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Gender differences in bodily experience: Insights from virtual reality body illusion

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ABSTRACT

Virtual Reality has significantly improved the understanding of body experience, through techniques such as Body Illusion. Body Illusion allows individuals to perceive an artificial body as their own, changing body perceptual and affective components. Prior research has predominantly focused on female participants, leaving the impact of Body Illusion on males less understood. This study seeks to fill this gap by examining the nuanced bodily experiences of men in comparison to women. 40 participants (20 females and 20 males) were proposed with visuo-tactile synchronous and asynchronous Body Illusion to explore changes in body satisfaction and body size estimation across three critical areas: shoulders, hips, and waist. Results revealed significant initial disparities, with females displaying greater body dissatisfaction and a tendency to overestimate body size. After Body Illusion, females adjusted the hips perceived body size closer to that of the virtual body and reported increased body satisfaction independent of the condition. Conversely, males showed changes only in waist size estimation only after synchronous stimulation without significant shifts in body satisfaction. These results suggest a higher sensitivity of women to embodied experiences, potentially due to societal influences and a greater inclination towards self-objectification. These insights pave the way for creating more refined and effective interventions for body image issues, highlighting the importance of incorporating gender-specific considerations in VR-based prevention and therapeutical programs.

1. Introduction

Body illusions offer profound insights into understanding body experience and its underlying mechanisms, serving as a powerful lens through which the intricate relationship between physical self-perception and identity can be explored (Vankerckhoven et al., 2023).

In the last years, technological advances allowed the development of advanced paradigms for proposing bodily illusions that can cleverly modify core components of Bodily Self- Consciousness, namely the sense of owning a body (ownership), the sense of being in a body and occupying a specific physical space (self-location), and the sense of having control over the body (agency; de Vignemont, 2020). Specifically, technology allowed the transition from the classic rubber hand to making subjects experience a fake rubber hand as their own (Rubber Hand Illusion (Botvinick & Cohen, 1998)), to the use of whole mannequins that make people perceive a completely artificial body as their own (Full Body Illusion (Ehrsson, 2022; Preston et al., 2015)). Furthermore, the availability of low-cost technology has enabled more sophisticated techniques to emerge. In particular, the use of Virtual Reality (VR) has made it possible to create convincing, high-fidelity graphics for the proposal of Full-Body Illusions in which individuals identify with entire virtual bodies (Blanke & Metzinger, 2009; Preston et al., 2015; Scarpina et al., 2019). Immersive VR (IVR) experiences have outperformed traditional, non-digital techniques in terms of their effectiveness in promoting the identification of artificial bodies (or body parts). This progress opened new avenues for understanding the complex relationship between human cognition and the perception of one's physical self. In this regard, researchers have developed paradigms where the artificial body presented in IVR can be drastically different from the user's actual body, a process referred to as Full Body Illusion (FBI) (Petkova & Ehrsson, 2008; Serino et al., 2019). During FBI, individuals can experience having a different body - such as one that is thinner, taller, larger, or smaller than their actual body (Petkova & Ehrsson, 2008; Serino et al., 2019; Serino, Pedroli, et al., 2016). This possibility provided profound insights into the malleability of body representation.

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1.1. The multisensory integration process (MSI)

The core principle underpinning body illusions is the reliance on the body's Multisensory Integration Process (MSI). Indeed, body representation is developed and updated through an MSI process where concurrent spatial and temporal information coming from different sensory modalities are unified into a coherent and unique percept (Brizzi, Sansoni, Di Lernia, et al., 2023; Brizzi, Sansoni, & Riva, 2023). Body illusions fully exploit MSI: the phenomenon of embodiment - namely the identification with an artificial body experienced through body illusions - is promoted by synchronous multisensory stimulation where sensory information from the artificial and real bodies are spatially and temporally congruent (Blanke & Metzinger, 2009; Costantini & Haggard, 2007; Petkova & Ehrsson, 2008).

Typically, embodiment induction requires that the virtual body is presented from a first-person perspective so that the visible virtual body and the hidden physical body are aligned (i.e., they have the same self-location), and they are congruently stimulated in the same body region at the same time (i.e., synchronous visuo-tactile stimulation) or synchronized in terms of movements (i.e., visuo-motor synchronization; Blanke & Metzinger, 2009; Spanlang et al., 2014).

The illusion strength is instead usually reduced when the stimulation is applied without temporal and spatial synchronization between what the individual sees (i.e., the virtual body being touched on the abdominal area) and feels (i.e., the real body not being touched, being touched in another body area, or with perceivable delay; Blanke & Metzinger, 2009; Keenaghan et al., 2020; Spanlang et al., 2014). Despite synchronous and asynchronous stimulation remaining widely used as experimental and control conditions respectively (e.g., Di Lernia et al., 2023), recent studies observed that proved that a certain level of visual-temporal mismatch does not affect the illusion (Burin et al., 2018) or even a complete mismatch between visuomotor feedback (Burin et al., 2020).

1.2. Virtual reality body-focused interventions

Groundbreaking studies revealed that IVR-based Full Body Illusion (IVR-FBI) significantly altered body perception, leading to perceptual and affective alterations (Keizer, Van Elburg, et al., 2016; Scarpina et al., 2019; Serino et al., 2019). In this context, we refer to BS as a subtype of full-body illusion where there is no correspondence between the user's body and the artificial one (**Petkova and Ehrsson,** 2008). For example, the embodiment of a thinner virtual body was found to increase body satisfaction in females (Porras Garcia et al., 2019; Preston & Ehrsson, 2018), whereas the embodiment of an obese body was found to trigger body dissatisfaction and anxiety (Porras Garcia et al., 2019; Preston & Ehrsson, 2014a, 2018). Similarly, it was observed that body size estimation changed significantly towards the virtual body after the FBI in samples of female participants (Keizer, van Elburg, et al., 2016; Serino et al., 2019). Moreover, the study by Preston and colleagues (2018) showed that owning an obese body decreased body satisfaction, and owning a slimmer body increased body satisfaction in females.

These findings led to the proposal of using this procedure for manipulating and correcting the body experience of patients affected by disorders characterized by altered relationships between the self and the body. In particular, FBI has been used to alter body experience in patients with Eating and Weight disorders such as Anorexia Nervosa and Obesity (Serino, Scarpina, et al., 2016). For example, in women suffering from Anorexia Nervosa, exposure to a normal-weight body has been shown to reduce the overestimation of body size typically reported by those suffering from the disorder, thereby contributing positively to the healing and recovery process (Keizer, Van Elburg, et al., 2016; Serino et al., 2019; Serino, Scarpina, et al., 2016). Similarly, female patients affected by obesity and healthy controls reported significant changes in the estimation of their abdomen circumference after embodying a slim body according to the artificial body measures (Keizer, van Elburg, et al., 2016; Serino et al., 2019).

Overall, IVR-BS emerged as a valuable tool for addressing altered body experience in two core components: the ability to accurately assess one's body size and spatial awareness (the perceptual component), and the emotions and sensations associated with one's body (the emotional component; (T. F. Cash, 2000; de Vignemont, 2010; Longo et al., 2009)).

1.3. Gender differences and virtual reality body-focused interventions

Nevertheless, significant questions remain to be answered before fully integrating IVR-based body-focused procedures in clinical practice, particularly regarding how different genders might respond to these experiences. A substantial proportion of previous research indeed predominantly focused on female subjects and patients grappling with eating and body image disorders. Notably, this applies not only to conditions with a higher prevalence in women such as Anorexia Nervosa, but also to pathologies with a higher prevalence in men, such as obesity (Muscogiuri et al., 2023). For instance, studies using IVR-BS to treat obesity primarily focused on females (Serino, Pedroli, et al., 2016; Serino, Scarpina, et al., 2016; Scarpina et al., 2019), so it is not clear whether this body-focused intervention might be beneficial also for males.

This understanding is crucial to tailor effective treatments and maximize the therapeutic potential of IVR in the area of body representation and experience. This becomes even more critical in light of the growing body of research that suggests that body-self issues are not exclusively female concerns: men tend to experience a critical relationship with their bodies too, which can lead to distress and problems in various areas of life, from social to psychological (Eisenberg et al., 2006; Neumark-Sztainer et al., 2006).

Hence, understanding the transformative potential of FBI to alter body-self relationships requires a nuanced appreciation of gender-specific similarities and differences (Eisenberg et al., 2006; Talbot & Mahlberg, 2023). This is also in light of data demonstrating that body size misestimation and dissatisfaction are widespread across the population, highlighting a widespread propensity, even among non-clinical populations, to overestimate one's body width and to be dissatisfied with one own body (Eisenberg et al., 2006; Talbot & Mahlberg, 2023). This misperception and affective state are not merely a benign cognitive bias: they have profound implications, entwined with various facets of an individual's psychological well-being, and even the onset and maintenance of disordered eating behaviors.

In other words, it is not enough to recognize that such illusions can alter body perceptions: it is essential to understand the magnitude and direction of these changes, and how they may affect men and women differently. The development of therapeutic and preventive interventions aimed at improving body image and promoting mental health might benefit greatly from this understanding, as interventions can then be tailored to be universally effective and flexible enough to be adapted to specific demographic groups or individuals. Then, this study investigated how body size perception and body satisfaction changed after IVR-BS in males and females. To this end, we developed a gender-specific version of the currently used Virtual Reality Full Body Illusion and investigated how this procedure affected body self-experience from affective (i.e., body satisfaction) and perceptual (i.e., body size estimation) levels.

2. Methods

2.1. Participants

A total of 43 participants participated in the experiment (21 males and 22 females), according to the sample size calculation (G*Power) for repeated measures ANOVA with within-between interactions (alpha = 0.05, beta = 0.8, effect size f = 0.25, number of groups = 2, number of measures = 3, correlation among measures = 0.5) and based on previous research (Preston & Ehrsson, 2018; Serino et al., 2019). We included only healthy participants with no current diagnosis of psychopathological and/or neurological conditions based on self-reported information.

Participants completed the General Health Questionnaires before starting the study to assess their psychological well-being. Three participants (two females and one male) were removed from subsequent analysis because of scoring GHQ higher than 14, indexing possible psychological distress. Then, the final sample consisted of 20 males and 20 females. Table 1 reports the final sample descriptives.

2.2. Procedure

Participants were first asked to sign the informed consent form and were then introduced to the experimental procedure and technology. They were asked to complete initial questionnaires (i.e., socio-demographic information, Body Image State Scale, and General Health Questionnaire) and to estimate the circumference of three different body parts in a randomized order (i.e., hips, waist, and shoulders, according to the Body Size Estimation task procedure; BES). They were then presented with IVR experience - i.e., FBI. Participants wore the headset and were asked to look around the virtual room. They saw a body and were instructed to align themselves with the virtual body (the instruction was as follows: "Can you see a virtual body in the room? Perfect, now align yourself with the virtual body as if you were about to enter the body"; Serino, Pedroli, et al., 2016; Serino, Scarpina, et al., 2016; Di Lernia et al., 2023). Once the gender-matched virtual and physical body locations coincided, participants were instructed to look down and focus on their abdominal area (the instruction was as follows: "Now, you have just to look at your belly"). To promote embodiment over the virtual body, the experimenter stimulated the abdominal area of the avatar and the participants' real body with the controller, while the same stimulation was applied to the avatar. After 120 s of visual-tactile stimulation (based on Preston & Ehrsson, 2014b), they were asked to complete the Embodiment Questionnaire to assess embodiment strength and had to estimate a second time to estimate the circumferences of three body regions (Body Size Estimation task) and rate their body satisfaction (Body Image State Scale). The procedure was administered twice to all participants in counterbalanced order, providing both synchronous and asynchronous visuo-tactile stimulation to avoid possible order effects. Consequently, the study used a mixed design with two factors: the participants' gender (male or female) and the different assessment times (body satisfactionand body size estimation at the baseline, after the asynchronous, andsynchronous virtual experience).

2.2.1. General health questionnaire

The General Health Questionnaire 12 (GHQ-12; (Politi et al., 1994)) is a non-clinical instrument designed to gauge an individual's overall psychological well-being. It serves as a preliminary screening tool, not for diagnosis but to assess general mental health. The questionnaire consists of 12 items that ask questions about the respondent's recent experiences and feelings. This self-administered questionnaire comprises 12 items, which inquire about a person's recent feelings and experiences. Respondents indicate their agreement with each item using a Likert scale that ranges from 0 (more than usual) to 3 (much less than usual). A score of 19 or above is considered a potential indicator of psychological distress. The GHQ-12 addresses various aspects of well-being, such as enjoyment of daily activities, problem-solving capacity, feelings of unhappiness and depression, loss of self-confidence, and general happiness. The Italian adaptation of the GHQ-12 was developed at the University of Verona using a back-translation method and has repeatedly been validated and confirmed as a reliable tool (Piccinelli et al., 1993). GHQ-12 was used as a screening for psychological distress so that only participants with a total score higher than 14 (indexing the absence of distress) were then included in the analysis.

2.2.2. Full body illusion in virtual reality

Participants initiate the virtual experience by donning a head-mounted display, specifically the Oculus Quest 2. Within the virtual environment, they view an avatar and are instructed to align their physical body with the virtual gender-matched one to ensure the real and virtual bodies are spatially congruent. Following this, the experimenter uses a controller to touch the avatar's abdomen—simultaneously replicating this touch on the participant's actual body. This dual stimulation lasts for 120 s (Preston & Ehrsson, 2014b). There are two methods used in this visuo-tactile stimulation to ensure the illusion happens and provide a control condition: synchronous, where the stimulation of the real and virtual bodies is temporally and spatially aligned, and asynchronous, where there is no such alignment and a delay of approximately 10 s separates the visual and tactile input (based on Serino, Pedroli, et al., 2016; Serino, Scarpina, et al., 2016; Di Lernia et al., 2023). The sequence in which the participants receive synchronous and asynchronous stimulation is counterbalanced to eliminate any potential bias from the order of presentation. The virtual avatars were designed based on prior studies, using Makehuman software to represent a normal-weight body (waist-to-height ratio equal to 0.4606; (Di Lernia et al., 2023; Keizer, Van Elburg, et al., 2016; Serino, Pedroli, et al., 2016)). Fig. 1 shows the body parameters (see Keizer et al., 2016a, b; Serino, Pedroli, et al., 2016; Serino, Scarpina, et al., 2016; Serino et al., 2019; Di Lernia et al., 2023).

2.2.3. Embodiment questionnaire (EQ)

An adapted version of the Embodiment Questionnaire developed by Piryankova and colleagues (2004) was administered at the end of the two virtual experiences (synchronous vs. asynchronous visual-tactile stimulation) to assess the effectiveness of this procedure in inducing an illusory sense of virtual body ownership (Di Lernia et al., 2023; Serino, Pedroli, et al., 2016). The EQ consists of 15 self-reported items on a 7-point Likert scale assessing the perception of the illusion in terms of ownership (e.g., "I felt like the virtual body was my body"), self-localization (e.g., "I felt like I was inside the virtual body") and agency (e.g., "I felt like I had power over the virtual body"). This version of the questionnaire has been used in previous research in Italian samples (Di Lernia et al., 2023; Serino, Pedroli, et al., 2016). Following the methodology of previous research (e.g., Di Lernia et al., 2023), we proposed the paper-based questionnaire immediately after the IVR experience.

Table 1
Sample descriptives. The table displays a detailed breakdown of average age, waist, hips and shoulders circumferences mean values, Body Mass Index (BMI), and General Health Questionnaire (GHQ) scores, segmented by gender, including both mean values and standard deviations.

Sample Descriptives							
	Gender	BMI	Age	Real_w	Real_h	Real_s	GHQ
Mean (sd)	Female	20.9 (1.76)	25.3 (3.03)	80.4 (11.60)	93.8 (8.01)	99.9 (6.40)	12.8 (2.21)
	Male	23.1 (1.99)	26.6 (3.76)	101 (5.25)	106 (4.88)	118 (8.30)	11.7 (2.35)
Minimum	Female	18.4	20	63.2	76.9	90	7
	Male	19.4	20	86.8	94.2	103	7
Maximum	Female	24.4	32	102	109	110	14
	Male	27.4	33	110	113	132	14

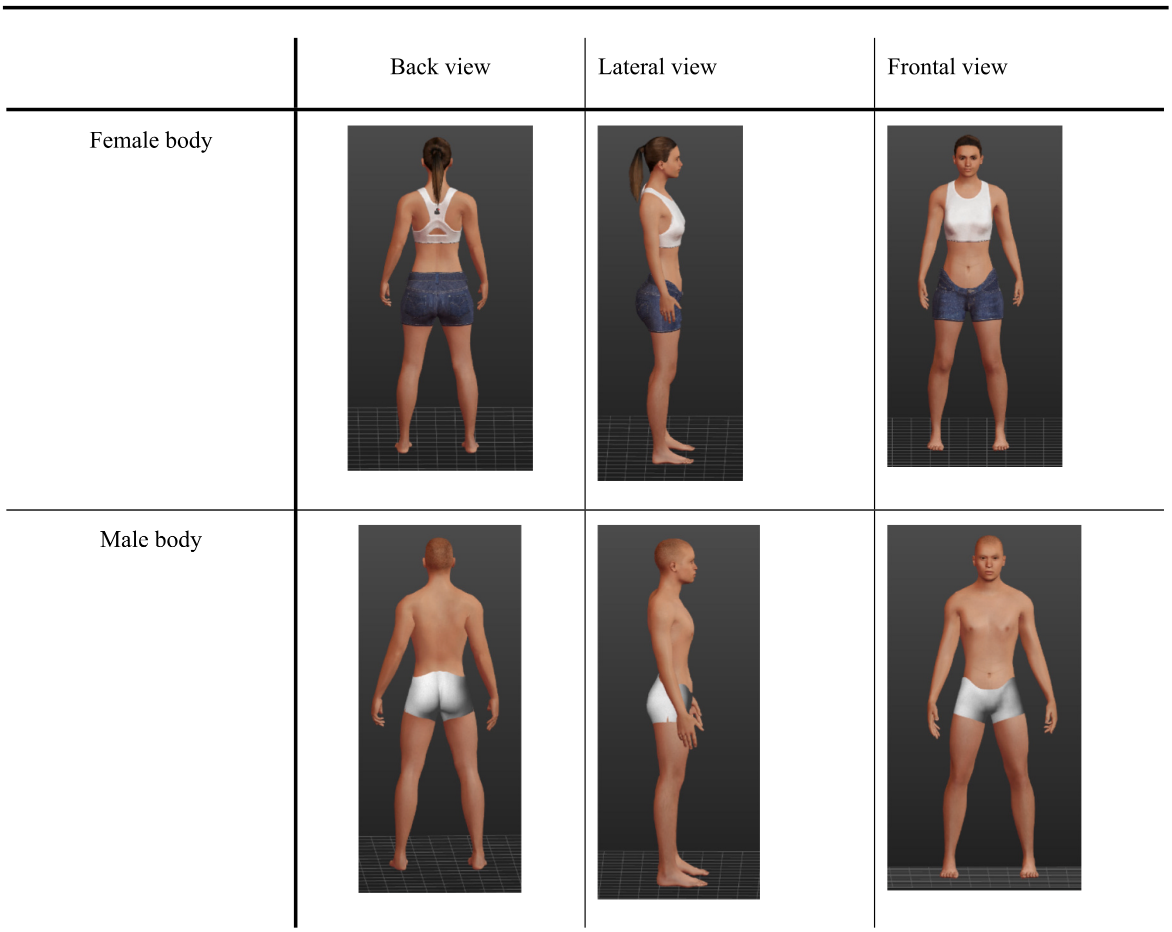

Fig. 1. Avatar parameters. Height = 160.54, age = 25, front chest distance = 26.58, bust circumference = 82.99, underbust circumference = 66.57, waist circumference = 73.95, nape to waist = 38.34, waist to hip = 19.01, shoulder distance = 14.14. The same measures were used for the male body (Keizer et al., 2016a, b).

2.2.4. Body size estimation (BES) task

The Body Size Estimation task was developed to investigate the perceptual component of how individuals perceive their body size. The task requires estimating the circumference and/or width of different body parts (e.g., hips, waist, and shoulders) using a string. Based on previous research (Serino, Pedroli, et al., 2016; Serino, Scarpina, et al., 2016; Di Lernia et al., 2023), participants had to estimate the circumference of the above-mentioned body parts by placing a piece of rope in a circle/oval on the floor. Subsequently, the estimate of each body area is compared with the subject's actual measurement to obtain a measure of accuracy (i.e., the ratio between the estimation and the actual measure; (Farrell et al., 2005)). Each body part was estimated separately and in counterbalanced order. This can be considered an implicit task for body representation assessment as it requires participants to recall in memory their body dimensions and reproduce them with a string (Serino, Pedroli, et al., 2016; Serino, Scarpina, et al., 2016, 2019).

2.2.5. Body image state scale (BISS)

The Body Image State Scale is a self-reported questionnaire to assess state body image (Bardi et al., 2021; T. Cash et al., 2002). It comprises 6 items and answers are rated on a 9-point Likert-type scale. Each item starts with the sentence "At this moment, I feel" [e.g. "At this moment, I feel (extremely dissatisfied to extremely satisfied) with my physical appearance"]. The score is an average of each element. Higher scores indicate higher body satisfaction.

3. Analysis and results

Analyses were run in Jamovi. For the Body State Satisfaction Questionnaire, we derived an aggregate score (BISS_Tot) by averaging the responses across items for each experimental condition. Similarly, we assessed accuracy in the Body Size Estimation task by computing the ratio of participants' estimations to the actual measurements of each body part (Accuracy), again considering each condition separately (based on (Serino, Pedroli, et al., 2016)). Outliers were defined as values lying >2.5 standard deviations from the mean in either direction. No outliers were detected. We looked at skewness and kurtosis (threshold +/− 2.5) to evaluate the distribution of BISS and Accuracy scores; results indicated no deviations from normality. Regarding the Embodiment Questionnaire, we computed mean scores for each subscale, applying a similar protocol for outlier detection and exclusion—values were discarded if they were more than two standard deviations away from the mean, in either direction. Then, a set of analyses was planned specifically aimed at answering our research questions: 1) investigating gender differences at the baseline on body estimation accuracy and body dissatisfaction, and 2) see if and how males and females change their body satisfaction and perceptual accuracy level after the FBI experience.

3.1. Embodiment questionnaire

First, we wanted to evaluate differences in embodiment strength across conditions. We performed a non-parametric paired *t*-test (Wilcoxon test) to compare embodiment strength after synchronous and asynchronous stimulation, observing significant differences across all

EQ subscales. Notably, values after the synchronous stimulation were overall higher than after the asynchronous one. Table 2 shows the mean and standard deviation of each EQ subscale and t-test results. and comparisons (Serino, Pedroli, et al., 2016).

3.2. Body satisfaction (BISS) at the baseline

An independent sample t-test was used to examine differences in body satisfaction between genders at the baseline, before the body illusion. The analysis revealed a significant difference between genders($t(26.4) = -6.51$, $p < 0.001$; Cohen's d = −2.06). Specifically, the female BISS mean value was lower for females than males (the mean for females was equal to 3.92 (0.53), whereas the mean for males was equal to 4.80 (0.23)). Then, result suggested that young women tended to be more dissatisfied with their bodies as compared to men.

3.3. Body satisfaction (BISS) changes after full body illusion

A repeated measures ANOVA was performed to examine the impact of body illusion on body satisfaction in male and female participants. We considered Condition (baseline, synchronous, asynchronous) as within factor, Gender (male, female) as between factor, and Body Satisfaction (BISS score) as the independent variable. Greenhouse-Geisser correction was applied when the assumption of sphericity was violated. Subsequently, post hoc analyses with Bonferroni correction were conducted to investigate within gender variations.

We observed a significant main effect of Condition ($F(2, 76) = 17.5$, $p < 0.001$, $\eta^2 = 0.045$) and Gender ($F(1, 38) = 33.6$, $p < 0.01$, $\eta^2 = 0.38$), as well as a significant interaction effect Gender*Condition ($F(2,76) = 11.4$, $p < 0.01$, $\eta^2 = 0.02$; Fig. 2). Post-hoc comparisons revealed that females changed their satisfaction level both after synchronous and synchronous stimulation as compared to baseline, whereas no differences were observed for males did not. Table 4 reports post-hoc results.

3.4. Body size estimation (BES) at the baseline

An independent sample *t*-test was performed to investigate gender differences in the Body Size Estimation task at baseline for each body area. The analysis revealed that there were no significant differences between males and females in the estimation of waist and shoulder circumferences whereas differences emerged when considering hips estimation. Table 3 presents analysis results. Then, even though both males and females tended to overestimate their body dimensions (values >0), females tended to overestimate their hips more than males.

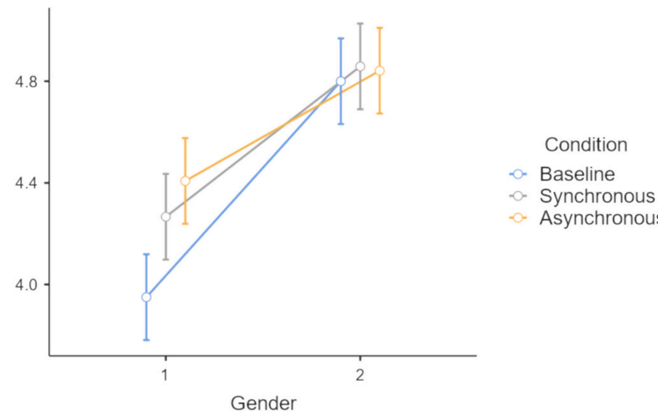

Fig. 2. BISS changes in females and males across conditions. 1 = females, 2 = males.

3.5. Body size estimation (BES) after full body illusion

A repeated measures ANOVA was performed to examine the impact of body illusion on body satisfaction in male and female participants separately. We considered condition (baseline, synchronous, asynchronous) and body areas (shoulders, hips, waist) as within factors, gender (male, female) as between factor, and accuracy in body estimation (BES task performance) as the independent variable. The greenhouse-Geisser correction was applied when the assumption of sphericity was violated. Subsequently, post hoc analyses with Bonferroni correction were conducted to investigate within gender variations.

Results revealed a main significant effect of Condition ($F(2, 76) = 18.006$, $p < 0.001$, $\eta^2 = 0.015$), Body Area ($F(2, 76) = 12.923$, $p < 0.001$, $\eta^2 = 0.090$) and Gender, ($F(1,38) = 7.76$, $p = 0.008$, $\eta^2 = 0.089$) as well as a significant interaction effect Condition*Gender*Body Area ($F(4,152) = 3.858$, $p = 0.005$, $\eta^2 = 0.006$). Fig. 3 shows three way interaction results.

Post hoc analysis within each gender revealed a significant change in hip estimation in female participants after both synchronous and asynchronous conditions as compared to the baseline. Specifically, the comparison between the baseline and synchronous conditions revealed a significant mean difference of 0.082 (SE = 0.017, $t(228) = 4.857$, $p < 0.01$), and the comparison between baseline and asynchronous condition comparison showed a significant mean difference of 0.079 (SE = 0.017, $t(228) = 4.651$, $p < 0.01$). A significant change was instead observed for males in waist estimation only after synchronous stimulation as compared to baseline (difference = 0.068, SE = 0.017, $t(228) =$

Table 2
Wilcoxon test comparing illusion strength after synchronous and asynchronous stimulation. The table reports the descriptives for each subscale of the Embodiment Questionnaire (EQ) and Paired-Sample *T*-Test results. Sync = synchronous stimulation; Async = asynchronous stimulation; Loc = location; Own = ownership; Ag = agency.

EQ Descriptives	N	Mean	SE
Sync_Own	40	3.48 (0.487)	0.0769
Async_Own	40	1.69 (0.477)	0.0754
Sync_Loc	40	3.88 (0.836)	0.1322
Async_Loc	40	1.70 (0.544)	0.086
Sync_Ag	40	2.42 (0.626)	0.099
Async_Ag	40	1.11 (0.265)	0.0419

							95 % Intervallo di Fiducia		
			W	p	Mean difference	SE	Inferior	Superior	Effect size
Sync_Own	–	Async_Own	820	< 0.001	1.78	0.0786	1.61	1.94	1.00
Sync_Loc	–	Async_Loc	820	< 0.001	2.13	0.1164	1.88	2.38	1.00
Sync_Ag	–	Async_Ag	666	< 0.001	1.5	0.1069	1.25	1.75	1.00

Table 3
Results of independent sample t-test for BES performance at the baseline. The table details the comparative analysis of gender-based differences in body dimension accuracy across different body areas.

	Group	N	Mean	SE
Accuracy_shoulders	Female	20	1.18 (0.130)	0.029
	Male	20	1.12 (0.139)	0.031
Accuracy_waist	Female	20	1.30 (0.182)	0.04
	Male	20	1.21 (0.124)	0.027
Accuracy_hips	Female	20	1.24 (0.134)	0.029
	Male	20	1.08 (0.092)	0.02

Independent Samples T-Test		Statistic	df	p		Effect Size
Accuracy_shoulders	Student's t	1.23	38	0.227	Cohen's d	0.389
Accuracy_waist	Student's t	1.81	38	0.079	Cohen's d	0.571
Accuracy_hips	Student's t	4.31	38	< 0.001	Cohen's d	1.363

Table 4
BISS changes within genders. The table presents post-hoc comparison within gender to investigate changes in BISS scores across conditions. Base = baseline; Sync = synchronous stimulation; Async = asynchronous stimulation.

Condition	Gender		Condition	Mean Difference	SE	df	t	$p_{bonferroni}$
Base	Female	–	Sync	−0.316	0.062	76	−5.095	< 0.001
		–	Async	−0.457	0.062	76	−7.363	< 0.001
	Male	–	Sync	−0.058	0.062	76	−0.939	1
		–	Async	−0.041	0.062	76	−0.669	1
		–						
Sync	Female	–	Asyncs	−0.14	0.062	76	−2.268	0.393
	Male	–	Async	0.016	0.062	76	0.27	1

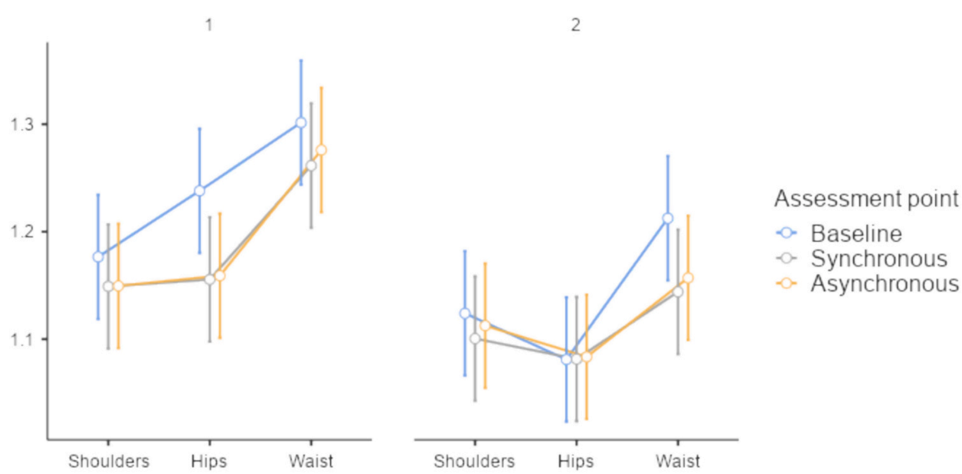

Fig. 3. BES changes across different body areas and conditions. The plot shows how females (1) and males (2) changed their body size estimation across conditions divided for different body areas.

4.033, $p = 0.011$).

4. Discussion

This study investigates how FBI into a different normal-weight body alters body representation from perceptual and emotional viewpoints in a sample of healthy male and female participants. Unlike previous studies, the current research emphasizes similarities and differences in body experience across genders, specifically concerning body size estimation and body satisfaction.

4.1. Gender differences at the baseline

4.1.1. Body satisfaction

The first result of this study showed that females tended to be more dissatisfied with their bodies as compared to males. This is in line with a wide body of literature (Pingitore et al., 1997; Quittkat et al., 2019), indicating that women generally report heightened levels of body dissatisfaction and experience greater pressure to conform to certain aesthetic standards as compared to men, especially within Western cultures (Santhira Shagar et al., 2021). Then, even though males are growingly exposed to messages promoting idealized body types, the effects of such messages seem to be not as deeply rooted or impactful as they are for females.

This may partially relate to differences in self-serving approaches.

Specifically, previous research suggested that men tend to adopt self-enhancement and self-protection strategies which could bolster their self-esteem, finding alternative sources of self-worth outside the body domain (e.g., achievements, personal strengths, non-appearance-related qualities (Brennan et al., 2010; Burlew & Shurts, 2013; Grossbard et al., 2009; Voges et al., 2019). On the other hand, Brennan et al. (2010) observed that men tend to be quieter about their body negativity as compared to females, even though they still struggle with their bodies. In this regard, future research could employ implicit measures of body satisfaction, which may circumvent explicit measures biases (e.g., social and response biases). For instance, body satisfaction implicit measures might include Relational Responding Task (Glashouwer et al., 2018), and Implicit Association Tests (Preston & Ehrsson, 2018; Velkoff & Smith, 2020).

Nonetheless, socio-cultural determinants might contribute to gender differences in body satisfaction. Indeed, the cultural role of female and male bodies was not the same. Traditionally, the female body was depicted as a symbol of beauty and desire – i.e., it was objectified – leading females to self-objectify themselves (Calogero et al., 2010; Fredrickson & Roberts, 2016; Rollero & De Piccoli, 2017). Specifically, girls' bodies have been seen as objects whose main goal is to appeal to the observer and be in line with societal ideals. Notably, high degrees of self-objectification have a profound effect on how one experiences one's own body, adversely affecting both body-self relationship as well as psychological well-being more broadly (Calogero et al., 2005, 2010; Fredrickson & Roberts, 2016; Riva et al., 2015; Rollero & De Piccoli, 2017; Winn & Cornelius, 2020). Conversely, the male body has historically been under-examined, with the masculine form typically linked to attributes of power, proficiency, and achievement (Lefkowich et al., 2017). This might lessen the Self-Objectification process and downplay the importance of physical appearance in males, shifting the focus towards other parameters such as performance, and social standing (Lefkowich et al., 2017).

On the other hand, recent studies highlighted the escalating male pursuit of muscular physiques (Eik-Nes et al., 2018a). That is, males in recent years seem to desire to be more muscular and/or perceive to be not enough muscular (Blashill et al., 2020). However, research revealed that excessive preoccupation with a perceived one's appearance is a broader concept as compared to the drive for muscularity (see Blashill et al., 2020). Consequently, while global and general measures of body satisfaction may be effective for evaluating females, they may not be as suitable for exploring male body-self relationships. The idea that body satisfaction might assume different facets depending on gender, is supported by previous studies revealing that only girls associated body dissatisfaction with the concept of self-esteem (Furnham et al., 2002).

This would imply using different tools to assess the level of body satisfaction based on the specific sample of interest (e.g., the Drive for Muscularity Attitudes Questionnaire for a male sample; Morrison and Harriman, 2005). Recent studies have attempted to construct tools capable of accounting for both thinness and muscularity, proposing assessment tools that displayed a series of 3D bodies modified along these two parameters (Arkenau et al., 2020; Steinfeld et al., 2020). Participants were asked to respond by marking the body that best reflected their real body and their ideal body, where the discrepancy provided an index of body satisfaction in line with the classic procedure of Figure Rating Scales (Arkenau et al., 2020; Steinfeld et al., 2020). On one hand, this approach allows standardized measures for both males and females, whereas on the other these are non-immersive 3D tools (Arkenau et al., 2020; Steinfeld et al., 2020) that are not able to discriminate the influence of the two specific factors, so that separate and specific scales might be developed. This implies that body satisfaction is a complex construct that necessitates the use of gender-specific assessment instruments and methodologies.

Currently, we are facing a notable shift in societal norms and attitudes, with the male body increasingly subject to objectification processes as well (Bocarsly et al., 2023). This suggests that although objectification may have been internalized by males to a certain extent, its full impact remains to be thoroughly examined in the current socio-cultural corner. Given the crucial role of objectification in the development of an altered body-self relationship, future longitudinal studies might involve young boys to track and understand the potential long-term effects of this trend, twinning that which has been historically observed for females.

4.1.2. Body size estimation

A second important finding from this study refers to the body estimation abilities, namely in the accuracy with which people estimate their body dimensions. In line with previous research, we observed that both males and females misestimate their body dimensions, with an overestimation tendency (Martynov et al., 2020). However, what is innovative about the present study is related to gender differences across different body areas.

We found that females tended to overestimate the hips size more than males. Again, this may be related to socio-cultural standards of beauty that emphasize hip size and shape as critical elements of the female form. These standards glorify body types that are typically slender and curvaceous at the hips, a beauty ideal not typically applied to men (Singh & Young, 1995). Building on this concept, the process of self-objectification could result in a cognitive bias wherein women view their bodies through the prism of societal expectations. Moreover, hips are a focal point of femininity and attractiveness, and this can lead to a heightened awareness and critical assessment of their own body in comparison to these ideals (Singh & Young, 1995). For males, instead, we observed that they tended to overestimate the waist circumference significantly more than females. Parallelly to what emerged for females, this is in line with the societal ideal body for men, which demands a developed musculature (particularly the upper body) and leanness to produce a "v" shaped torso (Gruszka et al., 2022).

Then, while both genders may overestimate their body dimensions, what makes our findings particularly intriguing is the observed gender differences concerning body areas that are socially and culturally regarded as symbols of femininity and masculinity. Assuming the absence of perceptual deficits, results seem to suggest that socio-cultural factors and emotional aspects drive the observed overestimation. A more in-depth analysis would benefit from investigating the precise relationship between the perceived size of specific body areas, the level of satisfaction with these regions (using tools like the Body Area Satisfaction Scale), and the degree of Objectification to specifically verify this hypothesis.

Notably, some research observed that women were more likely to misperceive themselves as overweight, while men were more likely to perceive themselves as underweight (Weng et al., 2023; Griffiths et al., 2015). The authors discussed their findings referring to possible intervening variables such as BMI, age, media exposure, and social comparison. Whereas in our study BMI and age were not significantly different between groups, a future analysis might consider whether social media use might influence body size estimation abilities. It might be that girls tend to use social media to be exposed to images of girls with a body that conforms to the beauty standards of thinness, while boys use social media to look at a different kind of content, hence this might have an effect on their body perception.

4.2. Body representation after full body illusion

4.2.1. Body size estimation task

Concerning the change in body representation after the FBI, data revealed that females changed their hips estimations after both synchronous and asynchronous stimulation as compared to the baseline.

Our findings align with prior studies indicating that experiencing embodiment through a simulated body can influence perceptions of object size, including one's own body. This result can be explained by referring to the predictive coding framework of brain functioning and

Virtual Reality technology functioning (Millidge et al., 2021; Talsma, 2015). Specifically, when participants engage with a virtual body that doesn't match their anticipated body expectation (priors), there is a conflict between the incoming sensory information and the brain's prediction (prediction error); to reconcile this, the brain adjusts its representation of the body to align with the new multisensory inputs (Pedroli, et al., 2016; Riva, 2018; Serino, Pedroli, et al., 2016; Serino, Scarpina, et al., 2016). As a result, individuals might tend to overestimate their body dimensions because they build their representation on inaccurate expectations and priors (Brizzi, Sansoni, Di Lernia, et al., 2023). However, when they swap into a different body through multisensory immersive technology, like Virtual Reality, the prediction error prompts the brain to update the body representation (Brizzi, Sansoni, Di Lernia, et al., 2023; Brizzi, Sansoni, & Riva, 2023; Serino et al., 2019). On these bases, Virtual Reality seems to be able to modify the body memory, at least temporarily.

This idea that embodiment over an artificial body significantly affects body perception was found in previous research involving healthy participants and patients affected by body image disturbances such as Eating and Weight Disorders (i.e., Anorexia Nervosa and obesity; Keizer, Van Elburg, et al., 2016; Scarpina et al., 2019; Serino, Scarpina, et al., 2016). Following these results, research has recently focused on the development of procedures exploiting Virtual Reality body illusions to correct dysfunctional body-self relationships and facilitate the recovery journey. For instance, FBI has been effectively employed to assess and treat body image distortions in females with Anorexia Nervosa (Ferrer et al., 2020; Porras Garcia et al., 2019; Porras-Garcia, Serrano-Troncoso, et al., 2020) and obesity (Scarpina et al., 2019).

These results underscore the potential of Virtual Reality as a transformative tool. This is because of specific features of this technology: it is immersive, cognitive, and simulative, namely that it can mirror the brain's predictive functions and then has the potential to impact the bodily information processing pathways (Riva et al., 2017, 2019). These are the reasons why IVR has been proposed to be the core of a new transdisciplinary research field - embodied medicine - whose main goal is the use of multisensory and immersive technologies to alter the body experience by replacing multisensory bodily contents with synthetic ones (Riva et al., 2017, 2019).

Notably, the efficacy of this approach seems to be higher when there is crossmodal congruency between the real and the virtual world. This is because multisensory integration of spatially and temporally congruent crossmodal signals is at the basis of how our experiences, including the body. This explains why changes in body estimation were primarily observed after synchronous stimulation (Blanke, 2012; Brizzi, Sansoni, Di Lernia, et al., 2023; Ehrsson, 2012; Rossi Sebastiano et al., 2022).

However, the literature provides mixed findings concerning the exact mechanisms behind the effects of synchronous and asynchronous stimulation on body size estimation. If the most of studies highlighted the importance of spatial and temporal synchrony between the virtual and real environments to drive change (Malighetti et al., 2022), the present study and previous research found different results. For instance, Van Der Hoort and colleagues (2011) found that the overestimation of object sizes after experiencing a small body occurred through synchronous visuo-vestibular as well as through asynchronous visuo-tactile stimulation. Similarly, Keizer and colleagues (2016) found that the embodiment of a virtual body altered body size estimation irrespective of the type of stimulation. Here, the authors suggest that processing information from other sources of input (e.g., proprioception, interoceptive signals, tactile information) might allow for a more holistic experience of the body, which in turn might enhance body size estimation accuracy (Keizer, Van Elburg, et al., 2016). Other authors, instead, suggested that change after asynchronous stimulation was linked to the weight attributed to visual information during the predictive process (Thaler et al., 2018). If these hypotheses are true, embodiment might then not be necessary to observe changes.

This aligns with our results and previous research (e.g., Serino, Pedroli, et al., 2016; Serino, Scarpina, et al., 2016), where changes in body estimation were detected despite low levels of embodiment in the synchronous condition (around the mean value of a scale ranging from "totally disagree" to "totally agree"). This aligns with the suggestion by Longo and colleagues (2008): the authors performed a psychometric evaluation of embodiment measures, observing a mean value of around 0 (on a scale ranging from −3 to 3). From their discussion, embodiment should not be perceived as a binary state but rather as a progressive process assessed along a continuum. On the other hand, previous research (e.g., Serino, Pedroli, et al., 2016; Serino, Scarpina, et al., 2016; Keizer et al., 2016a, b; Di Lernia et al., 2023) considered embodiment successfully induced in light of significant differences between synchronous and asynchronous stimulation. That is, what seems to matter is the difference across conditions and multisensory stimulation.

Notably, other parameters might account for contrasted findings, such as the software and the experimental setting, among others. For instance, it might be that the graphic quality or the realism of the avatar significantly impacts the illusion experience and then the observed change (Mottelson et al., 2023). In this regard, it might be important to use similar approaches in future research to make results comparable and drive conclusions. Further research is needed to discern whether this synchrony is an absolute prerequisite for any perceptual change, or if it is merely a beneficial factor that amplifies the effect of change.

On the other hand, differently from female participants, we found males changed waist estimations only after synchronous stimulation.

This might be attributed to gender-specific approaches to processing body-related information and the varying levels of concern over the body. Previous research indicates that women generally place a greater emphasis on appearance, leading to a higher investment in contemplating and attempting to modify their bodies as compared to men (Quittkat et al., 2019). Consequently, it might be that males tend to have a more rigid and less malleable body, making their body representation more resistant to alteration through multisensory stimulation. Subsequent research should specifically investigate body representation malleability and its relationship with body investment. Moreover, future studies might consider exploring the cumulative effects of repeated FBI: this would aim to determine whether sustained and repeated sessions could lead to any significant modifications in body size estimation and overall body representation also among males. It may be possible to conduct a repeated measures study in which several FBI sessions are offered several times. Furthermore, comparisons could be made between the effects of exposure to a normal-weight body (as is the case in procedures with female patients) and/or to a muscular body. Such a procedure could clarify whether the lack of change in men is related to the use of the specific avatar or the duration of exposure.

Another reason that might partially explain our finding might be related to the embodiment process: males may tend to experience the illusion less than females, which in turn translates into a different body estimation change. This might be because body illusions are based on multisensory conflicts, and previous studies reported gender differences in multisensory tasks (Collignon et al., 2010). However, as described above, other findings observed body experience changes both before synchronous and asynchronous stimulation, namely with and without embodiment or at least independently on the level of embodiment. That is, it is not clear whether the embodiment is necessary for body perception to change, or whether visual information alone might promote changes (Maselli & Slater, 2013; Pavone et al., 2016; Tieri et al., 2017).

It might also be that the difference between females and males related to the virtual body. That is, it might be that the difference between the virtual body and the real one in the case of girls was sufficiently similar to promote greater identification. In contrast, for males the differences might be too vast for this projection process to occur. However, this hypothesis is discomfirmed by evidence suggesting that virtual bodies are embodied equally strongly regardless of their similarity to the real body - e.g., bodies of own- and other-race (Banakou et al., 2016; Pyasik et al., 2023), smaller and larger size (Tambone et al., 2021), different genders (Tacikowski et al., 2020), bodies of historical figures that do not resemble own bodies at all (Banakou et al., 2018).

However, going more into detail about our previous finding, data revealed that the body size estimation differed across genders for specific body areas. Specifically, females significantly changed the estimation of their hips after the illusory experience, whereas males changed significantly their waist estimation only after synchronous stimulation.

Specifically, we found that the body areas typically considered emotionally salient to each gender (the hips for women and the waist for men) are the ones that change the most following FBI (Zavorsky et al., 2007). It might be that the most critical and emotionally charged areas may also be the most malleable and susceptible to multisensory manipulations. To date, studies on body illusions involving individuals affected by Anorexia Nervosa revealed that patients tend to show a more flexible body representation than healthy controls, so they tend to experience the illusion strongly and their body representation can be easily influenced by external stimuli (Keizer et al., 2014). In light of the body-self alteration that characterizes this condition, it might be body areas that are particularly emotionally salient tend to be more susceptible to modifications and alterations. Notably, previous authors suggested that when we ask individuals to judge the dimension of body parts, perhaps we are measuring the perceptual dimension together with the feelings, concerns, and preoccupation about those body parts, affecting the judgment itself (Riva, 2018; Riva & Dakanalis, 2018). However, further and specific research is needed to confirm this hypothesis.

An interesting result is that alterations were reported in the body areas of the avatar that were visible to the participants. Unlike other studies, we did not observe changes in the estimation of shoulder circumference, which was not visible in the avatar since the participants' attention was directed to the hips and waist (as presented in the procedure section, the task of the participants was to look at and focus on the abdominal area). This finding aligns with the idea that visual information plays a key role in shaping our perception —meaning that sight may carry more weight in the predictive process compared to other sensory information (Alexi et al., 2018). However, exact mechanisms need to be better investigated. For instance, the observed changes might be due to a serial dependency bias due to the exposure. In addition, more refined mechanisms, such as a change in the multisensory integration process, might have an influence too. On one hand, the short-time effects observed in body estimation change after the illusion seems to provide evidence for the first hypothesis (Keizer, Van Elburg, et al., 2016). Conversely, the enduring effects noticed in clinical populations following multiple exposures might suggest that while single-session effects may be attributed to cognitive biases, repeated engagements with the illusion might induce more profound and lasting changes (Porras-Garcia, Ferrer-Garcia, et al., 2020). Follow-up assessment measures can be additionally used to assess this aspect.

4.2.2. Body state satisfaction

The last finding from this study relates to body satisfaction change after FBI. We observed that the exposure to a virtual body did not significantly change body satisfaction in male participants, whereas an improvement was found for females independently of the stimulation.

This gender difference seems to be consistent with data related to body size estimation. Then, we observed congruence between the emotional and perceptual components (Ramos et al., 2019). This might be related to the avatar used: unlike previous studies (Preston & Ehrsson, 2018), we presented a slim body that was comparable for both males and females. However, it is possible that such a body type is not particularly desirable for males, who might idealize a more muscular body (Eik-Nes et al., 2018b; Frederick et al., 2005). Therefore, this paradigm might not be optimal for studying male body experience. However, studies using muscular bodies in line with sociocultural standards found resistance to change in body satisfaction at both an implicit and explicit level (Preston & Ehrsson, 2018).

A speculative explanation could concern the flexibility with which body representation changes in males and females: as mentioned earlier, it could be that females tend to fluctuate more in their level of body satisfaction than males. This aligns with the findings of a meta-analysis showing that merely observing ideal bodies (for example, in images or social media posts) can significantly alter body satisfaction in females by triggering comparison mechanisms (Grabe et al., 2008). Hence, there may be a different susceptibility and suggestibility to body-related stimuli across genders, although further and more specific research is required (Arkenau et al., 2022). Another possible explanation of this finding could be related to baseline differences: since males started from a higher level of body satisfaction, changes might be less pronounced. Moreover, the same intervening variables explaining baseline satisfaction differences might play a role, including both methodological choices (e.g., the use of explicit measures) as well as psychological factors (e.g., women tend to rely more on self-critical strategies when evaluating their physical appearance, whereas men tend to rely more on self-hopeful strategies; Franzoi et al., 2012).

It is also possible that resemblance to the avatar and the level of embodiment impact such change (Preston & Ehrsson, 2018). For instance, greater subjective similarity to the avatar might result in less change or higher levels of embodiment might be associated with greater change.

4.3. Limitations and future research

This study confirmed previous findings related to gender differences in body-self relationships and provides novel insights into the effects of body illusions on body representation. However, some caveats should be considered in the interpretation of our data. First, a larger sample size is needed to verify the reproducibility of our results. Second, this study focused on bodily perceptual and emotional components, but other factors might be better investigated to understand their role in determining a change and gender differences, such as objectification level or self-esteem among others. Future studies might include also these possible intervening variables to see if and how they influence body change.

Another limitation relates to the experimental tools: in line with previous research (e.g., Keizer et al., 2016a, b; Serino, Pedroli, et al., 2016; Serino, Scarpina, et al., 2016; Di Lernia et al., 2023), participants could not move and the avatar was static. This is why we did not assess cybersickness and motion sickness in this study. However, the brain seems more responsive to human action than static images, with possible implications on body representations (Cazzato et al., 2012; Peuskens et al., 2005). This insight opens new avenues for future research, particularly in exploring the potential of inducing embodiment with an avatar through visuomotor integration - where the virtual body's movements are synchronized with the participant's movements – seeing whether discomfort during the VR experience might emerge as a critical factor that could limit VR efficacy.

Notably, the static nature of the proposed experience might explain the low levels of embodiment we observed in both in synchronous and asynchronous conditions. Indeed, similarly to previous works that used the same procedure (Serino et al., 2019; Serino, Pedroli, et al., 2016; Serino, Scarpina, et al., 2016; Keizer et al., 2016a, b; Di Lernia et al., 2023) participants overall reported low embodiment levels around the mean value. However, specific parameters and cut-offs to better determine whether embodiment can be considered reached are needed. This even because in the case of virtual full-body illusion, the first-person perspective was shown to be sufficient to induce embodiment without any kind of synchronous multisensory stimulation (Maselli & Slater, 2013; Pavone et al., 2016; Tieri et al., 2017), asynchronous visuotactile, and even visuomotor, stimulation might not be sufficient to disrupt the embodiment (Keenaghan et al., 2020; Maselli & Slater, 2013). Then, future research might include a different control condition, such as visual-only stimulation – i.e., observation of the virtual body without any tactile/motor stimulation. This type of research might elucidate mechanisms underlying changes both after synchronous and asynchronous stimulation. For example, it might be that mere visual exposure might induce changes because individuals tend to rely more on visual information compared to others.

Lastly, we used explicit measures to assess embodiment and body satisfaction (Preston & Ehrsson, 2018). Since self-reported explicit results might be biased due to social and desirability biases, future research might then consider including implicit measures. For instance, the Relational Responding Task (Glashouwer et al., 2018) or the Implicit Association Tests (Preston & Ehrsson, 2018; Velkoff & Smith, 2020) can be used for assessing body satisfaction, whereas skin conductance and temperature (Palomo et al., 2018) can be used to measure embodiment strength. This can also better elucidate whether embodiment was successfully induced, ideally solving the issue of determining embodiment strength with questionnaires that do not present a specific cut-off to determine whether the illusion occurred.

5. Conclusions

The results of this study underscore the potential of Virtual Reality to create immersive, embodied, and multisensory environments. IVR can effectively alter the body's affective and perceptual experience, distinctly in males and females. The small changes observed in males, however, suggested that they can benefit from interventions when reflecting their specific needs. Research is needed to understand how to design effective body illusion experiences for males. In this regard, it might be possible to investigate whether repeated exposure to FBI might affect male body experience by using longitudinal studies.

Another point to highlight is providing useful recommendations for practitioners and policymakers interested in implementing IVR-based interventions for body image concerns.

In this regard, it should be noted that the opportunity provided by IVR to work on the Self-body relationship is unparalleled, as it allows the individual to inhabit a body different from their own. While in the field of clinical psychology, this exercise has traditionally been proposed through imaginative techniques, having access to an embodiment process capable of engaging all the subject's sensory channels would significantly enhance the opportunity to undergo an experience so transformative as to influence one's sense of bodily satisfaction.

Finally, it ought to be underlined that the use of virtual reality tools can generate ethical problems, considering for example the fact that using virtual reality entails the risk of cybersickness. Concerning this phenomenon, symptoms may include headache, nausea, dizziness, visual fatigue, and disorientation. Despite these ethical implications, it is important to underline that measures to prevent or reduce the possible onset of cybersickness are easily applicable. For example, to obtain important results in terms of improving one's body satisfaction, it may be enough to use IVR for a very short time. From this perspective, therefore, it is as if IVR, requiring minimal effort from the subject, manages to achieve maximum output.

This research area is poised to deepen our understanding of the body-self relationship, offering insights for the development of solutions for both men and women grappling with body-self concerns. Addressing this aspect is crucial for psychological health and preventing mental health disorders such as Eating Disorders (Cash & Brown, 1987; Dakanalis et al., 2016). On these bases, IVR interventions might indeed offer support before dysfunctional or pathological behaviors. In other words, such a stance not only promises to improve individual well-being but also aims to preempt the development of severe psychopathological conditions.

Ethical approval

The study received Ethical Approval from the Catholic University of Sacred Hearth.

CRediT authorship contribution statement

Giulia Brizzi: Writing – original draft, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Fabio Frisone:** Writing – original draft. **Chiara Rossi:** Writing – review & editing, Formal analysis, Data curation. **Giuseppe Riva:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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