownership over a slim body was induced (Preston & Ehrsson, 2014). Similar results were reported in another study (Piryankova et al., 2014) in which participants significantly overestimated their own body size and the space needed to pass through two virtual pillars after being exposed to an overweight avatar compared to when they were exposed to a slim avatar.

There have been also few studies that used bodily illusions to investigate bodily self-plasticity and BID in people with eating disorders. In a 2012 study, Eshkevari and colleagues (Eshkevari, Rieger, Longo, Haggard, & Treasure, 2012) applied a RHI to both healthy controls and participants with eating disorders to examine the differences in body representation between the two groups. The results showed that individuals with eating disorders experienced a significantly stronger embodiment illusion compared to healthy individuals, and that the strength of the embodiment illusion was positively correlated with eating disorders' symptoms, i.e. individuals with eating disorders showed a increased bodily self-plasticity compared to healthy controls. A later study (Keizer, Smeets, Postma, van Elburg, & Dijkerman, 2014) not only replicated these results but also showed a decrease in hand size estimations in patients with AN after the RHI was applied, even though this effect was found after both synchronous and asynchronous stroking. Finally, when a FBI of a standardized healthy avatar was induced in both healthy individuals and participants with AN (Keizer, Van Elburg, Helms, & Dijkerman, 2016), results showed a decrease in AN patients' overestimation of their shoulders, abdomen and hips, although these effects were also present in the healthy controls group and after both synchronous and asynchronous visuo-tactile stroking. While the results from these studies seems to suggest that FBIs might be an effective tool for reducing BID in AN, further experimental inquiry is required to disentangle if these effects are due to the embodiment illusions or are just the effect of the mere exposure to different sized body parts and virtual bodies.

The following two chapters of the present work will illustrate two studies that investigated body image distortion in anorexia nervosa by using the full body illusion of different size avatars in both anorectic patients and healthy control. In Study 1, we built personalized avatars for each participants and measured the effect of the embodiment of three different sized avatars (the perceived body, a +15% fatter body and a -15% thinner body) on participants' body dissatisfaction. In the Study 2, we applied a interpersonal multisensory stimulation on a normal weight BMI avatar and an underweight BMI avatar and measured the effect of the embodiment illusion on participant's body perception and body schema. The aim of both of these studies was to extend the current knowledge regarding the efficacy of full body illusions in immersive virtual reality in characterizing and even reducing body image distortion in anorexia nervosa and increasing the experimental data available in support the possible application of both virtual reality and the embodiment illusion in the treatment of anorexia nervosa.

2. Study 1

2.1 Introduction

Anorexia nervosa (AN) affects mostly adolescent and young women (Gaudio et al., 2014), has the highest mortality rate among all psychiatric disorders (Arcelus, 2011) and is largely resistant to currently available treatments (Cornelissen, Bester, Cairns, Tovée, & Cornelissen, 2015). As reported above, a core clinical symptom of AN is body image distortion (BID), which affects both perceptual and cognitive-emotional components of the body representation (Cash & Deagle, 1997). Furthermore, BID plays a crucial role in the onset, prognosis, and relapse of AN (Farrell, Lee, & Shafran, 2005).

The use of new sophisticated and biometrically plausible distortion methods, made possible by immersive virtual reality contexts, has paved the way for precisely measuring body overestimation e.g., (Piryankova et al., 2014), whereas the development of interpersonal multisensory stimulation (IMS) paradigms has increased insights into the plasticity of the bodily self (Berlucchi & Aglioti, 2010; Piryankova et al., 2014). IMS paradigms have been extended to virtual avatars observed from a first-person perspective (1PP) (Maselli & Slater, 2013), even of different sizes (van der Hoort et al., 2011), which might lead to a change in one's own body perception according to the avatar size (Normand et al., 2011) and affect body overestimation and body satisfaction/dissatisfaction (Preston & Ehrsson, 2014, 2016).

Embodiment illusions might thus represent a promising tool to reduce BID in AN, as the few existing studies using embodiment illusions in AN patients tentatively suggest that a normalization of BID is possible (Keizer et al., 2014, 2016). Yet, it is still unclear how robust the effect is, to what degree it is linked to embodiment per se [for example, body overestimation reduction occurred after both synchronous and asynchronous IMS, suggesting that it might not be due to the embodiment per se, but rather to purely visual effects (Keizer et al., 2016)], and how such illusions affect and interact with the affective-emotional components of body representation, which are central to BID (Cash & Deagle, 1997; Sepúlveda, Botella, & León, 2002b).

Here, we addressed these issues by: (i) individualizing the avatars for each of our participant' body (unlike previous studies); (ii) assessing the embodiment strength both at the explicit (questionnaires, e.g., (Lenggenhager et al., 2007; Tieri, Tidoni, Pavone, & Aglioti, 2015)) and implicit level (body temperature, e.g., (Tieri, Gioia, Scandola, Pavone, & Aglioti, 2017), but see (de Haan et al., 2017) for a critical account), and (iii) measuring both perceptual and emotional aspects of BID before and after the embodiment of three different sized avatars was induced. We tested young females with AN and low-BMI age-matched HC with no diagnosis of eating disorders.

We expected AN patients to overestimate their body size (Gardner & Brown, 2014) and to show higher body dissatisfaction than HC (Keel et al., 2005), as indexed by clinical measures (clinical questionnaires' scores) and by the higher discrepancy between one's own perceived and ideal body (H. M. Mohr et al., 2011). Furthermore, according to Eshkevari and colleagues (Eshkevari et al., 2012), we expected higher bodily self-plasticity (namely higher embodiment measured both at the implicit and explicit level) in AN patients compared to HC, since the decreased interoceptive sensitivity found in AN with respect to HC participants (Fassino et al., 2004; Pollatos et al., 2008) might lead these patients to rely more on exteroceptive signals to represent their bodily self Thus, IMS based on visuo-tactile exteroceptive signals might induce stronger embodiment illusion in AN than HC. Importantly, we hypothesized that body dissatisfaction would decrease in AN patients as an effect of embodying a body which corresponds or is thinner than the perceived one (Preston & Ehrsson, 2014). Lastly, we expected that embodying an avatar larger than the perceived one would enhance negative emotions in AN patients more than HC.

2.2 Materials and Methods

2.2.1 Participants

A total of 21 female patients diagnosed with AN and 22 age-matched HC were recruited. All AN patients were diagnosed with anorexia nervosa (restricting type) by the Department of Psychiatry and Eating Disorder of the Hospital Policlinico Umberto I, which followed the criteria of Diagnostic and Statistical Manual of Mental Disorder –

5 (American Psychiatric Association, 2013). One AN patient was later excluded because of diagnostic migration, i.e. the diagnosis changed from AN to major depression as primary disorder with a secondary eating disorder component. Two HC were excluded for technical problems. A total of 20 AN patients ((mean ± standard error (SE)) (age = 23.30 ± 7.61, BMI = 15.87 ± 1.12)) and 20 HC participants (age = 23.85 ± 3.23, BMI = 18.98 ± 1.01) finally participated in the study. For the HC, the presence and/or history of any eating disorder and/or other psychiatric disorders constituted an exclusion criterion, whereas a BMI score in the lower normal range (i.e. between 17 and 21) was an inclusion criterion. The study was approved by the Ethical Committees of Policlinico Umberto I and IRCCS Santa Lucia Foundation and in accordance with the ethical standards of the 2013 Declaration of Helsinki. All the participants read and signed the informed consent

2.2.2 Procedure

The experiment consisted of two sessions: a pre-experimental (X.3) and an experimental session (X.4), with about one week break in between, in which the individualized avatars were created.

2.2.3 Pre-experimental session

This session lasted about one hour. Participants filled out a series of questionnaires presented in randomized order on a computer using E-Prime® 2.0 software. To assess symptoms severity of the eating disorder pathology, we administered the following questionnaires:

1. The Eating Disorder Inventory - 2 (EDI-2) (Garner, 1991). A 91-item self-report questionnaire measuring the clinical and psychological components of both anorexia and bulimia nervosa on a 6-point Likert scale. The test is organized into 12 primary

scales: Drive for Thinness, Bulimia, Body Dissatisfaction, Low Self-Esteem, Personal Alienation, Interpersonal Insecurity, Interpersonal Alienation, Interoceptive Deficits, Emotional Dysregulation, Perfectionism, Asceticism, and Maturity Fears.

2. The Body Shape Questionnaire (BSQ) (Cooper et al., 1987). A 34-item self-report questionnaires measuring body shape preoccupations typical of bulimia nervosa and anorexia nervosa on a 6-point Likert scale.

3. The Body Uneasiness Test (BUT) (Cuzzolaro, Vetrone, Marano, & Garfinkel, 2006). A 71-item self-report questionnaire that consists of two parts: BUT*A which measures weight phobia, body image concerns, avoidance, compulsive self-monitoring, detachment and estrangement feelings towards one's own body (depersonalization); and BUT*B which looks at specific worries about particular body parts or bodily behaviours. Items are answered on a 6-point Likert scale.

4. The Bulimic Investigatory Test, Edinburgh (BITE) (Henderson & Freeman, 1987). A 33-item self-report questionnaire measuring bulimic behaviours and binge eating symptoms. The test consists of a Symptom subscale that assesses the presence of bulimic and binge eating symptoms and a Severity subscale that indicates the severity of binge eating and purging behaviours based on frequency. Items are answered in a binary yes-no format.

Additionally, to assess for the presence of others psychiatric symptoms we used the Symptom Checklist-90-R (SCL-90-R) (Derogatis, 1994), which is a 90-item self-report questionnaire measuring 9 primary symptoms dimensions: Somatization, Obsessive Compulsive, Interpersonal Sensitivity; Depression; Anxiety; Hostility; Phobic Anxiety; Paranoid Ideation and Psychoticism. Additionally, SCL-90 provides three global indices of distress (Global Severity Index, Positive Symptom Distress Index, Positive Symptom Total). Items are answered on a 5-point Likert scale

After participants completed all the questionnaires, a female experimenter measured circumferences and lengths of selected body parts of each participants and took pictures of participants' body standing up (front, back and profile view) with a Nikon D40 mounted on a tripod. Participants' pictures and body measures served to create personalized avatars for each participant.

2.2.4. Avatars modelling

A 3D modelling software (MakeHumans, open source tool for making 3d characters) was used to recreate the personalized avatar that matched participants' real body in terms of height, shape and body size and two more avatars that reproduced verisimilar weight loss of 30% and a weight gain of 50% of the original weight (Figure 1, panel A). Additionally, Adobe Photoshop 7.0 (Adobe Systems Incorporated, San Jose, CA, USA) was used to create highly detailed skin, clothes and material textures. Subsequently, these three avatars were imported into 3dsMax (Autodesk Inc., Mill Valley, CA), a 3D modelling and animation software, which we used to create two sets of 28 avatars incrementing in size in steps of 3%, in a continuum starting from the thinnest (-30%) to the fattest avatar (+50%). One of these of avatars set was made of 28 standing avatars to be later used for the subsequent experimental tasks, i.e. the Avatar Selection Task (X.5.1) and the Perceived and Ideal Body Tasks (X.5.2). The other set was made of 28 avatars lying on a deck chair (Figure 1, panel B) and used during the Embodiment Procedure (X.5.3). We decided to utilize a set of avatars going from -30% to +50% of the original body size in order to do not end up with unrealistically thin bodies (especially in the case of the AN) and to be able to measure the presence of body overestimation in the range suggested by a recent meta-analysis (Gardner & Brown, 2014).

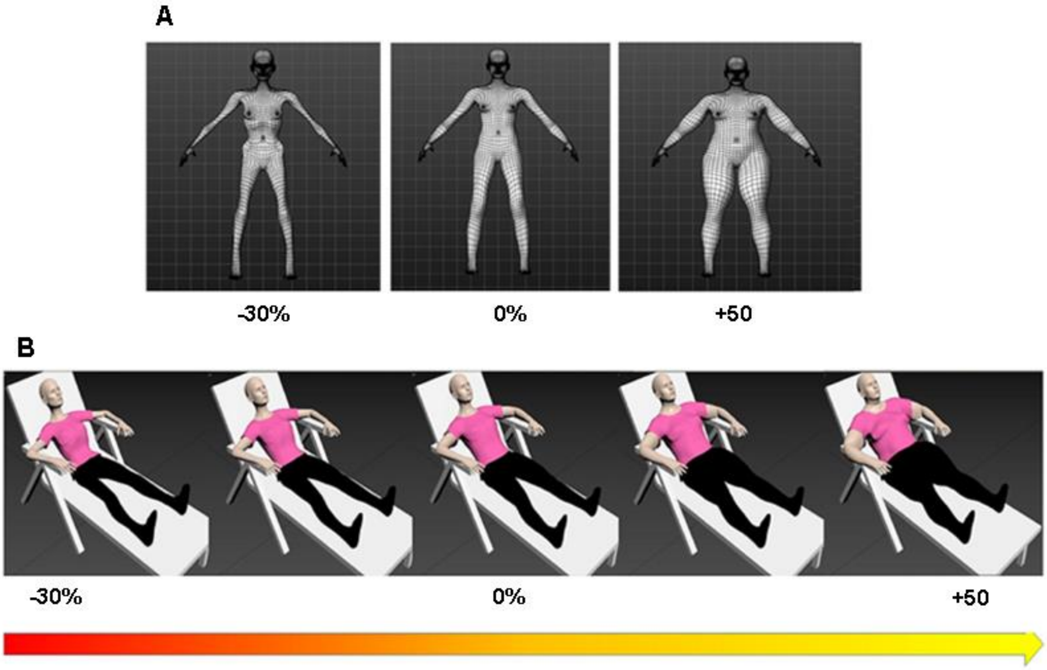

Figure 1. Creation of 3D Stimuli. **(A)** Example of 3 customised avatars built accordingly to participant's body measures and pictures: an avatar that reproduced participant's real body (avatar 0%), a thinner avatar (avatar -30%) and fatter avatar (+50%). **(B)** Example of avatars selection extracted from the continuum of avatars lying on a deck chair and increasing in size in steps of 3%, starting from the thinnest (-30%) to the fattest avatar (+50%).

2.2.5 Experimental session

This session lasted about two hours (see Figure 2 for an illustration of the procedure). Participants first performed the Avatar selection task (Section X.4.1). Then they put on clothes that matched the avatar's outfit and lay down on the deck chair to perform the perceived and ideal body tasks (Section X.4.2). Afterward, participants experienced synchronous and asynchronous IMS (Section X.4.3) with three different body size avatars (Avatar 0%., i.e., the avatar they chose in the Avatar selection task; Avatar −15% and Avatar +15%, i.e., an avatar 15% thinner and one 15% fatter than the one reproducing their own perceived body) in separate runs, counterbalanced across participants. Within each run participants received synchronous and asynchronous IMS in separate blocks (counterbalanced across participants) with the same avatar size. Immediately after each IMS block, participants performed the perceived body task (first 6 blocks) or the ideal body task (second 6 blocks, or vice versa). Then, we collected explicit and implicit measurements of embodiment (Section 2.4.4) and the emotional response (Section 2.4.5) to the IMS. At the end participants were also asked to rate the avatars in terms of similarity and attractiveness (Section 2.4.6).

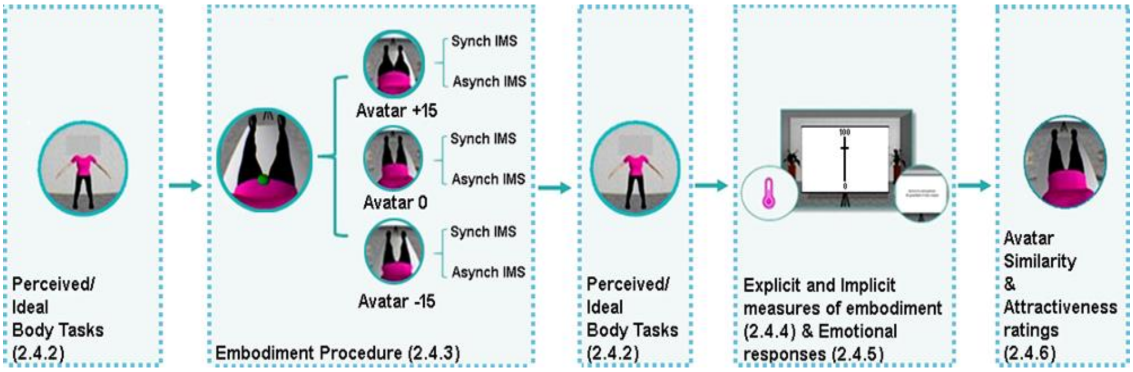

Figure 2. Experimental procedure. After selecting the avatar most similar to their perceived body and the one most resembling their ideal body, participants were enrolled in embodiment blocks in which synchronous and asynchronous IMS were applied to three different bodies (the perceived body, -15% thinner body, +15% fatter body). After each embodiment block participants repeated the Perceived and Ideal Body tasks to measure the effects of the embodiment of different sized avatars on body dissatisfaction. Explicit and implicit measures of the embodiment illusion, as well as the emotional response after being exposed to a/synchronous touching of different sized avatars were recorded after each embodiment block. At the end of the experiment we asked participants to rate from a first-person perspective the three avatars in terms of similarity to their own body and overall attractiveness

2.2.6 Avatar Selection Task

Participants were asked to choose the avatar that best fits their own body from a continuum ranging from a body that was 30% thinner to another one that was +50% fatter than the actual body (the body that was reproduced on the bases of each participant's body size and shape). Participants initially saw the avatar in the middle of this continuum and were specifically instructed to explore all the continuum before choosing the avatar's body that best resembled their own in terms of shape and size. In this task participants were standing up and the avatars were presented in a specular congruence with respect to their actual body, i.e. from a 3PP, as if they were looking at themselves in a mirror. The selected avatar (0% Avatar), the one 15% fatter (+15% Avatar) and the one 15% thinner (-15% Avatar) than the 0%, were used as virtual body stimuli for the embodiment blocks (paragraph X.4.3).

2.2.7 Perceived and Ideal Body tasks: Body Dissatisfaction

To assess participants' body dissatisfaction immediately before and after the IMS we asked them to choose the avatar which best resembled their real (Perceived Body Task) and ideal (Ideal Body Task) body in terms of size/shape/weight along the -30% - +50% continuum (Figure 3, panel A). Differently from the Avatar Selection Task, however, judgments were performed while participants were laying down on the deck chair and avatars were projected standing up in front of them, i.e. from a 3PP. As these tasks were performed before and immediately after IMS, participants were left lying on the desk chair to avoid disrupting any induced feelings of ownership over the avatar's body.

Each task (Perceived and Ideal Body Task) comprised two trials, presented in counterbalanced order: in one trial participants started the selection from the thinnest avatar, in the other from the fattest one. Trials' scores were then averaged for the final score. The discrepancy between the size of the ideal and the perceived body, calculated as the absolute difference between the two, was considered an index of participants' body dissatisfaction.

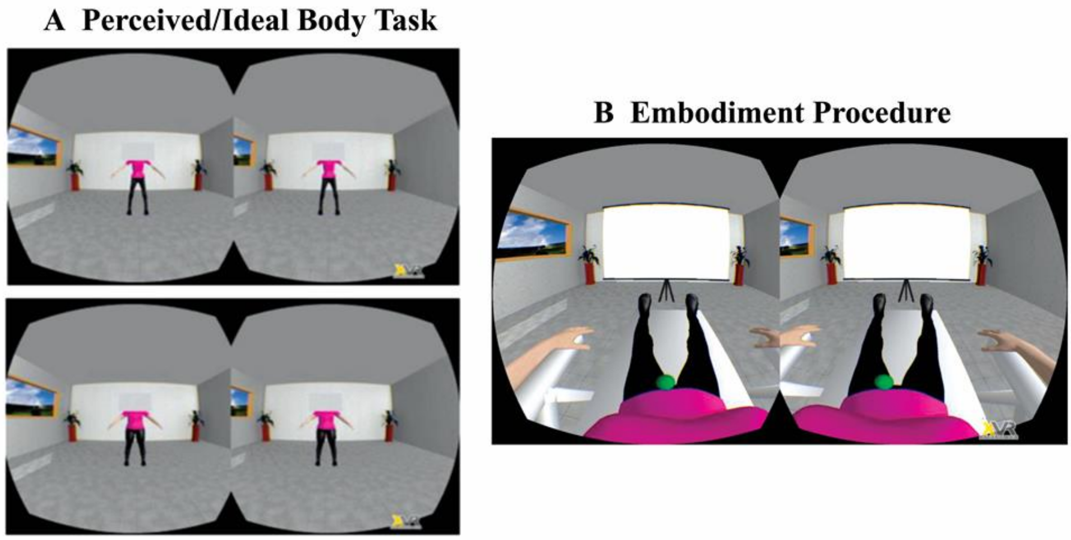

Figure 3. (A) Perceived/Ideal Body Task. In separate blocks, participants choose the avatar which was the most similar to their own body (Perceived Body Task) and the avatar which best resembled their ideal body (Ideal Body Task) along a continuous of avatars presented from a 3PP. Each task comprised two trials presented in counterbalanced order: in one trial participants started the selection from the thinnest avatar (upper part of panel A), in the other from the fattest one (lower part of panel A). **(B)** Embodiment procedure. During the embodiment procedure a three minute of a/synchronous visuo-tactile stimulation was delivered. During the embodiment participants observed one of three different avatars from a 1PP. A virtual ball was programmed to touch the avatar on 3 different spots around the belly button in 8 different ways (single touches and stroking movements).

2.2.8 Embodiment Procedure

During the IMS procedure participants saw the body from a 1PP (Figure 3, panel B) through a head-mounted display (Oculus Rift Developers Kit Dk1). Thus, the virtual body replaced the participant's body in space. A calibration was performed to assure a proper positioning of the virtual camera and a precise overlap between the touch felt on the abdomen and the one observed on the avatar. Then, three minutes of visuo-tactile IMS were applied to the participant's and the avatar's body. The IMS was performed by a female experimenter, who received through headphones audio cues indicating the time and the location of each touch.

For the experimental condition (Synchronous-IMS), we aimed to reach the maximal multisensory congruence between the real and the virtual body. Thus, in the synchronous condition the observed and felt touch matched in time and location, and we tracked participants' head movements online to adjust visual perspective. However, as the visuo-proprioceptive congruence given by observing an avatar from a 1PP can be enough to induce feelings of ownership over a virtual body (Slater, Spanlang, Sanchez-Vives, & Blanke, 2010), we also aimed to reduce the possible occurrence of such illusory effects in the asynchronous control condition. Thus, we tried to boost the discrepancy in the control condition by delivering touches that were asynchronous in both time and location as previous studies found that this stimulation was effective in maximizing the difference between synchronous and asynchronous conditions (Apps & Tsakiris, 2014; Bufalari et al., 2014) and we locked participant's head tracking during the asynchronous IMS.

During visual-tactile stimulation, the participants were asked to look at the belly that was stimulated, and not to move their head. Before starting the stimulation, the experimenter made sure that the participant always looked at the virtual belly by continuously checking: i) the orientation of the participants' head (which had to be directed toward their real belly) and ii) the virtual scenario on the PC monitor (where the virtual belly always had to be positioned in the centre of the monitor) and reminded her to not move the head during the stimulation.

2.2.9 Explicit and implicit measures of embodiment

As an explicit measure of embodiment, we used a self-reported questionnaire adapted from previous studies (Lenggenhager et al., 2007; Tieri et al., 2015) assessing the strength of the illusion on three different components: Ownership, i.e. the sense of virtual body being one's own, Agency i.e. the sense of being in control of the virtual body and Referral of Touch, the feeling of directly being touched by the seen ball. We also administered three control items to deviate participants' attention from the study hypothesis. Participants replied to the 9 items by expressing their degree of agreement to each statement on a visual analogue scale (VAS) presented in VR ranging from "completely agree" (100) and "completely disagree" (0). The order of the items (see Table 1) was randomised.

Table 1. Embodiment questionnaire items assessing participants' degree of explicit embodiment on four subscales.

Embodiment Questionnaire Items	
Items	**Subscales**
I felt I was looking at my own body	Ownership
I felt the virtual body was my own body	Ownership
I felt I could control the virtual body	Agency
I felt I could move the virtual body	Agency
I felt the virtual body obeyed or could obey my will	Agency
I felt that the touch I received was caused by the ball moving on the virtual body	Referral of Touch
I felt I was receiving the touch where the ball was touching the virtual body	Referral of Touch
I felt I had more than one body	Control
I felt I did not own a body anymore	Control

As an implicit measure of embodiment, we recorded participants' body temperature, taken through an infrared thermometer (IFR 100, microlife, precision: ± 0.2°C, 32.0 ~ 42.2 °C) under participants' right armpit immediately after each block of IMS to compare ratings taken after synchronous vs asynchronous embodiment blocks. Since we wanted to exclude participants with altered body temperature (due for example to febrile illness) we also took the body temperature before the experimental session started.

2.2.10 Measure of emotional response induced by embodiment

Valence and intensity of the emotional response induced by being exposed to a/synchronous touching of the three differently sized avatars, was assessed by a visual analogue scale (VAS) ranging from “very negative” (0) to “very positive” (100) presented after both synchronous and asynchronous IMS.

2.2.11 Similarity and Attractiveness ratings of the avatars

As part of the final debriefing procedure, we checked how the -15%, 0% and +15% avatars used during the embodiment blocks were actually perceived by the participants. Therefore, we asked participants to verbally rate on 0-100 VAS how much the three avatars resembled their own body (Similarity Ratings) and how attractive they thought these were (Attractiveness Ratings). The avatars were presented from a 1PP while participants were still laying down on the deck chair. Thus, ratings were collected while there was a spatial congruence between the actual participant’s body and the avatar’s body, i.e. while participants observed the three avatars replacing their own body in space.

2.3 Results

Data were analysed using STATISTICA version 8.0 (StatSoft, Tulsa, OK, USA). Significance was set at $p < .05$. The Duncan test was used for post-hoc comparisons. Bayes Factors were calculated by means the open-source software JASP (Love et al., 2019) which allows quantification of evidence in favour of the alternative or null hypothesis.

2.3.1 Baseline measures

Descriptive statistics and independent sample t-tests were used for group comparisons of the demographical variables, eating disorder pathology and all the other baseline measures (Table 2).

Table 2. Means (M) and Standard Deviations (SD) of demographic and eating disorders variables for the two groups (healthy controls -HC, and anorexic -AN), and results of the t-tests.

Demographic and Eating Disorder Variables							
	HC (N = 20)		**AN (N= 20)**				
	M	**SD**	**M**	**SD**	**T**	**df**	**p**
Age	23.85	3.23	23.30	7.60	.29	38	.767
BMI	18.94	.98	15.86	1.12	9.22	38	.001
EDI - drive for thinness	2.00	3.54	13.05	7.42	-6.01	38	.001
EDI - bulimia	.40	.99	.95	2.19	-1.02	38	.313
EDI - body dissatisfaction	4.00	3.66	13.10	7.15	-5.07	38	.001
BSQ	64.55	17.13	118.75	32.89	-6.54	38	.001
BUT-A GSI[1]	.93	.28	2.58	1.01	-7.07	37	.001
BITE Symptoms	6.10	3.97	11.80	6.41	-3.38	38	.002
BITE Severity	1.15	1.18	2.80	3.96	-1.79	38	.082
BES	5.95	4.63	12.40	8.44	-3.00	38	.005

BMI = Body Mass Index; EDI = Eating Disorder Inventory; BSQ = Body Shape Questionnaire; BUT GSI = Body Uneasiness Test, General Symptom Index subscale, BITE = Bulimic Investigatory Test, Edinburgh.

Patients with anorexia nervosa (AN) reported higher symptoms severity scores in all scales (the Eating Disorder Inventory (EDI)—drive for thinness, EDI—body dissatisfaction scales, Body Shape Questionnaire (BSQ), Body Uneasiness Test—Global Severity Score (BUT GSI), but not at the EDI—bulimia, and at the Bulimic Investigatory Test, Edinburgh (BITE)). Patients with AN also had a lower body mass index (BMI) compared to healthy controls (HC). Body dissatisfaction (calculated as perceived minus ideal body) was higher in AN patients than in HC. While both groups were accurate and did not differ on the estimation of their perceived body, AN patients considered a thinner body as ideal compared to HC (see Table 3 for detailed statistics).

Table 3. Means (M) and standard deviations (SD) of perceived body, ideal body, and body dissatisfaction (perceived body minus ideal body) tasks measured at the baseline of the two groups (healthy controls-HC, and anorexic patients-AN), and results of the t-tests, i.e., p-values (p) and Bayesian factors (BF). Values are expressed as a % of the real bodies of the participants (100 is the real body size).

Perceived, Ideal and Body Dissatisfaction Measures								
	HC		AN					
Task	**M**	**SD**	**M**	**SD**	**t**	**df**	**p**	**BF**
Perceived Body	101.65	8.02	102.85	14.06	-.33	38	.742	0.32
Ideal Body	94.65	1.38	87.10	1.59	2.28	38	.028	2.26
Body Dissatisfaction	8.45	7.85	19.95	12.97	-3.39	38	.002	20.90

2.3.2 Explicit and Implicit Measures of Embodiment

Three separate 2 × 2 × 3 ANOVAs were run for each component (i.e., Ownership, Agency, and Referral of Touch) of the illusion, each with the factors Group, IMS, and Avatar. They revealed a main effect of IMS for the Ownership, Agency, and Referral of Touch (all Fs > 13.34; all ps < 0.001; all $\eta s2 > 0.259$), suggesting a stronger illusion for synchronous as compared to the asynchronous IMS. We also found a main effect of Avatar on Ownership ($F(1,38) = 7.85$, $p < 0.001$, $\eta 2= 0.171$)), with participants reporting higher scores for the +15% Avatar ((mean ± SE) (39.38 ±1.89)) compared to the 0% (33.78 ± 2.26) and to the −15% (32.08 ± 2.27) (all ps < 0.001). All the other main and interaction effects were not significant (all Fs< 3.35 all ps > 0.084).

Results from the 2x2x3 ANOVA run on the body temperature revealed a main effect of IMS [$F(1,38) = 1.80$, $p= .002$, $\eta 2= .221$)] showing a lower body temperature after the synchronous stimulation (34.91 ± 0.14) compared to the asynchronous one (35.02 ± 0.13). None of the other main and interaction effects were significant (all Fs <1.27, all ps>.287). It is important to say that even if our thermometer had a precision of: ± 0.2°C, the error interested all the conditions in the same measure. However, to be more conservative and check that our results were not influenced by the measurement error, we performed an additional analysis where we subtracted the temperature measured in the synchronous conditions from those measured in the asynchronous ones and derived an index of the effect. We then removed all the differences that were lower than ± 0.2°C and performed a t-test against zero (i.e. no differences between synchronous and asynchronous conditions). Results from t-test against zero ($t(10) = 4.998$; $p = 0.0005$) supported our original finding, i.e., the two conditions significantly differed.

2.3.3 Body Dissatisfaction after Embodiment

A 2 × 2 × 3 ANOVA with Group (AN, HC) as between-and IMS (synchronous, asynchronous) and Avatar (−15%, 0%, +15%) as within-subjects factors showed no significant main or interaction effects (all $Fs < 3.39$, all $ps > 0.073$, all $\eta^2 < 0.065$). Given that classical null hypothesis testing is not the ideal statistical tool for drawing conclusions about non-significant results [47,48], we also performed a Bayesian ANOVA which allows quantification of evidence in favour of the alternative or null hypothesis. The full model including main effects and the interaction between them provides evidence in favour of the null hypothesis ($BF_{10} = 8.131 \times 10^{-5}$), suggesting that embodiment of avatars of different body sizes did not change body dissatisfaction in AN and HC.

2.3.4 Emotional Response after Embodiment

The 2 × 2 × 3 ANOVA on the emotional ratings with the factors Group, IMS, and Avatar revealed a main effect of IMS ($F(1,38) = 18.01$, $p < 0.001$, $\eta^2 = 0.321$), explained by more positive emotions following synchronous (59.44 ± 3.34) compared to the asynchronous (44.34 ± 2.93) IMS. The Avatar × Group interaction was also significant ($F(2,76) = 7.21$, $p < 0.001$, $\eta 2 = 0.159$) (Figure 4) and shows that independently of the IMS, AN patients felt more negative emotions after being exposed to the +15% Avatar (44.71 ± 3.95) compared to the −15% Avatar (53.59 ± 4.50) ($p = 0.017$). The opposite trend was true for the HC who showed significantly more negative emotional response after being exposed to the −15% (50.02 ± 4.49) compared to the +15% (58.60 ± 3.95; $p = 0.020$) and marginally to the 0% Avatar (56.88 ± 3.99; $p = 0.057$). Finally, AN patients experienced more negative emotions to the +15% Avatar (44.71 ± 3.95) than HC (58.60 ± 3.95; $p = 0.040$). No other main or interaction effects were significant (all $Fs < 3.73$, all $ps > 0.061$). These results suggest that differently from the HC group, AN patients experienced negative emotions when they observed an avatar replacing their own body in space which reproduced a verisimilar increase in weight of 15%, with respect to the one that reproduced verisimilar decrease of weight of the same magnitude. This happened independently from the type of IMS used to induce the embodiment.

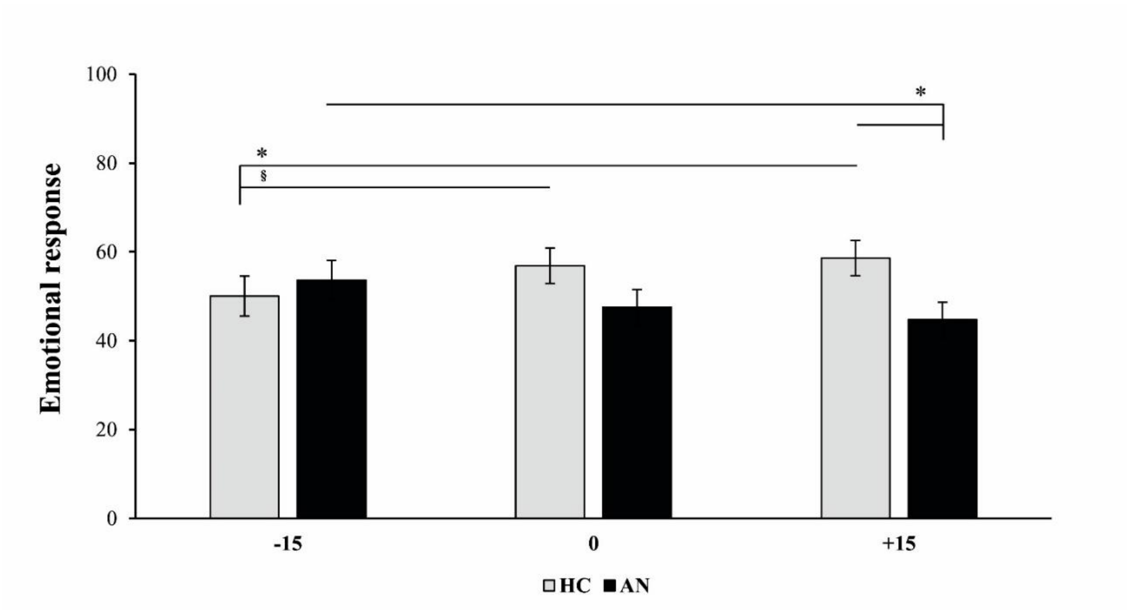

Figure 4. Emotional response after embodiment. Graph showing the effect of the interaction between avatar size (−15%; 0%; +15%) and group (healthy controls—HC; patients with anorexia nervosa—AN) on the emotional scale ranging from 0 (very negative emotions) to 100 (very positive emotions). Error bars represent standard error of the mean. * = $p < 0.05$, § = marginally significant ($p = 0.057$).

2.3.5 Avatars' Similarity and Attractiveness Ratings

The 2 × 3 ANOVA with the factors Group and Avatar performed on the similarity ratings revealed a main effect of the Avatar ($F(2,76) = 39.14$, $p < 0.001$, $\eta^2 = 0.50$): participants perceived the 0% (66.82 ± 3.26) and the +15% Avatar (69.37 ± 3.91) as more similar to their real body than the −15% Avatar (33.72 ± 4.52) (all ps < 0.001) (Figure 5, panel A). All the other main and interaction effects were not significant (all Fs < 0.59; all ps > 0.446). These results show that an increase in weight of 15% with respect to one's own perceived body size might pass unobserved in both patients and controls, while a loss of weight of similar magnitude is detected.

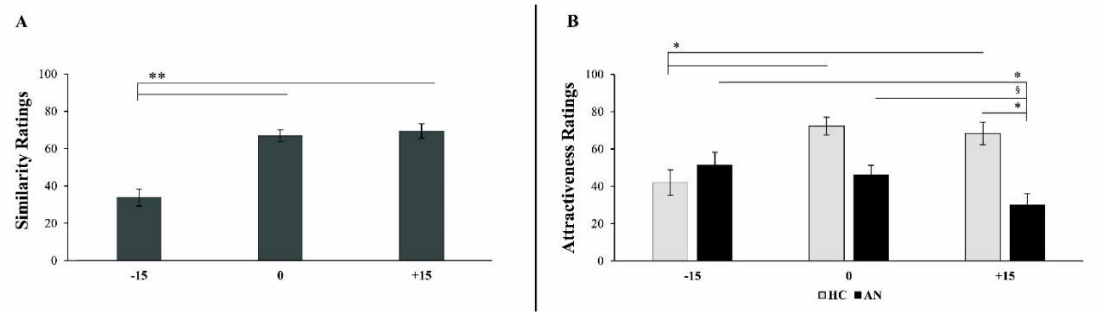

Figure 5. (A) Avatars' similarity ratings. Graph showing the main effect of Avatar size (−15%; 0%; +15%) on similarity ratings given during the observation of the avatars from a 1PP. **(B)** Avatars' attractiveness ratings. Graph showing the effect of the interaction between Avatar size (−15%; 0%; +15%) and Group (healthy controls, HC; patients with anorexia nervosa, AN) on attractiveness ratings given during the observation of the avatars from a 1PP. Error bars represent standard error of the mean. ** = $p < 0.001$, * = $p < 0.05$, § = marginally significant, i.e., $p = 0.058$.

The same ANOVA performed on the attractiveness ratings revealed a main effect of Group ($F(1,38) = 12.07$, $p = 0.001$, $\eta 2 = 0.241$). HC rated the avatars as more attractive than AN (60.87 ± 3.71 vs. 42.63, ± 3.71). The Avatar × Group interaction was also significant ($F(2,76) = 9.47$, $p < 0.001$, $\eta 2 = 0.119$) (Figure 5, panel B). AN considered the +15% Avatar as the least attractive ((30.10 ± 5.99) vs. the −15% Avatar (51.45 ± 6.83; $p = 0.016$) and the 0% Avatar (46.35 ± 4.82; $p = 0.058$. HC instead considered the −15% Avatar as the least attractive ((42.00 ± 6.83) vs. the 0% Avatar (72.25 ± 4.82; $p < 0.001$) and +15% Avatar (68.35 ± 5.99; $p = 0.002$)). The main effect of Avatar was not significant ($F(2,76) = 2.74$, $p = 0.070$). These results show that a loss of 15% of body weight is associated in AN patients to an increase in body attractiveness with respect to the perceived body weight (even though marginally) and to a verisimilar gain of the same magnitude in body weight, while it results in a decrease in body attractiveness with respect to the same categories of virtual bodies in HC participants.

2.3.6 Correlations between +15% Avatar Emotional Response and Symptoms Severity

Finally, we tested, separately for each group, whether the emotions experienced with the exposure to the +15% Avatar (which was considered highly similar to the self and minimally attractive (Section 3.5)), was associated to self-reported body shape preoccupations, as indexed by the Body Shape Questionnaire (BSQ), and to the presence of abnormal body image concerns and eating behaviours, as indexed by the global severity index of the Body Uneasiness Test (BUT-GSI). We found that in AN patients, there was a significant correlation between the emotions experienced with the +15% Avatar and the strength of the concerns about the body shape ($r = 0.62$; $p = 0.004$; $BF_{10} = 14.05$). Also, the correlation between the emotions experienced with the +15% Avatar and the BUT-GIS was significant ($r = 0.69$; $p = 0.001$; $BF_{10} = 37.07$). These correlations therefore suggested that the higher the symptoms' severity was, the higher the negative emotional experience with the +15% Avatar (Figure 6, right panels). No significant correlation was found in the HC group (all rs < 0.05; all ps > 0.826; BFs10 < 0.283), Figure 6, left panels).

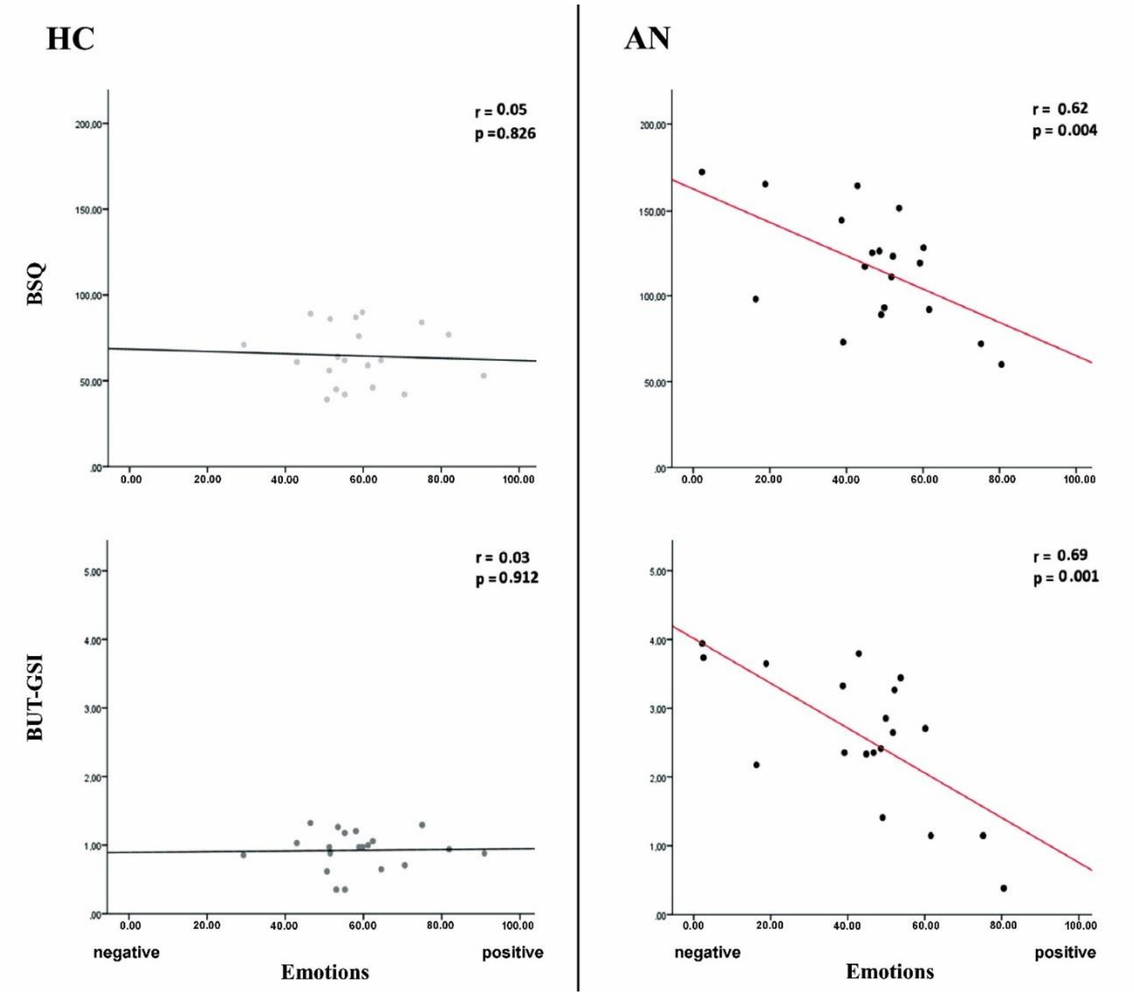

Figure 6. Correlations between +15% Avatar emotional response and symptoms severity. Scatterplots showing correlations between emotional changes after the exposure to the +15% Avatar and severity symptoms scores in the two groups. In the group of patient with anorexia nervosa (AN), the +15% Avatar emotional index correlated significantly with scores at the Body Shape Questionnaire (BSQ) and with the global severity index of the Body Uneasiness Test (BUT-GSI), while correlations were not significant in the healthy control (HC) group.

2.4 Discussion

We aimed to characterize, and eventually reduce, perceptual and cognitive-emotional components of body image distortion (BID) in AN using virtual bodies and embodiment illusion. To the best of our knowledge, only one study (S. C. Mölbert et al., 2017) investigated the body image in AN by: (i) using biometric self-avatars and (ii) reproducing the daily life experience of looking at oneself in the mirror. No studies instead coupled the creation of biometric self-avatars with multisensory bodily illusion paradigms.

Our results confirm that AN patients show higher body weight/shape concerns, drive for thinness (self-report questionnaires) and body dissatisfaction (perceptual minus ideal body size) compared to HC. However, body dissatisfaction in AN was not caused by a body overestimation, as suggested by previous literature (Gardner & Brown, 2014). Indeed, both AN patients and HC were accurate and did not differ in estimating the size of their real bodies, but AN patients desired a thinner body than HC. Although unexpected, these results are in line with a recent study (S. C. Mölbert et al., 2017) that adopted a virtual reality (VR) approach similar to the present one. Molbert and colleagues (S. C. Mölbert et al., 2017) measured body overestimation in AN by using a body scanner to create 3D avatars that faithfully reproduced participants' real body and then manipulated these avatars to reproduce weight gains and losses. Analogously to our findings, results from this study show that AN patients perceived their body similar to the HC but, differently from them, they desired a thinner body. Thus, all together these results support the idea that BID in AN is characterized by distorted attitudes concerning the desired body rather than by perceptual overestimation of the body size. Moreover, in agreement with the results of a recent meta-analysis (S. C. Mölbert et al., 2017), our findings also support the idea that estimation of one's own body size based on depictive methods (i.e., when participants estimate their body size by selecting a visual representation of their own body, like in this study) is less adapt to capture body size overestimation with respect to metric methods (i.e., when participants estimate their body size using quantifiable spatial estimations). This might be due to different features characterizing body representation that are targeted by these two types of methods. According to the body model proposed by Longo (Longo, 2015b), the metric measures use both explicit and implicit knowledge of the body while the depictive measures, rely on explicit knowledge only, therefore they might be less automatic and more controllable.

The main aim of the present study was to investigate whether embodiment of differently sized avatars could reduce BID in AN. Therefore, we coupled virtual reality with a visuo-tactile IMS setup to induce embodiment of differently sized avatars, and measured embodiment strength and changes in perceptual and cognitive-emotional components of BID after embodiment induction. We adopted a controlled IMS procedure that differed from previous studies in several ways (M Botvinick & Cohen, 1998; Piryankova et al., 2014) and had the final aim of maximizing the congruence of virtual and real bodily signals. Thus, we adopted both the 1PP and the head tracking during the synchronous IMS condition. This was particularly relevant in case of embodiment of bodies that patients might consider unattractive, as the ones reproducing their own weight and maximally in those reproducing a gain of 15% of this weight. However, differently from (Preston & Ehrsson, 2014), we used both synchronous and asynchronous IMS in order to disentangle the effects of embodiment and of observing the avatars from a 1PP. To this aim, we adopted a particular asynchronous control condition, in which we tried to maximize the incongruence between the virtual and real bodily signals. Indeed, the simple visuo-proprioceptive congruence between the real body and avatar's body given by presenting the avatars from a 1PP might result per-se in illusory feelings of ownership of the observed body. Thus, to reduce the possible occurrence of such illusory effects also in the asynchronous control condition, we applied spatio-temporal asynchronous touches as in (Apps & Tsakiris, 2014; Bufalari et al., 2014). Also, we locked the head tracking of the virtual camera (differently from (Piryankova et al., 2014)), to reduce the visuo-motor congruency between the self and the virtual body and further disrupt possible illusory embodiment in the control condition (see Section 2.4.3 of the methods for details). Instead of using the same avatar size for all participants (Preston & Ehrsson, 2014), we created customized avatars, matching actual weight, height, and body parts' dimensions/shape and induced embodiment with the avatar reproducing participant's perceived body size/shape and avatars reproducing realistic loss and gain in weight of 15% with respect to the perceived weight.

Both explicit (scores at the embodiment questionnaire) and implicit (body temperature data) measures of the embodiment suggest that our synchronous visuo-tactile stimulation was effective in inducing higher embodiment compared to the asynchronous one. Specifically, the answers at the self-report questionnaire show higher ratings after the synchronous compared to the asynchronous visuo-tactile stimulation for all the three components of corporal awareness. Participants were more likely to: (i) feel that the avatar's body was their own one (Ownership), (ii) feel in control of its movements (Agency), and (iii) feel that the perceived touch was caused by the virtual one (Referral of Touch). These illusory sensations were independent of group and no interaction with the avatar size was found. Only for the Ownership component there was a main effect of the avatar size, with higher ratings attributed to the fatter avatars compared to both the 0% and the −15% avatar independently of group and type of IMS. Implicit measures of the embodiment mirror the explicit ones, as we found a change in body temperature between synchronous and asynchronous conditions independently of group and avatar size. However, the interpretation that this change in body temperature might be considered an implicit index of embodiment is currently highly debated in the literature(de Haan et al., 2017). Indeed, some studies reported body temperature decreases of the real body while others reported body temperature increases, and - at present – direction of body temperature changes occurring during embodiment is not clearly attributable to any factor (de Haan et al., 2017). However, we think that our results on temperature might be different from the results by (F. Mancini, Longo, Kammers, & Haggard, 2011; Moseley et al., 2008) where decrease in body temperature/pain perception was interpreted as a phenomenon originated from the dis-ownership of the real hand in favour of the embodied one (the rubber hand). Supporting the results of a previous study (Llobera, Sanchez-Vives, & Slater, 2013), our data show that when a 1PP is used for creating the full body illusion in virtual reality, participants' real body representation is integrated with the virtual body and no dis-ownership feelings are generated. Still, more evidence is needed to better understand how body temperature is modulated by the embodiment illusions and to attribute the occurrence of such body temperature change to any evident factor.

All in all, our measures on embodiment strength converge in showing that plasticity of body representation was similar in AN and HC. This result apparently contradicts previous literature which showed stronger bodily illusion for body parts (i.e., hands) in AN compared to HC participants (Keizer et al., 2014). It has been shown that bodily illusion negatively correlated with interoceptive abilities (Eshkevari et al., 2012) and that higher bodily plasticity in AN plausibly results from altered multisensory integration of exteroceptive and interoceptive signals (Pollatos et al., 2008). In line with our results, HC and AN showed similar levels of embodiment of full bodies (Keizer et al., 2016). A conceivable reason for these contrasting results (rubber hand vs. full body illusion) might reside in the body part where touch is delivered. During the full body illusion touch is delivered to a highly salient and problematic body part for AN, i.e., the area around the abdomen. This may cause unpleasant sensations and negative emotions that in turn may dampen the embodiment in AN patients, making it similar to the level experienced by HC. Even though unpleasantness of the touch was not directly assessed in this study, AN patients anecdotally reported it.

An interesting finding of the present study is the fact that, independently of IMS type, AN patients showed more negative feelings after being exposed to the fatter avatar and that the strength of this effect correlated with clinical symptoms' severity. HC, instead, showed more negative emotional reactions toward the thinner avatar, which were unrelated to body concerns and eating disorder measures. This is even more interesting when considering how much the three differently sized avatars were retrospectively considered physically attractive and similar to the self. Both AN and HC participants rated the perceived and the fatter avatars as most similar to themselves (compared to the −15%). However, AN patients found them to be the least attractive (and the −15% as the maximally attractive), while HC rated them as the most attractive (and the −15% as the minimally attractive). Thus, anorexics reacted negatively to fatter avatars which were considered highly self-resembling and less attractive. These results mirror results from a previous study in HC who embodied obese avatars (BMI of 32.3) observed from 1PP (Preston & Ehrsson, 2016). This experience increased body dissatisfaction and negative emotional reactions, and at a neural level changed activity of anterior cingulate cortex and anterior insula. Such regions are known to mediate negative body-related emotional and affective experiences, such as pain and disgust (Jabbi, Bastiaansen, & Keysers, 2008; Wiech et al., 2010). While these results may shed light on negative emotions experienced by anorexics, it is worth noticing that we did not include obese avatars. The personalized avatars increased by 15% were still below the over-weight range, considering the average BMI (18.98) in HC. We would like to notice that both in the synchronous and in the asynchronous IMS blocks the avatars were presented in the 1PP. As we reported above, simple visuo-proprioceptive congruence (1PP) may induce some illusory feelings of embodiment even during asynchronous visuo-tactile stimulation. Even though we introduced spatial and temporal incongruent touches and motor discrepancy to get illusory sensations in the asynchronous condition as low as possible, it is possible that such sensations were able to trigger an emotional response as in the synchronous condition.

Importantly, contrary to our predictions embodiment of differently sized avatars did not significantly change participants' body dissatisfaction. This result stands in contrast with the results of a previous study by Preston and Ehrsson (Preston & Ehrsson, 2014) conducted in HC only, which found that embodiment of a standardized slim body decreased body size perception and increased body satisfaction. Several differences may acknowledge for the discrepant results. Here, we measured body size perception with a task based on a visual representation of the body, i.e., participants had to estimate their body size on a customized avatar presented from a 3PP (body image). Instead, in the study by Preston and Ehrsson (Preston & Ehrsson, 2014), perception of hip size was estimated by asking participants to indicate the distance on a ruler which reproduced their hip size in the absence of visual feedback (body schema). Participants were quite accurate in our body size estimation task, while participants in Preston and Ehrsson's study (Preston & Ehrsson, 2014) overestimated the size of their hips. In line with the above-mentioned discussion about the effectiveness of metric vs. depictive measures in detecting body size overestimation, these contrasting results suggest that IMS might be able to change body schema more than body image.

Absence of changes in body dissatisfaction might also be explained from a theoretical point of view by considering differences between the egocentric frame of reference (Galati, Lobel, & Vallar, 2000; Haggard, Longo, & Aza, 2010), i.e., body perceived from the 1PP based on its present state constituted by interoceptive and exteroceptive inputs, vs. the allocentric frame of reference, i.e., a somatic representation of the body as a 3PP based on beliefs and attitudes related to the body. According to the Allocentric Lock Theory (Riva, 2012b), people with AN are locked in their allocentric representation of the body and are unable to update it through egocentric sensory inputs. Indeed, in our study participants experienced embodiment of avatars of different sizes from an egocentric frame of reference, whereas the estimation of real/ideal body size was performed from an allocentric frame of reference. We can speculate that, even if the embodiment of differently sized avatars could have been successful in affecting the body image as experienced from an egocentric frame of reference, the inability for the AN patients to update their allocentric representation of the body through egocentric sensory inputs might have led to no changes in body dissatisfaction induced by the embodiment.

Related to the point above, our results also let us speculate that observing one's own body from a 1PP (as it usually happens when we look down to our own body) or observing its reproduction from a 3PP (as it usually happens in front of a mirror, in pictures or videos) might bias our perception of its dimension. Indeed, when participants judge 3D reproduction of themselves without spatial or specular congruence with the self-body (as in the perceived body task), they are quite good at estimating their own body size. However, when they observe their own body by looking directly at it (as in similarity ratings task) they are more sensible to detect a loss than an increase in weight. Indeed, results from the similarity ratings show that an increase in weight of 15% with respect to one's own perceived body size might pass unobserved in both patients and controls, while a loss of weight of similar magnitude is detected. This shows an asymmetry in how weight loss and gain might be considered by our perceptual system that seems to be detectable only when the to-be-judged body replaces our own in space. Also, our results suggest that the above-mentioned perceptual asymmetry is probably due to how we affectively experience our own body. Indeed, loss of weight is associated in controls to a decrease in body attractiveness, while in anorexic patients it is associated to an increase in body attractiveness. An increase of 15% in body weight is instead considered as attractive as the perceived body weight, both in patients and controls. If we focus on patients only, our results also suggest that when dealing with the affective component of the body, it does not matter whether one's own body size is observed from a detached third-person perspective (ideal body task) or through directly looking at it (attractiveness ratings). One's own perceived body size seem to be considered less desirable and attractive than a simulated loss of weight of 15%. On the same line, the simulated illusory experience of a gain in one's own body weight is negatively experienced by anorexic patients, but not by controls (results from the emotional response task).

Overall, the present study suggests that the cognitive-emotional component of body image and not the perceptual one is severely altered in AN. Despite the inability to reduce body dissatisfaction in AN patients, our procedure was successful in inducing a strong embodiment of differently sized avatars, as measured at both the explicit and implicit level, and in enhancing negative emotional responses of anorexics to the fattest avatar which scaled with symptoms' severity. Future research and clinical trials should aim at changing the distorted cognitive-emotional components of body image through the internalization of a normal weight body and the reduction of the emotional distress caused by weight gain, more than at changing the perceptual ones. Additionally, even if one should be cautious in using stimuli of enlarged bodies, virtual reality could be used to gradually expose and habituate AN patients to healthier versions of their bodies and to act as an intermediary step prior to the in vivo body image exposure, as some therapeutic protocols are already showing (see (Koskina, Campbell, & Schmidt, 2013) for a review).

2.5 Limitations

While we did recruit only patients with a diagnosis of AN-r (anorexia nervosa restrictive type), we could not control for confounding factors such as psychiatric comorbidity and treatment history, which might have had an influence on the measured dependent variables, i.e. ideal and perceived body, emotional response after embodiment etc. Also, even if we built personalized avatars based on the participants' real body measurements, participants were later able to modify these avatars only in incremental/decremental steps of 3% of the original body size and across a spectrum that went from -30% to +50% of the original body size, thus putting a limitation on the ability for the participants to freely adjust their perceived and ideal body size during these tasks.

3. Study 2

3.1 Introduction

In our previous study (Provenzano et al., 2020) we aimed to investigate whether embodiment of differently sized avatars could reduce Body Image Distortion (BID) in anorexia nervosa (AN). In particular, we induced the embodiment of three differently sized avatars (i.e. an avatar reproducing participant's perceived body, a -15% thinner avatar and a +15% fatter avatar) and measured the effect of the embodiment of these different avatars on the perceptual and cognitive-emotional components of BID. We were successful in inducing a strong embodiment illusion for all the different sized avatars, both at the explicit and implicit level, and in underlining the distortion of the cognitive-emotional component of body image in AN, with anorectic patients reporting enhanced negative emotions after being exposed to the fatter avatar. Concerning the reduction of BID in AN, our embodiment procedure was unable though to change body dissatisfaction in our participants, and in particular it was unable to reduce body dissatisfaction in our anorectic patients. We advanced several different arguments on why this was the case (see 2.4 for a detailed discussion). On the one hand, we argued that these results could be explained by the difference between depictive and metric methods of body size estimation task: indeed, in our previous experiment we asked our participants to estimate their body size by selecting the avatar that best resembled their real and ideal body, i.e. we used a depictive method (or “whole body” method (Cash & Deagle, 1997; Farrell et al., 2005; Gardner & Brown, 2014)), which in a recent review and meta-analysis (Simone Claire Mölbert et al., 2017) has been found to be less adapt in capturing body size overestimation compared to methods in which participants are asked to estimate their body size through spatial estimates, i.e. metric methods (Cash & Deagle, 1997; Farrell et al., 2005; Gardner & Brown, 2014). On the other hand, our participants experienced the embodiment illusion of different sized avatars from a first person perspective (1PP), i.e. egocentric frame of reference, whereas the estimation of their own real and ideal body size was done from a third person perspective (3PP), i.e. allocentric frame of reference, which accordingly to the Allocentric Lock Theory (Riva, 2012b) anorectic patients are unable to modify through egocentric body experiences.

To address these issues, in the present study we decided to focus our attention on the body experienced from a first person perspective view, i.e. egocentric frame of reference, which includes both the body perception and body schema components of body representation. Body perception refers to the mental models describing one's own body shape and location (Zopf, Contini, Fowler, Mondraty, & Williams, 2016), and it based on the integration of the somato-perceptive signals of one's own body. The body schema refers to the dynamic sensorimotor representation of the body that initiates and guides actions (de Vignemont, 2010). Body schema can be elicited by action, regardless of whether the action is anticipated, executed or just imagined (Guardia et al., 2010). Accordingly to the theoretical framework proposed by Longo (Longo, 2015b), both body perception (or perceptual body image) and body schema are aspect of the somatoperception, i.e. the implicit representation of the body which underlie the formation of immediate percepts of one's own body and of the world around it, whereas the cognitive and emotional components of body image are aspect of the somatorepresentation, i.e. the explicit representation of the body which comprises feelings, thoughts and abstract knowledge about one one's body and about bodies in general (Longo, 2015b).

There are already some experimental evidence that BID in AN interests both the aforementioned components of the body somatoperception, i.e. body perception and body schema. In a 2012 study by Keizer and colleagues (Keizer et al., 2012), anorectic patients overestimated the size of tactile stimuli applied to their own's bodies compared to healthy controls, showing a distortion in both somatosensory perception and in the metric properties of the body representation. Other studies also indicate the presence of a distorted body schema in anorexia nervosa: anorectic patients greatly overestimated their shoulders' width when asked to walk through a door's like opening compared to healthy controls (Keizer et al., 2013), and the same overestimation was found by using a body-scaled action-anticipation task, in which the act of walking through a door was just imagined (Guardia et al., 2010). Furthermore, a follow-up study (Guardia et al., 2012) showed that anorectic patients overestimated the passability rate through a door's aperture only when the task was performed from a 1PP, i.e. egocentric frame, whereas there was no difference between anorectic patients and healthy controls' accuracy when the task was performed by a 3PP, therefore suggesting that the overestimation of the passability rate in anorectic patients is more likely caused by an alteration of their body schema rather than by a general distortion in perceptual discrimination.

In the present study we wanted to assess whether the embodiment of different sized avatars could reduce both body perception and body schema distortion present in anorexia nervosa. For the body perception measurement we adopted a metric body size estimation task from Preston and colleagues (Preston & Ehrsson, 2014), in which participants are asked to estimate the width of their hips while having no vision of their own body. For the body schema measurement we used an immersive virtual reality version of the door's aperture task (Piryankova et al., 2014). Also, avatars body size was selected on the basis of results of previous study (Provenzano et al., 2020). In the present study, we decided to not individualize the avatars and present an avatar with a underweight body (BMI = 15) and an avatar with normal weight (BMI = 19) to all participants. Furthermore, in order to disentangle even more the effect of the embodiment illusion from the mere observation of an avatar from a first person view (1PP), we changed our asynchronous IMS condition by applying asynchronous touches to an avatar observed from a third person perspective (3PP).

We measured the embodiment strength both at the explicit (Lenggenhager et al., 2007; Tieri et al., 2015) and implicit level (Tieri et al., 2017), and we also measured participants' emotional response after being exposed to the underweight and normal weight avatars (Provenzano et al., 2020). Finally, we asked participants to rate the avatars observed from a 1PP in terms of similarity to their own body, overall attractiveness and implicit disgust.

We expected anorectic patients to show an overestimation in both the body perception (Preston & Ehrsson, 2014) and body schema (Guardia et al., 2012, 2010) measurements compared to healthy controls, and we expected this overestimation to correlate with eating disorder' symptoms severity. We also hypothesised a reduction of both body perception and body schema overestimation in AN patients after the embodiment of the underweight avatar when compared to the normal weight avatar. Finally, we expected anorectic patients to rate the underweight avatar as the most attractive and to give higher rating in both similarity and implicit disgust to the normal weight avatar.

3.2 Materials and Methods

3.2.1 Participants

The current study was approved by the Ethical Committees of the IRCCS Santa Lucia Foundation in Rome and was carried out in accordance with the ethical standards of the 2013 Declaration of Helsinki. All participants read and signed the informed consent. Parental consent was required for participants of minor age (N = 5).

We performed a power analysis with G*Power 3.1.9.2 to calculate the sample size needed for comparing the means of two groups with mixed repeated measures ANOVA. The effect size f was based on a previous study that investigated changes in body size estimation in anorectic patients after a Full Boy Illusion (FBI) was induced (Keizer, Van Elburg, Helms, & Dijkerman, 2016). A total sample of 50 participants (25 for each group) was required to obtain a power of 0.80, with alpha set at 0.05 and f at 0.33.Unfortunately, due to the spread of the COVID-19 pandemic, we were forced to stop collecting data in order to preserve the health and safety of all the parties involved.

A total of 19 female anorectic patients [(mean ± s.e.) (age = 20.00 ± 3.76, BMI = 16.82 ± 0.84)] and 24 female healthy controls (HC) (age = 21.75 ± 2.31, BMI = 20.14 ± 1.58) participated in the study. All the anorectic patients were recruited at the Eating Disorder Centre of ASL 1 Rome, that also performed a diagnosis of Anorexia Nervosa (restricting type) following the DSM-5 criteria. For the HC group, the presence and/or history of any eating disorder and/or other psychiatric disorders constituted an exclusion criterion.

3.2.2 Stimuli Preparation: Virtual Scenario and Avatars creation

The virtual scenario consisted of a virtual room containing a deck chair, a sliding door, a desk and other realistically modelled furnishes created ad hoc in order to increase the immersiveness of the virtual scenario without distracting the participants from the experimental tasks (Figure 1). All the 3D modelling and texturing of the virtual scenario was performed in Autodesk 3ds Max 2017.

Figure 1. Experimental settings. The virtual scenario consisted of a room resembling the one the participants were currently in, with the avatar laying down on a deckchair similar to the one the participants were sitting on during the whole experimental procedure. The virtual door was placed at a distance of 3 meters from the point of view of the participant (Piryankova et al., 2014).

A 3D modelling software (MakeHumans) was used to create the underweight BMI avatar (BMI = 15) and the normal weight BMI avatar (BMI = 19). These avatars reproduced the bodies of a control participant and a AN patient (which took part in the Study 1, but not to this one) which had similar height and a BMI of 19 and 15 respectively. Finally, Adobe Photoshop 7.0 was used to create highly detailed skin, clothes and material textures for both avatars. All the experimental tasks were coded in C Sharp and implemented in Unity 2017.3.1f1.

3.2.3 Pre-Experimental Session: self-report questionnaires

After receiving verbal instructions, participants were asked to fill a series of questionnaires to assess body dissatisfaction and symptoms severity of the eating disorder pathology, namely the Eating Disorder Inventory - 2 (EDI-2) (Garner, 1991), the Body Shape Questionnaire (BSQ) (Cooper et al., 1987) and the Body Uneasiness Test (BUT) (Cuzzolaro et al., 2006) (see 2.3.3 for a detailed description of all the questionnaire) . Moreover, in order to assess the awareness of their internal bodily signals, participants filled the Italian version of the Multidimensional Assessment of Interoceptive Awareness, Version 2 (MAIA-2) (Calì, Ambrosini, Picconi, Mehling, & Committeri, 2015). The MAIA-2 is a 37-item state-trait self-report questionnaire to measure multiple dimensions of interoception. The questionnaire consists of 8 sub-scales: Noticing, Not-Distracting, Not-Worrying, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, and Trust. Items are answered on a 6-point Likert scale.

Anorectic participants filled out the questionnaires *intramoenia* assisted by the medical staff of the of the Eating Disorder Centre of ASL 1 Rome, whereas HC group filled out the questionnaire at the Social and Cognitive Neuroscience Laboratory at the Department of Psychology of Sapienza, University of Rome.

3.2.4 Experimental Session

A graphical description of the experimental session is provided in Figure 2. Before starting with the testing phase, participants were provided with standardized clothes (a pink t-shirt and a pair of black leggings) and asked to wear them in order to match the avatar's outfit.

Participants were then asked to lay down on a deck chair and put on the VR head-mounted display (HMD, Oculus Rift) to perform the Body Perception Task (3.2.5) and the Body Schema Task (3.2.6) before the induction of the embodiment illusion (baseline measure). Subsequently participants experienced synchronous congruent and asynchronous incongruent Interpersonal Multisensory Stimulation (IMS) with two different avatars: one with a BMI in the underweight range (15 BMI) and the other with a BMI in the normal weight range (19 BMI) (3.2.7).

The order of presentation of the Avatar Size (under and normal weight BMI avatar) blocks and the type of IMS (synchronous-congruent and asynchronous-incongruent) within each avatar block were counterbalanced across participants. At the end of each IMS block, we collected in sequential order: 1) an implicit measure of the strength of the embodiment illusion (3.2.8); 2) the Body Perception/Body Schema task measures; 3) participants' emotional response to the embodiment procedure (3.2.9); 4) explicit measure of the strength of the embodiment illusion (3.2.8) and 5) feelings of thinness and fatness (3.2.8). Finally, at the end of the experimental session, we asked participants to rate the under- and normal weight BMI avatars (presented from a first-person perspective) in terms of similarity, attractiveness and implicit disgust (3.2.10).

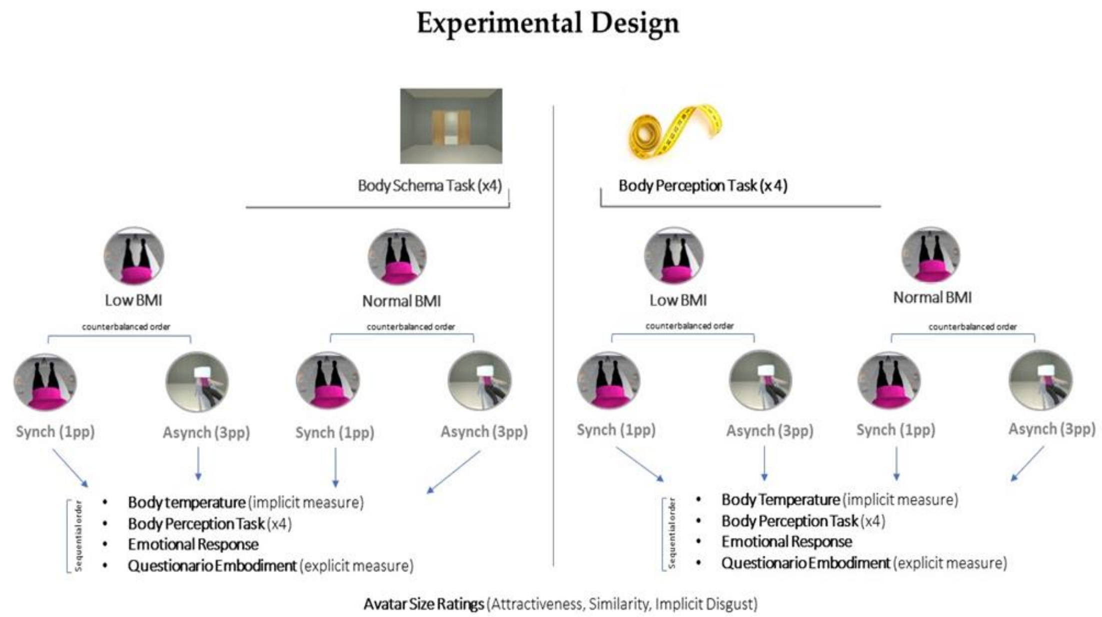

Figure 2. After estimating the minimum door's aperture width in order to pass through (Body Schema Task) and the width of their hips (Body Perception Task), participants were enrolled in embodiment blocks in which synchronous and asynchronous interpersonal multisensory stimulation (IMS) were applied to two different bodies (normal and underweight BMI avatars). After each embodiment block participants repeated the Body Perception and Body Schema tasks to measure the effects of the embodiment of the two different sized avatars on the estimation of the door's aperture width and width of their hips. Explicit and implicit measures of the embodiment illusion, feelings of thinness/fatness and the emotional response after being exposed to a/synchronous touching of the two different sized avatars were recorded after each embodiment block. At the end of the experiment we asked participants to rate from a first-person perspective normal and underweight BMI avatars in terms of similarity to their own body, attractiveness and body's odour (implicit disgust rating).

3.2.5 Body Perception Task

During the Body Perception Task participants laid down on a deck chair and were asked to make an estimation of the width of their own hip by relying entirely on the non-visual perception of their own body. Indeed, during the task participants were asked to wear the HMD with the screens turned off, so that the vision of their own body was occluded. They held a ruler in front of them with the index finger and thumb of both hands and they were asked to estimate the size of their hips by adjusting the distance between their hands in order to match the perceived width of their hips. While they were making the estimation, an experimenter blocked the right hand of the participants in a fixed position, which was placed on the median line of their body, so that only the left hand was free to move. This was done in order to prevent the participants from aligning their hands with the hips of their own body. Participants were asked to repeat the estimation four times. similarly to (Preston & Ehrsson, 2014).

3.2.6 Body Schema Task

During the Body Schema Task participants were asked to imagine themselves walking through a virtual sliding door's aperture and to estimate the minimum aperture's width required to walk through the door without twisting their body (see Figure 3A). The participants were able to adjust the door's aperture (widening or reducing it) using a joypad (Belkin Nostromo Speedpad n52) placed on the deckchair. The door was placed inside the virtual room at 3m from the point of view of the participants (Figure 3B), and the task consisted of four trials, each starting with a different door's aperture (0.30m, 0.60m, 0.90m and 1.20m), similarity to previous studies (Piryankova et al., 2014). The order of presentation of the four trials was randomized for each participant.

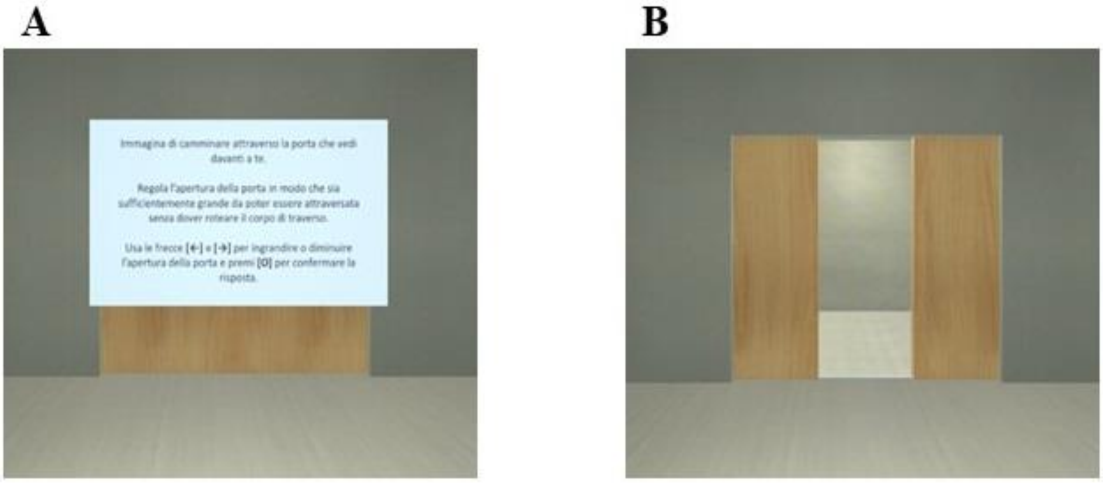

Figure 3. Body Schema Task **(A)** We displayed the instructions for the Body Schema Task on a white board that was placed in front of the participants inside the virtual scenario. Participants were asked to imagine themselves walking through the door without having to twist their body and to adjust the door's aperture accordingly by using the joypad placed on the deck chair. **(B)** The task consisted of four trials, each one starting with a different door's aperture (0.30m, 0.60m, 0.90m and 1.20m). Participants could narrow or widen the door's aperture by clicking on the left and right arrows of the joypad on the until they found the desired door's aperture. The order of presentation of the four trials was randomized for each participant.

3.2.7 Embodiment Procedure

At the start of the Embodiment Procedure we performed a calibration of the camera position, to assure a precise overlap between the participant's real body and the avatar's body. Participants were asked to look at the avatar's belly and tell the experimenter if the touch observed on the avatar matched the location of the touch felt on their own body. Once the calibration was completed, FBI was induced with both synch-congruent (experimental condition) and asynch-incongruent (control condition) IMS and with both under- and normal weight BMI avatars.

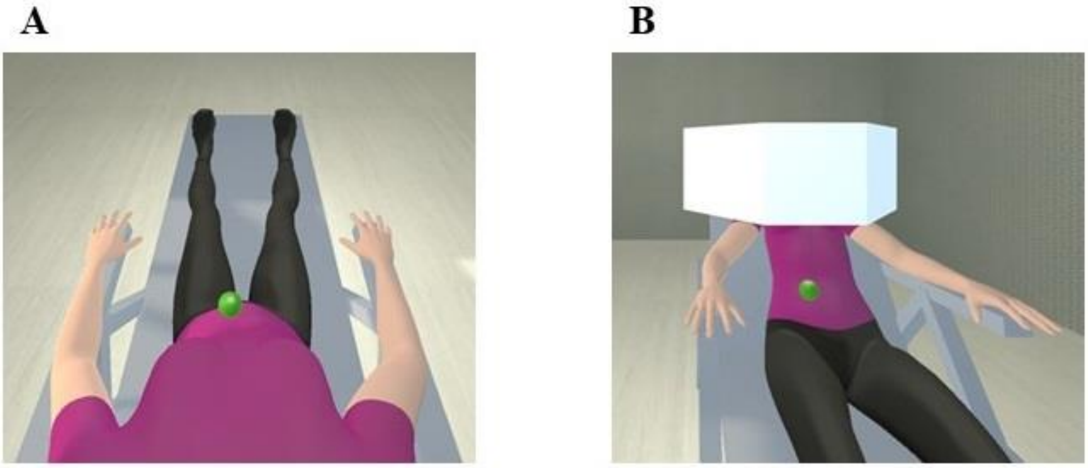

Figure 4. Embodiment Procedure. During the embodiment procedure a virtual ball was programmed to touch the avatar's belly on 3 different spots in 3 different ways (single/double touches and stroking movements). **(A)** During the synchronous condition, participants observed an avatar from a 1PP and experienced a tactile stimulation that matched in time and location the virtual touches they were observing on the avatar, therefore achieving a visuo-tactile-proprioceptive congruency between their real body and the observed virtual body. **(B)** During the asynchronous condition, participants observed an avatar placed slightly at their right from a 3PP and experienced a tactile stimulation that did not match for time and location the virtual touches they were observing on the avatar, therefore experiencing a complete visuo-tactile-proprioceptive discrepancy between their real body and the observed virtual body.

During the synchronous congruent IMS, participants observed a tactile stimulation applied to an avatar from a 1PP, therefore there was a complete visuo-tactile-proprioceptive congruence between participants' real body and the observed virtual body. Tactile stimuli felt on the participants' body matched in time and location the touches observed on the avatar (Figure 4A). During the asynchronous incongruent condition, participants observed an asynchronous touch applied to an avatar observed from a 3PP, which maximized both the visuo-proprioceptive and the visuo-tactile discrepancy between the participants and the avatar. Tactile stimuli felt on the participants' body were asynchronous in both timing and location with respect to the observed ones (Figure 4B). In order to avoid a specular congruency between the participant ‘s body and the observed avatar, the avatar was slightly moved to the right of the participant’s midline.

In both the conditions, participants and avatars bodies were touched in an area around the belly. Participants were asked to look at the belly of the avatar while being stimulated and to not move their head. All the touches were applied by a female experimenter receiving audio cues signalling the time and location of each touch.

3.2.8 Explicit and Implicit Measures of Embodiment

We used a self-reported questionnaire (Provenzano et al., 2020) as an explicit measure of embodiment. The questionnaire assessed three key components of the embodiment illusion: Ownership, i.e. the sense of virtual body being one’s own, Agency i.e. the sense of being in control of the virtual body and Referral of Touch, i.e. the feeling of being touched by the virtual object. Control items were also administered to deviate participants’ attention from the study hypothesis and to control for response biases (see Table 1 for the complete list of the questionnaire’s items). The questionnaire also contained two additional items measuring the subjective feeling of “feeling slimmer” or “feeling fatter” than usual (Preston & Ehrsson, 2018). The questionnaire was administered inside the virtual reality scenario by projecting the items on a white board placed in front of the participants. During the questionnaire no avatar was present in the virtual scenario. The participants were asked to rate how much they agreed with each item on a Visual Analogue Scale (VAS) ranging from 0 (“I do not agree at all”) to 100 (“I completely agree”).

Table 1. Embodiment questionnaire items assessing participants' degree of explicit embodiment on four subscales.

Embodiment Questionnaire Items	
Items	**Subscales**
I felt I was looking at my own body	Ownership
I felt the virtual body was my own body	Ownership
I felt I could control the virtual body	Agency
I felt I could move the virtual body	Agency
I felt the virtual body obeyed or could obey my will	Agency
I felt that the touch I received was caused by the ball moving on the virtual body	Referral of Touch
I felt I was receiving the touch where the ball was touching the virtual body	Referral of Touch
I felt I had more than one body	Control
I felt I did not own a body anymore	Control
I felt like my body was thinner than usual	Feelings of Thinness
I felt like my body was fatter than usual	Feelings of Fatness

As an implicit measure of embodiment, we recorded participants' body temperature before and immediately after each IMS block. Body temperature was recorded under participants' right armpit with an infrared thermometer (IFR 100, microlife, precision: ± 0.2°C, 32.0 ~ 42.2 °C).

3.2.9 Measure of emotional response induced by embodiment

We measured valence and intensity of the emotional response due to being exposed to a underweight BMI and a normal weight BMI avatar by asking participants to rate their experience on a VAS ranging from zero ("very negative") to 100 ("very positive") after each IMS block. The VAS was projected on a white board inside the virtual reality scenario, and no avatar was present in the virtual scenario during the task.

3.2.10 Similarity, Attractiveness and Implicit Disgust Ratings of the Avatars

At the end of the experiment we asked participants to rate the underweight BMI and normal weight BMI avatars in terms of their physical attractiveness (Attractiveness), similarity to participant's actual body (Similarity), and un/pleasantness of body odour (Implicit Disgust). For the Attractiveness rating, ratings were given on a VAS ranging from 0 ("not attractive at all") to 100 ("maximally attractive"). For the Similarity rating, ratings were given on a VAS ranging from 0 ("not similar at all") to 100 ("completely similar"). Finally, we measured participants' Implicit Disgust toward the avatars by asking participants to imagine the observed avatar's body odour and to rate it on a VAS ranging from 0 ("maximally unpleasant") to 100 ("maximally pleasant").

The avatars were presented from a 1PP while participants were lying on the deck chair, thus there was a spatial congruency between participant's real body and the virtual body they were rating. Presentation order of the two avatars was counterbalanced across participants and of presentation order of the three questions was randomized.

3.3 Results

All analyses were performed with Statistica 8.1 software (Statsoft Inc., Tulsa, OK, 2007). Significance was set at $p < .05$. Considering the unequal *n* of our sample, we conducted Welch's t-tests to compare the AN and the HC group. The Unequal N Tukey HSD test was used for post-hoc comparisons. The open-source software JASP (Love et al., 2019) was used to perform Bayesian analyses which allow quantification of evidence in favour of the alternative or null hypothesis.

3.3.1 Demographics and baseline measures

Independent samples t-tests were used to compare the two groups on all the relevant demographic variables, eating disorders pathology's severity (Table 1) and baseline measures of the Body Perception and Body Schema tasks (Table 2). Anorectic patients and healthy controls did not differ with respect to age, but in terms of BMI, drive for thinness (EDI), body dissatisfaction (EDI), body shape preoccupations (BSQ), body uneasiness (BUT), the ability to listen to one own's body for insight and the experiencing of one's body as safe and trustworthy (MAIA) (Table 2).

Table 2. Means (M) and Standard Deviations (SD) of demographic and eating disorders variables for the two groups (healthy controls -HC, and anorexic -AN), and results of the t-tests.

Demographic and Eating Disorder Variables							
	HC (N = 24)		**AN (N = 19)**				
	M	**SD**	**M**	**SD**	**T**	**df**	***p***
Age	21.75	2,31	20.00	3.76	1.78	41	.070
BMI	20.14	1.58	16.82	0.84	8.86	41	<.001
EDI - drive for thinness	3.42	5.40	14.83	7.62	−5.42	41	.<001
EDI - bulimia	1.96	3.58	1.22	2.77	0.75	41	.457
EDI - body dissatisfaction	7.71	6.71	15.56	8.42	−3.25	41	.003
BSQ	84.71	32.72	118.56	42.16	−2.83	41	.008
BUT GSI	1.38	0.88	2.80	0.99	−4.78	41	<.001
MAIA Body Listening	2.88	0.92	1.78	1.25	3.13	41	.004
MAIA Trusting	3.11	1.28	1.35	1.31	4.25	41	<.001

BMI = Body Mass Index; EDI = Eating Disorder Inventory; BSQ = Body Shape Questionnaire; BUT GSI = Body Uneasiness Test, General Symptom Index subscale, MAIA = Multidimensional Assessment of Interoceptive Awareness

Anorectic patients also significantly overestimated the width of their hips (Body Perception Task) and minimum aperture's width required to walk through the door (Body Schema Task) compared to the healthy control participants (Table 3).

Table 3. Means (M) and Standard Deviations (SD) of Body Perception and Body Schema tasks measured at the baseline on the two groups (healthy controls -HC, and anorexic patients -AN), and results of the t-tests, i.e. p-values (p).Values are expressed as a % of the real width of the hips (Body Perception) and shoulders (Body Schema) of the participants (100 is the real body part width).

Body Perception and Body Schema Measures							
	HC		**AN**				
Task	**M**	**SD**	**M**	**SD**	**t**	**df**	***p***
Body Perception	85.48	17.11	108.79	28.23	−3.17	41	0.003
Body Schema	140.64	25.79	173.54	45.61	−2.81	41	0.009

3.3.2 Explicit and Implicit measures of embodiment

For each component of the embodiment illusion (i.e. Ownership, Agency and Referral of touch), we performed a 2x2x2 ANOVA with Group as between-subjects factor, Avatar's size and IMS as within-subjects factors. The analysis revealed a main effect of the IMS condition for the Ownership, Agency and Referral of Touch components of the embodiment illusion [all $Fs > 34.59$; all $ps < .000$; all $\eta s2 > .458$], indicating a stronger bodily illusion after the synchronous IMS compared to the asynchronous IMS. Significant was also the main effect of the Avatar's size condition for all the embodiment illusion's components, i.e., Ownership, Agency and Referral of Touch [all $Fs > 4.91$; all $ps < .032$; all $\eta s2 > .107$], suggesting that participants felt a stronger embodiment illusion after being exposed to the normal weight BMI avatar compared to the underweight BMI avatar.

The same 2x2x2 ANOVA with Group as between-subjects factor, Avatar's size and IMS as within-subjects factors and participants' body temperature as dependent variable revealed no significant main effect nor significant interaction effect (all $Fs < 2.45$; all $ps > .125$).

3.3.3 Body Perception Task estimations after embodiment

We performed a 2x2x2 ANOVA with Group as between-subjects factor, Avatar's size and IMS as within-subjects factors and Body Perception Task estimations after embodiment as dependent variable. The analysis revealed a significant main effect of the Group [$F(1,41) = 4.96$, $p = .031$, $\eta 2 = .108$]. Independently of the size of the avatars and the type of IMS applied, anorectic patients reported higher estimations in the Body Perception Task, i.e., reported higher estimations of their hip's width (1.17 ± 0.08)

compared to HC participants (0.92 ± 0.07). The main effect of the Avatar's size was also significant [F (1,41) = 4.67, p = .037, η2 = .102], with all participants reporting higher estimation of their own hip's width after being exposed to the normal weight BMI avatar (1,07 ± 0.06) compared to the underweight BMI avatar (1.02 ± 0.05). The other main effect and all the interactions were not significant (all Fs < 3.85; all ps > .057).

3.3.4. Body Schema Task estimations after embodiment

We performed a 2x2x2 ANOVA with Group as between-subjects factor, Avatar's size and IMS as within-subjects factors and Body Schema Task estimations after embodiment as dependent variable. The analysis revealed a main effect of the Group [F (1,41) = 8.53, p = .006, η2 = .172]. Independently of the size of the avatars and the type of IMS applied, anorectic patients reported higher estimations in the Body Schema Task, i.e., reported wider doors' apertures (1.81 ± 0.10) compared to HC participants (1.39 ± 0.09). The main effect of the Avatar's size was also significant [F (1,41) = 4.22, p = .046, η2 = .102], with all participants reporting wider door's aperture after being exposed to the normal weight BMI avatar (1.63 ± 0.07) compared to the underweight BMI avatar (1.57 ± 0.07). Finally, significant was also the triple interaction between Group, Avatar's size and IMS [F (1,41) = 4.35, p = .043, η2 = .096] (Figure 5).

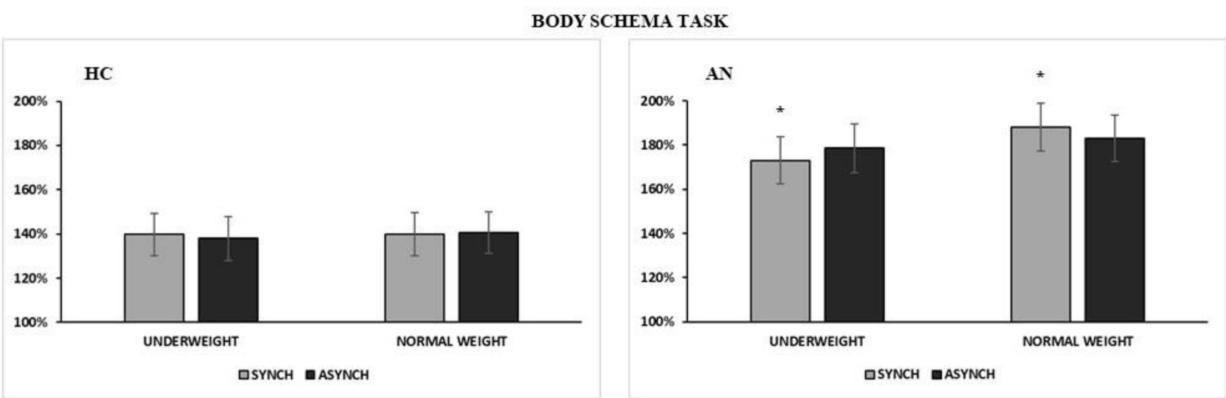

Figure 5. Body Schema Task estimations after embodiment. Graph showing the effect of the triple interaction between group (healthy controls—HC; patients with anorexia nervosa—AN), avatar size (underweight vs normal weight avatar) and IMS (synchronous vs asynchronous IMS) on the body schema task estimations (estimations are presented as a % of the participants' body size, 100% represent the actual body size). Error bars represent standard error of the mean. * = $p < 0.05$.

Post-hoc analysis revealed that that anorectic patients reported a smaller door's aperture estimation after the synchronous IMS condition with the underweight BMI Avatar (1.73 ± 0.11) compared to the synchronous IMS condition with the normal weight BMI Avatar (1.88 ± 0.11) ($p < .001$), whereas the HC participants estimations of the door's aperture did not differed in all conditions (all ps > .327). All the other main effect and interactions were not significant (all Fs < 2.51; all ps > .120).

3.3.5 Feelings of Thinness/Fatness after embodiment

We performed a 2x2x2 ANOVA with Group as between-subjects factor, Avatar's size and IMS as within-subjects factors and Feelings of Thinness/Fatness after embodiment as dependent variable. The analysis revealed a main effect of the Group [$F(1,41) = 7.50$, $p = .009$, $\eta 2 = .155$], Avatar [$F(1,41) = 10.98$, $p = .002$, $\eta 2 = .211$]], which were explained by a significant interaction between the two conditions [$F(1,41) = 5.39$, $p = .025$, $\eta 2 = .116$] (Figure 6). Post-hoc analysis revealed that, while the HC participants experienced no significant change in their body representation after being exposed to the underweight (-9.19 ± 8.82) and normal weight BMI avatar (-2.38 ± 6.33) ($p = .878$), anorectic patients felt significantly fatter after being exposed to the normal weight BMI avatar (39.00 ± 7.12) compared to the underweight BMI avatar (0.38 ± 9.92) ($p = .003$).

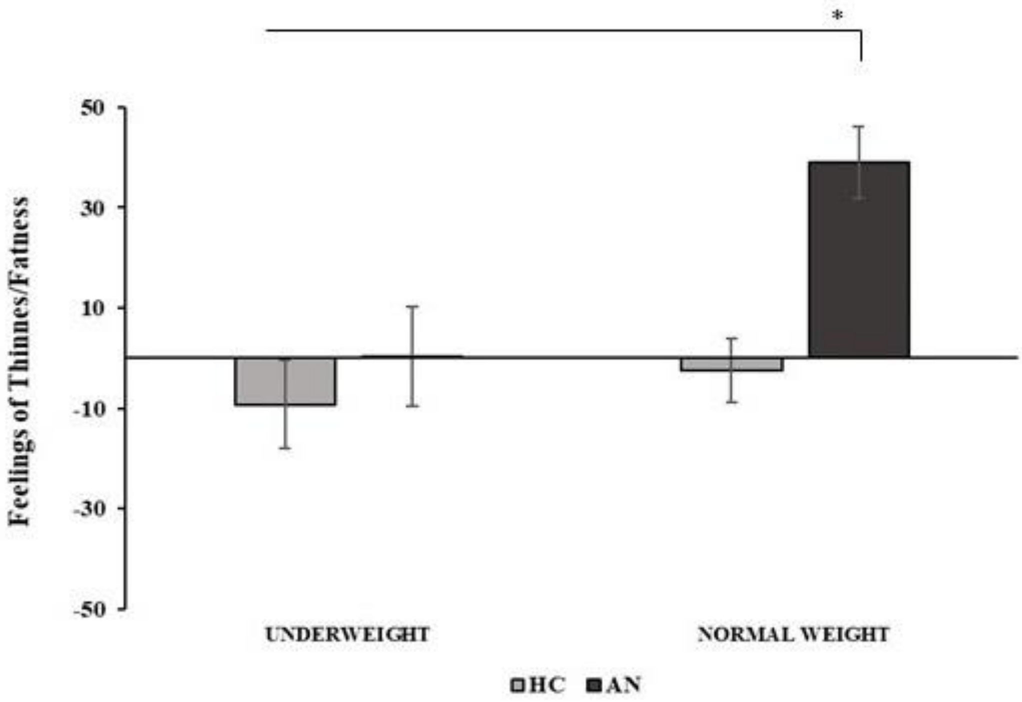

Figure 6. Feelings of Fatness/Thinness after embodiment. Graph showing the effect of the interaction between group (healthy controls—HC; patients with anorexia nervosa—AN) and avatar size (underweight vs normal weight avatar). Positive values indicate feelings of feeling fatter than usual, while negative values indicate feelings of feeling thinner than usual. Error bars represent standard error of the mean. * = $p < 0.05$.

There was also a significant main effect of IMS [$F\ (1,41) = 5.87$, $p = .020$, $\eta2 = .125$] which was explained by its significant interaction with the Avatar's size [$F\ (1,41) = 5.78$, $p = .021$, $\eta2 = .124$]. Post-hoc analysis showed that all participants reported to feel thinner than usual after the synchronous IMS with the underweight BMI avatar (-19,37 ± 8.47) compared to all the other conditions (all ps < .008). The other interaction effects were not significant (all Fs < 0.02; all ps > .888).

3.3.6 Emotional response after embodiment

We performed a 2x2x2 ANOVA with Group as between-subjects factor, Avatar's size and IMS as within-subjects factors and emotional ratings after embodiment as dependent variable. The analysis revealed a significant main effect of the Group [F (1,41) = 5.82, $p = .020$, $\eta 2 = .124$]. Anorectic patients reported more negative emotions after being exposed to the avatars, independently of the size of the avatars and the type of IMS applied (39.01 ± 3.85), compared to HC participants (51.45 ± 3.43). All other main effects and interactions were not significant (all Fs < 3.79; all ps > .058).

2.3.7 Avatar's similarity, attractiveness and implicit disgust ratings

We performed a 2x2 ANOVA with Group as between-subjects factor, Avatar's size as within-subjects factor and the similarity ratings on the avatars observed from a 1PP as dependent variable. The analysis revealed a significant main effect of the Avatar's size (under vs normal weight BMI) [F (1,41) = 39.67, $p < .000$, $\eta 2 = .492$] (Figure 7). Independently of the group, participants perceived the normal weight BMI avatar as more similar to their real body (51.84 ± 3.38) compared to the underweight BMI avatar (19.26 ± 2.80). The other main effect and interaction were not significant (all Fs < 0.07; all ps > .788).

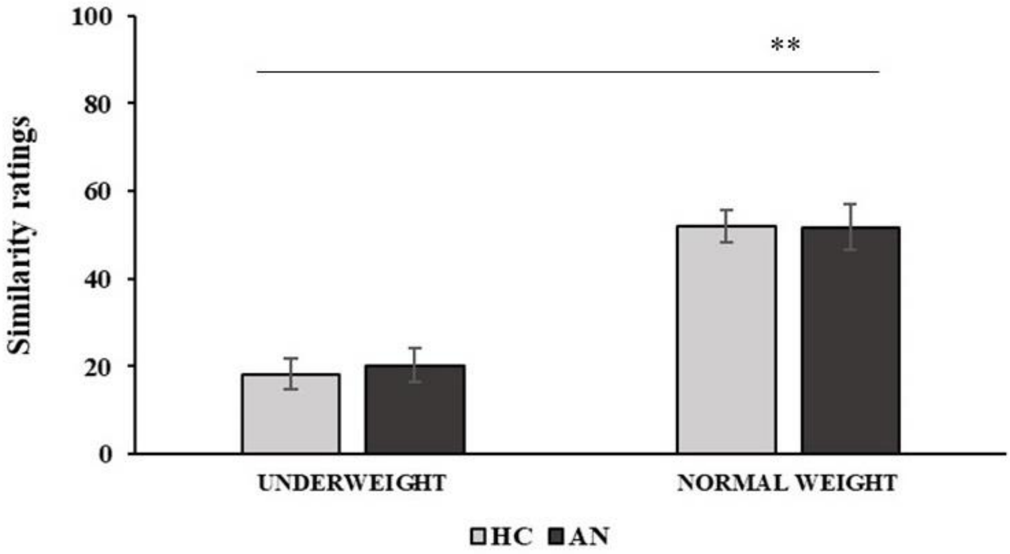

Figure 7. Avatars' similarity ratings. Graph showing the main effect of Avatar size (underweight and normal weight) on similarity ratings given during the observation of the avatars from a 1PP. Error bars represent standard error of the mean. ** = $p < 0.01$.

The 2x2 ANOVA with Group as between-subjects factor and Avatar's size as within-subjects factor on attractiveness ratings revealed a significant interaction between Group (AN vs HC) and Avatar's size (under vs normal weight BMI) [$F (1,41) = 12.68$, $p < .000$, $\eta 2 = .234$] (Figure 8)) and no other significant main effect (all Fs < 0.58; all ps > .450). Anorectic patients considered the underweight BMI avatar significantly more attractive (49.00 ± 6.11) compared to the normal weight BMI avatar (26.50 ± 5.02) ($p = .006$), whereas the HC showed an opposite trend, with higher attractiveness ratings for the normal weight BMI avatar (53.44 ± 4.47) vs the underweight BMI avatar (28.96 ± 5.30) ($p = .052$). The main effects of Group and Avatar's size were not significant (all Fs < 0.58; all ps > .450).

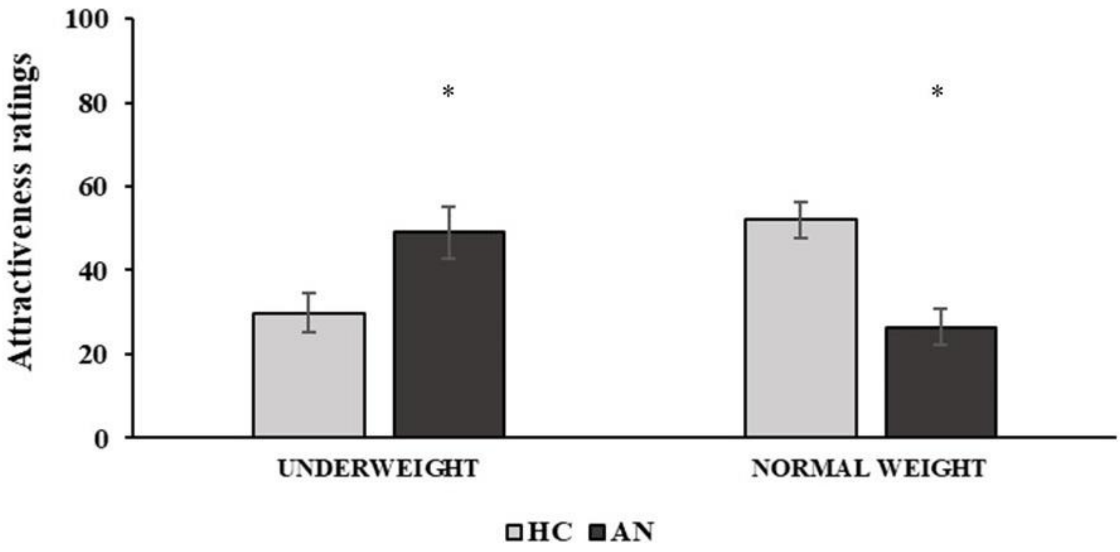

Figure 8. Avatars' attractiveness ratings. Graph showing the effect of the interaction between Avatar size (underweight and normal weight) and Group (healthy controls, HC; patients with anorexia nervosa, AN) on attractiveness ratings given during the observation of the avatars from a 1PP. Error bars represent standard error of the mean. * = $p < 0.05$.

Finally, the results of same 2x2 ANOVA with the implicit disgust ratings on the avatars observed from a 1PP as depended variable showed a main effect for the Group [$F(1,41) = 10.53$, $p = .002$, $\eta 2 = .204$] and an interaction effect between Group and Avatar's size [$F(1,41) = 11.75$, $p = .001$, $\eta 2 = .223$] (Figure 9). Post-hoc analysis of the interaction revealed that anorectic patients rated the normal weight BMI avatar as the avatar with the least pleasant odour (34.92 ± 3.58), therefore showing significantly higher implicit disgust for the normal weight BMI avatar compared to the underweight BMI avatar (55.00 ± 3.75) ($p = .009$). AN patients gave higher unpleasantness scores to the normal weight avatar with respect also to the HC participants' ratings of both avatars (all ps < .013). The main effect of Avatar's size was not significant [$F(1,41) = 2.44$, $p = .125$, $\eta 2 = .056$].

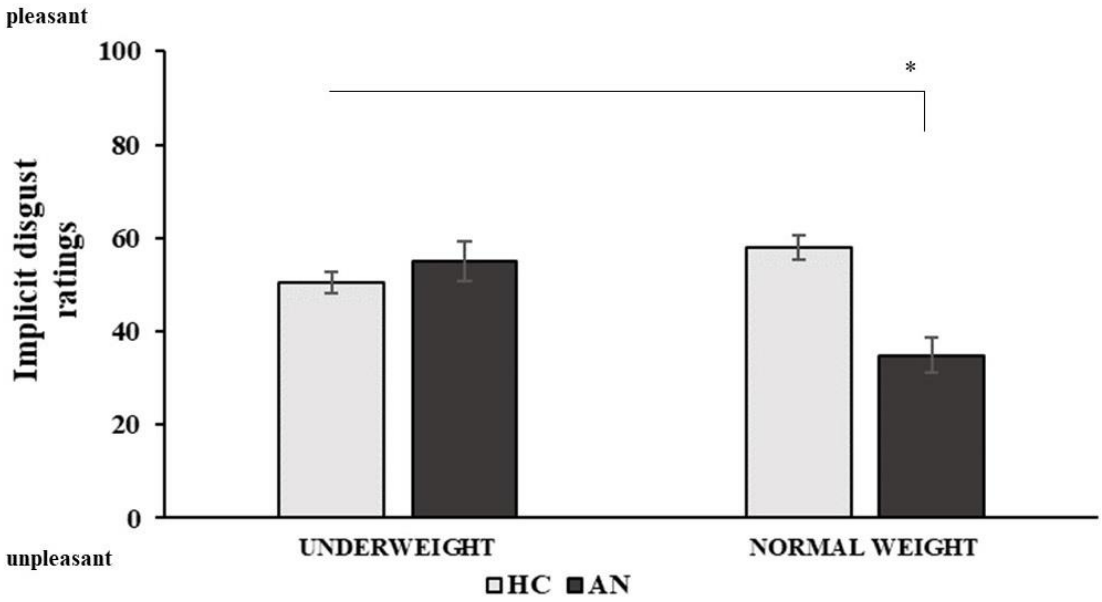

Figure 9. Avatars' implicit disgust ratings. Graph showing the effect of the interaction between Avatar size (underweight and normal weight) and Group (healthy controls, HC; patients with anorexia nervosa, AN) on implicit disgust ratings given during the observation of the avatars from a 1PP. Error bars represent standard error of the mean. * = $p < 0.05$.

3.4 Discussion

The main aim of the current study was to investigate whether the embodiment of virtual bodies of different sizes could affect and eventually reduce Body Image Distortion (BID) in AN. In our previous study (Provenzano et al., 2020) we found evidence of the alteration of the cognitive-emotional component of body image in anorexia nervosa (AN), i.e. AN patients reported higher body dissatisfaction than healthy controls (HC) and showed more negative emotions after being exposed to the fatter avatar. However, we did not find any difference in the perceptual estimation of one's own body size between AN patients and HC, i.e. our AN patients show no sensible perceptual overestimation of their own body size compared to HC. We explained these results by discussing the differences between metric and depictive body size estimation tasks (Cash & Deagle, 1997; Farrell et al., 2005; Gardner & Brown, 2014) and between the egocentric and allocentric frame of reference (Galati et al., 2000; Haggard et al., 2010; Riva, 2012a) (for a detailed discussion see x.4).

In the current study we adopted metric body size estimation methods to measure both body perception and body schema in AN patients and healthy controls, and we kept an egocentric frame of reference for both the body estimation tasks and the full body illusion (FBI). We expected that before the FBI was induced AN patients would show an overestimation of their body size compared to HC in both the Body Perception and Body Schema tasks. The results confirmed our hypothesis: AN patients significantly overestimated the width of their hips and minimum aperture's width required to walk through the door (which is an indirect estimation of one's own shoulders' width) compared to HC. These finding supports the idea that metric methods of body size estimation are more adapt to capture body size overestimation compared to depictive methods (Simone Claire Mölbert et al., 2017). The reason of this discrepancy in results between the two body estimations methods could be explained by the differences between implicit and explicit body image (Longo, 2015b). According to the framework proposed by Longo, body representation is the result of multiple body representations that are characterized alongside two dimensions, i.e. perceptual vs conceptual and implicit vs explicit: body schema and body perception are both located in the perceptual / implicit end of these dimensions, whereas body image would be located in the more conceptual / explicit dimensions. While depictive methods may address more explicit representations of body image by relying predominantly on visual perception and on individuals thoughts and feelings about their own body, thus being more controllable by the participants, metric methods could elicit more implicit representations of body image, relying on less controllable and more automatic somatosensory and motor representations of one's own body, both of which are severely altered in AN (Gaudio et al., 2014; Guardia et al., 2010; Keizer et al., 2012).

We induced FBI by applying synchronous and asynchronous interpersonal multisensory stimulation (IMS) over two different sized avatars i.e., an underweight BMI avatar and a normal weight BMI avatar, and measured embodiment strength and changes in body perception and body schema estimation after the embodiment procedure. Our explicit measure of the embodiment illusion strength (self-report questionnaire's scores) suggest that the synchronous IMS was effective in inducing a significant stronger embodiment illusion compared to the asynchronous IMS. Regardless of the group, all participants reported higher ratings after the synchronous compared to the asynchronous visuo-tactile stimulation for all the investigated components of the embodiment illusion, i.e. Ownership, Agency and Referral of Touch, confirming our previous results. Furthermore, we also found a main effect of the avatar size for all the aforementioned components of the embodiment illusion, with higher embodiment ratings attributed to the normal weight BMI avatar compared to the underweight BMI avatar independently of group and type of IMS. Interestingly, the Feelings of Thinness/Fatness index shows that AN patients felt significantly fatter after being exposed to the normal weight BMI avatar compared to the underweight BMI avatar (while HC participants did not), and all participants felt to be slimmer after embodying (i.e. during synchronous IMS condition) the underweight avatar.

This is even more interesting when taking into consideration the ratings of similarity, attractiveness and implicit disgust that participants attributed to the underweight and normal weight BMI avatar at the end of our experiment. While all participants rated the normal weight BMI avatar as the most similar to their real body, AN patients and HC greatly diverged on the ratings of attractiveness and implicit disgust ratings attributed to the two avatars. Indeed, while HC participants expressed similar ratings of attractiveness and implicit disgust for both normal weight and underweight BMI avatars, AN patients expressed significantly lower ratings of attractiveness and significantly higher rating of implicit disgust for the normal weight BMI compared to the underweight BMI avatar. Thus, anorectic patients considered the normal weight BMI avatar as the most similar to themselves and at the same time the least attractive / more disgusting, while also feeling fatter after being exposed to it. These results in our opinion clearly underlines the body dissatisfaction component of body image disturbance (BID) in AN, which is a core component of BID in AN, as anorectic patients are extremely dissatisfied with the appearance of their body size, shape and form (Cash & Deagle, 1997), and is also one of the most consistent risk and maintaining factor of the eating disorder pathology (Exterkate, Vriesendorp, & de Jong, 2009). Beside a general attitudinal dissatisfaction toward their own body, body dissatisfaction in AN is also characterized by the discrepancy between the perceived physical body and the ideal thin bodies (Mizes, 1992; Moscone, Amorim, Le Scanff, & Leconte, 2017): AN patients overestimate their own body size, which in returns increase their drive for thinness, i.e. the desire for an extremely thin body. Even if it is not a direct measure of body dissatisfaction, in our opinion these results elegantly highlights the higher body dissatisfaction found in AN patients compared to healthy women (Hrabosky et al., 2009), as they illustrate the discrepancy in AN patients between the undesired body that induces feeling of being fat and the desired thin attractive body.

Regarding the implicit measure of the embodiment illusion, the results did not mirror the explicit ones, as we found no significant change in participants' body temperature between synchronous and asynchronous conditions. These results contradict the results from our previous study (Provenzano et al., 2020), where we found a change in participants’ body temperature between synchronous and asynchronous IMS conditions. The interpretation of changes in body temperature as a reliable measure of body ownership has been supported by several studies (Kammers, Rose, & Haggard, 2011; Moseley et al., 2008; M. Tsakiris, Jimenez, & Costantini, 2011) and disputed by several others (David, Fiori, & Aglioti, 2014; Grynberg & Pollatos, 2015; Rohde, Wold, Karnath, & Ernst, 2013). Many other factors apart from the embodiment illusion could affect body temperature changes, such as environmental temperature fluctuations (de Haan et al., 2017), the duration of the IMS procedure (Abdulkarim & Ehrsson, 2016; Moseley et al., 2008; Preston, 2013) and the characteristics of the experimenter (Gazzola et al., 2012; A. Serino, Giovagnoli, & Làdavas, 2009; Van Stralen et al., 2014). In our current study data collection for HC participants and AN patients was conducted in different places, as AN patients data had to be collected at the Eating Disorder Centre of ASL 1 Rome under the supervision of the medical staff. These discrepancies in the experimental settings could have resulted in different fluctuations of the environmental temperature, which in return could have masked the changes in body temperature caused the embodiment illusion. As there is still no real consensus on whether changes in body temperature might be considered an implicit index of the embodiment illusion (de Haan et al., 2017), further studies will be needed to assess how body temperature might actually affected by the embodiment illusion.

Regarding the effect of the embodiment of different sized avatars on participants’ body perception and body schema, we found that AN patients reported larger estimation of their own hips and door aperture widths compared to HC participants. Furthermore, being exposed to underweight BMI avatar compared to the normal weight BMI avatar resulted in lower hips and door aperture width estimations in all participants.

Importantly, the difference in door aperture width estimation was specific for the synchronous IMS condition and occurred only in AN patients. While embodiment did not affect HC participants estimation of the minimum door aperture width required to pass through it, AN participants reported larger door aperture widths after the embodying (i.e. synchronous IMS condition) the normal weight avatar with respect to the underweight avatar.

To our knowledge, this is the first study to report a distinct effect of a synchronous full body illusion on anorectic patients' body image. Previous studies (Piryankova et al., 2014; Preston & Ehrsson, 2014) reported a lower estimation of one's own body size in neurotypical participants after being exposed to a thin virtual body, but this effect occurred after both synchronous and asynchronous visuo-tactile stimulation, suggesting that the effect was caused by the simple observation of thin body rather than by the illusionary embodiment of the virtual body. Similarly, in a study conducted with AN patients (Keizer et al., 2016), a decrease in body size estimation was found in both the AN and HC participants, but the effect could not be attributed to the embodiment illusion as it was found after both synchronous and asynchronous visuo-tactile stimulation. Interestingly, a recent single case study (S. Serino, Polli, & Riva, 2019) applied three sessions of a VR-based full body illusion on an anorectic patient, finding during the first session a stronger reduction of the abdomen size estimation after the synchronous visuo-tactile stimulation compared to the asynchronous one, a result which was only partially replicated in the other two following VR sessions. Here we found that the estimation of one's own body schema, measured by asking participants to estimate the minimum door's aperture required to pass through it, changed accordingly to the size of the virtual body only after the synchronous visuo-tactile stimulation and only in AN patients, clearly indicating that the effect was caused by the illusionary body ownership of the different sized virtual bodies. Furthermore, the fact that these effect was found in AN patients but not in HC participants support the idea of an increased bodily self-plasticity in people with eating disorders compared to neurotypical individuals (Eshkevari et al., 2012).

In the present study, to characterize body image distortion in AN and further qualify the results we found in Study 1, we choose to have just Body Perception and Body Schema at baseline and before any IMS was applied. Indeed, we considered the asynchronous IMS (and not the baseline) as the proper control condition to evidence eventual changes in body overestimation due to the embodiment illusion. Alternatively we could have opted for a pre-post treatment design, by collecting 4 pre- and 4 post synchronous/asynchronous IMS body perception and body schema estimations. This however might have invalidate the measure of interest by inducing learning effects and standardized responses due to several repetitions of the tasks.

We found a difference in AN patients' body schema estimations taken after a synchronous IMS was applied to the normal weight and to the underweight avatar, but we found no difference between the asynchronous conditions. Thus, interpreting the direction of our effect has to be made with caution. However, if we observe AN patients door's aperture width estimations at baseline and after synchronous/asynchronous IMS with underweight and normal weight avatars, we can notice that the estimation of door aperture width after the embodiment (i.e. synchronous IMS) of the normal weight avatar is the only condition that significantly deviates from the baseline values. Thus, the effect found in AN patients' body schema task estimations might be explained by an increase in the door aperture width necessary to pass through due the embodiment of the normal weight avatar rather than by a reduction of the overestimation due to the embodiment of an underweight avatar. As we could not collect the data on the planned number of AN patients due to COVID-19 restrictions, this interpretation might stand only as a speculation, as we can expect to disambiguate the directionality of this effect by finding differences between synchronous and asynchronous conditions if a more ample sample of AN participants is collected.

3.5 Limitations

Similar to Study 1, we tried to control for the heterogeneity of our clinical sample by recruiting only anorectic patients with a diagnosis of AN-r (anorexia nervosa restrictive type) and that were under treatment at the Eating Disorder Centre of ASL 1 Rome for no more than two years (we did this as a control for the severity of the pathology). However, like in Study 1 we could not control for confounding factors such as psychiatric comorbidity and treatment history, which might have had an influence on the measured dependent variables, i.e. body perception and body schema estimations, feelings of thinness/fatness, emotional response after embodiment etc. Also, as previously mentioned, due to the spread of the COVID-19 pandemic, we could not collect all the data needed to meet the required participants' sample size, and as the moment of writing this thesis we are still pondering if we will be able to collect the required missing data in the future or not.

4. General Discussion

The aim of both of these studies was to use immersive virtual reality (IVR) and full body illusion to reduce body image distortion (BID) in anorexia nervosa (AN). Following the previous literature (Keizer et al., 2016; Normand et al., 2011; Preston & Ehrsson, 2014), we applied interpersonal multisensory stimulations to virtual bodies of different sizes to change participants body image in all its different components. In Study 1 we induced embodiment of three different sized avatars (perceived body, a + 15% fatter body and -15% thinner body) and then measured the effect of the illusion on both the perceptual and the cognitive-emotional components of body image by asking participants to choose the avatar the best resembled their real and ideal body (i.e. we used depictive methods of body size estimation). In Study 2 the embodiment illusion was induced over a an underweight (BMI = 15) and a normal weight avatar (BMI = 19), and we measured the effect on participant's body perception and body schema by asking them to estimate the width of their hips and the door's aperture width required to pass through (i.e. we used metric methods of body size estimation). In both studies, the results showed a distortion of the cognitive-emotional component of body image in AN patients, as they rated the bigger avatar as the most similar to themselves while also rating it as the least attractive and the one with the least pleasant odor (i.e. implicit disgust rating). Also, differently from the healthy controls (HC) participants, AN patients rated the thinner avatar as the most attractive, which clearly show the discrepancy between their undesired perceived body and their desired thin ideal body that is at the core of their high body dissatisfaction (Mizes, 1992; Moscone et al., 2017). In the Study 2 we also found an overestimation in AN participants of both their body perception and body schema, further corroborating the idea that metric measures are more apt in capture the perceptual overestimation component of BID in AN (Farrell et al., 2005; Simone Claire Mölbert et al., 2017). Furthermore, in Study 2 we also found evidence of the increased bodily-self plasticity of AN patients (Eshkevari et al., 2012; Pollatos et al., 2008), as we found a difference in AN patients' body schema estimations after the embodiment of the underweight avatar vs normal weight avatar, while we found no difference in HC participants' body schema estimations after embodiment.

Overall, the findings presented thus fur tells us that it is possible to modulate BID in Anorexia Nervosa by taking advantage of the multisensory integrative processes through which the brain recognize the body as belonging to the self. We should consider that a coherent visual representation of one's own face (and body) is formed and continuously updated by matching facial (and bodily) somatosensory and motor experiences with what is seen in the mirror. This is reminiscent of what happens in synchronous IMS where the felt touch is surprisingly mirrored on what is seen on another's face (or body). According to the predictive coding account of the embodiment illusion (Apps & Tsakiris, 2014), the processes of constructing and updating a mental representation of one's own body may conform to the principles of predictive coding within the free-energy theoretical model: the congruency between the observed and felt touch initially generates surprise. However, since participants cannot move, and thus they cannot check whether the observed face/body is effectively their own, the brain may attempt to minimize the surprise by including the features of others into the self-representation. If we consider that AN patients typically overestimate their body and that in our study they rated the normal weight avatar as the most similar to the self, during the synchronous IMS condition with the normal weight avatar they might have experienced reduced or no conflict at all because the observed body closely matched the delusional representation of their own body.

From this perspective, the result of Study 2 suggest the possibility that delivering synchronous IMS to a normal weight body, whose measure mirrors AN patients body image distortion, might confirm the erroneous belief of owning a body that is fatter than the actual (and ideal) one. In other words, embodying a normal weight body avatar might strengthen the erroneous association between multisensory congruence (at the basis of body ownership detection) and the distorted visual appearance of the self-body.

If this interpretation holds true, this paves the way to the intriguing possibility of using IMS and IVR to reduce the strength of this maladaptive association by repeatedly exposing AN patients to incongruent multisensory exteroceptive (and even interoceptive) signals applied to an avatar whose body matches the perceived (and undesired) own body size, while on the other hand applying congruent multisensory exteroceptive/ interoceptive signals to an avatar whose body matches the ideal and actual body size.

PART II

BODILY SELF-CONSCIOUSNESS AND DECEPTIVE BEHAVIOUR IN THE DIGITAL WORLD

5.1 General Introduction

5.1.1 Dishonest behaviour

Deceptive, dishonest and unethical behaviours are universally diffuse (Stephens-Davidowitz, 2017) and represent a major threat to both single individuals and societies, affecting interpersonal relationships, organizations and entire economic systems, e.g. corruption in the EU countries amounts to 120 billion euro each year according to the EU Anti-Corruption Report. Dishonest behaviours are defined as 'illegal or morally unacceptable to the larger community' actions that have harmful repercussions on others (Gino, Schweitzer, Mead, & Ariely, 2011). At their core, dishonest behaviours involve a conflict between the temptation to gain a personal benefit and the desire to conform to moral norms and/or avoid unfavourable social consequences (Mazar, Amir, & Ariely, 2008; Mead, Baumeister, Gino, Schweitzer, & Ariely, 2009). Dishonest behaviours are affected by individual variables such as personality (DePaulo, B. M., Kashy, D. A., Kirkendol, S. E., Wyer, M. M., & Epstein, 1996; Panasiti, Pavone, Merla, & Aglioti, 2011), emotional and cognitive intelligence (Canale, Rubaltelli, Vieno, Pittarello, & Billieux, 2017; Sarzyńska et al., 2017) and group affiliation, e.g. religion (Arbel, Bar-El, Siniver, & Tobol, 2014b; Bar-El & Tobol, 2017), and research on whether individual dishonesty is affected by social context did not provide unequivocal results (Gächter & Schulz, 2016; Hugh-Jones, 2016; Shalvi, 2016). While not excluding the influence of social context on moral behaviour, the fact that dishonest behaviours are found across all societies implies a common core in all humans in their tendency to deceive, which in our hypothesis is to be found in the relationship between body related signals in the brain and dishonest behaviour.

5.1.2 Bodily self-consciousness and embodied cognition

Bodily self-consciousness (BSC) is the basic primitive of the self, arising from the integration of interoceptive signals, i.e. heartbeat, hunger, thirst, pain etc., and exteroceptive signals i.e., vision, touch, hearing etc. (Berlucchi & Aglioti, 2010). BSC is composed of the sense of ownership (Blanke & Metzinger, 2009; Matthew Botvinick, 2004; Park et al., 2014; Manos Tsakiris, 2010), which refers to the sense of owning one's own physical body, and the sense of agency (Manos Tsakiris, Longo, & Haggard, 2010; Manos Tsakiris, Schütz-Bosbach, & Gallagher, 2007), which refers to being in control of one's own body actions and is directly linked to the notion of free will and accountability (Haggard, 2017). The idea that low level body related signals can affect high level psychological functions, i.e., embodied cognition (Barsalou, 2008), has been investigated by researchers for the last two decades, with evidence of embodied cognition in many emotional (Gelder, 2006; Tamietto & De Gelder, 2010) and cognitive (Moro et al., 2008; Urgesi, Candidi, Ionta, & Aglioti, 2007) psychological functions. According to the somatic-marker hypothesis (Bechara & Damasio, 2005; Damasio, 1996), bodily related signals can also influence decision making, although is unclear the specific effect that the different components of BSC, i.e. body ownership and body agency, have on decisions. In particular we are interested in how body ownership and body agency affects moral behaviours, and how selectively weakening or enhancing each component of BSC can influence these behaviours in individuals.

5.1.3 Two hypothesis regarding the relationship between BSC and moral behaviour

We will discuss two different hypothesis regarding the relationship between BSC and moral behaviour: the "Will Hypothesis", which involves the body agency component of BSC, and the "Grace Hypothesis", which involves the body ownership component of BSC.

On one hand, according to the "Will Hypothesis" (Greene & Paxton, 2010), honest behaviour is the result of the active resistance to temptation, which means that honesty demands individual self-control. In order to behave honestly, people must either have altruistic motivations, i.e. a prescriptive morality based on what people in general should do, or they must inhibit their egoistic tendency, i.e. a proscriptive morality based on what people in general should not do. In either cases, honest behaviour is based on people volition, thus on the action component of BSC, i.e. the sense of agency. In support of this hypothesis, it has been shown that the sense of agency is higher in moral actions (Moretto, Walsh, & Haggard, 2011), and that when an individual is coerced into doing an immoral action, both the implicit sense of agency and the neural activity underlying one's action processing are decreased (Caspar, Christensen, Cleeremans, & Haggard, 2016). Despite these results, is it still unclear if a higher sense of agency might actually increases or decreases honest behaviour, as the sense of agency is related to both moral disengagement (Bandura, 2002; Yoshie & Haggard, 2013) and sense of power (Obhi, Swiderski, & Brubacher, 2012), two variable that have opposite effect on honest behaviour (Panasiti et al., 2014, 2011). On one hand, a high sense of power derived from a strong sense of agency over one's own action might for instance lead an individual to focus more on his own self and engaging in selfish behaviour disregarding other's need by disinhibiting his immoral impulses (Lammers, Galinsky, Dubois, & Rucker, 2015). On the other hand, an increased sense of agency might lead to a decrease in moral disengagement and in return increase individual responsibility towards one's own action, leading to honest behaviour.

At the neural level, several studies (Haggard, 2017; Khalighinejad, Di Costa, & Haggard, 2016) have reported that the sense of agency is associated with the activity of the dorsolateral prefrontal cortex (DLPFC), which has been found to be highly involved in morally related decisions (Greene & Paxton, 2010).

On the other hand, according to the "Grace Hypothesis" (Greene & Paxton, 2010), honest behaviour is the result of the absence of temptation, which means that individuals who behave honestly are the ones who do not perceive temptations. Thus, honest behaviour is based on the individual sensitivity to one own's internal and external bodily signals, i.e. the body ownership component of BSC. In line with this hypothesis, enhancing the attention towards one's own body signals should increase selfish behaviour. A 2011 study (A. Mancini, Betti, Panasiti, Pavone, & Aglioti, 2011) found that delivering a painful stimulation through thermal laser during the ultimatum game (Guth & Schwarze, 1982) increased selfish behaviour in participants by decreasing the fairness of their economic offers and increasing their acceptance rate regardless of the fairness of the received offers. Furthermore, listening to one's own heartbeat while playing the ultimatum game (Lenggenhager, Azevedo, Mancini, & Aglioti, 2013) showed similar results, as it increased participants' subjective feeling of unfairness towards unfair offers and increased the amount of unfair offers they made while playing in the proposer role, i.e., enhancing the attention towards participants' bodily signals promoted a more selfish and self-centred behaviour. These results are in line with previous studies that have found that that interoceptive signals like thirst, hunger and sexual arousal incentivize dishonest and risky behaviours in individuals (Ariely & Loewenstein, 2006; Ditto, Pizarro, Epstein, Jacobson, & MacDonald, 2006; Loewenstein, 1996).

It must be also taken in consideration that BSC plays also a crucial role in the sensitivity to a reward, as the homeostatic state of our body dictates the perceived value of a stimulus (Paulus, 2007), which is particularly important in the study of dishonest behaviours as a higher sensitivity to rewards has been shown to predict a higher tendency to deceive and a higher activity of the DLPFC when refraining from dishonest behaviours (Abe & Greene, 2014).

Besides the differences between the two aforementioned hypothesis, the experimental data at our disposal shows that there is a substantial overlap between the area involved in BSC and those involved in morally related decision-making, which suggests that increasing or decreasing the different components of BSC, i.e. the sense of ownership and the sense of agency, could in return affect moral behaviour.

5.1.4 Embodied cognition in the digital world

The recent technological advancements in portable devices and in immersive virtual reality (IVR) have been rapidly changing how we interact with the world and with other people by giving individuals the opportunity to project themselves into digital worlds and interact outside their physical bodies. Through IVR for instance it is possible for an individual to perceive himself in places that are different from where his physical body is located and to interact with object in ways that would not be physically possible in reality (Sanchez-Vives & Slater, 2005). Also, more and more people nowadays interact with the world and with others through their digital identities (Facebook, Instagram, Twitter, Amazon etc) by buying and selling goods, sharing their opinions and everyday life events, meeting and building relationships with other digital identities and so on. Considering this digitalization of our social, work and economic interactions, one important question concerns how these transformative technologies are influencing basic individual features like BSC, and how these changes in individual BSC may affect high level psychological functions such as dishonest behaviour. Is our moral behaviour different when we act through are body-free digital 'extended selves' (Sheth & Solomon, 2014) compared to when we act through our physical bodies? Is our dishonest behaviour affected by the virtual situations we are experiencing? The aim of the current project is to answer some of these questions, which at a present day remain largely unanswered (Galanxhi & Nah, 2007; Whitty & Joinson, 2008). In particular, the main experimental aim of the present study is to investigate how selectively weakening and/or enhancing the specific components of BSC, i.e. body ownership and body agency, can affect individual dishonest behaviour in digital web-mediated interactions.

To investigate how changes in BSC influence deceptive behaviour in the digital world we will use the 'Roll and Tell' app, which is a mobile application inspired by an experimental paradigm that has already been successfully used to study dishonest behaviour (Arbel, Bar-El, Siniver, & Tobol, 2014a; Fischbacher & Föllmi-Heusi, 2013). In the original experimental paradigm, participants rolled a die privately and received a payoff dependent on the reported roll of the die, with higher numbers resulting in a higher payoff, i.e. participants were incentivized to behave dishonestly in order to gain a higher payoff. We modified the original experimental paradigm in order to allow participants to play a competitive online die game, in which they will have to report the outcome of their die roll to the other player. There will be three different version of the app: i) the 'Roll and Tell' mobile app, ii) the 'IVR Roll and Tell Ownership' app, in which participants will experience illusionary body ownership of the avatar rolling the die and iii) the 'IVR Roll and Tell Ownership and Agency' app, in which participants will experience both ownership and agency over the avatar rolling the die.

Thus, in the first version of the experimental paradigm participants will play an online game die game on their smartphone without any experimental manipulation on specific component of the BSC. For this step we expect that participants behaviour will be affected by factors like the current game's score during a particular match, their position on the leaderboard and the status of the opponent. The results from this first step will serve as a baseline and will later be compared with the results of the following two steps.

In the second version of the app participants will wear a head-mounted display (HMD) and play an immersive virtual reality version of the experimental paradigm in which they will play the same die game while observing a virtual avatar from a first-person perspective (1PP). This second step is designed with the intent of manipulating the body ownership component of participant's BSC by inducing the embodiment illusion of the observed virtual avatar, thus enhancing their attention towards their own body signals while playing. In the line with the results of the previously discussed studies (see 5.1.3), we expect that a stronger illusion of embodiment will be a predictor of a more self-centred and selfish behaviour, i.e. participants will lie more the more they feel the observed virtual body as their own real body.

Finally, in the third and final version of the app participants will be not only experience illusionary body ownership over the virtual body but they will also be able to throw the die by moving the avatar’s arm, thus experiencing also a sense of agency over the virtual body. We expect that the increased sense of agency while playing the online die game might lead participants to behave more honestly or dishonestly depending on whether increasing the sense of agency will increase participant’s sense of power or decrease their moral disengagement. In the next paragraph we will discuss the first of the three aforementioned apps, which will investigate deceptive behaviour in the digital world without any experimental manipulation of the BSC of the participants. As the project is still currently being worked on, the following paragraph will only illustrate the experimental design and its technical implementation.

5.2 Methods

The ‘Roll and Tell’ is an app for mobile phone that allows participants to play an online die game against either Facebook friends or Facebook non-friends. The app is built with Unity 2019.2.18f1 (Unity Technologies, San Francisco) and Android Studio SDK (Google LCC, Mountain View) and is currently being developed on Android devices. Once the internal testing is completed, the app will also be converted for iOS devices. A Facebook account is required to play: once started, the app will check if the player is logged with his Facebook account and it will inform the player if they are ready to play or not (Figure 1). Once the log in is done, the app will store all the participants’ relevant information (username and email) on a secure Firebase server (Google LCC, Mountain View). Only the experiments will be able to visualize participants’ personal information on the server, which will enforce specific server’s side rules that will allow access to the stored data only to authenticated and authorised personnel.

Figure 1. Facebook SDK (Facebook Inc., Menlo Park) is used to allow participants to log into the app with their Facebook account. Once started, the app will prompt participants to log in with their Facebook account, and will disable all the online functions until the log in is completed. Once the log in is completed, the app will inform the players of the successful log in and will re-enable all the online functions.

Once the they are logged in, participants will gain access to the lobby menu. From there, they will be able to either look for an online opponent to play against or check their ranking on the global online leaderboard (Figure 2).

Figure 2. The lobby menu gives to players the option to either look for an opponent or check the current global ranking of all the players. The app utilises an automatic matchmaking system that will look for any currently available opponent; if after 30 seconds no available opponent is found, the app will give to the player the option to either refresh the search for a new opponent or go back to the lobby menu.

If they decide to search for an opponent, the app will pair the player with the first random opponent available. The online gameplay is built by using Photon Engine (Exit Games, Hamburg), which is a dedicated multiplayer engine & cloud storage service that handles both the matchmaking system and the online play. Once an opponent is found, the app will inform the player if the person he is playing against is either a Facebook friend or a Facebook non-friend; participants will not be able though to know the name of the person they are playing against, whose identity will remain hidden even in the global ranking chart. Once two players are paired together, the app will wait 5 seconds and after that the match will start.

A game of ‘Roll & Tell’ consist of ten turns, and participants will earn a point for each turn won and two points for winning the entire game. For each turn, participants will be prompted to roll a virtual die and they will only be able to see the outcome of their respective die roll. Once the die is cast, participants are then asked to report the outcome of their die roll to the other player by pressing the appropriate number on the screen. Participants are told that the players who reports the higher number wins, while in case of a tie both participants lose. Participants are free to report any number from 1 to 6, and while they are not explicitly told that they can lie, we expect that a strategy based on victory seeking may imply that a player will be biased towards deception (Figure 3).

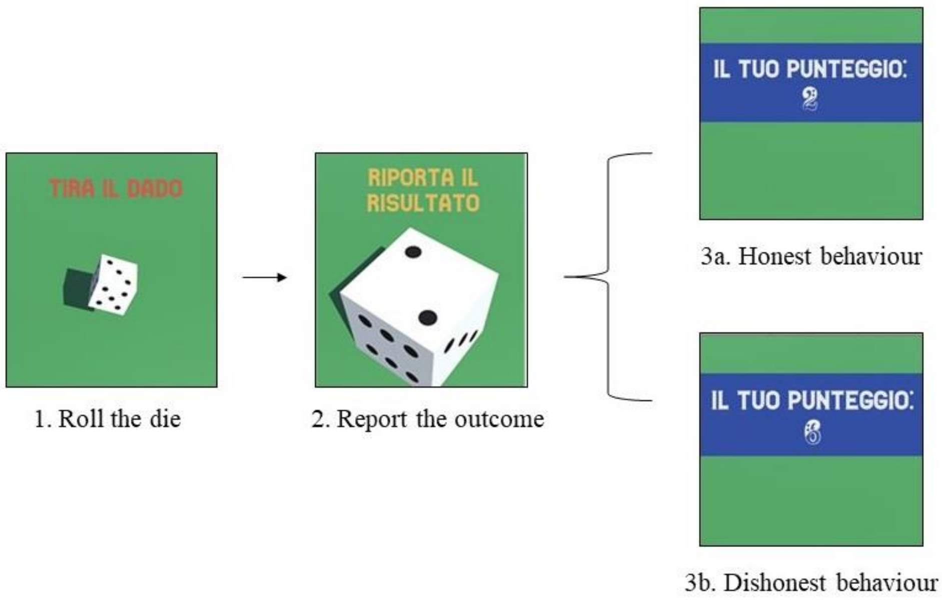

Figure 3. Example of a turn of ‘Roll and Tell’**.** At the start of each round, participants will be prompted to roll their die by swiping the touch screen of their mobile phone with their finger (1). Once the die is cast, participants will have to wait for the die to stop and then they will be prompted to report the outcome of the die to their opponent (2). Participants are free to either report the real outcome of the die roll, i.e. behave honestly (3a) or report a different outcome, i.e. behave dishonestly (3b),

For each die roll, a deception index is calculated based on the difference between the actual die outcome and the participants' reported outcome, with positive values indicating an altruistic lie, i.e. a lie that does not benefit oneself and does not hurt the other, negative values indicating an egoistic lie, i.e. a lie that benefits oneself and hurt the other, and with a value of zero indicating a completely honest behaviour, i.e. an exact match between the die outcome and the reported outcome. For each game, the app will store on the cloud server the following information: the status of the opponent (Facebook friend vs Facebook non-friend), the outcome of the die, the reported outcome of the die, the deception index for each turn and the game score. All the played matches are then recorded into an online leaderboard (Figure 4), and participants will be able to check at any time their position on the global ranking of all the players.

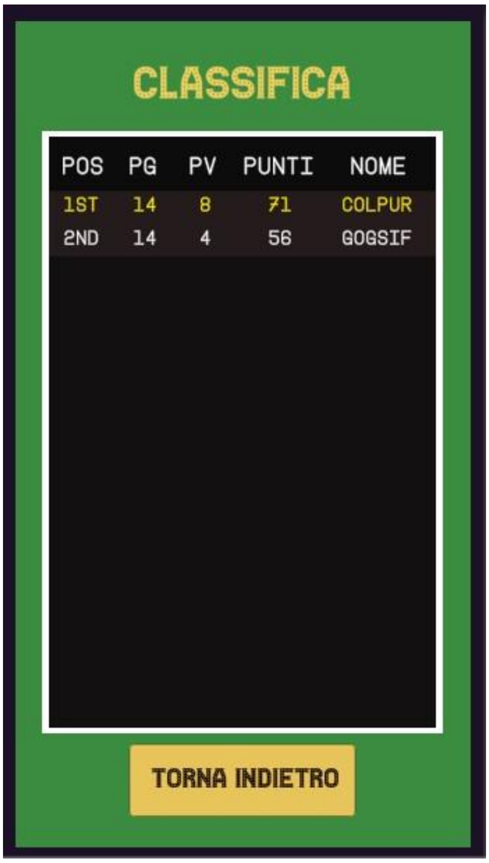

Figure 4. The global online leaderboard. Participants will be able to access at any time the online leaderboard containing the ranking of all the players. The leaderboard will display the current ranking position of all the players (POS), the number of games played (PG), the number of games won (PV) and the score (PUNTI). To preserve the privacy of the participants the names displayed on the leaderboard will be composed by letters randomly ordered and selected from participants' name and surname (NOME).

The experiment will last for six months, and during that time participants will be asked to play at least 60 games. A the end of this period, the first three top players of the global ranking will be awarded a prize of 300, 200 and 100 euros respectively.

5.6 Expected results

In the first step of this project there will be no experimental manipulation of the bodily self-consciousness of the participants, as we will record participants' honest/dishonest behaviour without directly affecting their sense of ownership and/or sense of agency. Thus, we expect that participants' deceptive behaviour might be modulated by the following three factors: a) the status of the opponent they are playing against, i.e. Facebook friend vs Facebook non-friend, b) the number of turns lost during a particular game and c) the actual position on the online global ranking.

5.7 Closing comments

Here we introduced the methods and the technical implementation of the first of a series of three studies that will investigate how the different components of the bodily self-consciousness (BSC), i.e. the sense of ownership and the sense of agency, might affect individual honest/dishonest behaviour in digital and web mediated interactions with other people. The implementation of such an experimental paradigm resulted in a real technical challenge for us, as this was the first time that we had to develop a research project on mobile phones while also implementing an extensive set of online features. However, the realization of the ‘Roll and Tell’ app will allow our participants to participate in our studies over an extended period of time and in an ecological setting, as they will be able to take part in our experiment at any time during their daily life by just logging into the app and playing an online match versus another participant. Also, the live recording of all experimental data into an online server will allow the researchers to monitor the status of the experiment in real time and to access the experimental data at any moment from their computer over the course of the experiment.

As the overall goal of the research is to investigate how changes in BSC influence deceptive interactions in the digital world, the next two steps of the project will combine IVR and mobile technology and will let participants play an IVR version of the ‘Roll and Tell’ app. In this version of the app, through the use of a VR head-mounted display (HMD), participants will be immersed in a realistic virtual scenario and will be able to play the ‘Roll and Tell’ game while feeling illusionary ownership over a virtual body viewed from a first-person perspective (IVR Roll and Tell Ownership’ app) and also experience agency over the virtual body by throwing the die with the movement of their real arm (‘IVR Roll and Tell Ownership and Agency’).

The digitalization of our bodily self-consciousness is already here, as we spend every day more time immersed in digital and web-mediated interactions, while applications of the telepresence such as telemedicine and drone strikes are already drastically changing our world. Thus, understanding the relationship between these transformative technologies and our BSC, and especially the effect on our honest/dishonest behaviour, is a research question that demands to be answered.

MODULATING ACUTE AND CHRONIC PAIN VIA VIRTUAL SOCIAL TOUCH

6.1 General Introduction

6.1.1 Social touch

Touch has an important role in our life, as it is the first sensory modality to develop and it gives us the 'sensory scaffold on which we come to perceive our own bodies and our sense of self' (Bremner & Spence, 2017; Cascio, Moore, & McGlone, 2019), i.e. it is through touch that, early on as *in utero* development, humans start exploring the environment around them and their own selves, starting the process that will later lead to self-awareness (Ciaunica, Constant, Preissl, & Fotopoulou, 2021) Social touch in particular plays a fundamental role in key areas of human life: cognitive (Seelke, Perkeybile, Grunewald, Bales, & Krubitzer, 2016; Seidl, Tincoff, Baker, & Cristia, 2015), emotional (Bai, Repetti, & Sperling, 2016; Pickles, Sharp, Hellier, & Hill, 2017) and physical development (Maitre et al., 2017) are crucially affected by social touch, and there is experimental evidence that supports the idea that social touch plays also an important role in both interpersonal relationships (McGlone, Vallbo, Olausson, Loken, & Wessberg, 2007) and behaviour (Olausson, Wessberg, Morrison, McGlone, & Vallbo, 2010). With the term social touch we refer to nonsexual, pleasant affective touch that is social in nature and that is characterized by the activation of specifics types of unmyelinated mechanoreceptors in the skin, the CT-fibres, that are activated when the skin is stroked at a speed of around 3cm/sec, which corresponds to a gentle, caress-like stroking (Löken, Wessberg, Morrison, McGlone, & Olausson, 2009). Social touch can affect emotions, reducing stress and pain (Liljencrantz et al., 2017) similarly to what happens in primate during allogrooming (Dunbar, 2010), as well as reducing the perception of pain in both infants (Gray, Watt, & Blass, 2000) and adults (Goldstein, Weissman-Fogel, Dumas, & Shamay-Tsoory, 2018). The results from several recent studies suggest that the analgesic effect of social touch is strongly associated with the CT-fibres activity (Gursul et al., 2018; M. Von Mohr, Krahe, Beck, & Fotopoulou, 2018), further corroborating the idea that a tactile stimulation that activates the CT-fibres can modulate pain perception.

6.1.2 Acute and chronic pain

Pain is a ‘sensory and emotional experience associated with real or potential injuries’ (Almeida, Roizenblatt, & Tufik, 2004), and can be classified in acute pain, which is a form of pain that is limited in time and extinguished by the resolution of the pathological process, and chronic pain (CP), which persists well beyond the normal healing time of the pathological process. Since determining the end of the healing time of a pathological process can be difficult, pain is considered chronic when it last for more than three consecutive months (International Association for the Study of Pain).

CP is a serious worldwide health problem, representing a significant social and economic burden (Gaskin & Richard, 2012). Individuals affected by CP live with a crippling disability for most of their existence which deeply affects the quality of the their life, in some cases even leading to suicidal ideation and behaviour (Campbell et al., 2016). Currently available strategies to deal with CP include physical exercise and cognitive-behavioural interventions, which both shows only short-term effect (Matamala-gomez et al., 2019), and pharmacological based interventions, such the ones based on opioids, which not only have limited efficacy but can also have both important health side effects (Carter et al., 2014) and a serious social and economic cost (Florence, Zhou, Luo, & Xu, 2016). Thus, there is a huge incentive for researchers to find new and more effective methodologies to deal with CP. The next paragraph will briefly present some studies that have attempted to use the embodiment of virtual bodies in immersive virtual reality (IVR) for pain's treatment.

6.1.3 VR for pain treatment

The first application of VR for pain treatment was in a 2000 study (Hoffman, Doctor, Patterson, Carrougher, & Furness, 2000), in which researchers provided two burn patients with a 3 mins VR experience during a wound care session and compared its pain reduction efficacy against the distraction provided by playing normal video games. Results showed that, during the VR experience, both patients reported a significant decrease in pain perception compared to when they were playing video games, leading the researchers to suggest that VR may be effective in reducing pain perception by drawing away individuals' attention from the 'real world' (Hoffman et al., 2000). While later studies were able to obtain similar results (Hoffman et al., 2004, 2007), in all these studies the pain reduction effect was caused by the powerful distractive capacity of VR and by participants' positive emotions while experiencing it (Triberti, Repetto, & Riva, 2014) instead of being caused by the immersiveness of the VR experience, as participants were not presented with virtual bodies to embody and thus they did not experience any real sense of presence.

Studies conducted in healthy subjects have shown an analgesic effect for the vision of one's own body during experimentally induced pain via laser stimulation (Longo, Betti, Aglioti, & Haggard, 2009; Longo, Iannetti, Mancini, Driver, & Haggard, 2012). In a 2014 study (Martini, Perez-Marcos, & Sanchez-Vives, 2014), Martini and colleagues tried to replicate this visually induced analgesia by using IVR: participants observed a virtual body from a first person perspective (1PP) and, depending on the experimental condition, were able to synchronously or asynchronously move the index finger of the virtual hand by moving their own index finger while a thermal stimulation was being applied on their forearm. The results of this experiment showed an increase in participants' thermal pain threshold during the synchronous condition, i.e. the embodiment of the observed virtual arm had an analgesic effect on the pain experienced on the real arm. A subsequent study (Romano, Llobera, & Blanke, 2016) investigated the effect of a full body illusion (FBI) of a virtual avatar on pain perception, and while participants did not experience any change in the conscious perception of pain, the changes in skin conductance response (SCR) after the synchronous condition showed that the embodiment illusion was effective in modulating pain processing at an implicit level. Finally, in a recent study (Solcà et al., 2018), patients with upper limb complex regional pain syndrome (CRPS) were immersed in a virtual scenario in which they observed a virtual replica of their affected limb flashing synchronously and asynchronously with their own heartbeat. The results of this experiment showed that after the synchronous condition patients experienced both a reduction in pain perception and an alteration of their heart rate variability, which is considered a physiological marker of pain, while also reporting improvement in the motor function of the affected limb.

6.1.4 Combining social touch and IVR for pain treatment

The aim of the present research project is to combine social touch and IVR to investigate the analgesic effect of a virtual social touch on both acute pain and CP. There are already some experimental evidence that have shown how a virtual caress can elicits pleasant sensations in participants (M. Fusaro, Tieri, & Aglioti, 2016; M Fusaro et al., 2019). In particular, individuals observing a virtual body from a 1PP while a virtual caress was delivered experienced a pleasant sensation and behaved as if a real caress was delivered. Also important for the hypothesis of the present study is the Motivation-Decision Model of pain conceptualized by Fields (Fields, 2006), which postulates that anything that could be considered more important than pain for surviving could exert an antinociceptive effect and therefore predicts that the reward received from a pleasant stimulus could reduce pain perception (Tracey & Mantyh, 2007).

Therefore, based on what has been presented so far, the present research will explore the analgesic effect of social touch in IVR by conducting two studies: the first study will investigate the analgesic effect of virtual social touch on experimentally induced acute pain, whereas the second study will investigate the analgesic effect of virtual social touch on experimentally induced prolonged pain. In both studies participants will be immersed in a IVR scenario in which they will observe a virtual body from a 1PP being gentle caressed on the virtual hand while a painful stimulation will be delivered on their real hand. Thus, thanks to the use of IVR we will be able to apply the pleasant stimuli on the same spatial location of the painful stimuli, i.e. participant's right hand. Furthermore, to control that the analgesic effect is indeed being caused by the social touch quality of the virtual touch, we will have one control condition in which the touch is caused by an inanimate object instead of being a caress, and a second control condition in which both the caress and inanimate object touch will be applied at a speed of 18cm/sec, i.e. a touch that does not preferentially activate the CT-fibres and that is not associated with pleasant sensations. To measure the analgesic effect of the virtual caress we will measure pain perception both at the explicit level, i.e. subjective ratings of pain, and at the implicit level, i.e. variations in both SCR and HRV.

Unfortunately, due to the COVID-19 pandemic, we were unable to collect any experimental data. Thus, while we eagerly await to be able to start our data collection as soon as possible, at this moment we can only present the methods and the expected results for both studies.

6.2 Methods

6.2.1 Participants

We calculated the sample size needed by performing a power analysis with G*Power 3.1.9.2 . The effect size f was based on previous studies conducted in our laboratory that investigated social touch and pain in immersive virtual reality (M. Fusaro et al., 2016; Martina Fusaro, Lisi, Tieri, Lucia, & Aglioti, 2020), A total sample of 30 participants (15 females and 15 males, all right-handed) will be required to obtain a power of 0.80, with alpha set at 0.05 and f at 0.25. The exclusion criteria will be the followings: presence of chronic pain, a diagnosis of depressive syndrome, presence of relevant psychiatric, medical and neurological conditions, presence of scars, wounds, tattoos and skin conditions on the right hand's dorsum.

6.2.2 Painful stimuli

In the first study, to induce short acute pain we will use nociceptive heat stimuli generated by an infrared neodymium yttrium aluminium perovskite (Nd:YAP) laser with a wavelength of 1.34 μm. These laser pulses, each lasting 5ms, are able to selectively activate the Aδ and C-fibre nociceptive terminals located in the superficial layers of the skin, causing a transitory pain similar to the pain caused by a puncture needle. The laser pulses will be delivered on the right hand's dorsum of the participants, and to prevent fatigue or sensitisation of the nociceptors, the position of the laser beam will be slightly altered after each pulse. Furthermore, in order to find the individual pain threshold for each participant, before the experiment we will perform a calibration phase during which participants will receive laser stimuli of increasing intensity in steps of 0.25 Joules (J) and they will be asked to rate each stimuli on a visual analogue scale (VAS) ranging from zero (“not painful at all”) to 100 (“extremely painful”).

In the second study, to induce tonic pain we will apply a 1% capsaicin cream on right hand’s dorsum of the participants, on an area of around 8cm, as the capsaicin has been found to activate the C-fibre nociceptive terminals and to cause a prolonged burning sensation (Fitzgerald, 1983). To obtain an appropriate pain intensity, the capsaicin cream will be applied on participants 40 minutes prior to the start of the experimental session (Bouffard, Bouyer, Roy, & Mercier, 2014).

6.2.3 Experimental procedure

Participants will wear the head-mounted display (HMD) and observe a virtual body from a 1PP sitting on a chair with the right hand placed on a desk. Thus, the virtual body will replace the participants’ body and it will replicate the same positioning of their real body. Participants will have some time to familiarize with the virtual scenario, and after that they will be asked to focus their attention on the virtual right hand. Four different stimuli will be delivered to the right virtual hand (Figure 1): 1) a hand caressing the virtual hand at 3cm/s, 2) a hand caressing the virtual hand a at 18cm/s, 3) a ball stroking the virtual hand a 3cm/s and 4) a ball stroking the virtual hand a 18cm/s.

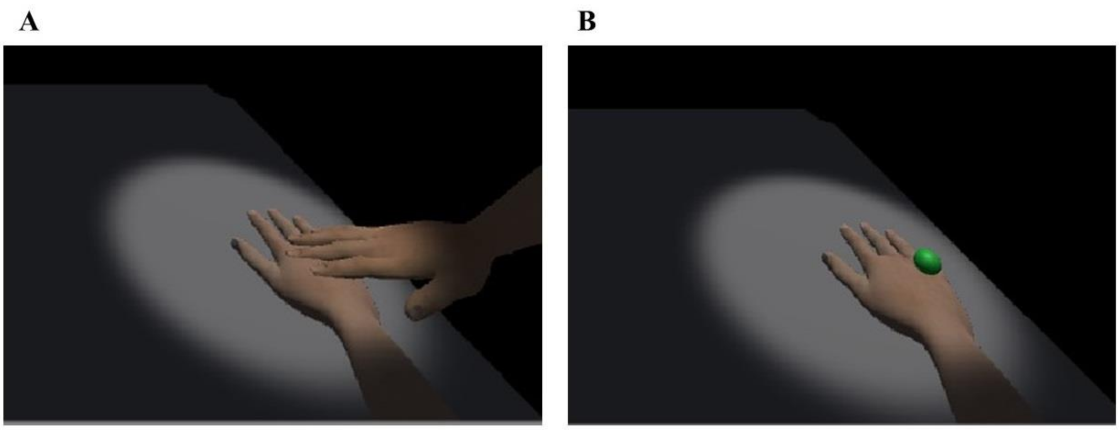

Figure 1. Depending on the experimental condition, participants will either see a hand caressing the right virtual hand **(A)** or a ball stroking the right virtual hand **(B)**. Furthermore, each stimuli will be delivered at two different speed i.e. a slow 3cm/s speed and a fast 18cm/s speed.

Each trial will start with 5 seconds of passive observation followed by 15 seconds of stimulation with one of the aforementioned stimuli. After 12 +/-2 seconds from the start of the trial a painful laser stimulation will be delivered to the real right hand of the participants. The timing of the laser stimulation will be randomized for each trial, and the experimenter will receive an audio cue in order to deliver the laser stimuli synchronously to the virtual stimuli. After each trial, we will ask participants to rate both the virtual and the painful stimuli with on a virtual visual analogue scale (VAS) (Figure 2).

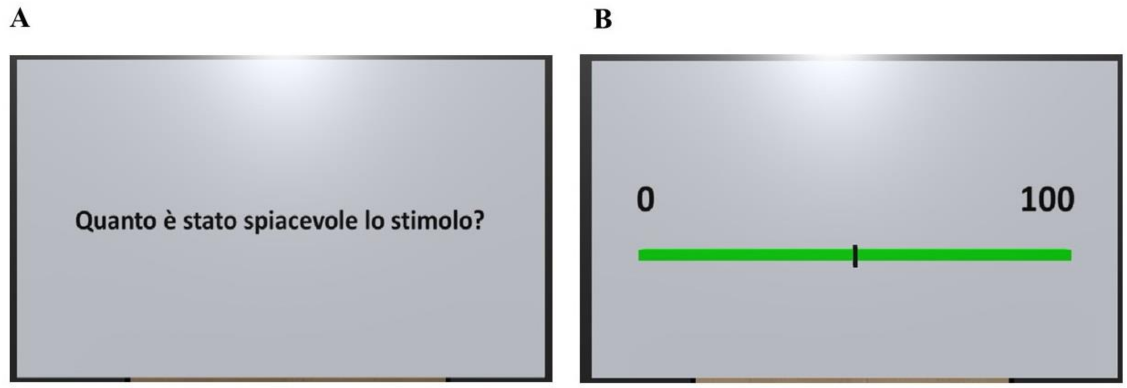

Figure 2. (A) After each trial, participants will be presented with three different questions: 1) how painful was the stimulus?, 2) how intense was the stimulus? and 3) how pleasant was the visual stimulus?. **(B)** For each item participants will be able to rate the stimuli on a 0 to 100 VAS. Participants will be able to answer the questions by pressing the appropriate keys on the keyboard with their left hand.

After answering all the questions, the participants will asked to focus their attention once again on the right virtual hand and a new trial will begin. Each experimental condition will be repeated 12 times, and for each condition there will also be a catch trial during which no laser stimulation will be delivered, thus the experimental session will consist of 52 total trials and will last for approximately 25 minutes. A the end of experimental session we will also rate the strength of the embodiment illusion by asking participant to rate on a VAS how much they felt the virtual hand was a part of their own body. Finally, for the whole duration of the experimental procedure we will record both SCR and HRV.

A similar experimental procedure will be use for the second study, which will retains all the aforementioned experimental conditions. In this study there will be no painful laser stimulation, as a tonic pain induced by the capsaicin cream will be already present on participants' right hand. In this study each condition will be presented 3 times over a 2 minutes block, for a total duration of 24 minutes. Finally, the same explicit ratings and physiological measure of Study 1 will be recorded.

6.3 Expected Results

We expect that the 3cm/s virtual caress will have the strongest analgesic effect among all the experimental condition, and we also expect that the 18cm/s ball stroking will be the least effective in affecting pain modulation. Particular interesting will be which stimuli between the 18cm/s virtual caress and the 3cm/s ball stroking will have the strongest analgesic effect, as it will give us information about which quality is most important in order to induce an analgesic effect, i.e. the human nature of the touch vs the speed at which it is delivered. The explicit ratings of pleasantness will be used to control each experimental stimuli. Furthermore, we expect a possible correlation between the explicit ratings of pleasantness and pain reduction.

Regarding the physiological measures, we expect that a reduction in pain perception will result in a reduction in the SCR compared to the others experimental conditions. As for the HRV, we expect a change in the low frequency/high frequency (LF/HF) ratio following pain induction, indicating a decrease in sympathetic activity and an increase of the vagal activity (Koenig, Jarczok, Ellis, Hillecke, & Thayer, 2014).

6.4 Closing comments

While VR distraction has already been used as a tool for reducing experimentally induced pain and in the treatment of patients with burn injuries (Malloy & Milling, 2010), here we briefly introduced two studies that aim to use the immersive quality of

VR for modulating pain perception through the application of a virtual social touch. We have seen that social touch can reduce pain perception in both infants and adults and how this analgesic effect is strongly associated with the activity of the CT-fibres, a type of unmyelinated mechanoreceptors in the skin (Goldstein et al., 2018; Gray et al., 2000; Gursul et al., 2018; M. Von Mohr et al., 2018), and also presented experimental evidence of the effectiveness of a virtual caress in eliciting pleasant sensations (M Fusaro et al., 2019). In these studies we plan to use a virtual caress not only for reducing phasic (acute) pain, but also for reducing tonic pain, which could be particular important for the treatment of chronic pain conditions, which are particular resistant to both behavioural and pharmacological treatments (Carter et al., 2014; Matamala-gomez et al., 2019). Furthermore, the use of IVR will give us the possibility to apply the virtual caress on a body part that is already in pain; this aspect could be particularly important for individuals affected by allodynia, i.e. 'pain elicited by a stimulus that normally does not cause pain' (Jensen & Finnerup, 2014). Allodynia is a common symptom in individuals affected by neuropathic pain, which is a form of chronic pain present in a wide arrays of conditions that are usually caused by diseases or lesions affecting the somatosensory nervous system (Jensen et al., 2011). As more than two-thirds of patients suffering from neuropathic pain do not benefit from the currently available pain treatments (Finnerup, Sindrup, & Jensen, 2010), the proposed IVR paradigm could results beneficial in brining relief to the everyday suffering of these individuals, as the availability of cheap VR head-mounted display could give these patients the ability to receive the treatment directly at home.

7. Conclusion

In the present work we discussed a series of studies that utilised immersive virtual reality (IVR) and the embodiment illusion to investigate how virtual bodily illusions can affect key components of the bodily self (body image), behaviour (tendency to deceive the other) and perception (pain modulation).

In the first and main part of the thesis we presented two studies that aimed to reduce body image distortion (BID) in anorexia nervosa (AN) by using immersive virtual reality and full body illusions (FBI) of differently sized avatars. In both of the discussed studies our results confirmed the distortion of the cognitive-emotional component of body image in AN (Cash & Deagle, 1997; Gardner & Brown, 2014), as evidenced by the difference between anorectic patients' desired and perceived body, as in both studies anorectic patients rated the thinner avatars as the most attractive while rating the bigger avatars as the most similar to themselves. Our results also confirm the idea that metric methods of body size estimations are best suited to detect body size overestimation compared to depictive methods (Farrell et al., 2005; Simone Claire Mölbert et al., 2017), as we did find a body size overestimation in anorectic patients when they were asked to estimate the width of their hips (body perception measure) and the minimum door's aperture required to walk through it (body schema measure), which are both metric methods of body size estimations, compared to when they were asked to choose the avatar that best resembled their perceived body, which is a depictive method of body size estimation. Furthermore, although our virtual embodiment paradigms were not successful in reducing BID in anorectic patients, in Study 2 our experimental procedure did manage to affect anorectic patients' body schema estimations, as their estimation of the minimum door's aperture wide changed accordingly to the size of the embodied avatar, thus confirming previous experimental evidence about the increased bodily-self plasticity of anorectic individuals (Eshkevari et al., 2012; Pollatos et al., 2008). Overall, the results of these studies indicate that it is possible to modulate body image in Anorexia Nervosa by inducing illusionary body ownership over differently sized virtual bodies. Furthermore, it is our opinion that, on the one hand, a modified version of the presented experimental paradigms could be used in virtual reality exposure therapy (Butler & Heimberg, 2020; Riva et al., 2000) to habituate anorectic patients to a healthier version of their own body. On the other hand, as the anorectic patients in our studies consistently found the larger avatars to be the most similar to themselves, we advanced the hypothesis that by repeatedly exposing anorectic patients to incongruent multisensory stimulations with these larger avatars which are erroneously perceived as similar to themselves, it could be possible to dampen the overestimation of their own body size by inducing a dis-ownership of the overestimated perceived body, i.e. reduce anorectic patients body overestimation.

In the second part of the thesis we introduced two studies in their preliminary stage, as the COVID-19 pandemic halted the progress on both of these researches and prevented us from collecting experimental data. Nevertheless, in chapter 5 we presented an online study that will investigate how the different components of the bodily self-consciousness (BSC), i.e. body ownership and body agency (Berlucchi & Aglioti, 2010; Blanke, 2012; Haggard, 2017), can affect individuals’ honest behaviour in digital interactions, as participants will be asked to compete against each other in an online die game. We will measure how manipulating individuals’ BSC will affect their tendency to lie during the game, i.e. report a different die outcome compared to the real one. To this aim we are developing three different applications in which participants will be able to: i) play the online die game on their smartphone (no manipulation of the BSC); ii) play the online game while embodying an avatar in a immersive virtual reality setting (manipulation of the body ownership component of BSC by increasing the attention towards one's own bodily signals) and iii) play while being able to throw the die by moving the embodied avatar's arm, thus experiencing also body agency over the virtual body. We think that the results of this study will be helpful not only to assess individuals' honest behaviour in digital interactions, but also to measure which component of the BSC are important in the modulation of people's tendency to deceive. As the moment of writing this final chapter, Microsoft has just announced Mesh, a mixed reality application that will let individuals project their holographic or virtual avatars from anywhere and interact with other individuals' avatars, share their experience with them, work on projects together and so on. The once thought distant future in which we will interact with each other through our virtual selves is actually already knocking on our doors then, and it is our opinion that knowing how each components of BSC can affect moral behaviour in digital interactions will be crucially important to promote individual ethical behaviour in these not so distant digital societies. Finally, in chapter 6 we introduced two studies that will attempt to use a virtual social touch to reduce both experimentally induced phasic and tonic pain. Participants will be immersed in a virtual scenario in which they will observe a virtual caress touching the hand of the embodied avatar while they will experience phasic pain induce by a thermal laser stimulation or tonic pain inducing by applying capsaicin cream. The aim of this research is to asses if virtual reality can be used for the treatment of pain not only for its distracting capabilities (Triberti et al., 2014) but by replicating the analgesic effect of social touch (Goldstein et al., 2018; Gray et al., 2000) in a immersive virtual reality setting, which could potentially pave the way for new chronic pain treatments directed to individuals suffering from neuropathic pain and allodynia.

Overall, the present work illustrated different applications of immersive virtual reality and bodily illusions in the study of aspects of our bodily self and body related behaviour and perception. While they investigate different topics, all these different studies rely on the fact that our bodily consciousness is an online construct, constantly updating through interoceptive and interoceptive signals (Berlucchi & Aglioti, 2010), which is molded by our experience and can thus be manipulated through these virtual bodily illusions. Furthermore, all these studies rely on the theorical framework of the embodied cognition (Barsalou, 2008), which states that all our high level psychological functions are dependent upon features and signals related to our physical body. Thus, we think that all these works might suggest the idea not that not only immersive virtual reality in the future might shape the reality around us and how we interact with each other, but it is already capable right now of affecting how we perceive our own selves, and consequently also our own perception and behaviour.

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9. Appendix: overview of publication status of thesis chapters

Chapter number and title	Original text (not published before)	Submitted: no feedback received	Submitted: revision requested or submitted	Accepted/published
INVESTIGATING BODY IMAGE DISTORTION AND BODILY SELF-PLASTICITY IN ANOREXIA NERVOSA VIA IMMERSIVE VIRTUAL REALITY 1. General introduction	X			
2. Study 1				X
3. Study 2	X			
4. General Discussion	X			
5.BODILY SELF-CONSCIOUSNESS AND DECEPTIVE BEHAVIOUR IN THE DIGITAL WORLD	X			

6. MODULATING ACUTE AND CHRONIC PAIN VIA VIRTUAL SOCIAL TOUCH	X			
7. Conclusion	X			