Virtual Reality (2023) 27:2665–2672
https://doi.org/10.1007/s10055-023-00836-6

ORIGINAL ARTICLE

360-degree video-based body-ownership illusion for inducing embodiment: development and feasibility results

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Received: 29 June 2022 / Accepted: 2 July 2023 / Published online: 21 July 2023

Abstract

Illusions that create a sense of ownership over a virtual body have been widely used to investigate the characteristics of our bodily experience. Despite the great potential of 360-degree videos to implement full-body ownership illusion, research is in its early stages, and no validated tools—neither commercial nor free—are available for the scientific and clinical community. In the current study, we present and discuss the development and feasibility results of a free 360-degree video-based body ownership illusion that researchers and scholars can experience using a cardboard headset with their smartphones. Forty-six participants underwent the 360-degree video-based full-body ownership illusion, visualizing in a first-person perspective (1PP) or in a mirror view the pre-recorded body of a young female performer. All participants were exposed to a congruent visuo-tactile condition (embodiment condition) and to an incongruent visuo-tactile condition (control condition). Participants completed the Embodiment Questionnaire and the Objectified Body Consciousness (OBC) scale. Results revealed that in the congruent visuo-tactile condition (compared to the control one), participants experienced a strong illusion in terms of body ownership, self-location, and agency. In terms of visual perspective, there was no difference in embodiment feelings between participants who experienced the illusion in 1PP and those who underwent a mirror perspective. Lastly, the control beliefs subscale (i.e., OBC scale) displayed a positive correlation with the self-location illusion susceptibility. Overall, these results point to the feasibility of this novel tool as immersive 360-degree video-based scenarios to deliver bodily illusions, and they open new avenues for future clinical interventions.

Keywords Bodily Illusion · 360-degree videos · Body Ownership · Embodiment

1 Introduction

Since Botvinick and Cohen's well-known experiment (Botvinick and Cohen 1998) demonstrating how to induce in individuals the illusion that a rubber hand is part of their own body (i.e., Rubber Hand Illusion – RHI), there has been an increasing diffusion of "body-ownership illusions" to investigate and manipulate our bodily experience (Kilteni et al. 2015; Maselli and Slater 2013; Matamala-Gomez et al. 2021). In the RHI, the individual perceives a congruent touch on their actual (not visible) hand while also seeing a touch on a rubber hand, resulting in the illusionary impression that the rubber hand is the "real" one. A consistent body of studies demonstrated that a body-ownership illusion can be induced toward a full body by using a mannequin (e.g., Petkova and Ehrsson 2008) or a virtual body (e.g., Slater et al. 2010); in this case, individuals experience the feeling of being the owner of another entire (fake) body. Body ownership is indeed defined as the individual's self-attribution of a body that is the perception that one's body is the source of the sensations felt (Blanke et al. 2015; Kilteni et al. 2015). Together with a sense of self-location (i.e., the experience of being located inside a body) and agency (i.e., the sensation of controlling the motor actions of the physical body and its intentions), body ownership is one of the elements that

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contribute to the experience of *embodiment*, the perception that people sense when the qualities of the fake body (e.g., body shape) are processed as if they belong to the real one (Blanke et al. 2015; Riva 2018). Through body-ownership illusions, people can embody artificial bodies that are processed as belonging to or substituting their physical body (for a recent systematic review, see Matamala-Gomez et al. 2021), enabling researchers to pinpoint the specific components that merge in our bodies' holistic experience (Maselli and Slater 2013; Tian et al. 2020). For this reason, body illusions have been reported to be effective techniques for investigating in experimental settings the characteristics of our bodily experience in both healthy (Kilteni et al. 2015) and clinical populations (Serino and Dakanalis 2017).

For the full body-ownership illusion to work, specific characteristics must be present. According to Maselli and Slater (2013), to elicit the feeling of being the owner of another artificial body, two characteristics can modulate the strength of illusion: a) synchronous stimulation (visuo-tactile or visuo-motor stimulation) of the real and artificial body, and b) congruent appearance and realism (e.g., texture, shape, skin tone, clothes). To elicit a strong body-ownership illusion, we need congruence of bottom-up (i.e., multimodal perceptual information) and top-down processes (i.e., comparison with the internal representation that the person has of their own body) (Maselli and Slater 2013). Regarding the role of visual perspective, participants can observe their virtual bodies in first-person perspective (1PP) or look at themselves in a mirror. While some studies suggest that 1PP is required to elicit the embodiment of the virtual body (Petkova and Ehrsson 2008; Slater et al. 2010), other studies have found that a mirror view (namely, an allocentric perspective) (Preston et al. 2015) can also elicit it.

To experimentally recreate body illusions, Virtual Reality (VR) is a tool of choice in that its ability to let the user interact with the virtual scenario simulates the sensorial richness that people have in their real life, reducing the distance between the real and virtual world (Riva et al. 2019). VR environments are often computer-generated environments built with software engines such as Unity or Unreal. In that regard, VR enables a solid experimental control over all the variables mentioned above to induce embodiment toward an external body (Kilteni et al. 2015; Maselli and Slater 2013; Riva et al. 2018).

However, the development of such VR content can be rather costly in terms of time and economic resources. An alternative solution is using 360-degree videos, namely spherical recordings captured by sophisticated cameras equipped with omnidirectional lenses capable of collecting images from all over *real* space. Since 360-degree cameras can capture both the visual and auditory stimuli presented in the recorded scene, they seem feasible to create holistic, immersive, and ecological scenarios. The spherical video may then be watched using a VR headset as if it was a regular digital scenario, allowing the user to actively explore the live-action video in all directions (Serino and Repetto 2018). 360-degree video-based immersive content has already proven its potential for inducing a sense of embodiment (Aitamurto et al. 2018; Ventura et al. 2021, 2022a, b) and creating body illusions (Ventura et al. 2022a, b), showing no significant differences from computer-generated VR in creating a sense of presence and improving emotional responses (Brivio et al. 2020). Despite their advantages of being easier to develop, less expensive than traditional VR scenarios, and more flexible in varying aspects of bodies and experimental conditions, thus representing an optimal candidate to implement body illusions, 360-degree videos are not widely used. No validated tools—neither commercial nor free—are available for the scientific and clinical community.

In the current study, we present and discuss the development and testing of a novel 360-degree video-based full-body ownership illusion—freely available for any interested researcher (the download can be done here: https://osf.io/jnerz/?view_only=d07e204ad385439b9f2b1e78f04dd52a)—consisting of a pre-recorded 360-degree video in both 1PP and mirror view featuring a female body. To evaluate its feasibility, first, we examined whether this new setup could produce the illusion. To accomplish this, we employed a questionnaire used in the literature on bodily illusions to assess whether the illusion was successfully induced: female participants were asked to explicitly report the effects of the illusion in terms of a sense of ownership (i.e., the experience of the body as mine), self-location (i.e., where I believe my body is), and sense of agency (i.e., the feeling of control over my actions). We expect that our novel 360-degree video-based body illusion will be able to induce the illusion in the congruent (namely, the experimental condition) but not in the incongruent visuo-tactile stimulation (namely, the control). Second, we investigated potential embodiment differences between a 1PP and a mirror view. As previously stated, the VR literature on this topic yields conflicting results. Accordingly, we explored whether using a different visual perspective could modulate embodiment processes within 360-degree video-based body illusion. Finally, we explored potential individual differences in embodiment processes. Specifically, we examined whether potential individual differences in self-objectification (as measured by the Italian Objectified Body Consciousness Scale (Riva et al. 2017) would be related to the strength of this novel illusion. In general, self-objectification can be defined as a tendency toward the (bodily) self-characterized by constant monitoring of the body and thinking about how it appears. Individuals higher in this attitude are usually more likely to adopt an allocentric image of themselves (Riva et al. 2014, 2015) and often have a less stable body representation that is more susceptible to external stimuli (Kaplan et al. 2014).

Following the findings from Valzogher and colleagues (Valzolgher et al. 2018), we predict that individuals with higher levels of self-objectification will be more susceptible to the illusion.

2 Methods

2.1 Participants

A convenience sample of 46 female volunteers (mean age = 22.6 ± 1.27) was recruited through university announcements and invited to take part in the study. Volunteers between the ages of 18 and 30 were eligible to participate in the study if they had no history of neurological diseases, no current physical conditions known to alter their bodily experience (i.e., pregnancy), and no current or prior history of psychiatric illness (e.g., eating disorders). Half of the participants were randomly allocated to the 1PP (Group 1- 1PP) group (mean age = 22.5 ± 1.16), and the other half were randomly allocated to the mirror view (Group 2- Mirror View) group (mean age = 22.7 ± 1.40). The experiment was conducted in compliance with the Declaration of Helsinki (of 1975, as revised in 2008), and it was approved by the Ethical Local Board of the "Università Cattolica del Sacro Cuore" (Catholic University of the Sacred Heart, Milan, Italy).

2.2 360-degree video-based body ownership illusion

The 360-degree video-based Body Ownership Illusion was created with a Samsung Gear 360 Camera (SamsungElectronics Co., Ltd.) with a resolution of 2,560 × 1,280 pixels and a frame rate of 60 Hz. The videos were edited with the software Gear 360 ActionDirector (Vers. 2.0.1619.0) and, in the current study, presented via a head-mounted display (VR Shinecon headset) that enables an immersive video experience. For developing 360-degree videos, we had one female performer with a comparable body shape to the actual bodies of the participants. She was dressed in blue shorts and a white crop top. For the 1PP condition, 360-degree videos were recorded in a stimulus-free room, with the camera positioned in front of the female performer (standing upright) so that participants could later view the scene from the performer's perspective (1PP). For the allocentric perspective condition, the setting was identical, except for a mirror facing the performer, so that participants could later observe the scene also from a mirror view perspective. The experimenter applied a 180-s tactile stimulus to the performer's right arm during the video recording. A stick with a small sphere at the bottom was utilized to administer accurate stimulation at four spots (from the bottom up) at a rate of one second per touch for a total of 180 tactile stimulations over 180 s. The 360-degree video-based illusion and detailed instructions can be retrieved here: https://osf.io/jnerz/?view_only=d07e204ad385439b9f2b1e78f04dd52a

2.3 Instruments

2.3.1 Embodiment questionnaire

We adapted a questionnaire based on multisensory illusion literature (Botvinick and Cohen 1998) to investigate the effect of congruent (vs. incongruent) visuo-tactile stimulation on bodily experience. The questionnaire contained 29 items. Participants were asked to rate their agreement with each item on a 7-point Likert scale (from 1 = completely agree to 7 = completely disagree) at the end of each condition. The questionnaire included three subscales: body ownership (14 items, such as "I felt as if the body I saw in the video was my body"), self-location (11 items, such as "I felt as if I was inside the body I saw in the video"), and agency (4 items, such as "I felt as if I had control over the body I saw in the video"). The scales have been computed by averaging the items for each dimension.

2.3.2 Self-objectification

We used the Italian Objectified Body Consciousness (OBC) scale to assess self-objectification (Dakanalis et al. 2017a, b). The questionnaire contains 24 items divided into three subscales. The first subscale dealt with body surveillance (e.g., "I think about how I look a lot during the day"), the second one with body shame (e.g., "I feel like a bad person when I don't look as good as I could"), and the last one with appearance control beliefs (e.g., "I really don't think I have much control over how my body looks"). Cronbach's alpha values found in this study indicated that the internal consistency for the three subscales was acceptable (body surveillance, $\alpha = 0.770$; body shame, $\alpha = 0.710$; appearance control beliefs, $\alpha = 0.738$). The scales have been computed by averaging the items for each dimension.

3 Procedure

Participants were given written information about the study and asked to sign the required informed consent form upon arrival at the laboratory. Following that, firstly participants completed the Objectified Body Consciousness (OBC) scale. All participants were instructed to stand upright and to put on the Head-Mounted Display (HMD) (VR Shinecon headset) to experience the 360-degree video-based Body Ownership Illusion. They visualized in a 1PP (Group 1-1PP) or in a third-person perspective (3PP) mirror view (Group 2-Mirror

View) the 360-degree video-based scenario that included the pre-recorded body of the young woman (i.e., the performer) in a 1PP or through the mirror (i.e., Mirror View). All participants were exposed to two different conditions in a counterbalanced order:

- Congruent visuo-tactile stimulation (*embodiment condition*): during this experimental condition, the experimenter provided tactile stimulation on the participants' right arm for 180 s. As for the video recording, a stick with a small sphere at the bottom was utilized to administer accurate stimulation at four spots (from the bottom up) at a rate of one second per touch for a total of 180 tactile stimulations over 180 s. In this condition, there was a coherence between what participants saw in the video, and what they perceived in their physical body (i.e., a concurrent tactile stimulation provided by the experimenter);
- Incongruent visuo-tactile stimulation (*control condition*): the experimenter stimulated the participants' left arm for 180 s in reverse order of the visual inputs (not from bottom to top, but rather from top to bottom). A stick with a small sphere at the bottom was also used in this condition to deliver accurate stimulation at four different spots at a rate of one second per touch for a total of 180 tactile stimulations over 180 s. There was, therefore, an incongruence between what participants saw, and what they felt on their bodies.

Following each experience, participants were asked to complete the Embodiment Questionnaire.

4 Data analysis

Data were entered into Microsoft Excel and analyzed using SPSS version 18 (Statistical Package for the Social Sciences–SPSS for Windows, Chicago, IL, USA). First, for each of the three subscales of the Embodiment Questionnaire, a mixed ANOVA with Group ("Group 1-1PP" vs. "Group 2-Mirror View") as between-subject variable and Condition ("Congruent visuo-tactile stimulation" vs. "Incongruent visuo-tactile stimulation") as a within-subject variable was conducted separately to investigate the effect of the illusion on bodily experience, and whether the strength of the illusion differed between illusion susceptibility indices (i.e., ownership, self-location, and agency). Out of 46, only 32 participants completed the OBC Scale. Accordingly, on a subsample of 32 participants, to additionally investigate if individual differences in self-objectification influenced susceptibility to the multisensory illusion, we used Pearson correlation analysis. The aim was to investigate the association between the self-objectification scores with the normalized difference between congruent and incongruent scores (i.e., illusion susceptibility), for each of the three main components of the embodiment questionnaire separately (i.e., ownership, self-location, and agency).

5 Results

5.1 Effect of 360-degree video-based body ownership illusion on body perception

In terms of the effect of 360-degree video-based Body Ownership Illusion on bodily experience, a main effect of Condition emerged for all three subscales of the Embodiment Questionnaire, with higher scores in the congruent visuo-tactile condition compared to the incongruent one (See Table 1 for descriptive statistics). Specifically, results revealed that in the congruent condition (Factor: Condition) the feeling of body ownership was significantly higher with respect to the incongruent one [$F(1,44) = 106.675$; $p < 0.001$; partial $\eta 2 = 0.707$)]. In parallel, when participants received congruent multisensory stimulation, they also reported higher feelings of being in the same spatial location as the body in the video (self-location) [($F(1,44) = 217.236$; $p. < 0.001$; partial $\eta 2 = 0.832$)] and a higher level of agency ($F(1,44) = 46.9$; $p. < 0.001$; partial $\eta 2$. 516)]. There was no significant difference between the two groups in terms of

Table 1 Means, standard deviation (in brackets) for the Embodiment Questionnaire (ownership, self-location, agency) for the first-person perspective (Group 1-1PP) or in a mirror view (Group 2-Mirror View), as a function of Congruent (embodiment) and Incongruent (control) visuo-tactile condition

			Mean (SD)
Ownership	1PP	Congruent visuo-tactile condition	4.97 (0.899)
		Incongruent visuo-tactile condition	3.16 (1.46)
	3PP	Congruent visuo-tactile condition	4.66 (1.25)
		Incongruent visuo-tactile condition	3.15 (1.30)
Self-location	1PP	Congruent visuo-tactile condition	5.26 (0.679)
		Incongruent visuo-tactile condition	3.28 (1.08)
	3PP	Congruent visuo-tactile condition	5.08 (0.944)
		Incongruent visuo-tactile condition	3.36 (1.07)
Agency	1PP	Congruent visuo-tactile condition	4.52 (1.67)
		Incongruent visuo-tactile condition	3.27 (1.68)
	3PP	Congruent visuo-tactile condition	4.17 (1.94)
		Incongruent visuo-tactile condition	2.92 (1.67)

visual perspective (Factor: Group 1 vs. Group 2), nor interaction effects (all $ps > 0.05$).

5.2 Self-objectification and susceptibility to the multisensory illusion

First, we computed the illusion susceptibility as recommended by Valzogher and colleagues (Valzolgher et al. 2018): [Incongruent(A) – Congruent values (S)] / [A + S].

Table 2 reports the Pearson correlation coefficients between individual differences in self-objectification and the difference between incongruent and congruent scores (i.e., illusion susceptibility). Results revealed that the OBC questionnaire's appearance on the control beliefs scale was positively correlated with self-location illusion susceptibility ($r = 0.338$, $P = 0.040$).

6 Discussion

Recently, 360-degree videos have gained popularity and a wide range of applications employ them, providing users with an immersive and realistic experience. Nevertheless, much more research is needed to provide scholars and clinicians with validated tools to use in both laboratory and clinical settings. To fill this gap, we aimed to preliminarily investigate whether it is feasible to use 360-degree videos to deliver a body-ownership illusion. In the current study, participants viewed a pre-recorded 360-degree video of a female body through a head-mounted display in either 1PP or mirror mode. The visuo-tactile stimulation was delivered either congruently (embodiment condition) or incongruently (control condition).

First, our findings provide preliminary evidence supporting the viability of the novel 360-degree video-based body ownership illusion in inducing a vivid illusion. The Embodiment Questionnaire results revealed indeed that in the congruent visuo-tactile condition (as compared to the control one), participants experienced a strong illusion in terms of body ownership, self-location, and agency, confirming our first goal. This means that individuals perceived the body of the young performer in the pre-recorded 360-degree videos as their own actual body, they felt "inside" it, and reported having control over it. Our results are interesting especially given the numerous benefits associated with the use of 360-degree videos (e.g., the same sense of presence and emotional response as a digital environment, but lower cost and no need for programming skills), supporting the idea that it is possible to elicit body illusions also through a more user-friendly technology medium.

Our second goal was to explore possible differences between a 1PP and a mirror view in eliciting embodiment, to shed light on the contrasting evidence currently existing on the topic. In terms of visual perspective, our findings indicated there was no difference in all sub-scales of the Embodiment Questionnaire between participants who experienced the illusion in 1PP and those who underwent a mirror perspective. This result is in line with previous VR studies, indicating that not only the 1PP could play an important role in eliciting the illusion (Matamala-Gomez et al. 2021). For instance, Preston and colleagues (Preston et al. 2015) investigated potential differences in feelings of ownership over a mannequin viewed from a 3PP through a mirror, a 3PP without a mirror, and a 1PP. What they found is that congruent stimulation over the participant's actual body and the mannequin body viewed in the mirror elicited strong feelings of ownership over the mannequin when compared to the incongruent (control) condition. Surprisingly, there were no differences in the perceived feeling of embodiment between viewing the mannequin in a mirror and in the 1PP. From a theoretical point of view, how can a vivid body ownership illusion be induced by a mirror perspective? According to Riva (2018), our bodily experience includes both an egocentric and an allocentric (mirror-view) perspective since it is constructed from infancy through the continuous integration of sensory and cultural inputs. It evolves through six different bodily representations. The first three body representations (Sentient Body, Spatial Body, and Active Body) are associated with the concept of body schema and include an *egocentric* perspective (the body as a reference to first-person experience). The last three body representations (Personal Body, Objectified Body, and Social Body) are concerned with reflective body knowledge and are required to store a "body memory" using an *allocentric* view (the body as an object of third-person experience), thus referring to the

Table 2 Pearsons' correlations result between illusion susceptibility indices (body ownership, self-location, and agency) and self-objectification subscales (body surveillance, body shame, appearance control beliefs)

	Illusion susceptibility—Body ownership	Illusion susceptibility—Self-location	Illusion susceptibility—Agency
Body surveillance	−0.177	−0.024	0.218
Body shame	−0.319	−0.246	0.210
Appearance control beliefs	0.234	0.338*	0.049

* $p < 0.05$

concept of body image. As a result, our findings supporting the use of 360° technology for bodily illusions could be exploited for the development of psychological novel interventions targeting conditions in which the "allocentric" memory of the body is altered (e.g., eating disorders) (Riva et al. 2014, 2017) or where there is an abnormal sense of self-location, and people undergo out-of-body experiences, assuming a 3PP and experiencing disembodiment: post-traumatic stress disorder with dissociative symptoms (Rabellino et al. 2018), depersonalization/derealization disorder, panic attacks (Sierra and David 2011), or dissociative symptoms in victims of sexual harassment (Adams-Clark et al. 2019). As already shown in the study of Serino et al. (2016), body illusions may be useful to support people with such difficulties, updating the stored (allocentric) representation of their bodies.

Finally, our last objective was to explore possible individual differences in the strength of the body illusion. Interestingly, our findings revealed that the degree of perceived control over body appearance was related to susceptibility to the illusion, specifically with the feelings of self-location. This result is consistent with the findings of Valzagher and colleagues (Valzolgher et al. 2018), who discovered that self-objectification was positively correlated with illusion susceptibility. However, it should be noted that our results were obtained from a sub-sample of participants, and future studies with a larger sample should be conducted to corroborate these initial findings obtained.

From a theoretical and clinical perspective, the abovementioned relation between illusion susceptibility and self-objectification is in line with previous studies which also showed that people who have a higher tendency to see themselves as "objects" have a less stable body representation, being more susceptible to external stimuli (Kaplan et al. 2014). From a clinical point of view, high self-objectification has been observed in people who suffer from eating disorders, depression, and body image concerns (e.g., body shame, social physique anxiety) (Dakanalis et al. 2017a, b; Peat and Muehlenkamp 2011; Riva et al. 2015). According to the objectification theory (Fredrickson and Roberts 1997; Riva et al. 2015), this mostly happens in women, in that they are culturally pushed to view their own bodies from an external perspective in several social contexts (i.e., due to sexual objectification). Because of this, women become less aware of their own internal circumstances (e.g., emotional signals or hunger) and focus on their outside look, developing self-objectification. A consistent body of research investigated the bodily self in individuals suffering from eating disorders by using body ownership illusions (Matamala-Gomez et al. 2021): 360-degree videos that target self-objectification to modify the "allocentric memory" of the body could therefore support women in switching their perspective from an external to a more internal view, promoting a less objectified perception of their body.

Despite these interesting results, however, our study is not without limitations. First, it should be noted that we used only a self-report measure of embodiment, while physiological measurements would have been useful for more implicit testing of the feasibility of this novel illusion. Second, the sample included only female participants, not allowing the generalization of the results. Future studies should hence focus on male participants to study embodiment processes in this population, too. In addition to this, as previously mentioned, our sample size was quite small: even if it could be considered appropriate for investigating the feasibility of this novel illusion among healthy participants, further research is needed to test our tool with a larger sample with the ultimate goal of further testing the feasibility of this novel tool and promoting the diffusion 360-degree video-based body illusions among the scientific and clinical community. Connected to this point, structured feasibility studies (Orsmond and Cohn 2015) are needed to assess participants' responses to the tool and evaluate whether our 360-degree video-based full-body ownership illusion can concretely be used in different settings with little expertise on VR and body illusions. After that, it will be possible to validate the potential clinical efficacy of this tool through properly powered, methodologically rigorous clinical trials evaluating both clinical outcomes and safety in target patients receiving our novel 360-degree video body-ownership illusion compared with appropriate control interventions. As already shown in previous literature (e.g., (Matamala-Gomez et al. 2021; Riva et al. 2021a, b; Sansoni et al. 2022a, b; Sansoni and Riva 2022), innovative body illusions may be useful to support people with a dysfunctional bodily experience. For this reason, future studies should employ 360° video-based body illusion paradigms in such clinical contexts to target a dysfunctional bodily experience and promote an update of the stored representation of their body.

6.1 Conclusion

Overall, our findings suggest the feasibility of this novel tool as immersive 360-degree video-based scenarios to deliver bodily illusions, allowing for versatile applications in embodiment research in both experimental and clinical settings. Embodiment in VR has already proven to be a promising tool in healthcare (e.g., (Matamala-Gomez et al. 2021; Riva et al. 2021a, b; Sansoni et al. 2022a, b; Sansoni and Riva 2022) and can be a key experience in the metaverse (Riva et al. 2021a, b; Riva and Wiederhold 2022). However, since the use of 360-degree videos is still limited, our 360-degree full-body illusion tool could be a promising instrument for facilitating the use of 360-degree body illusions in psychological research and clinical activity. Thanks to this tool, it would be therefore possible also for research teams or clinicians who do not have the expertise nor the economic availability necessary to develop digital VR-based environments to take advantage of the benefits associated with immersive technologies, body illusions, and VR.

Acknowledgements The work in this paper was partially supported by the project Arcadia VR - Assistenza e Riabilitazione del Comportamento Alimentare tramite Dispositivi basati sull'Intelligenza Artificiale e sulla Realtà Virtuale (Assistance and Rehabilitation of Eating Behavior through Devices Based on Artificial Intelligence and Virtual Reality) - MINISTERIAL DECREE DECEMBER 31, 2021 - INNOVATION AGREEMENTS and by the Italian Ministry of Health.

Funding Open access funding provided by Università degli Studi di Milano - Bicocca within the CRUI-CARE Agreement.

Data availability The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare they have no conflicts of interest.

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