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ORIGINAL ARTICLE

Self-conversation with a sporting celebrity enhances later physical exercise: an exploratory study

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Abstract
There is a world-wide deficit in physical exercise with many deleterious effects on health. Methods to enhance the uptake of physical exercise include digital applications and celebrity endorsements. Here we introduce a Virtual Reality (VR) self-conversation method combined with celebrity endorsement. Participants had a conversation with a virtual representation of a sporting celebrity to discuss ways of enhancing their exercise routine. However, they took both sides of the discussion—embodied as themselves and as the celebrity, swapping between the two bodies. A between groups experiment was carried out with three conditions: Video (n = 25), General (n = 20) and Self (n = 20). All participants watched a video of the celebrity athlete working out. Participants in the General condition additionally experienced the VR scenario with their own self representation as a general sex-matched virtual body. In the Self condition their virtual body was a likeness of themselves. The results showed that participants had improved in their exercise routines one week after the VR exposure. However, for women the improvement was superior with the General body, and for men with the Self body. The difference between the outcomes for males and females is probably due to the greater likelihood of body dissatisfaction amongst women. This is an exploratory study of a new technique with promising results.

Keywords Body ownership · Self-Conversation · Body swapping · Physical exercise · Virtual reality · Celebrities

1 Introduction

Well before covid-19, physical inactivity worldwide was already a pandemic (Kohl 3rd et al. 2012), further exacerbated by covid-19. The problem of insufficient physical activity increased between 2001 and 2016, particularly in high-income countries, with 81% of adolescents (aged 11–17) being insufficiently active (Guthold et al. 2020). A survey by Hoffman et al. (2022) found that 37% of U.S. adults aged 50–80 reported decreased physical activity during the pandemic. The lack of physical activity may contribute to immunological deficiencies in older people (Damiot et al. 2020) and is associated with various health issues: chronic diseases (Booth et al. 2012), obesity (Silveira et al. 2022; Swift et al. 2018), obesity and diabetes (Venables and Jeukendrup 2009), cardiovascular mortality (Abohashem et al. 2022), and mental health (Marconcin et al. 2022) including depression (Pearce et al. 2022).

The benefits of increased exercise include improved health, mental health, sleep, cardiovascular functioning, immune system functioning, and resilience to some cancers (Haseler and Haseler 2022). Remedies to enhance exercise include motivational strategies in gyms (Rodrigues et al. 2019), digital methods like smartphone applications (Negreiros et al. 2022), and exergames, which show promise for adolescents (Williams and Ayres 2020) and older people (Pacheco et al. 2020; Reis et al. 2019). Virtual reality-based exergames also demonstrate potential for improving physical and mental health (Costa et al. 2019; Pyae 2021).

Another approach to promote exercise is through celebrity sponsorship or 'fitspiration' on platforms like YouTube, Instagram, and TikTok. Trustworthiness and attractiveness of the influencers are crucial in inducing intentions to exercise

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(Durau et al. 2022). However, a survey by Sokolova and Perez (2021) suggested that social media influencers mainly succeed with those who already engage in physical exercise, while others watch for entertainment rather than inspiration.

We carried out an experimental study that combines virtual reality (VR) and celebrity influencers in a unique way. This study used a self-counselling approach, made possible through the use of a VR technique which enables embodiment of people in virtual bodies. VR delivered through a wide field-of-view, head-tracked stereo head-mounted display can place people in a separate reality leading to the strong illusion of being in the rendered place (Place Illusion) with the illusion that the virtual events are really occurring (Plausibility) (Bystrom et al. 1999; Sanchez-Vives and Slater 2005; Sheridan 1992; Slater 2009; Slater et al. 2022). Participants can be represented by life-sized virtual human bodies that visually substitute their own bodies. Hence, through real-time head-tracking, when participants look down towards themselves they will see a virtual body coincident with their (obscured) real body. Through real-time body tracking, as they move their own body the virtual body moves synchronously and correspondingly. Multisensory integration of proprioception (via body movement) synchronous with vision (seeing the virtual body move) typically leads to the illusion of body ownership over the virtual body, so that it feels as though it is the person's own body. This has been demonstrated multiple times, for example (Banakou and Slater 2014; Kokkinara and Slater 2014; Petkova and Ehrsson 2008; Slater et al. 2010), with the theory behind this discussed in (Blanke et al. 2015; Ehrsson 2020; Kilteni et al. 2012).

Since in VR it is possible to embody someone in a virtual body, it is possible to embody them sequentially in two different bodies, swapping between them, and while in one talking to the other, thus maintaining a self-conversation. This is the basis of the ConVRSelf paradigm (conversations with yourself in virtual reality) that we discuss in more detail in the next section.

2 Background and research questions

The ConVRSelf method is premised on Solomon's Paradox (Grossmann and Kross 2014), the idea is that we give better advice to a friend than to ourselves, so that when people are able to consider a problem from a third person perspective they are able to reach wiser conclusions. Solomon's Paradox forms part of self-distancing theory (Kross and Ayduk 2017). It has been applied to many situations—for example, coping with worries about a health crisis (Kross et al. 2017), dealing with criticism (Leitner et al. 2017), post-traumatic stress disorder (Wisco et al. 2015), emotional regulation (Moser et al. 2017) and depression (Hollar and Siegel 2020). Xu et al. (2022) argue that Solomon's Paradox is based on self-transcendence, whereby when, in general, people adopt a perspective that transcends the self (whether through following a cause or falling in love) there is dissolving of ego boundaries and a greater connectedness with others so that one's personal problems are seen in a wider perspective and can be addressed from the perspective of greater psychological distance. For example, a series of studies reported by Liberman et al. (2007) show that the greater the psychological distance the more that events and situations are represented by people at a higher level, i.e., in a more abstract way, and are thus more amenable to rationality beyond the boundaries of too much self-involvement.

The self-counselling technique in VR was initially used for personal problem solving by Osimo et al. (2015). Participants first embodied a virtual replica of themselves and explained a personal issue to a virtual counsellor representing Sigmund Freud. They then switched to inhabit the counsellor's avatar, witnessing their own look-alike virtual body presenting the problem, and then provided advice from the counsellor's embodied perspective. The conversation continued with repeated body-swapping. The counsellor's avatar either resembled Freud with synchronous movements, or with asynchronous movements, or was a replica of the participant's own body. Although all conditions yielded improvements in problem resolution, the most effective involved synchronous movements leading to a strong sense of body ownership while embodying the Freud avatar.

Slater et al. (2019) used the same paradigm, but the comparison was between talking with Freud as above (synchronous visuomotor feedback) or with a pre-animated Freud, without body swapping. This was to test whether simply talking about the personal problem would be sufficient to result in an improvement. The results showed that the body swapping was more effective compared with talking with the animated counsellor.

The potential advantage of ConVRSelf is that a perspective from outside of the self does not have to be imagined, but is concrete. From the perspective of the counsellor, participants see and hear a representation of themselves talking, with full body gestures, gaze direction, voice, and now that head-mounted displays have inbuilt eye tracking, direct accurate eye contact will be possible in the near future. Other applications of ConVRSelf have been concerned with patients suffering from obesity (Anastasiadou et al. 2024, 2023), and prisoners interacting with a future version of themselves (Van Gelder et al. 2022). However, here we do not deal with personal problems identified by the participants, but with enhancing exercise. LeBron James and Serena Williams were identified in a pre-experiment survey as appropriate people with whom to discuss this issue. Thus

this particular application of ConVRSelf could be viewed as a combination of the effects of self-distancing plus celebrity endorsement or 'fitspiration' as discussed in the Introduction.

Following from previous findings, in this study, we were interested in exploring two main issues: First, we wanted to investigate whether the ConVRSelf method, where participants have a self-conversation with a sports celebrity, would be successful in enhancing their exercise regime. Second, an issue not addressed in previous ConVRSelf studies, was whether or not the participant's own self-representation needs to actually look like the participant, or whether it can be a general virtual human body with some characteristics in common with the participant (such as age and sex). To answer these questions, we carried out an exploratory study consisting of an experiment with participants using ConVRSelf where the conversation was about their physical exercise, and the counsellors were virtual representations of celebrity sportspeople–either LeBron James (for men) or Serena Williams (for women).

3 Methods

In this section we present information about a pre-experimental survey that was carried out in order to elicit information about well-known sports celebrities who could be modelled and used as counsellors in the ConVRSelf setup. We then discuss the ethics approval, experimental design, information about participants and their recruitment. In order to measure the success or not of the intervention we used a standard instrument which is described next. We then discuss the VR hardware used and software implementation. This is followed by the experimental procedures. Finally in this section we discuss in some detail the statistical methods we use, which are Bayesian, and perhaps of less familiarity to some readers compared with standard statistical methods.

3.1 The pre-experiment survey

Some weeks prior to the study, we conducted a survey through social media amongst the population of potential participants. The survey had a single question: "With which world-renowned personality would you like to discuss your exercise regime?" Respondents could choose from seven different options, including Cristiano Ronaldo, Leo Messi, LeBron James, Michael Jordan, Serena Williams, Alex Morgan, and the option to add a different athlete of their choice. Additionally, we asked participants to specify their gender (male, female, or prefer not to say). Out of 101 responses, 68 were male and 33 were female. The results showed that LeBron James was the most popular choice with 32% of the votes, followed by Michael Jordan with 18%, Serena Williams with 12%, Leo Messi with 10%, and Cristiano Ronaldo and Alex Morgan with 4% each. The remaining options received less than 2% of the votes. This survey determined our choice of LeBron James (for male participants) and Serena Williams (for females) as the celebrity athletes to be used in the study.

In this survey, we chose celebrity athletes based on their global fame, recent achievements, and representation in various sports, aiming for a well-rounded view of athletic role models. The choices also aligned with the most popular sports in the country where the study took place: Soccer, Basketball, and Tennis. To balance capturing well-known figures and allowing personal preferences, we provided a mix of options and an 'Other' category. The selected athletes are widely recognised internationally, making our study relevant to a diverse audience.

3.2 Ethical approval

The main experiment was approved by the Reichman University School of Psychology Review Board, with ethical clearance number P_2021110. Participants gave written and informed consent and all methods were carried out in accordance with relevant guidelines and regulations. The images and data available for this paper do not identify any study participants.

3.3 Experimental design

The experimental design was between groups with three conditions, Video, General and Self. Those in the Video condition watched a motivational video about LeBron James (Basketballprosworkouts 2018) or Serena Williams (Pain and Gain 2018) that lasted 1 m 30 s. In the General condition, participants watched the video followed by a ConVRSelf session where their self-representation was a general virtual human, matched in declared gender, and approximately by age. Those in the Self condition, first watched the video, and then entered into a ConVRSelf session where their virtual body was designed to look like themselves. Participants interacted either with virtual representations of LeBron James or Serena Williams depending on their self-declared gender. The method is illustrated in Fig. 1 and Supplementary Movie S1 (https://youtu.be/HRVRKbpevLE). Table 1 shows the sample sizes, age and gender distributions.

Psychology and Communication students from Reichman University were recruited through advertisements on the experiment recruitment system of the Faculty of Psychology and posts on student Facebook groups. Exclusion criteria were people with epilepsy or who were pregnant.

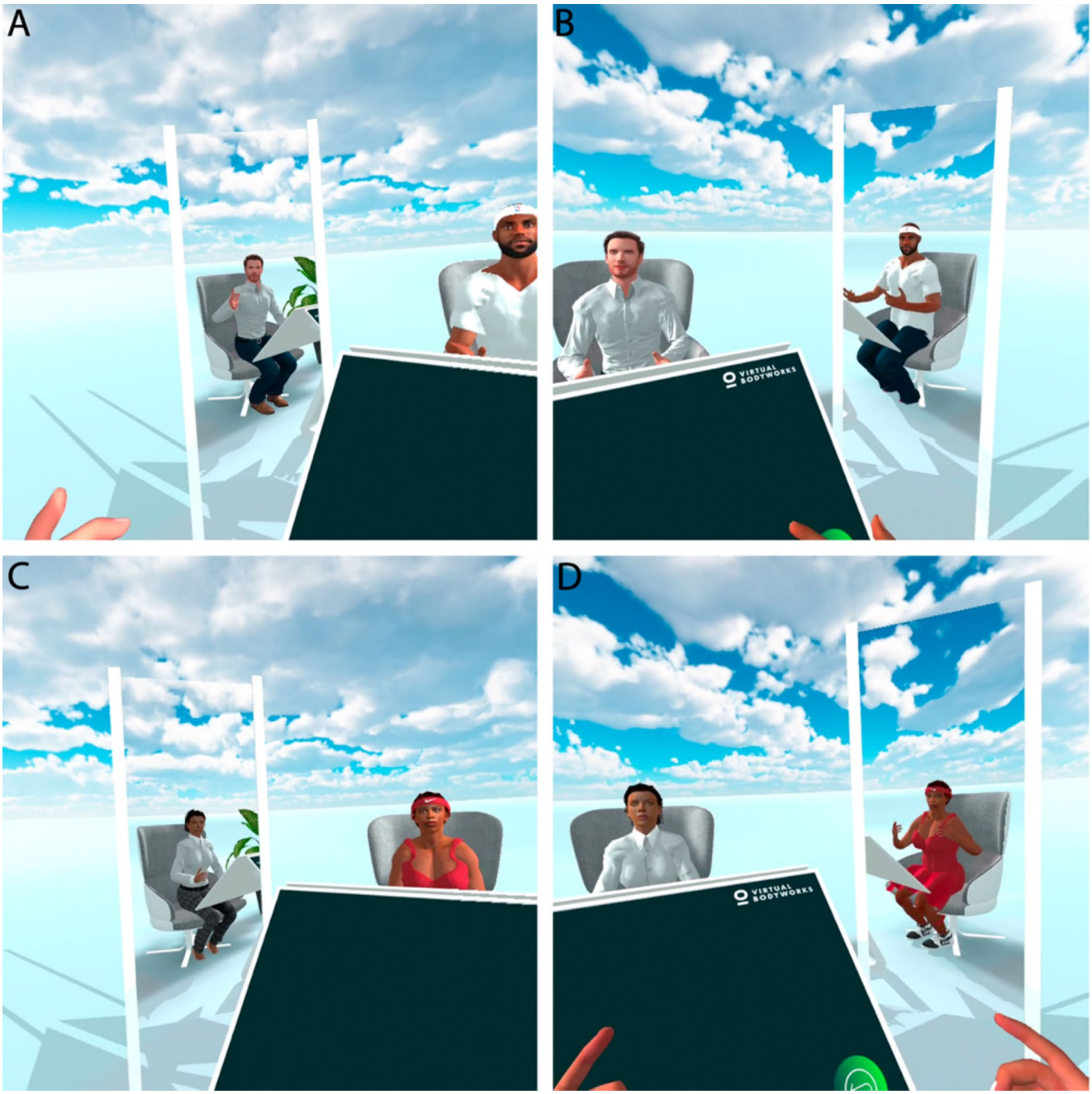

Fig. 1 Self conversation with a sports celebrity. **A** The participant is embodied and can see his reflection in the virtual mirror to the left. He is sitting opposite and converses with virtual LeBron James. **B** The participant is embodied as LeBron James, with a mirror reflection to the right, and sees and listens to his own self representation in front explaining the problem about exercise. **C** The participant is embodied and can see her reflection in the mirror to the left, sitting opposite virtual Serena Williams. **D** She is embodied as Serena Williams, seen in the mirror to the right, and can watch and listen to her self-representation, in front

Table 1 Distribution, age and gender of participants by condition

	Video	General	Self
N	25	20	20
Age (Mean±SD)	25.2±2.71	24.7±2.65	23.5±2.61
No. of women	16	12	15

Both Hebrew and English speakers were recruited for course credits. Further details about the participants are given in Supplementary Table S1. This was based on a questionnaire administered prior to the VR experience.

Participants in the experimental groups were asked to send a photo of their faces according to technical requirements (facing the camera directly, evenly lit-no shadow on

Table 2 Questionnaires on body ownership, agency and recognition

Variable Name	Question
Own body responses	
medown	When I was sitting in front of the counsellor: I felt that the virtual body I saw looking down was my own body
memirror	When I was sitting in front of the counsellor: I felt that the virtual body that I saw when I looked towards the mirror was my own body
mymovements	When I was sitting in front of the counsellor: I felt that the movements of the virtual body were caused by my own movements
recognise	Did you recognize yourself in the virtual body that was sitting in front of the counsellor?
Counsellor (celebrity) body responses	
cdown	When I was in the counsellor's body: although the virtual body did not look like me physically, I felt that the virtual body that I saw looking down was my own body
cmirror	When I was in the counsellor's body: I felt that the virtual body that I saw when I looked towards the mirror was my own body
cmovements	When I was in the counsellor's body: I felt that the movements of the virtual body were caused by my own movements
cresemble	To what extent did the counsellor avatar resemble in physical appearance Serena/LeBron?

All scales are 1 to 8 where 1 means strong disagreement and 8 means strong agreement

one half of the face, no smile or a smile without teeth, no hair should cover the face). The experimenters prepared the personalized VR scenario with a look-alike avatar of the participants in advance.

Next we return to the response variables used to evaluate the preconditions for and the effect of the ConVRSelf exposure.

3.4 Questionnaires on body ownership, agency and recognition

The questions that were asked at the end of the ConVRSelf session (for those in the General and Self groups, but not those in the Video condition) are shown in Table 2. The questions 'down', 'mirror' refer to the degree of body ownership in the self body (prefixed by 'me') and the counsellor body (prefixed by 'c'). The questions 'movements' refer to how much participants felt that the movements of their virtual body reflected their own movements. These were also a check on how well the body tracking functioned, since it was programmed that the movements of the virtual body were actually based on real body movements. The questions 'recognise' and 'cresemble' refer to how much the virtual body of the self was recognised as the self and the counsellor body represented the corresponding celebrity.

Table 3 The Godin Leisure time exercise questionnaire

During a typical 7-Day period (a week), how many times on the average do you do the following kinds of exercise for more than 15 min during your free time (write on each line the appropriate number)	
Mild	Mild/light exercise (minimal effort) (e.g., yoga, archery, fishing from riverbank, bowling, horseshoes, golf, snow-mobil, easy walking)
Moderate	Moderate exercise (not exhausting) (e.g., fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, popular and folk dancing)
Strenuous	Strenuous exercise (heart beats rapidly) (e.g., running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long-distance bicycling)

The scores are calculated from Eq. (1)

The ConVRSelf method requires participants to experience subjective body ownership with respect to their own and the body of the athlete with whom they interacted, and that those in the Self condition recognise their own body representation as themselves, and in all conditions that they recognise the athletes. Further, we needed to check that there were no systematic differences with respect to body ownership and recognition between the General and Self conditions. We are not making inferences about these to the general population from which the sample was drawn, it is only important to check that this particular sample did experience body ownership and self-recognition and that these did not vary by condition. Hence we only present descriptive results for the questions of Table 2. The 'movements' questions of Table 2 are a check on how well the body tracking worked, since the program was designed so that in fact the movements of the currently embodied virtual body would be caused by the movements of the participant.

3.5 Main response variable: the Godin Leisure-time exercise questionnaire

Participants were asked to rate their levels of physical exercise one week before ('pre') and one week after ('post') their VR exposure using the Godin Leisure-Time Exercise questionnaire (Amireault et al. 2015; Godin and Shephard 1985). This asks participants to assess the number of times per week they had engaged in mild, moderate or strenuous exercise, as shown in Table 3. The questionnaire is scored as:

$$score = 9 \times strenuous + 5 \times moderate + 3 \times mild \quad (1)$$

The scores are interpreted as:

- Active (Substantial benefits): $score \geq 24$

- Moderately active (Some benefits): $14 \leq score \leq 23$
- Insufficiently active (Less substantial or low benefits): $score < 14$

3.6 Materials

We used the Meta Quest 1 head-mounted display working standalone (i.e., without being connected to a computer). This has 1600 × 1440 resolution per eye and weighs 571 g. It has full 6 degrees of freedom head tracking, and the participant's hand movements are tracked in 6 degrees of freedom using separate hand-held controllers. The Oculus Quest 1 uses the Qualcomm Snapdragon 835 processor for processing so that it does not need to be connected to an external computer. Data generated during the execution of a program on the Quest 1 can be stored on its internal flash storage. Hence programs can run natively and data generated can be stored on the Quest itself without the need for any connection to an external computer.

The VR program was developed in Unity3D 2020.3. The participant's virtual body representation was created using an automated method from a photograph of the participant's face by using Reallusion's Character Creator (www.reallusion.com/character-creator/) HeadShot Plugin (www.reallusion.com/character-creator/headshot), such that the virtual character has a strong resemblance to the person's face. The participant's body shape parameters were estimated by a Convolutional Neural Network (CNN) similar to the one described in (Alvarez de la Campa Crespo and Spanlang 2021). The output from Character Creator is a virtual character in fbx file format that includes a skeleton for body animation and blendshapes to perform facial expressions. An avatar pipeline was created that converts the fbx from Character Creator to a Unity3D asset bundle in binary format, with materials optimised for visualisation on the mobile VR headset. The resulting asset bundle that describes the participant's virtual body is loaded at runtime by the VR system. Through inverse kinematics techniques (www.root-motion.com/finalikdox/html/index.html), hands, arms and upper body movements of the participants could be inferred from the VR tracking system's real-time tracking data and mapped to their virtual representation to give them a sense of agency over their virtual body. The virtual environment included two virtual mirrors through which the participants could observe their virtual body either from their self or the celebrity's perspective. Participants could see their virtual representation when looking down towards their body and by looking at their virtual body in the virtual mirror.

The audio of the participant's voice was captured through a microphone and in real-time mapped to mouth movements by using a lipsync module (http://developer.oculus.com/documentation/unity/audio-ovrlipsync-unity/) to further enhance the participant's sense of agency over their virtual body. The voices of the participants were recorded, and then disguised and replayed when they switched to the athlete's virtual body. In order to accomplish this we used the pitch shifting effect of the Unity AudioMixer to reduce the pitch of the voice by 2 semitones. The pitch shifting effect has a pitch change parameter with a possible range between 0.5 and 2.0 which represents a change of pitch from one Octave deeper to one Octave higher than the original voice. By default this value is set to 1.0 which represents no pitch change. To achieve a pitch change of 2 semitones lower we set the pitch shift value to $1/2^{n/12}$ with n=2 which is approximately 0.892. The pitch shifting process keeps the original length of the audio.

3.7 Procedures

At their initial meeting with the experimenter participants were provided with written and verbal information about the experimental procedure and signed the consent form if they agreed to participate. They were asked to complete a questionnaire about their exercise routine (Godin and Shephard 1985) and then watched a video of the athlete working out for 1:30 min (LeBron James or Serena Williams, gender matched). Next, those participants in the General or Self conditions were asked to sit on a chair in front of a desk. They were given the following instructions: "When you start the VR session, you will meet an athlete, and you will have a consulting session, like with a personal trainer or a counsellor, where the goal is for you to improve your exercise routine. Describe your exercise routine and the improvement you want to achieve".

Participants were told that they would be embodied in a virtual body. The experimenter showed them the hand controllers and told them that they would need to press the central button in the virtual environment each time they start or finish speaking. Participants then donned the Quest. When embodied in each virtual body (their own and one of the athletes) for the first time, they were instructed by a pre-recorded voice to carry out certain body movements, such as raising their arms or waving, while looking towards the virtual mirror and also down towards themselves. This embodiment period lasted 30 s.

After the embodiment period, participants explained to the virtual athlete counsellor their exercise routine, and how they wanted to improve it, and then pressed the button to switch bodies when they had finished speaking. After pressing the button, the participants would be embodied in the athlete's body, and from that perspective see and hear their virtual body sitting across the table ask about improving their exercise routine. Then while still in the athlete's body, they could provide a response to themselves. Upon

completing this, they would again press the button to switch body, return to their own body representation, and then see and hear the athlete's response (i.e., their response) in a disguised voice. After replying to the athlete, participants would again press the button to be in the athlete's body. This conversation could continue as long as they wanted, although they were told that they should do a minimum of 3 body swaps. No upper limit was imposed on the duration or number of body swaps to avoid the possibility of disrupting an important moment of the self-conversation. See Supplementary Movie S1 for an illustration of the whole process in the VR.

At the end of the VR session, the Quest and the controllers were removed, and the participants were asked to complete questionnaires on the computer monitor. The experimenters reminded the participants that they would receive their course credits after returning the post-questionnaires, which would be sent to them one week after the VR session, by email.

3.8 Statistical methods

The main response variable is the score of the physical exercise questionnaire of Table 3. Here interest focuses on how these scores vary with condition (Video, General, Self), and whether there are differences with respect to gender. The response variable is postscore taken one week after the VR exposure, and prescore, taken one week before the exposure, is included as a covariate. We use a standard analysis of variance model, expressing the response variable as an affine combination of main and interaction effects.

Let y_i be the ith observation on postscore and x_i on prescore, $i = 1, 2, \ldots, n$. Typically we examine how the mean of the response varies with an affine function of the independent and explanatory variables. This function of independent and explanatory variables is referred to as the 'linear predictor'. Then the linear predictor for the expected value of y_i(mean, μ_i) is of the form:

$$\text{Condition} + \text{Gender} + \text{Condition} \times \text{Gender} + \text{prescore} + \text{Condition} \times \text{prescore}$$

and formally:

$$\mu_i = \mu + \alpha_{c[i]} + \beta_{g[i]} + \gamma_{c[i],g[i]} + \lambda x_i + \theta_{c[i]} x_i \qquad (2)$$

where, for the ith individual

$$c[i] = \begin{cases} 1, & Video \\ 2, & General \\ 3, & Self \end{cases}$$

$$g[i] = \begin{cases} 1, & Male \\ 2, & Female \end{cases}$$

The parameter μ is the general mean. The parameters α, β are the main effects of condition and gender respectively, and γ is the interaction effect. The parameter λ is the main effect of the covariate (prescore). θ allows for interaction between condition and the covariate. The values of the parameters corresponding to Video are all set to 0, so that the model expresses contrasts with respect to Video, i.e.,

$$\alpha_1 = \beta_1 = \gamma_{1,j} = \gamma_{i,1} = \theta_1 = 0$$
$$i = 1,\ 2,\ 3$$

Hence the Video condition corresponds to: $\mu_i = \mu + \lambda x_i$ for males and $\mu_i = \mu + \lambda x_i + \beta_2$ for females.

This is the standard model corresponding to a two-way ANOVA with a covariate. However, since there are outliers (see Sect. 3.3), it would be inappropriate to use a normal distribution for the y_i, and instead we use the Student t distribution, since with low degrees of freedom the distribution has high dispersion and can accommodate outliers. Hence the model is:

$$y_i \sim Student\_t\,(\upsilon, \mu_i, \sigma) \quad i = 1, 2, \ldots, n \qquad (3)$$

where $\upsilon > 0$ is the degrees of freedom parameter and $\sigma > 0$ is the scale parameter.

We did include an additional interaction term in the model for Gender × prescore but this did not contribute at all to the model fit or alter the findings and hence was excluded for succinctness. Similarly we did include age as a covariate but found no age effect.

We use the Bayesian method to make inferences about the parameters of the model. This involves choosing prior distributions for each parameter, which are updated by the data to produce posterior distributions. We can compute any probabilities of interest from the posterior distributions. The model includes all response variables simultaneously, so there is no issue with multiple comparisons (which results in problems in the interpretation of significance levels in classical null hypothesis testing). In this model all data is used to make all inferences, there are not separate analyses for the different conditions nor gender. Bayesian analysis provides a framework for making probability statements about our parameters of interest, offering a more intuitive understanding of the results in the context of our research questions, rather than simply quoting P values and rejecting or not a null hypothesis. Instead we can compare, for example, posterior credible intervals with the priors, and see at a glance the impact of the data.

The prior distributions for the parameters α, β, γ, θ are taken as normal with a mean of 0 and a standard deviation (SD) of 20. This choice is based on (Lemoine 2019) providing priors that aim to provide enough flexibility without

overly influencing the posterior distributions. Such priors are referred to as 'weakly informative', ensuring that the model is not overly constrained by prior beliefs, yet are still proper probability distributions. A SD that is too large can lead to over-dispersed priors, while a SD that is too small can overly constrain the parameter estimates (Gelman et al. 2008; Lemoine 2019). A SD of 20 was chosen as it provides a balance between these extremes. We also tested different values for the SD, but found that variations around this choice resulted in almost identical outcomes, thus confirming the robustness of our results to this prior specification. The prior equal-interval 95% credible intervals for these parameters are from −40 to 40.

The parameters υ and σ are necessarily positive and therefore the prior distributions must be defined over the positive real line. Following Juárez and Steel (2010), we used a Gamma distribution with a shape parameter of 2 and a rate parameter of 0.1, yielding prior 95% credible intervals of 2.4 to 55.7. The mean of this distribution is 20 and variance 200 (standard deviation 14.14). Again this is a distribution with wide dispersion, but is, nevertheless, a proper probability distribution that allows the data to dominate the posteriors.

The model was evaluated using the Stan (https://mc-stan.org/) probabilistic programming language (Carpenter et al. 2016) with R studio (www.rstudio.com) using the rstan interface (https://mc-stan.org/users/interfaces/rstan/). Stan uses a Markov Chain Monte Carlo (MCMC) method to compute the posterior distributions. It does this in parallel over multiple computational threads or chains. It is conventional to use 4 chains with at least 2000 iterations on each chain. This means that 2000 observations on each of the 4 simulated distributions are obtained that provide the posterior distributions. Stan then mixes the results of each chain together, if all these simulations are compatible with one another. We used 4 chains with 2000 iterations per chain. Graphs and Tables were produced using Stata 16.1 (www.stata.com). See Supplementary Data S1 for the complete data and Stan program.

4 Results

4.1 Duration and number of body swaps

The duration of the sessions ranged between 10 and 15 min. The number of swaps had been stored on the head-mounted displays used for the experiment, but a software update unfortunately deleted most of the results of the numbers of swaps, so that only 14 cases are left. The number of swaps recorded ranged between 4 and 10, with the median 6 and interquartile range 6–8.

4.2 Body ownership, agency and recognition questionnaires

The box plots for results of the questions shown in Table 2 are shown in Fig. 2. The levels of body ownership do not differ substantially between the lookalike self body, the general body and the body of the celebrity counsellors. The 'movements' scores are high, indicating that the body tracking and mapping the movements to the virtual body worked well. Those in the Self condition recognised their virtual body as themselves more than those in the General condition, and the counsellor virtual bodies were judged to resemble the corresponding celebrities. Figure 2C suggests that females were more inclined to recognise the general body as themselves, but there was not much difference for the self body between males and females.

4.3 Physical exercise–descriptive

The basic results for the prescore and postscore variables for the Godin Leisure Time Exercise Questionnaire are shown in Table 4. Superficially the results suggest only a small effect size for the General condition. However, Fig. 3A shows substantial differences between the conditions when gender is taken into account. In particular the greatest effect is for males in the Self condition. Figure 3B shows that the relationship between postscore and prescore includes outliers, most especially one (female) participant who had a pre score of 84 and a postscore of 18. These outliers are the reason for using the Student t distribution in the model (Eq. 3).

4.4 Results of the statistical model

The summaries of the posterior distributions of the parameters are shown in Table 5. Note that the degrees of freedom parameter υ has a 95% credible interval between 1.42 and 7.93, supporting the decision to use the Student t distribution (for normality υ should be at least 30). Self has a high effect size (the mean of the distribution of the α_3 parameter) and the probability of being positive is 0.952. However, the interaction term Self × Female has a large (negative) effect size and a high probability of being negative (1 − 0.06 = 0.94). This supports the findings from Fig. 3A, that for males the Self condition fosters greater exercise than Video or General, but not for females.

The coefficient for interaction term Gender × prescore has 95% credible interval −0.32 to 0.25, and the point estimate of the coefficient is 0.02. The probability of the parameter being positive is just 0.47. Therefore, we have not included this term in the model.

The predicted posterior distributions for postscore, with prescore set at its median level (which is 23), are shown in

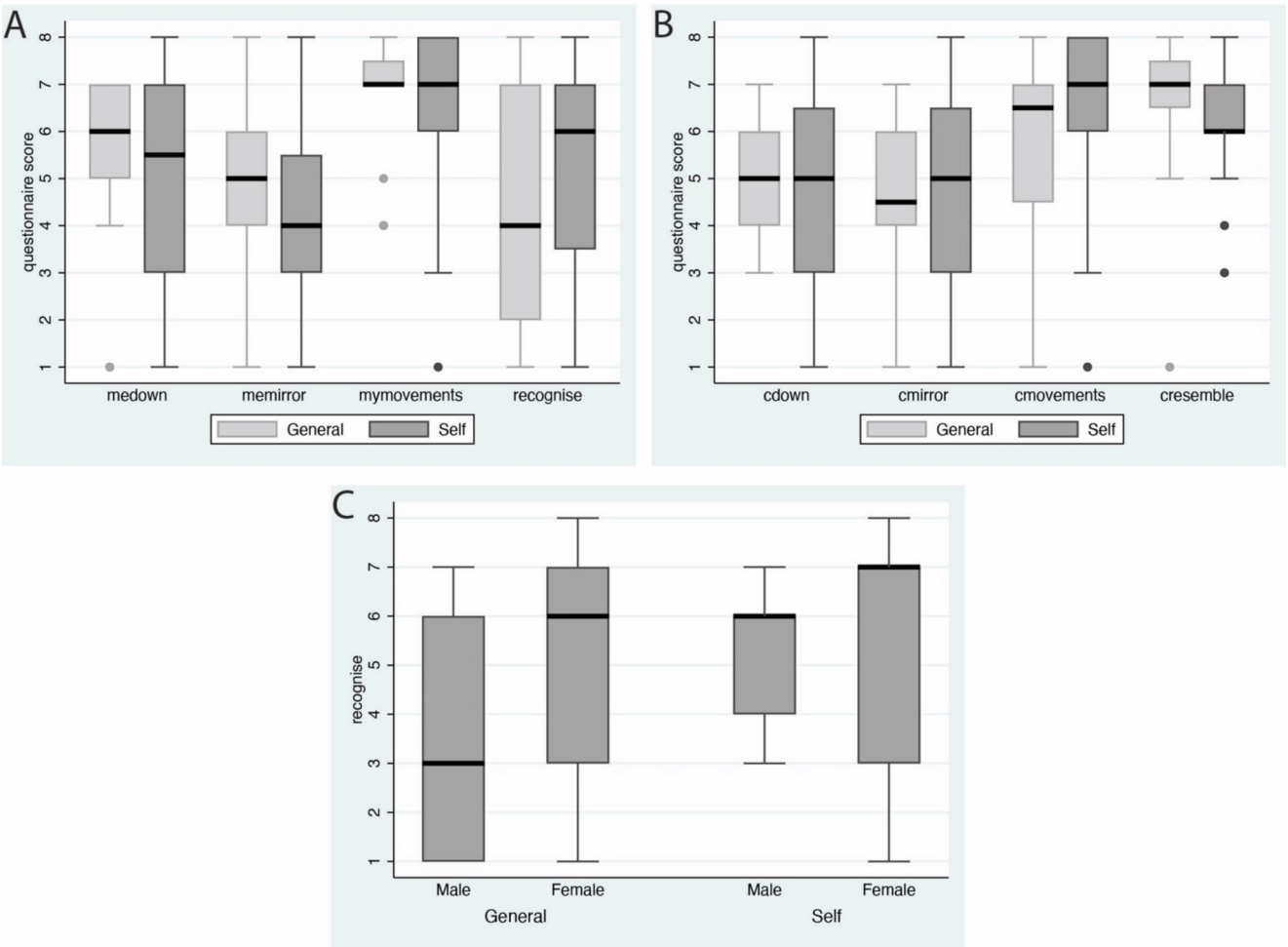

Fig. 2 Box plots for body ownership, agency and recognition by condition. **A** Relating to the self body representation **B** Relating to the counsellor body. **C** The recognise question by condition and gender. The thick horizontal lines are medians, the boxes interquartile ranges (IQR) and the whiskers range from max (min value, lower quartile − 1.5 × IQR) to min(max value, upper quartile + 1.5 × IQR). Points outside this range are shown individually

Table 4 The Godin Leisure time exercise questionnaire and mean ± S.E. scores by condition and Cohen's d for the difference between postscore and prescore

Condition	Prescore	Postscore	Cohen's d
Video	22.5 ± 2.89	23.4 ± 3.90	0.05
General	25.6 ± 3.56	29.2 ± 4.59	0.20
Self	29.5 ± 5.86	30.1 ± 5.81	0.02

The scores are calculated from Eq. (1). (Hedge's g effect sizes, that allow for small sample sizes, give the same results as Cohen's d)

Fig. 4 for males and females. These posteriors are produced from Eq. (2) using the posterior distributions of the parameters. For males the Self condition results in greater probability of high scores for those in the Self condition compared to General and Video. For females the Self condition has the lowest probable scores.

Using these posterior distributions we can find the probabilities of postscore being greater than the median prescore, i.e., an improvement over the median. These are shown in Table 6. For males it is clear that the most successful outcomes in terms of enhancing physical exercise is the Self condition, but for females the General condition produces the best outcomes.

4.5 Goodness of fit

The statistical model has a good fit to the data. The correlation between the means of the predicted posterior distributions of postscore with the observed values of postscore is 0.813 (95% confidence interval 0.711 to 0.882). The R-hat statistic is a diagnostic metric used to assess the convergence of MCMC sampling in Bayesian models implemented with Stan. An R-hat of 1 indicates that the 4 separate simulation chains that were used converged and mixed, as explained at the end of Sect. 3.8. All R-hat values were equal to 1.

To test goodness of fit we also used the 'leave one out' (loo) method (Vehtari et al. 2017). Leave-one-out cross-validation

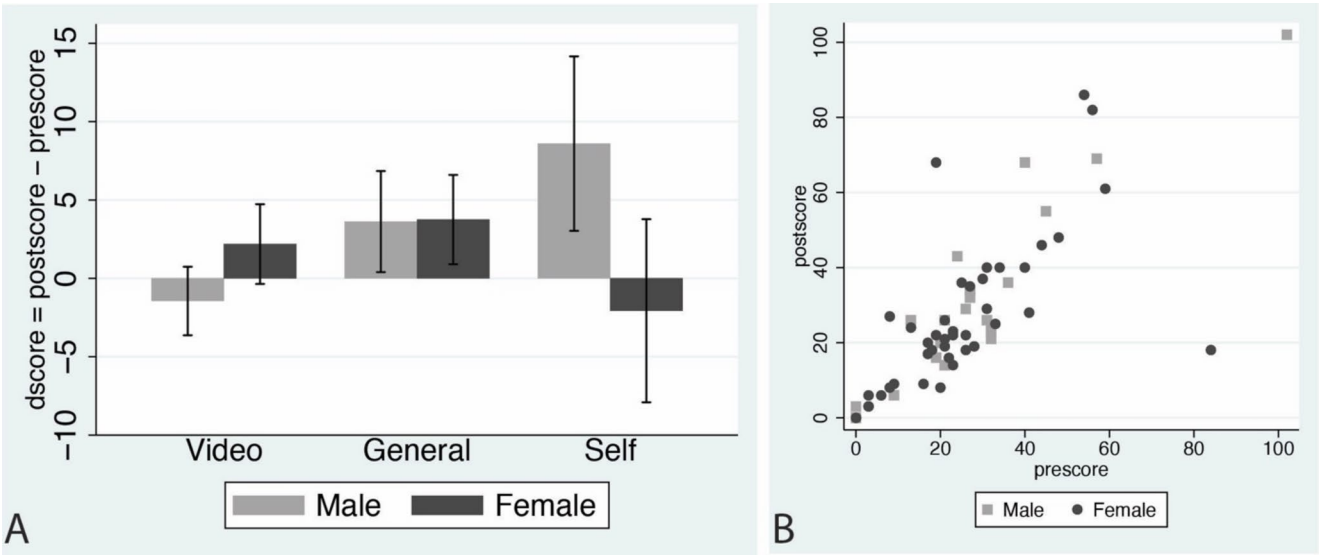

Fig. 3 Relationship between postscore, prescore and gender. **A** Bar chart showing the means and standard errors of the difference *postscore–prescore* for the three conditions and gender. **B** Scatter diagram of *postscore* on *prescore*. The lighter shading is for males and the darker for females

Table 5 Summaries of the posterior distributions of the model parameters showing the posterior means, standard deviations and 95% credible intervals

Parameter	Coefficient for	Mean	SD	95% C.I		Prob > 0
μ		−2.03	3.48	−9.31	4.55	0.279
α_2	General	1.87	5.47	−8.87	12.88	0.634
α_3	Self	10.56	6.54	−2.26	23.76	0.952
β_2	Female	1.71	3.23	−4.64	8.07	0.705
γ_{22}	General × Female	−2.37	5.07	−12.33	7.67	0.317
γ_{32}	Self × Female	−9.23	5.91	−21.08	2.28	0.060
λ	Prescore	1.05	0.13	0.80	1.32	1.000
θ_2	General × Prescore	0.07	0.19	−0.30	0.44	0.662
θ_3	Self × Prescore	−0.14	0.17	−0.47	0.17	0.207
υ	d.f	3.33	1.86	1.42	7.93	
σ	Scale	7.14	1.38	4.72	10.13	

Prob > 0 is the probability that the parameter is > 0

is a model evaluation technique in which a single observation is left out of the dataset, and the model is fit on the remaining data. The prediction error for the left-out observation is then computed. This process is repeated for all observations in the dataset, and the results are used to estimate the model's out-of-sample predictive performance. This provides an 'out-of-sample' estimate of fit rather than in-sample as in the case of the correlation. Pareto k estimates derived from this analysis refer to a diagnostic measure used to assess the validity of the leave-one-out cross-validation. The Pareto k statistic helps identify observations that may have a significant impact on the model's predictive performance and could potentially be influential or poorly fit by the model. The Pareto k statistic is calculated for each observation as part of this process. A high Pareto k value (greater than 0.7) indicates that the observation may have an undue influence on the model or that the model may not fit the observation well. We found Pareto k < 0.7 for all observations, and the Pareto k values are shown in Supplementary Table S2.

5 Discussion

In this study participants had a self-conversation about their physical activity with a virtual representation of a celebrity sportsperson (LeBron James for males and Serena Williams for females). To represent themselves they were embodied in a virtual body that had a likeness of their own body, or in a general sex-matched body also matched roughly for age. They engaged in embodied perspective taking from their own body representation and that of the celebrity body, maintaining a conversation between the two bodies. A control group only watched a video of the celebrities. Comparing their physical exercise from one week after their

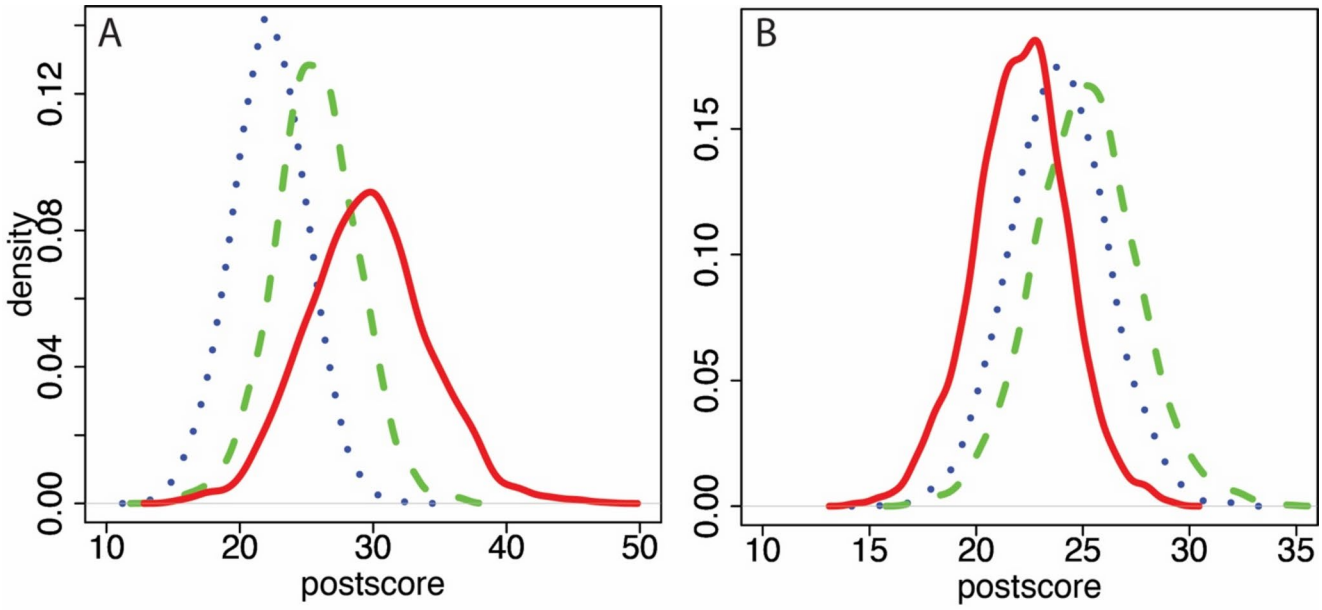

Fig. 4 Predicted posterior distributions for postscore for prescore at its median level (23) **A** Males **B** Females. The red solid curves are for the self condition, green dashed for general and blue dotted for video

Table 6 Posterior probabilities of postscore > median (prescore) by condition and gender

	Males	Females
Video	0.384	0.657
General	0.812	0.800
Self	0.929	0.310

exposure to one week before, males improved more with their own body likeness, and females with the general body, and the general and look-alike body both resulted in greater probability of improvement than the video only condition.

This approach is premised on body ownership, and the results found in our experiment are in line with previous results, for example (Banakou et al. 2013; Banakou and Slater 2014; Slater et al. 2010). It can be seen that even those with the general body had high levels of ownership (Fig. 2) (medown and cdown) supporting the notion that the driving force of the body ownership illusion is multisensory integration rather than the particular details of the body (Blanke et al. 2015). For example, high levels of body ownership have been obtained when embodying adults in a child body (Banakou et al. 2013), and numerous examples of 'white' people in a darker skinned body (Banakou et al. 2016; Maister et al. 2013; Peck et al. 2013) with an overview in Maister et al. (2015) and aneural network based explanatory model in (Bedder et al. 2019). In all of these examples, the virtual body was not designed to look like the real body. However, the scores on the 'mirror' questions are generally lower than have been obtained in other experiments (e.g., Supplementary Figure C in Slater et al. (2018)).

Although the ConVRSelf method had better results than the video only method, the effect is dependent on the avatar's appearance. For women, the general body, and for men the self lookalike body, were more effective in increasing the probability of subsequent greater exercise. This points to a possible different import of the body appearance between men and women. An fMRI study by Burke et al. (2019) found that for women their own body is more salient compared with men who focus more on the bodies of others rather than their own. In a study by Neyret et al. (2020) participants saw three different virtual body representations in VR: a body based on their own estimates of their body shape, their ideal body shape, and their actual body shape derived from tracking data. They saw these bodies from a first person perspective (i.e., embodied) or from a third person perspective. Female participants evaluated their own body negatively when they saw it from first person perspective but not when they saw it from third person perspective as if it were the body of someone else. This was not observed for males.

Similarly, amongst a large non-clinical sample of college students body image disturbance was found to be greater amongst women than men using the Body Image Disturbance Questionnaire (BIDQ) (Cash et al. 2004). The BIDQ measures not only dissatisfaction with perceived aspects of one's body appearance (weight, height, facial characteristics) but also how much this affects overall psychosocial functioning and the quality of life. A study by Quittkat et al. (2019) also found body dissatisfaction was greater amongst women than men, and that this was invariant to age: over

time the body dissatisfaction of men decreases, but not for women. Lin et al. (2021) introduced a new 'body talk scale' and found that men engaged in more positive body talk than women. Therefore it is possible that our findings may be due to this difference. However, from the embodied perspective of the athlete, i.e., as the counsellor, when they were looking at their self-body avatar, participants focussed on the question concerning how they could improve their exercise routine, and none of them made any comments that suggested any negative body talk about their own appearance. Their talk was concerned with schedule adjustments, motivation and will, but not about their appearance. Moreover, the differences between the results of males and females in the exercise study are unlikely to be because of different levels of recognition of the virtual bodies as their own. Figure 2C shows that women were, on the whole, only slightly more likely to recognise the body as themselves than males. Therefore it is more likely that recognising themselves led to greater dissatisfaction amongst women, and correspondingly greater stress. Learning in this condition is unlikely to take place since negative feelings result in cognitive inhibition and hinder attention, memory, and learning (Vogel and Schwabe 2016).

The main limitation of the study is the smaller number of men in each of the three groups compared to the women. However, the Bayesian method, starting from weakly informative priors, updates the posterior distributions with each data point, and the results are valid with respect to the amount of data collected. It is possible that with more data the posterior distributions might change radically, but as they stand the differences obtained are quite clear. Nevertheless, it is important to note that the population from which we drew the sample was limited to university students in their early 20 s, with about 29% international, and therefore we cannot generalise beyond such a population.

Since we found these differences in results between men and women, likely to be the result of greater body dissatisfaction amongst women compared with men, it would have been useful to include a measure such as the body image disturbance questionnaire mentioned earlier (Cash et al. 2004). The explanation for the gender difference remains a hypothesis for future studies.

It is possible that different levels of prior knowledge of the celebrity athletes amongst participants may have influenced the results. However, there is no reason to suppose that there would have been any systematic differences with respect to those assigned to the experimental conditions. Moreover, all the participants saw the video of the celebrities in all conditions prior to the VR exposure or the collection of any data. The videos showed the athletes' abilities and level. In addition, the fact that those athletes were ranked highly in the survey we carried out before the experiment implies that they were known within this population of students and volunteers.

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Author contributions Mel Slater, Doron Friedman and Bernhard Spanlang contributed to the study conception and design. Elena Álvarez de la Campa Crespo and Bernhard Spanlang implemented the scenario. Carrying out of the experiment, data collection and preparation was performed by Daniel Levy. Statistical analysis of the data and first draft of the paper was by Mel Slater. All authors contributed to revisions of the manuscript. All authors read and approved the final manuscript.

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Data availability The full data and programs for analysis are available via Supplementary Data S1.

Declarations

Conflict of interest BS, MS are founders of Virtual Bodyworks, and BS and EACC are employees. ConVRSelf is used as part of the suit of applications as products of Virtual Bodyworks in the field of diversity, equity and inclusion. All other authors declare no competing interests.

References

Abohashem S, Sayed A, Aldosoky W, Dar T, Abbasi T (2022) Impact of physical inactivity on cardiovascular mortality in united states: county-level analysis from 2011 to 2019. Eur J Prev Cardiol 29(Supplement_1):zwac56. https://doi.org/10.1093/eurjpc/zwac056.124

Alvarez de la Campa Crespo E, Spanlang B (2021) A deep CNN model for inferring 3D human body shapes using front and side images. In: Proceedings of 3DBODY.TECH 2021–12th international

conferences and exhibition on 3D body scanning and processing technologies, vol 32. https://doi.org/10.15221/21.32

Amireault S, Godin G, Lacombe J, Sabiston CM (2015) The use of the Godin-Shephard Leisure-time physical activity questionnaire in oncology research: a systematic review. BMC Med Res Methodol 15(60):1–11. https://doi.org/10.1186/s12874-015-0045-7

Anastasiadou D, Herrero P, Sebastián V-D, Garcia-Royo P, Spanlang B, Álvarez de la Campa E, Slater M, Ciudin A, Comas M, Ramos-Quiroga JA (2023) Virtual self-conversation using motivational interviewing techniques to promote healthy eating and physical activity: a usability study. Front Psych 14:308. https://doi.org/10.3389/fpsyt.2023.999656

Anastasiadou D, Herrero P, Garcia-Royo P, Vázquez-De Sebastián J, Slater M, Spanlang B, Álvarez de la Campa E, Ciudin A, Comas M, Ramos-Quiroga JA (2024) Assessing the clinical efficacy of a virtual reality tool for the treatment of obesity: randomized controlled trial. J Med Internet Res 26:e51558

Banakou D, Slater M (2014) Body ownership causes illusory self-attribution of speaking and influences subsequent real speaking. PNAS 111(49):17678–17683. https://doi.org/10.1073/pnas.1414936111

Banakou D, Groten R, Slater M (2013) Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. PNAS 110:12846–12851. https://doi.org/10.1073/pnas.1306779110

Banakou D, Hanumanthu PD, Slater M (2016) Virtual embodiment of white people in a black virtual body leads to a sustained reduction in their implicit racial bias. Front Hum Neurosci 10:601. https://doi.org/10.3389/fnhum.2016.00601

Basketballprosworkouts (2018) Lebron James 'long live the king' Motivational workout. YouTube. https://www.youtube.com/watch?v=FZTtcfm5NZE&ab_channel=basketballprosworkouts

Bedder RL, Bush D, Banakou D, Peck T, Slater M, Burgess N (2019) A mechanistic account of bodily resonance and implicit bias. Cognition 184:1–10. https://doi.org/10.1016/j.cognition.2018.11.010

Blanke O, Slater M, Serino A (2015) Behavioral, neural, and computational principles of bodily self-consciousness. Neuron 88(1):145–166. https://doi.org/10.1016/j.neuron.2015.09.029

Booth FW, Roberts CK, Laye MJ (2012) Lack of exercise is a major cause of chronic diseases. Compr Physiol 2(2):1143–1211. https://doi.org/10.1002/cphy.c110025

Burke SM, Majid DA, Manzouri AH, Moody T, Feusner JD, Savic I (2019) Sex differences in own and other body perception. Hum Brain Mapp 40(2):474–488

Bystrom KE, Barfield W, Hendrix C (1999) A conceptual model of the sense of presence in virtual environments. Presence-Teleoper Virtual Environ 8:241–244

Carpenter B, Gelman A, Hoffman M, Lee D, Goodrich B, Betancourt M, Brubaker MA, Guo J, Li P, Riddell A (2016) Stan: a probabilistic programming language. J Stat Softw. https://doi.org/10.18637/jss.v076.i01

Cash TF, Phillips KA, Santos MT, Hrabosky JI (2004) Measuring "negative body image": validation of the body image disturbance questionnaire in a nonclinical population. Body Image 1(4):363–372. https://doi.org/10.1016/j.bodyim.2004.10.001

Costa MTS, Vieira LP, de Oliveira Barbosa E, Oliveira LM, Maillot P, Vaghetti CAO, Carta MG, Machado S, Gatica-Rojas V, Monteiro-Junior RS (2019) Virtual reality-based exercise with exergames as medicine in different contexts: a short review. Clin Pract Epidemiol Mental Health CP & EMH 15:15. https://doi.org/10.2174/1745017901915010015

Damiot A, Pinto AJ, Turner JE, Gualano B (2020) Immunological implications of physical inactivity among older adults during the COVID-19 pandemic. Gerontology 66(5):431–438. https://doi.org/10.1159/000509216

Durau J, Diehl S, Terlutter R (2022) Motivate me to exercise with you: the effects of social media fitness influencers on users' intentions to engage in physical activity and the role of user gender. Digital Health 8:20552076221102770. https://doi.org/10.1177/20552076221102

Ehrsson HH (2020) Multisensory processes in body ownership. In: Sathian K, Ramachandran VS (eds) Multisensory perception: from laboratory to clinic. Elsevier, Amsterdam, pp 179–200. https://doi.org/10.1016/C2016-0-03465-4

Gelman A, Jakulin A, Pittau MG, Su Y-S (2008) A weakly informative default prior distribution for logistic and other regression models. Ann Appl Stat 2(4):1360–1383

Godin G, Shephard R (1985) A simple method to assess exercise behavior in the community. Can J Appl Sport Sci 10(3):141–146 (**PMID: 4053261**)

Grossmann I, Kross E (2014) Exploring Solomon's Paradox: self-distancing eliminates the self-other asymmetry in wise reasoning about close relationships in younger and older adults. Psychol Sci 25(8):1571–1580

Guthold R, Stevens GA, Riley LM, Bull FC (2020) Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1· 6 million participants. Lancet Child Adolescent Health 4(1):23–35. https://doi.org/10.1016/S2352-4642(19)30323-2

Haseler T, Haseler C (2022) Lack of physical activity is a global problem. BMJ 376:o348. https://doi.org/10.1136/bmj.o348

Hoffman GJ, Malani PN, Solway E, Kirch M, Singer DC, Kullgren JT (2022) Changes in activity levels, physical functioning, and fall risk during the COVID-19 pandemic. J Am Geriatr Soc 70(1):49–59. https://doi.org/10.1111/jgs.17477

Hollar SM, Siegel JT (2020) Self-distancing as a path to help-seeking for people with depression. Soc Sci Med 245:112700. https://doi.org/10.1016/j.socscimed.2019.112700

Juárez MA, Steel MF (2010) Model-based clustering of non-Gaussian panel data based on skew-t distributions. J Bus Econ Stat 28(1):52–66

Kilteni K, Groten R, Slater M (2012) The sense of embodiment in virtual Reality. Presence Teleoper Virtual Environ 21:373–387. https://doi.org/10.1162/PRES_a_00124

Kohl 3rd HW, Craig CL, Lambert EV, Inoue S, Alkandari JR, Leetongin G, Kahlmeier S, Group LPASW (2012) The pandemic of physical inactivity: global action for public health. Lancet 380(9838):294–305. https://doi.org/10.1016/S0140-6736(12)60898-8

Kokkinara E, Slater M (2014) Measuring the effects through time of the influence of visuomotor and visuotactile synchronous stimulation on a virtual body ownership illusion. Perception 43(1):43–58. https://doi.org/10.1068/p7545

Kross E, Ayduk O (2017) Self-Distancing: theory, research, and current directions. Advances in experimental social psychology, vol 55. Elsevier, Amsterdam, pp 81–136. https://doi.org/10.1016/bs.aesp.2016.10.002

Kross E, Vickers BD, Orvell A, Gainsburg I, Moran TP, Boyer M, Jonides J, Moser J, Ayduk O (2017) Third-person self-talk reduces ebola worry and risk perception by enhancing rational thinking. Appl Psychol Health Well Being 9(3):387–409

Leitner JB, Ayduk O, Mendoza-Denton R, Magerman A, Amey R, Kross E, Forbes CE (2017) Self-distancing improves interpersonal perceptions and behavior by decreasing medial prefrontal cortex activity during the provision of criticism. Soc Cogn Affect Neurosci 12(4):534–543

Lemoine NP (2019) Moving beyond noninformative priors: why and how to choose weakly informative priors in Bayesian analyses. Oikos 128(7):912–928. https://doi.org/10.1111/oik.05985

Liberman N, Trope Y, Stephan E (2007) Psychological distance. In: Kruglanski AW, Higgins ET (eds) Social psychology: handbook of basic principles. The Guilford Press, New York, pp 353–381

Lin L, Flynn M, O'Dell D (2021) Measuring positive and negative body talk in men and women: the development and validation of the body talk scale. Body Image 37:106–116. https://doi.org/10.1016/j.bodyim.2021.01.013

Maister L, Sebanz N, Knoblich G, Tsakiris M (2013) Experiencing ownership over a dark-skinned body reduces implicit racial bias. Cognition 128:170–178. https://doi.org/10.1016/j.cognition.2013.04.002

Maister L, Slater M, Sanchez-Vives MV, Tsakiris M (2015) Changing bodies changes minds: owning another body affects social cognition. Trends Cogn Sci 19(1):6–12. https://doi.org/10.1016/j.tics.2014.11.001

Marconcin P, Werneck AO, Peralta M, Ihle A, Gouveia ÉR, Ferrari G, Sarmento H, Marques A (2022) The association between physical activity and mental health during the first year of the COVID-19 pandemic: a systematic review. BMC Public Health 22(1):1–14. https://doi.org/10.1186/s12889-022-12590-6

Moser JS, Dougherty A, Mattson WI, Katz B, Moran TP, Guevarra D, Shablack H, Ayduk O, Jonides J, Berman MG (2017) Third-person self-talk facilitates emotion regulation without engaging cognitive control: converging evidence from ERP and fMRI. Sci Rep 7(1):4519

Negreiros A, Maciel RB, Carvalho de Barros B, Padula RS (2022) Quality assessment of smartphone fitness apps used to increase physical activity level and improve general health in adults: a systematic review. Digit Health 8:20552076221138304. https://doi.org/10.1177/20552076221138305

Neyret S, Bellido AI, Navarro X, Slater M (2020) Which body would you like to have? The impact of embodied perspective on body perception and body evaluation in immersive virtual reality. Front Robot AI 7:31

Osimo SA, Pizarro R, Spanlang B, Slater M (2015) Conversations between self and self as Sigmund Freud–a virtual body ownership paradigm for self counselling. Sci Rep 5:13899. https://doi.org/10.1038/srep13899

Pacheco TBF, de Medeiros CSP, de Oliveira VHB, Vieira ER, De Cavalcanti F (2020) Effectiveness of exergames for improving mobility and balance in older adults: a systematic review and meta-analysis. Syst Rev 9(1):1–14. https://doi.org/10.1186/s13643-020-01421-7

Pain & Gain (2018) Serena Williams-the best training in one video!!! YouTube. https://www.youtube.com/watch?v=Lt-14slWv3E&ab_channel=Pain%26Gain

Pearce M, Garcia L, Abbas A, Strain T, Schuch FB, Golubic R, Kelly P, Khan S, Utukuri M, Laird Y (2022) Association between physical activity and risk of depression: a systematic review and meta-analysis. JAMA Psychiat 79:550–559. https://doi.org/10.1001/jamapsychiatry.2022.0609

Peck TC, Seinfeld S, Aglioti SM, Slater M (2013) Putting yourself in the skin of a black avatar reduces implicit racial bias. Conscious Cogn 22:779–787. https://doi.org/10.1016/j.concog.2013.04.016

Petkova VI, Ehrsson HH (2008) If i were you: perceptual illusion of body swapping. PLoS ONE 3:e3832. https://doi.org/10.1371/journal.pone.0003832

Pyae A (2021) Towards understanding users' engagement and enjoyment in immersive virtual reality-based exercises. In: MobileHCI '21: adjunct publication of the 23rd international conference on mobile human-computer interaction, vol 9, pp 1–6. https://doi.org/10.1145/3447527.3474872

Quittkat HL, Hartmann AS, Düsing R, Buhlmann U, Vocks S (2019) Body dissatisfaction, importance of appearance, and body appreciation in men and women over the lifespan. Front Psych 10:864. https://doi.org/10.3389/fpsyt.2019.00864

Reis E, Postolache G, Teixeira L, Arriaga P, Lima ML, Postolache O (2019) Exergames for motor rehabilitation in older adults: an umbrella review. Phys Ther Rev 24(3–4):84–99. https://doi.org/10.1080/10833196.2019.1639012

Rodrigues F, Teixeira DS, Cid L, Monteiro D (2019) Promoting physical exercise participation: the role of interpersonal behaviors for practical implications. J Funct Morphol Kinesiol 4(2):40

Sanchez-Vives MV, Slater M (2005) From presence to consciousness through virtual reality. Nat Rev Neurosci 6:332–339. https://doi.org/10.1038/nrn1651

Sheridan TB (1992) Musings on telepresence and virtual presence. Presence Teleoper Virtual Environ 1:120–126. https://doi.org/10.1162/pres.1992.1.1.120

Silveira EA, Mendonça CR, Delpino FM, Souza GVE, de Souza Rosa LP, de Oliveira C, Noll M (2022) Sedentary behavior, physical inactivity, abdominal obesity and obesity in adults and older adults: a systematic review and meta-analysis. Clin Nutr Espen 50:63–73. https://doi.org/10.1016/j.clnesp.2022.06.001

Slater M (2009) Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. Philos Trans R Soc Lond 364:3549–3557. https://doi.org/10.1098/rstb.2009.0138

Slater M, Spanlang B, Sanchez-Vives MV, Blanke O (2010) First person experience of body transfer in virtual reality. PLoS ONE 5(5):e10564–e10564. https://doi.org/10.1371/journal.pone.0010564

Slater M, Neyret S, Johnston T, Iruretagoyena G, de la Campa A, Crespo M, Alabèrnia-Segura M, Spanlang B, Feixas G (2019) An experimental study of a virtual reality counselling paradigm using embodied self-dialogue. Sci Rep 9(1):10903. https://doi.org/10.1038/s41598-019-46877-3

Slater M, Banakou D, Beacco A, Gallego J, Macia-Varela F, Oliva R (2022) A separate reality: an update on place illusion and plausibility in virtual reality. FrontVirtual Real 3:914392. https://doi.org/10.3389/frvir.2022.914392

Sokolova K, Perez C (2021) You follow fitness influencers on YouTube. But do you actually exercise? How parasocial relationships, and watching fitness influencers, relate to intentions to exercise. J Retail Consum Serv 58:102276. https://doi.org/10.1016/j.jretconser.2020.102276

Swift DL, McGee JE, Earnest CP, Carlisle E, Nygard M, Johannsen NM (2018) The effects of exercise and physical activity on weight loss and maintenance. Prog Cardiovasc Dis 61(2):206–213. https://doi.org/10.1016/j.pcad.2018.07.014

Van Gelder J-L, Cornet LJ, Zwalua NP, Mertens EC, van der Schalk J (2022) Interaction with the future self in virtual reality reduces self-defeating behavior in a sample of convicted offenders. Sci Rep 12(1):2254. https://doi.org/10.1038/s41598-022-06305-5

Vehtari A, Gelman A, Gabry J (2017) Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. Stat Comput 27(5):1413–1432

Venables MC, Jeukendrup AE (2009) Physical inactivity and obesity: links with insulin resistance and type 2 diabetes mellitus. Diabetes Metab Res Rev 25(S1):S18–S23. https://doi.org/10.1002/dmrr.983

Vogel S, Schwabe L (2016) Learning and memory under stress: implications for the classroom. NPJ Sci Learn 1:16011

Williams WM, Ayres CG (2020) Can active video games improve physical activity in adolescents? A review of RCT. Int J Environ

Res Public Health 17(2):669. https://doi.org/10.3390/ijerph17020669

Wisco BE, Marx BP, Sloan DM, Gorman KR, Kulish AL, Pineles SL (2015) Self-distancing from trauma memories reduces physiological but not subjective emotional reactivity among veterans with posttraumatic stress disorder. Clin Psychol Sci 3(6):956–963

Xu W, Zhang K, Wang F (2022) The psychological mechanisms underlying Solomon's Paradox: impact of mood and self-transcendence. Front Psychol 13:901012. https://doi.org/10.3389/fpsyg.2022.901012