Physiological and Perceptual Responses to Athletic Avatars while Cycling in Virtual Reality

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ABSTRACT

Avatars in virtual reality (VR) enable embodied experiences and induce the Proteus effect—a shift in behavior and attitude to mimic one's digital representation. Previous work found that avatars associated with physical strength can decrease users' perceived exertion when performing physical tasks. However, it is unknown if an avatar's appearance can also influence the user's physiological response to exercises. Therefore, we conducted an experiment with 24 participants to investigate the effect of avatars' athleticism on heart rate and perceived exertion while cycling in VR following a standardized protocol. We found that the avatars' athleticism has a significant and systematic effect on users' heart rate and perceived exertion. We discuss potential moderators such as body ownership and users' level of fitness. Our work contributes to the emerging area of VR exercise systems.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; • **Applied computing** → *Computer games*; Consumer health.

KEYWORDS

virtual reality, Proteus effect, body ownership illusion, VR cycling, health intervention, virtual embodiment, perception of effort

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1 INTRODUCTION

Living in the age of digitalization almost everything is connected to a computer or mediating technology. This trend can also be observed for sports and recreational fitness, where professional and amateur athletes utilize computer-based technology such as sensor-based smartwatches or mobile applications to monitor personal fitness metrics and enhance their performance [112]. In recent years, virtual reality (VR) has gained popularity and importance in research as well as in the consumer market of interactive fitness applications [2, 27, 47, 70]. In immersive VR applications such as *FitXR* [31], for example, users perceive the virtual environment from first-person perspective (1PP) while their motions are registered by controllers and transmitted as user input during workouts in VR. Analogously to workouts in reality, the users' virtual performance correlates with their physical effort and activity while exercising in VR.

Previous work found that VR fitness training can improve physical fitness [62] and performance [23, 49], reduce the heart rate [63], and enhance motivation [42, 54, 58] and enjoyment [114] during physical activity. It can also decrease the perceived effort [49] and pain [68]. Although the effects of fitness applications in general and immersive VR workouts in particular have not been sufficiently evaluated yet [118], previous research suggests that developers can take advantage of VR to engage people and promote physical activity for a healthier way of life. Particularly in a time where physical inactivity poses one of the major public health concerns [117], the significance of such applications has increased.

Researchers and designers of VR applications aim at creating immersive experiences by using *avatars*—the digital representation of the user—to establish the sense of having an own body in the virtual environment. Hence, VR can induce the feeling of inhabiting the virtual avatar and being situated in its body through a head-mounted display (HMD) and a 1PP so that the users perceive the virtual environment through the eyes of the avatar. This can result in a phenomenon commonly known as the *body ownership illusion* (BOI) that describes the feeling of accepting the avatar as one's virtual alter ego [96]. Since the visual appearance of the avatar can be rendered in any desired style, VR, therefore, allows the user to embody any possible appearance.

Prior research revealed a phenomenon known as the *Proteus effect* that explains behavioral, attitudinal and perceptual changes due to the embodiment of avatars and the resulting associations connected with their visual appearance [121–123]. Ratan et al. [88] summarized in a meta-analysis that the Proteus effect could be evidenced in various contexts, even in physical exercises. Kocur et al. [49], for example, showed that the embodiment of muscular avatars can result in a lower perception of effort compared to non-muscular avatars in a physical task in VR. Results suggests that there is a systematic relationship between the avatar's muscular appearance and the user's perceived exertion. Results from real-world experiments demonstrated a strong positive linear relationship between the users' perceived exertion and their physiological responses to physical effort such as their heart rate (HR)—the number of times the heart beats per minute [13, 15, 16]. However, it is currently unknown whether avatars which are perceived as physically fit and athletic can indeed affect users' physiological responses to physical exercise and how these responses evolve over time.

Psychophysiological effects on users caused by avatars could be utilized by designers to affect their exertional responses during physical effort in VR. Immersive exergames or exercise sytems can take advantage of a reduced HR, for example, to positively affect physiological responses to effort and, therefore, utilize the VR experience as an intervention to engage the users and increase their physical activity. As the HR is a primary indicator for the intensity of physical effort, and a significant implicit measure for the users' level of fitness [75, 87, 104] and their exertion during exercise [29], a decreased HR during physical effort could result, for example, in a lower perception of effort [16], an improved endurance performance [77] with a potentially longer exercise duration [74], faster recovery after exercise [24], and an enhanced adherence to exercise programs [60, 78]. Additionally, it is important to know how an avatar's appearance affect the basal HR from a research perspective. If psychophysiological effects due to the embodiment of avatars occur, the avatar, therefore, has to be considered in the experimental design process.

In this paper, we investigate whether an avatar's athletic appearance affects user's perceived exertion and their HR while cycling in VR. We explored how the HR evolves over time to obtain first insights into the time dimensions of the Proteus effect. Hence, we conducted a study with 24 participants who embodied three avatars with different athletic appearance in VR while riding a stationary bicycle. We found that participants had a decreased HR when embodying the athletic avatar compared to the non-athletic and medium avatar during exercise. Furthermore, we replicate results from previous work by showing a systematic relationship between perceived exertion and the avatar's athletic appearance. Participants embodied in the athletic avatar perceived the exercise as less physically strenuous than when embodied in the non-athletic and medium avatar. We hypothesize that the participants' confidence to master the challenge of the exercise increased when embodying the athletic avatar resulting in a significantly lower HR. We discuss the findings based on potential moderators such as the experienced body ownership, the identification with the avatars and the user's level of fitness. Our work extends research on the Proteus effect in VR exercise environments and illustrates the psychophysiological impact of avatars on the users embodying them.

2 RELATED WORK

The work presented here is based on a body of work that demonstrated perceptual illusions in VR through avatars and the resulting effects on users of immersive applications. First, we discuss the underlying mechanisms of such effects and present previous work that addresses the Proteus effect in immersive and non-immersive environments. Afterwards, we summarize prior investigations that cover avatars' effects on users' performance in physical tasks in VR.

2.1 Body Ownership Illusion

Due to the plasticity of the human brain, VR can induce an illusory feeling of owning a virtual body—the BOI. First manifestations of the BOI were shown in real-world experiments such as the famous rubber hand illusion (RHI). In the RHI, Botvinick and Cohen [18] stimulated the illusion of owning an artificial rubber hand by simultaneously striking the rubber hand placed in an anatomically plausible position and the hidden real hand. This combination of congruent visual and tactile cues made the participants accept a rubber hand as part of their own body. This illusion is explained by the combination of multisensory cues into a unified percept [30]. Therefore, we can integrate artificial limbs or bodies into our own body and experience the illusion that they belong to us [64].

The idea of inducing perceptual illusions with artificial limbs or bodies was also transferred into VR. Yuan and Steed [125] replicated the RHI in VR and showed the illusion by a higher stress response to threat measured by electrodermal activity. Slater et al. [107] also utilized visuotactile correlations to invoke the illusion that a virtual 3D arm was part of one's body. Kokkinara and Slater [53] extended the experimental setup by visuomotor synchrony—a synchrony between movements of the real body and the virtual body—to make participants accept virtual legs as their own ones. The authors showed that visuomotor synchrony can induce a stronger BOI than visuotactile cues [53]. Petkova and Ehrsson [86] applied visuotactile stimulation and argue that a continuous match between visual and somatosensory cues combined with an expanded 1PP were critical conditions for the BOI to occur. Maselli and Slater [67], however, showed that a 1PP was the driving factor for eliciting a BOI and that there was no need for additional multisensory stimulation. This is in line with Slater et al. [108] and Petkova et al. [85] who revealed that a 1PP was a crucial determinant of the BOI, even if prior investigations showed that users could experience BOIs from third-person perspective (3PP) [4, 44]. Nonetheless, researchers agree that incongruent cross-modal stimulation can diminish the BOI. Banakou et al. [5] and Sanchez-Vives et al. [98] found that the BOI could not occur during asynchronous motion of the participants' virtual and real hand. Overall, results indicate that a congruent sensory stimulation in combination with a 1PP can be used to induce a BOI in VR amplifying behavioral changes caused by the Proteus effect [5, 76].

Previous work found that the external appearance of the virtual avatar could also affect the triggered BOI. Schwind et al. [102] and Schwind et al. [101] showed that the avatars' human-likeness and realism affected the experienced limb ownership in VR. This is in line with Maselli and Slater [67] who argued that appearance moderated body ownership. However, prior investigations revealed that users could accept virtual limbs and bodies different than their real ones. Participants reported feeling a sense of ownership over avatars that indicated having a different gender [101], being much younger [5] or older [7], having a different skin color [6, 38, 82] or altered body structures [48] or even being nonhumanoid, e.g. animals [1, 55]. However, little is still known about the virtual embodiment of fundamentally different avatars and the boundaries of tolerable deviations of the avatars' appearance from the own body still resulting in a feeling of body ownership.

Previous work applied measures from experiments conducted in the real world such as questionnaires and displacement measures, e.g. as used in the RHI [18], to measure the BOI. Sanchez-Vives et al. [98], for example, used the "proprioceptive drift" as a behavioral measure. They found that participants tended to estimate the position of their limbs towards the virtual avatar. Furthermore, physiological [125, 126] and motor responses [35, 46, 98], cortical activity [71], breaks in illusions [53] and different questionnaires [7, 34, 45, 96] were used to objectively and subjectively assess the BOI in VR.

2.2 Proteus Effect

Prior work reported that the virtual embodiment of avatars could change the user's attitude, perception and behavior. Changes that are based on the visual appearance of the avatars are attributed to the *Proteus effect* which was first coined by Yee and Bailenson [122]. The authors showed that users who embodied attractive avatars socially interacted with more confidence than in avatars which were perceived as less attractive. In a further experiment, they changed the avatars' body height and showed that participants with increased height behaved more confidently and aggressively in a bargaining task [121, 122]. These results imply that users change their behavior according to the expectations and associations connected with the visual appearance of the embodied avatar.

The Proteus effect can be explained by self-perception theory, which states that people deduce their behavior and attitude from observing themselves from an imaginary 3PP [9]. Transferring this idea to the Proteus effect in virtual environments, users infer their behavior and attitude based on their experience and knowledge associated with the avatars' characteristics, and behave in accordance with common expectations connected with the avatar's salient identity cues. As a consequence, older-looking avatars can affect walking speed [91], dark-skinned avatars can reduce racial bias [6, 37], and muscular avatars can enhance physical performance in virtual environments [49].

Another fundamental aspect of the Proteus effect is stereotyping [83]. Yang et al. [120], for example, found that players with dark-skinned avatars played more aggressively in a non-immersive violent game than with light-skinned avatars. This is in line with Yoon and Vargas [124] and Rosenberg et al. [95] who reported that users who played with an heroic avatar exhibited more prosocial behavior. Peña et al. [83] argued that users' stereotypical assessments about the avatar primed and activated related thoughts and in turn hindered inconsistent thoughts. The authors confirmed their hypothesis by showing that participants using avatars with a Ku Klux Klan-associated rope manifested a more aggressive and less affiliative behavior during the exposition [83]. Results indicate that self-perception, stereotypical priming and deindividuation [123] foster attitudinal, perceptual and behavioral changes caused by the Proteus effect, during and after avatar exposure [20, 88, 121, 122].

2.3 Avatars' Effects on Physical Performance

In a meta-analysis, Ratan et al. [88] concluded that the Proteus effect was a valid phenomenon with consistent effect sizes between small and medium. However, there is still little known about the effect on users' physical performance and responses to physical activity in virtual environments.

Peña and Kim [81] found that players of a competitive virtual tennis game were physically more active when playing with a normal avatar compared to an avatar with an appearance dubbed "obese" by the authors. They replicated these findings in a second study and identified the body composition of the opponent's avatar as a significant moderator [84]. The authors introduced the "take it easy" hypothesis - players are less physically active when they think they have an advantage over the opponent - and the "give up" hypothesis - players exercise less when their appearance indicates to have a disadvantage compared to the opponent [81]. This is in line with Keenaghan et al. [45] who found that cycling against an idealized version of oneself can have a negative impact on the physical performance due to self-discrepancy. Nonetheless, they also revealed that racing against avatars which depicted a realistic enhancement compared to an unrealistic idealized version could positively affect the users' achieved power output on an exercycle. Since these studies investigated the effects of avatars in virtual environments with multiple characters, their reciprocal impact has to be considered. Consequently, further psychological effects such as behavioral confirmation [111, 121], deindividuation [121] or competition [72] can occur and, therefore, moderate avatars' effects on users [51]. Based on the notion to improve interactions in VR using full-body avatars [52], Kocur et al. [49] showed that muscular avatars could decrease the perceived exertion during high-intensity tasks when being alone in VR. The authors also found that male participants had a higher grip strength in a muscular compared to a non-muscular and medium avatar. In line with previous work [5, 89], the authors discussed potential moderators of the Proteus effect such as identification with the avatars and experienced body ownership. As they did not control for the participants' physiological responses, psychophysiological effects due to the avatars' appearance during physical effort in VR are yet unknown.

2.4 Psychophysiological Effects during Physical Effort

Research in sports psychology provides evidence for a variety of psychophysiological effects on professional and amateur athletes during exertion. Lautenbach et al. [56], for example, concluded that high-fives can decrease stress in terms of a lower cortisol level during physical effort. A similar effect can occur while listenting to music. Brownley et al. [19] found that fast, upbeat music can positively affect an athlete's physiological responses while running. This is in line with Patania et al. [80], who showed advantageous effects of music on HR and perception of effort in endurance exercises. The authors explained the effects by music's ability to distract from negative feelings caused by exertion, such as discomfort, fatigue

Figure 1: Renderings of the 32 avatars for the online survey with an increasing proportion of body fat (0%, 33%, 66%, 100%) from bottom to top and an increasing proportion of muscularity (0%, 33%, 66%, 100%) from left to right for the female (left) and male (right) avatars.

or pain, and addressing the brain's emotion and reward system [3]. This attentional shift from negative affective responses in combination with an increased amount of pleasure during exertion could also be found in group exercises, which are associated with reduced dropout rates [115]. Furthermore, mental imagery interventions in sports are an effective psychological tool to enhance performance in terms of muscular power [109], endurance [69], and physiological responses to physical effort [106, 110, 116]. Decety et al. [25] showed, for example, that the pure mental imagination of physical effort could increase the participants' HR and that this rise in HR even correlated with a higher intensity relatively to the real physical effort. According to Giacobbi et al. [32], appearance imagery is one of the main types of mental imagination in exercises and describes the self-visualization with an improved physical appearance [90]. Razon et al. [90] found that participants using mental imagery techniques had a higher lactic acid level while cycling compared to participants without self-visualization. Based on these findings, the authors concluded that mental imagery could make the participants to put more effort into physical tasks. Overall, results suggest that psychophysiological effects can induce behavioral and perceptual changes during exercise, which in turn can potentially influence physical performance.

2.5 Summary

Previous work revealed a phenomenon known as the Proteus effect which describes behavioral, attitudinal, and perceptual changes caused by avatars' salient characteristics. However, it is unclear if avatars can also affect the users' physiological responses to physical effort in VR. This would enable designers and developers of VR exercise systems to utilize avatars' appearance to positively affect the users' physiological responses during physical exercise and, thereby, increase their performance and reduce their perception of effort.

3 METHOD

To understand if an avatar's athletic appearance has an effect on a user's physiological responses and perceived exertion, we asked participants to ride a stationary bicycle using a standardized exercise protocol [73] and three systematically designed avatars. We measured participants' HR, perceived exertion, pedal frequency and the covered distance. We also assessed identification with the avatar, self-perceived fitness and body ownership.

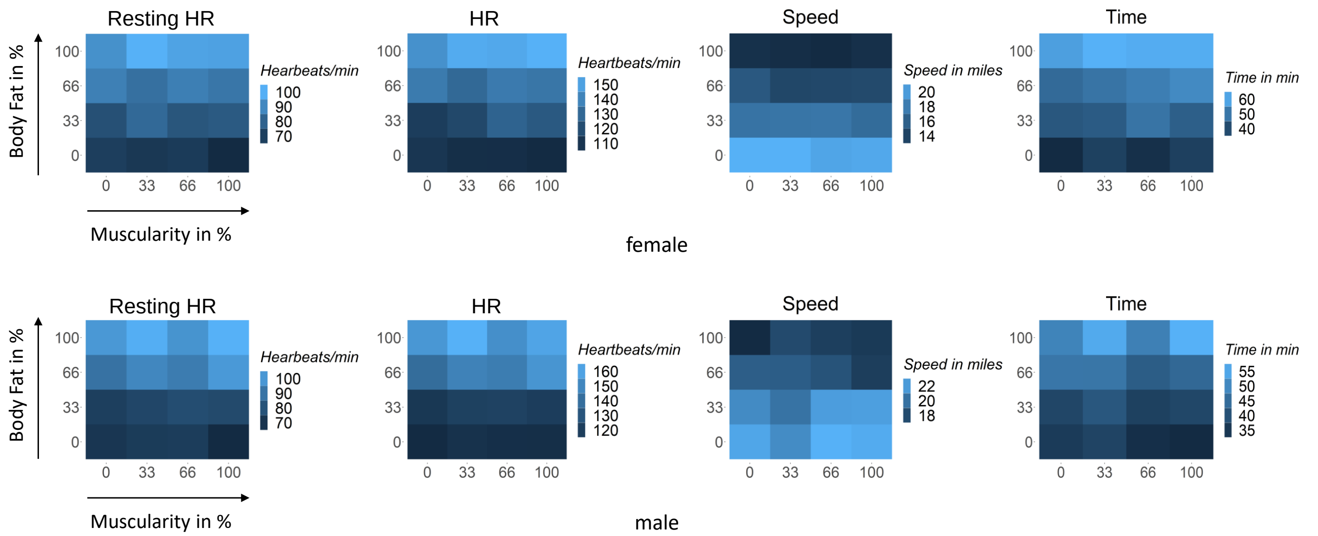

Figure 2: Heatmaps depicting the average scores of each measure assessed in the online survey for the female (top) and the male (bottom) avatars. The y-axis represents the proportions of body fat (0%, 33%, 66%,100%) and the x-axis the proportions of muscularity (0%, 33%, 66%,100%). Based on these scores per measure, we defined three female and three male avatars with different levels of athleticism.

3.1 Avatar Selection

Analyzing the effects of an avatar's athletic appearance requires avatars with different levels of expected physical fitness. Therefore, we conducted an initial study to systematically determine three male- and female-gendered avatars that range from being athletic on one end to unathletic on the other.

3.1.1 Stimuli. We designed 16 female- and 16 male-gendered avatars using the 3D-suite Daz3D[1]. The avatars are based on the characters Genesis 8[2] Male[3] and Female[4]. We used the two primary fitness indicators body fat and muscle proportion [28, 103] as dimensions to adapt the athletic appearance of the avatars. We started at 0% for each dimension and systematically increased the avatar's body fat and muscles by 33% using morph targets resulting in the 16 male- and 16 female-gendered avatars. We placed the avatars on a 3D model of a stationary bicycle in front of a virtual mirror and rendered the scenes in 1PP (see Figure 1).

As our study investigated performance in a physical exercise task, it uses measures dependent on biological sex characteristics. This necessitated designing female and male avatars. In the world of sports, there is a clear distinction between genders based on hormone levels and this distinction is linked to performance [41]. Female cyclists compare at different distances and speeds than male cyclists [99]. Consequently, our study asked participants directly about their biological sex, based on their hormone levels[5]. All of the participants identified as cisgender.

3.1.2 Survey Design and Measures. We conducted an online survey using a within-subjects design with the independent variable Body. The participants were presented with the renderings of the avatars of their previously reported gender in a randomized order. They were asked to imagine being the displayed avatar riding a stationary bike and to answer the questions from the avatar's perspective. Participants rated the perceived fitness of the avatars on a 13-points scale with an ascending level from 1 to 13 using the self-perceived fitness (SPF) questionnaire [26]. Additionally, they estimated the resting HR ranging from 40 and 240 beats per minute (bpm) and the HR while riding a stationary bike for 10 minutes with 16 miles per hour (mph) (ranging from 40 to 240 bpm). They also estimated the time required while cycling as fast as possible for 5 miles (ranging from 5 to 120 minutes) and the avatar's speed while cycling for 10 minutes with a HR of 120 bpm (ranging from 5 to 50 mph). These measures were used to determine the avatars' perceived fitness and performance on a stationary bicycle. We also assessed whether the avatars resembled the participants ("It feels as if the character is me") using a 7-point Likert item. Prior to the avatar ratings, participants were asked to report demographic data as well as their physical activity level using the SPF. The survey took about 20 minutes.

3.1.3 Participants. We recruited N=74 participants (36f, 38m) via the paid crowdsourcing platform Amazon Mechanical Turk (MTurk). Human HIT requirements were set to an approval rate of > 98%,

[1]https://www.daz3d.com/
[2]https://www.daz3d.com/genesis8
[3]https://www.daz3d.com/massive-morphs-for-genesis-8-male
[4]https://www.daz3d.com/massive-morphs-for-genesis-8-female-s

[5]In line with the SIGCHI gender guidelines, https://www.morgan-klaus.com/gender-guidelines.html#Health-Research

Figure 3: The real world (left) and the virtual scene consisting of the non-athletic, the medium and the athletic avatars (from left to right) on a stationary bicycle.

> 500 approved HITs, and within the US. Participant age ranged from 22 to 68 (M=40.76, SD=11.47). We offered 2$ for completing the survey.

3.1.4 Results. Estimated resting HR, HR while cycling, achieved speed, and required time are shown in Figure 2. Within each gender we observed similar patterns for all measures. We started creating the avatars by averaging the measures for each of them. Afterward, we determined the female- and male-gendered avatar with the highest and lowest overall performance resulting in the most and the least athletic avatar for both genders. Based on these avatars, we designed the respective medium avatar by determining the equidistant difference of body fat and muscularity between the athletic and medium, and medium and non-athletic versions. For the male-gendered avatars we used 66% body fat with 0% muscularity for the non-athletic, 33% body fat with 33% muscularity for the medium, and 0% body fat with 66% for the athletic version. To design the female-gendered avatars, we used 66% body fat with 33% muscularity for the non-athletic, 33% body fat and 33% muscularity for the medium, and 0% body fat with 66% muscularity for the athletic version. The final avatars are shown in Figure 3.

3.2 Study Design

To investigate the effects of the avatars' athletic appearance, we conducted a study using a within-subjects design with the independent variable Body with the three levels *non-athletic*, *medium* and *athletic*. Hence, participants embodied avatars of their identified gender with different athletic appearance. To reduce order effects, we counterbalanced the order of the avatars using a 3 × 3 Latin square.

3.3 Measures

While the participants were riding a stationary bicycle, we assessed the perceived exertion using the *Rating of perceived exertion* (RPE) scale [15]. We also measured the HR while cycling and during the resting periods after each condition. Furthermore, the covered distance and the pedaling frequency were measured to determine the rate at which the participants were turning the pedals. In addition to performance measures, participants were also asked to complete questionnaires after each condition such as the SPF, the body representation questionnaire (BRQ) [5, 7] for quantifying the experienced body ownership, and the subscales for similarity identification, embodied presence and wishful identification from the Player Identification Scale (PIS) [61] to measure the participants' presence and identification with the avatars.

3.3.1 Perceived Exertion. Based on a well-established experimental procedure [13, 15, 17], we determined the perceived exertion while riding a stationary bicycle. The participants were shown a visual scale—the psychophysical Borg's RPE scale [15]—at four different points in time—after 4:45, 9:45, 14:45, 19:45 minutes. The participants orally communicated the value that best represented their perception of effort. The RPE scale was designed to increase linearly with physical exercise intensity ranging from 6 (no exertion) to 20 (maximal exertion). The scale is designed to approximately estimate the current HR by multiplying each value by 10, so that an intensity of 15, for example, approximately matches a HR of 150 [15].

3.3.2 Heart Rate. Since the HR is frequently used as a predictor for one's level of physical fitness [75, 87, 100, 105], we measured the HR using an optical HR monitor worn at the participant's arm

(Polar OH1, Polar Electro, Finland) which can be employed as a valid measurement device during moderate and high intensity physical activities [40]. We assessed the HR throughout the experiment to get insights into the HR response while cycling and in the resting periods after each condition.

3.3.3 Pedaling Frequency. To investigate behavioral changes caused by the visual appearance of the avatars, we used the pedaling frequency (in revolutions per minute, rpm) as a dependent variable. We attached a cadence sensor (Polar Cadence Sensor Bluetooth Smart, Polar Electro, Finland) on the stationary bicycle to measure the pedaling rate per minute.

3.3.4 Self-Perceived Fitness. We used a version of the self-appraisal questionnaire from Borg and Skinner [14] adapted by Delignieres et al. [26] to assess the SPF per condition serving as a manipulation check. The authors created a questionnaire with the five dimensions endurance, strength, flexibility, body composition and fitness rated on a 13-point scale with an ascending level ranging from 1 to 13 [26].

3.3.5 Body Ownership. To quantify the induced body ownership, we used the BRQ [5, 7] with the single-item subscales vrbody ("I felt that the virtual body I saw when looking down at myself was my own body"), mirror ("I felt that the virtual body I saw when looking at myself in the mirror was my own body"), features ("I felt that the virtual body resembled my own real body in terms of shape, skin tone or other visual features"), twobodies ("I felt as if I had two bodies"), and agency ("I felt that the movements of the virtual body were caused by my own movements").

3.4 Apparatus

We used three male and three female avatars with different athletic appearance (see Figure 3). Each avatar model had the same skeleton with an identical configuration of bones. We used the game engine Unity3D (v. 2019.3.11f1) to implement the VR application. To allow the participants to focus on their virtual body, we used a simple virtual scene only consisting of a fitness room with dark walls, a stationary bicycle, and a mirror with stereoscopic reflections. We placed an electromagnetically braked bicycle ergometer (SportPlus Ergometer, Latupo GmbH, Germany) in our VR laboratory. We used the watt mode so that the ergometer dynamically adjusted resistance based on a given watt value resulting in a speed-independent workload. A HTC Vive tracker was firmly attached to each pedal using cable ties to register and transfer the pedal motion onto the virtual replica of the ergometer in the virtual environment. We substituted the participants' real body by the non-athletic, medium and athletic avatar using a HTC Vive HMD with a wide horizontal field-of-view of 100° and a spatial resolution of 1080 × 1,200 pixels per eye displayed at 90 fps. The participants perceived the virtual environment and their virtual bodies from 1PP. We placed a virtual mirror into the scene so that they could constantly perceive their virtual body while riding the bicycle ergometer. To track the participants' pedaling motion and transfer the leg postures onto the virtual skeleton of the avatars, we used real-time inverse kinematics[6]. We used an Android smartphone running the Polar Beat app compatible with the Polar HR sensor to measure the participants' HR. The VR application ran on a Dell G5 15 notebook PC (Windows 10, Intel i7-8750H, 8GB RAM, NVIDIA GeForce RTX 2060 Mobile graphics card).

[6]https://assetstore.unity.com/packages/tools/animation/final-ik-14290

3.5 Participants

We recruited 24 participants (12m, 12f) via a mailing list of our institution. Their age ranged from 23 to 33 years (M = 28.33, SD = 2.63). To assess the participants' level of fitness, we used the SPF questionnaire by Delignières et al. [26] as part of the demographic questionnaire. In addition, we calculated the individual body mass index (BMI) (M = 22.74, SD = 2.61) based on the participants' body weight and height, and determined their maximum HR (M = 191.67, SD = 2.63) using the age-predicted HR_{max} equation (i.e., $220 - age$) [113]. None of the participants owned a VR device but 10 participants already experienced VR before the study. No participant reported any pain in the legs before and after the study. Participants were informed that they could withdraw or discontinue participation at any time without penalty.

3.6 Procedure

Due to the COVID-19 pandemic, our government and institution developed hygienic regulations which we followed throughout the study. Based on Kocur et al. [50], we specified and implemented additional safety measures for our laboratory, which were approved by our institution, e.g. thorough disinfection of HMDs with a "three-day quarantine" after usage, extensive ventilation of the laboratory and detailed hygiene instructions for the experimenter such as wearing a face mask and gloves during the experiment.

First, we provided an introduction to the hygiene measures followed by questions about the participants' health conditions. If there were no indications of health concerns, the participants signed an informed consent form and completed the demographics questionnaire. Afterwards, they were given a brief introduction to VR and could get familiar with the VR equipment. Before starting the experiment, the participants could change their clothes and put on sportswear in a separate room in our laboratory. We attached the optical HR sensor onto the participants' forearm.

After the participants sat on the bike, we helped them with putting on the HMD, adjusted it to their head and calibrated the inter-pupil distance to ensure best visual results. The height of the bike's seat was adjusted so that the participants' knees were slightly bent when the pedals were at the bottom position. As we only tracked the motion of the pedals and used inverse kinematics to animate the legs and the torso, we asked them to remain in a comfortable position during cycling with their arms holding the handlebars. We started the scene and embodied the participants in the first avatar condition as soon as they entered VR. In the beginning of each condition, there was a five minute warm-up phase where the participants were asked to slowly pedal at a constant low-intensity load of 40 watts. Based on a standardized exercise protocol frequently used in clinical settings [73], we started the exercise phase at 50 watts and increased the workload by 10 watts every minute. After 10 stages (= 10 minutes) with a workload of 140 watts in the last stage, we included a five minute cool-down phase again with a constant workload of 40 watts resulting in a total exercise time of 20 minutes per avatar condition. Thus, we

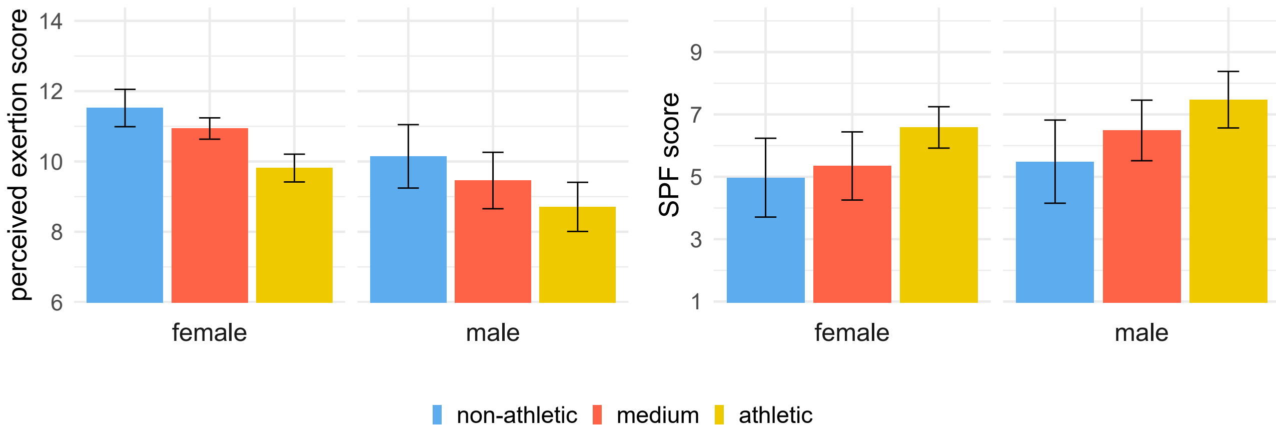

Figure 4: Average scores of the perceived exertion while riding the ergometer bicycle ranging from 6 to 20 (left) and the mean values of the SPF questionnaire ranging from 1 to 13 (right). For the sake of clarity, we calculated a total score from the subscales of the SPF questionnaire for this bar chart. The error bars show the 95% confidence interval.

ensured that the exercise intensity was identical for each avatar condition within the aerobic threshold of 75% of the maximum HR to avoid the lactate turn point [79].

Participants then took off the HMD, got off the bicycle and completed the questionnaires on a notebook computer. Prior to the next avatar condition, we included a resting period of at least 4 minutes to ensure that the participants reach their baseline HR before starting the next avatar condition. At the end of the study, the participants were asked to give general feedback about the virtual experience and the avatars. Neither verbal encouragement nor visual feedback regarding the performance measures were given during the study. The participants spent 60 minutes in VR resulting in a total time of approximately 90 minutes for the study including hygiene measures.

4 RESULTS

Our measures consist of parametric and non-parametric data. Shapiro - Wilk tests for normality were used to test the assumption of normal distribution for parametric data. Items of the BRQ, and SPF concern ordinal data. We used the ARTool package for R by Wobbrock et al. [119] to apply an aligned rank transform (ART) analysis of variance (ANOVA) for hypothesis testing of non-parametric data. The participant was entered as a random factor in all analyses. We included the avatars' Gender as a between-subjects variable in the statistical analysis to control for effects of female and male avatars' athleticism. All pairwise post-hoc comparisons are Bonferroni corrected. A summary of descriptive data and inferential statistics is shown in Table 1 and Table 2.

4.1 Heart Rate

To investigate the effects of the independent variable Body on the participants' HR response, we analyzed the time course per minute of the HR across the entire exercise including warm-up and cool-down (see Figure 5). In line with Northridge et al. [73], we calculated one-minute time intervals and included the factor Time in the statistical analyses. Furthermore, we evaluated the average HR during the exercise and the resting periods after each condition.

4.1.1 Time course of HR. A multifactorial mixed ANOVA revealed a significant effect of Body, $F(2, 1298) = 9.791$, $p < .001$, $\eta_p^2 = .014$, Gender, $F(1, 22) = 10.160$, $p = .004$, $\eta_p^2 = .315$, and Time, $F(19, 1298) = 5.986$, $p < .001$, $\eta_p^2 = .591$, on the *HR* across time.

There was no significant interaction effect of Body × Gender, $F(2, 1298) = 2.952$, $p = .052$, $\eta_p^2 = .004$, however, there was a significant interaction effect of Gender × Time, $F(19, 1298) = 7.814$, $p < .001$, $\eta_p^2 = .102$. Pairwise comparisons using t-tests within Body showed significant differences between the *non-athletic* and *athletic* ($p < .001$), and the *medium* and *athletic* ($p < .001$) avatars. We did not perform a pairwise cross-factor comparison to further analyze differences between Gender and Time, as the interaction did not provide further insights regarding the research question. Additionally, we performed a multi-variate linear regression analysis of each subdimension of the BRQ and of the PIS to test whether the variance in HR was affected by the experienced body ownership or identification with the avatars. We found a significant effect of the subdimensions *vrbody*, $\beta = -2.740$, $p < .001$, *mirror*, $\beta = 4.959$, $p < .001$, *features*, $\beta = -.911$, $p = .008$, and *twobodies*, $\beta = -1.370$, $p < .001$, on participants' HR across time, $F(5, 1434) = 38.740$, $p < .001$, $R^2 = .119$, $R^2_{adj} = .115$. Furthermore, we found a significant effect of the subscale *embodied presence* of the PIS, $\beta = 8.180$, $p < .001$, on participants' HR across time, $F(3, 1436) = 75.870$, $p < .001$, $R^2 = .136$, $R^2_{adj} = .134$. To determine if the participants' BMI had an effect on the HR across time, we performed a mixed ANCOVA and included the BMI as a covariate. We did not find a significant effect of the BMI, $F(1, 21) = 3.405$, $p = .079$, $\eta_p^2 = .139$, on the HR across time.

4.1.2 Average HR during exercise. A multifactorial mixed ANOVA did not find a significant effect of Body, $F(2, 44) = .815$, $p = .449$, $\eta_p^2 = .035$, however, there was an effect of Gender, $F(1, 22) =$

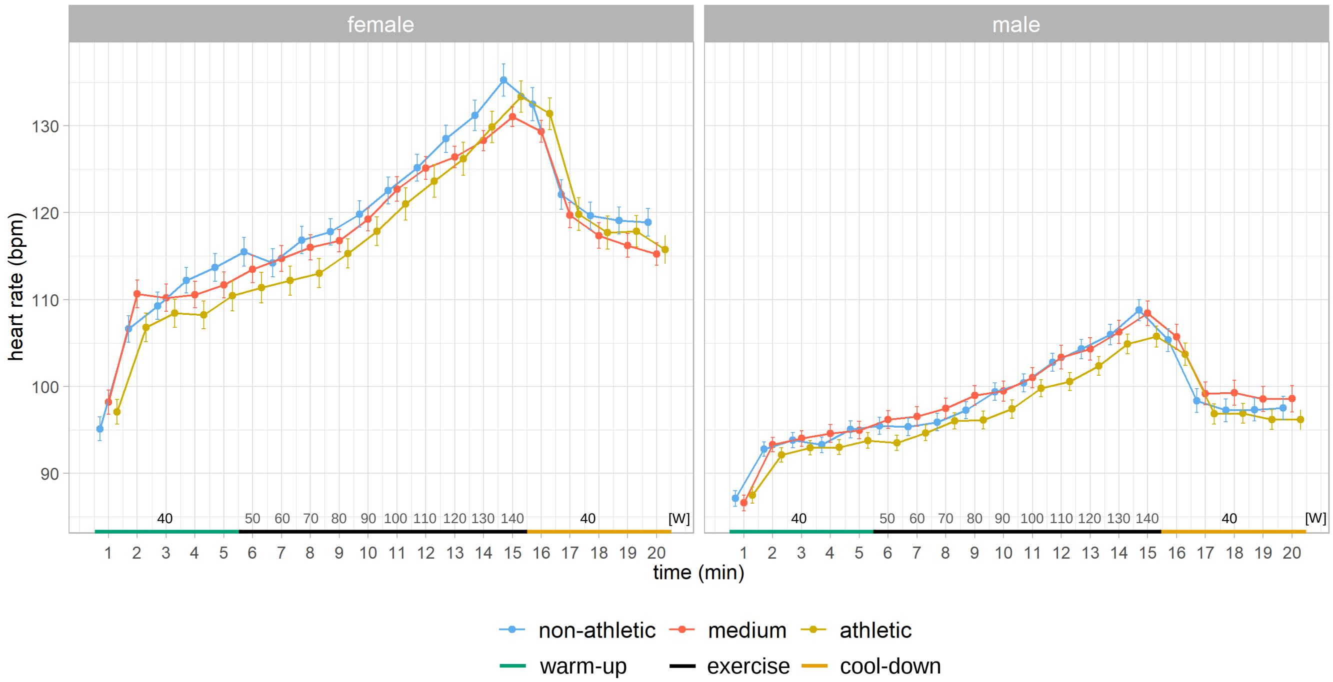

Figure 5: Average HR per minute during the warm-up, exercise, and cool-down phase with different workloads in watts [W]. The error bars show the 95% confidence interval.

10.140, $p = .004$, $\eta_p^2 = .315$ on the average HR during the exercise. There was no significant interaction effect of Body × Gender, $F(2, 44) = .248$, $p = .782$, $\eta_p^2 = .011$.

4.1.3 Average HR during resting periods. A multifactorial mixed ANOVA did not find a significant effect of Body, $F(2, 44) = 1.336$, $p = .273$, $\eta_p^2 = .057$, of Gender, $F(1, 22) = 2.853$, $p = .105$, $\eta_p^2 = .114$, nor an interaction effect of Body × Gender, $F(2, 44) = .251$, $p = .779$, $\eta_p^2 = .011$ on the average HR during the resting periods.

4.2 Perceived Exertion

A multifactorial mixed ANOVA revealed a significant main effect of Body, $F(2, 44) = 55.307$, $p < .001$, $\eta_p^2 = .715$, and Gender, $F(1, 22) = 7.712$, $p = .011$, $\eta_p^2 = .259$, on the perceived exertion. There was no significant interaction effect of Body × Gender, $F(2, 44) = 0.827$, $p = .444$, $\eta_p^2 = .036$. Pairwise comparisons using t-tests within Body showed significant differences between all avatars (all $p < .001$). Additionally, we performed a multi-variate linear regression analysis of each subdimension of the BRQ and of the PIS to test whether the variance in perceived exertion is affected by the experienced body ownership or identification with the avatars. We found a significant effect of the subdimensions *mirror*, $\beta = .401$, $p = .009$, and *agency*, $\beta = -.482$, $p = .002$, on participants' perceived exertion, $F(5, 66) = 4.056$, $p = .002$, $R^2 = .235$, $R^2_{adj} = .177$. However, we could not find a significant effect of the subscales of the PIS, $p = .340$, on participants' perceived exertion.

To determine if the participants' BMI had an effect on the perceived exertion, we performed a mixed ANCOVA and included the BMI as a covariate. We could not find a significant effect of the BMI, $F(1, 21) = .782$, $p = .386$, $\eta_p^2 = .035$, on the perceived exertion. Figure 4 depicts the mean ratings of the perceived exertion.

4.3 Pedaling frequency

We analyzed the time course per minute of the pedaling frequency by including the factor Time into the statistical analyses. Furthermore, the average pedaling frequency was evaluated. Figure 6 shows the time course of the pedaling frequency per minute.

4.3.1 Time course of the pedaling frequency. We performed a multifactorial mixed ANOVA and found a significant effect of Body, $F(2, 1298) = 7.071$, $p < .001$, $\eta_p^2 = .010$, however, there was no significant effect of Gender, $F(1, 22) = .320$, $p = .577$, $\eta_p^2 = .014$, on the pedaling frequency across time. We found a significant effect of Time, $F(19, 1298) = 8.486$, $p < .001$, $\eta_p^2 = .110$, and a significant interaction effect of Body × Gender, $F(2, 1298) = 16.537$, $p < .001$, $\eta_p^2 = .002$ and Gender × Time, $F(19, 1298) = 1.817$, $p < .016$, $\eta_p^2 = .025$. Subsequent pairwise comparisons using t-tests within Body showed significant differences between the *non-athletic* and *athletic* ($p = .002$), and the *medium* and *athletic* ($p = .027$) avatars. Pairwise cross-factor comparisons within the male avatars revealed a significant effect between the *non-athletic* and *athletic*, $p < .001$,

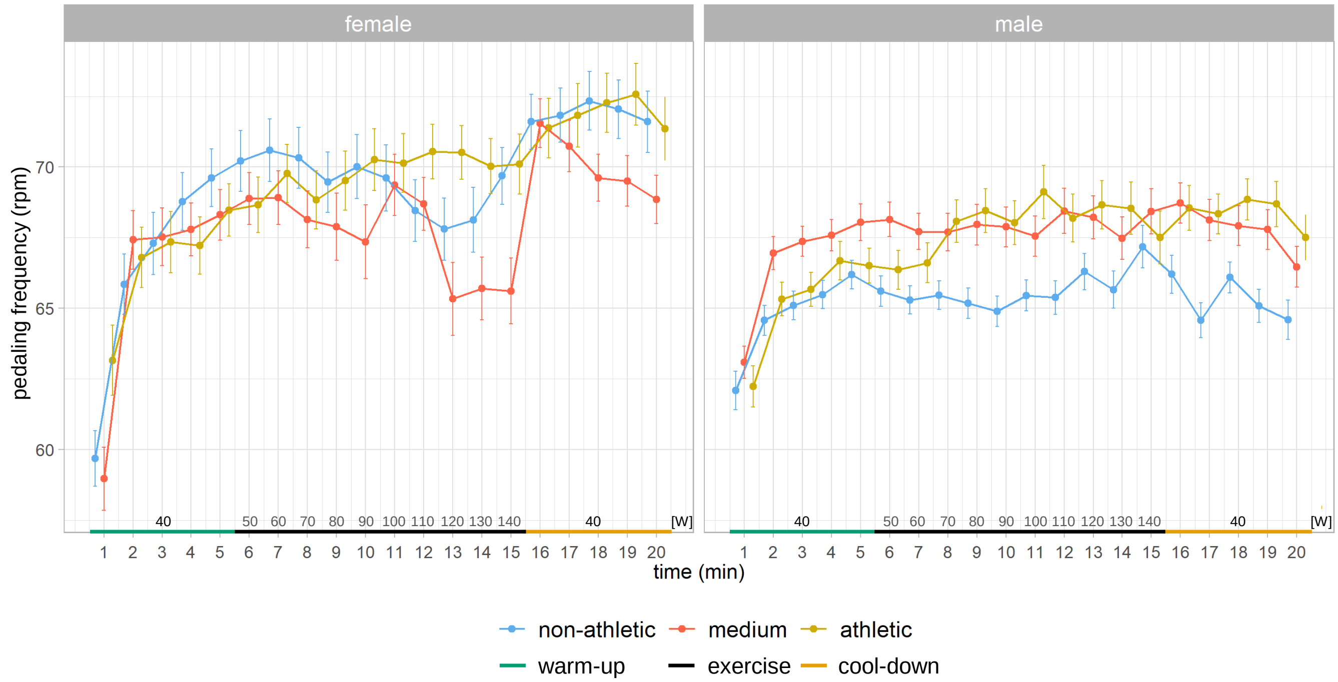

Figure 6: Average pedaling frequency per minute during the warm-up, exercise, and cool-down phase with different workloads in watts [W]. The error bars show the 95% confidence interval.

and the *non-athletic* and *medium*, $p < .001$, avatars. Pairwise cross-factor comparisons within the female avatars revealed a significant effect between the *non-athletic* and *medium*, $p < .001$, and the *medium* and *athletic*, $p = .001$, avatars. We did not perform further pairwise cross-factor comparisons to analyze differences between Gender and Time, as the interaction did not provide further insights regarding the research question. Furthermore, we performed a multi-variate linear regression analysis of each subdimension of the BRQ and of the PIS to test whether the variance in the pedaling frequency across time is affected by the experienced body ownership or identification with the avatars. We found a significant effect of the subdimensions *vrbody*, $\beta = 1.401$, $p < .001$, *mirror*, $\beta = -1.158$, $p < .001$, *features*, $\beta = .364$, $p = .033$, *twobodies*, $\beta = 1.204$, $p < .001$, and *agency*, $\beta = -2.756$, $p < .001$, on participants' pedaling frequency across time, $F(5, 1434) = 67.460$, $p < .001$, $R^2 = .190$, $R^2_{adj} = .187$. Furthermore, we could find a significant effect of the subscale *embodied presence* of the PIS, $\beta = -.838$, $p < .011$, and *similarity identification*, $\beta = 1.957$, $p < .001$, on participants' pedaling frequency across time, $F(3, 1436) = 10.730$, $p < .001$, $R^2 = .021$, $R^2_{adj} = .019$.

4.3.2 Average pedaling frequency. We performed a multifactorial mixed ANOVA and found neither a significant effect of Body, $F(2, 44) = .579$, $p = .565$, $\eta_p^2 = .025$, Gender, $F(1, 22) = .319$, $p = .578$, $\eta_p^2 = .014$, nor an interaction of Body × Gender, $F(2, 44) = 1.355$, $p = .269$, $\eta_p^2 = .058$ on the average pedaling frequency.

4.4 Distance

To detect significant differences in the covered distance for each avatar condition, we performed a multifactorial mixed ANOVA. We neither found a significant effect of Body, $F(2, 44) = 1.601$, $p = .213$, $\eta_p^2 = .067$, of Gender, $F(1, 22) = .328$, $p = .572$, $\eta_p^2 = .014$, nor an interaction effect of Body × Gender, $F(2, 44) = 2.011$, $p = .146$, $\eta_p^2 = .083$ on the distance covered on the stationary bicycle.

4.5 Body Ownership

We performed multiple multifactorial mixed ART ANOVAs on each subscale of the BRQ. We found a significant effect of Body, $F(2, 44) = 13.790$, $p < .001$, $\eta_p^2 = .385$, however, there was neither a significant effect of Gender, $F(1, 22) = 1.435$, $p = .243$, $\eta_p^2 = .061$, nor an interaction effect of Body × Gender, $F(2, 44) = 1.716$, $p = .191$, $\eta_p^2 = .072$, on the subscale *vrbody*. Pairwise comparisons using Wilcoxon signed-rank tests within Body revealed significant differences between the *non-athletic* and *athletic* ($p = .001$), and *medium* and *athletic* ($p = .049$) avatars.

We found a significant effect for Body, $F(2, 44) = 7.283$, $p = .001$, $\eta_p^2 = .248$ on the subscale *mirror*, however, there was no significant effect of Gender, $F(1, 22) = 3.672$, $p = .068$, $\eta_p^2 = .143$ and no interaction effect Body × Gender, $F(2, 44) = 1.270$, $p = .290$, $\eta_p^2 = .054$. Pairwise comparisons using Wilcoxon signed-rank

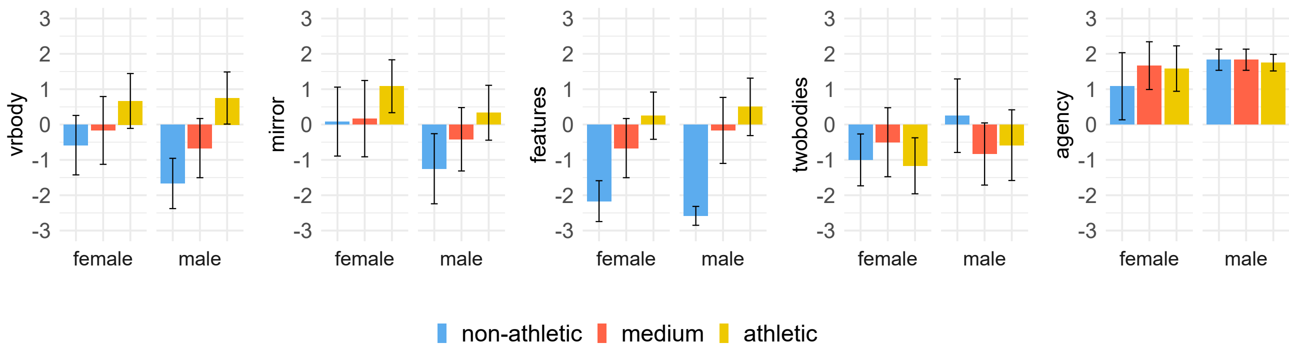

Figure 7: BRQ questionnaire scores on body ownership for each subdimension (vrbody, mirror, features, twobodies, agency). The error bars show the 95% confidence interval.

tests within Body showed significant differences between the *non-athletic* and *athletic* ($p = .003$) avatars. Other pairwise comparisons were not significant.

There was a significant effect for Body, $F(2, 44) = 27.433$, $p < .001$, $\eta_p^2 = .554$ on the subscale *features*, however, there was no significant effect of Gender, $F(1, 22) = .076$, $p = .784$, $\eta_p^2 = .003$ and no interaction effect Body × Gender, $F(2, 44) = 1.044$, $p = .360$, $\eta_p^2 = .045$. Pairwise comparisons using Wilcoxon signed-rank tests within Body showed significant differences between the *non-athletic* and *athletic* ($p < .001$), and *non-athletic* and *medium* ($p < .001$) avatars.

There was neither a significant effect of Body, $F(2, 44) = 1.047$, $p = .359$, $\eta_p^2 = .045$, Gender, $F(1, 22) = .757$, $p = .393$, $\eta_p^2 = .033$, nor an interaction effect of Body × Gender, $F(2, 44) = 2.327$, $p = .109$, $\eta_p^2 = .095$, on the subscale *twobodies*.

There was neither a significant effect of Body, $F(2, 44) = 1.115$, $p = .336$, $\eta_p^2 = .048$, Gender, $F(1, 22) = 1.678$, $p = .208$, $\eta_p^2 = .070$, nor an interaction effect of Body × Gender, $F(2, 44) = 1.746$, $p = .186$, $\eta_p^2 = .073$, on the subscale *agency*. Figure 7 shows the mean ratings for the subdimensions of the BRQ for each condition.

4.6 Self-Perceived Fitness

We performed multiple mulitfactorial mixed ART ANOVAs on each subscale of the SPF to detect differences in the perceived fitness for each avatar. We found a significant effect of Body, $F(2, 44) = 8.581$, $p < .001$, $\eta_p^2 = .280$, however, there was neither a significant effect of Gender, $F(1, 22) = .754$, $p = .394$, $\eta_p^2 = .033$, nor an interaction effect of Body × Gender, $F(2, 44) = .512$, $p = .602$, $\eta_p^2 = .022$, on the subscale fitness. Pairwise comparisons using Wilcoxon signed-rank test within Body showed significant effects between the *non-athletic* and *athletic*, $p = .016$, and the *medium* and *athletic* ($p = .020$) avatars.

We found a significant effect of Body, $F(2, 44) = 11.058$, $p < .001$, $\eta_p^2 = .334$, however, there was neither a significant effect of Gender, $F(1, 22) = 2.546$, $p = .124$, $\eta_p^2 = .103$, nor an interaction effect of Body × Gender, $F(2, 44) = .095$, $p = .909$, $\eta_p^2 = .004$, on the subscale endurance. Pairwise comparisons using Wilcoxon signed-rank tests within Body showed significant effects between the *non-athletic* and *athletic*, $p = .003$, the *medium* and *athletic*, $p = .014$, and the the *non-athletic* and *medium*, $p = .021$, avatars.

There was a significant effect of Body, $F(2, 44) = 7.862$, $p = .001$, $\eta_p^2 = .263$, however, we did not find a significant effect of Gender, $F(1, 22) = .597$, $p = .447$, $\eta_p^2 = .026$, nor an interaction effect of Body × Gender, $F(2, 44) = .190$, $p = .827$, $\eta_p^2 = .008$, on the subscale flexibility. Pairwise comparisons using Wilcoxon signed-rank tests within Body showed significant effects between the *non-athletic* and *athletic*, $p = .021$, and the *medium* and *athletic* ($p = .048$) avatar.

There was a significant effect of Body, $F(2, 44) = 5.583$, $p = .006$, $\eta_p^2 = .202$, and Gender, $F(1, 22) = 5.874$, $p = .024$, $\eta_p^2 = .210$, on the subscale strength. We did not find an interaction effect of Body × Gender, $F(2, 44) = .460$, $p = .633$, $\eta_p^2 = .020$. Pairwise comparisons using Wilcoxon signed-rank tests within Body showed significant effects between the *non-athletic* and *athletic*, $p = .044$, avatars. Other pairwise comparisons were not significant.

We found a significant effect of Body, $F(2, 44) = 8.925$, $p < .001$, $\eta_p^2 = .288$, however, there was neither a significant effect of Gender, $F(1, 22) = 2.662$, $p = .116$, $\eta_p^2 = .107$, nor an interaction effect of Body × Gender, $F(2, 44) = .407$, $p = .667$, $\eta_p^2 = .018$, on the subscale body composition. Pairwise comparisons using Wilcoxon signed-rank tests within Body showed significant effects between the *non-athletic* and *athletic*, $p = .017$, and the *medium* and *athletic*, $p = .011$, avatars. Figure 4 depicts the mean ratings of the SPF questionnaire.

4.7 User Identification

We performed multiple mixed ANOVAs on the measures of the PIS consisting of similarity identification, wishful identification and embodied presence. We found a significant main effect for Body, $F(2, 44) = 42.814$, $p < .001$, $\eta_p^2 = .660$, on similarity identification. There was neither a significant effect of Gender, $F(1, 22) = .008$, $p = .929$, $\eta_p^2 = .000$, nor an interaction effect of Body × Gender, $F(2, 44) = 1.036$, $p = .363$, $\eta_p^2 = .044$. Pairwise comparisons using

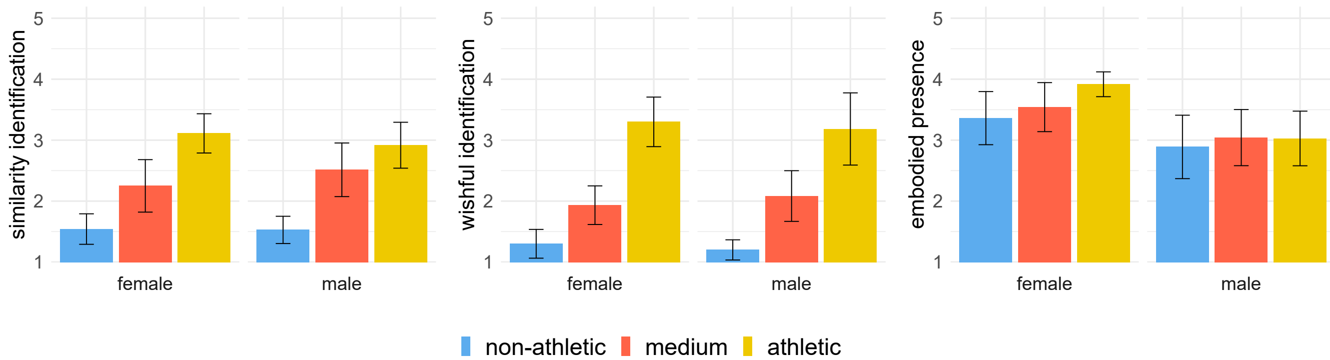

Figure 8: PIS questionnaire scores on user identification for each subdimension (similarity identification, wishful identification, embodied presence). The error bars show the 95% confidence interval.

t-tests within Body showed significant differences between the *non-athletic* and *athletic*, $p < .001$, the *medium* and *athletic*, $p = .005$, and the *non-athletic* and *medium*, $p < .001$, avatars.

We found a significant main effect for Body, $F(2, 44) = 70.192$, $p < .001$, $\eta_p^2 = .761$, on wishful identification. There was neither a significant effect of Gender, $F(1, 22) = .010$, $p = .923$, $\eta_p^2 = .000$, nor an interaction effect of Body × Gender, $F(2, 44) = .338$, $p = .681$, $\eta_p^2 = .017$. Pairwise comparisons using t-tests within Body showed significant differences between all avatars (all $p < .001$).

There was no significant effect of Body, $F(2, 44) = 2.530$, $p = .091$, $\eta_p^2 = .103$, however, we found a significant effect of Gender, $F(1, 22) = 4.845$, $p = .038$, $\eta_p^2 = .180$. There was no significant interaction effect of Body × Gender, $F(2, 44) = 1.138$, $p = .329$, $\eta_p^2 = .049$, on embodied presence. Figure 8 depicts the PIS questionnaire ratings for each condition.

5 DISCUSSION

The effects of the avatars' athleticism on perceived exertion replicate previous findings on the Proteus effect during physical tasks in VR [49]. We found a systematic relationship between the users' perception of effort and the avatar's athletic appearance. The analysis of quantitative data also shows that the participants' HR was significantly lower when embodying the athletic avatar compared to the non-athletic and medium avatar. These results imply that the avatar's appearance does not only affect the users' perceived exertion, but can also influence their HR while cycling in VR. We dismiss effects of fatigue as an explanation for the variance in HR between the avatars, since we adhered to a standardized protocol [73] to ensure that the participants had an identical workload per avatar condition within the aerobic threshold of 75% of the maximum HR [79].

5.1 Perception of Effort

Overall, these findings are consistent with the notion that an avatar's appearance representing certain traits can affect the users' performance during tasks that are in turn concomitant with the attributes of the virtual avatar. By inducing a feeling of owning a virtual body with a high level of athleticism, the users adopt the salient characteristics of the avatar and integrate them into their mental representation of the new self during exposition in VR. In line with self-perception theory [9], the users therefore attribute the avatars' characteristics to themselves and adhere to their new virtual identity. Hence, a perception-behavior process [21] is triggered so that the activated associations of athletic people performing well at physical exercises prime the users and, accordingly, affect their perception of effort.

The finding that an avatar's athletic appearance can potentially decrease the perceived exertion while performing physically demanding tasks is important and promising for designers and developers of VR exercise systems. It shows the potential of certain avatars to make users perceive an vigorous exercise less physically intense and exhaustive. Prior research in the field of exercise science showed that the perception of effort is a key factor of the psychobiological model which describes the regulation of human behavior during physical exertion [77]. The psychobiological model states that when a person's perception of effort is increased or decreased, the person will accordingly adapt the pace to compensate for the effects. Therefore, a higher perception of effort can limit endurance performance as we faster reach the maximum amount of effort we are willing to exert [66]. Similar applies to engagement and adherence to physical activities as a higher perception of effort reduces the exercise tolerance – the capacity to sustain physical exercise [77]. As perception of effort can be a barrier to regular physical activity and contributes to exercise adherence [8, 65], its reduction using avatars in VR exercises may, therefore, pose an opportunity to engage users and incentivize physical activity. This is in line with an editorial by Marcora [65] who debates the use of psychoactive drugs such as caffeine, which can reduce the perception of effort and unpleasant sensations during intense exercise to foster adherence to this kind of exercise.

5.2 Effects on HR

To explain the effect of a decreased HR when embodying the athletic avatar while cycling in VR, we refer to research in sports psychology that has shown different psychophysiological effects on professional and amateur athletes during exercise, for example, caused by

Descriptive Statistics

	Female (N = 12)						Male (N = 12)					
	non-athletic		medium		athletic		non-athletic		medium		athletic	
Measure	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Average HR during exercise (in bpm)	118.75	20.5	117.60	17.84	116.81	21.91	98.14	13.58	98.81	14.86	96.99	12.70
Average HR during resting period (in bpm)	90.01	18.41	90.67	19.03	87.28	28.10	79.64	15.22	81.43	16.34	79.28	15.45
Average Pedaling Frequency (in rpm)	69.23	12.57	67.78	12.06	69.52	12.28	65.31	6.83	67.56	7.97	67.38	9.01
Perceived Exertion	11.52	1.02	10.93	0.58	9.81	0.76	10.14	1.74	9.45	1.54	8.70	1.34
Distance (in km)	8.66	1.45	8.50	1.33	8.75	.144	8.14	0.74	8.49	0.90	8.50	0.97
BRQ- vrbody	-0.58	1.62	-0.16	1.85	0.66	1.49	-1.66	1.37	-0.66	1.61	0.75	1.42
BRQ - mirror	0.08	1.88	0.16	2.08	1.08	1.44	-1.25	1.91	-0.41	1.72	0.33	1.49
BRQ - features	-2.16	1.11	-0.66	1.61	0.25	1.28	-2.58	0.51	-0.16	1.80	0.50	1.56
BRQ - twobodies	-1.00	1.41	-0.50	1.88	-1.16	1.52	0.25	2.00	-0.83	1.69	-0.58	1.92
BRQ - agency	1.08	1.83	1.66	1.30	1.58	1.24	1.83	0.57	1.83	0.57	1.75	0.45
Similarity Identification	1.54	0.48	2.25	0.83	3.11	0.62	1.52	0.43	2.51	0.84	2.91	0.72
Wishful Identification	1.30	0.45	1.93	0.61	3.30	0.78	1.20	0.31	2.08	0.80	3.18	1.42
Embodied Presence	3.36	0.84	3.54	0.77	3.91	0.39	2.88	1.03	3.04	0.88	3.02	0.86
SPF - fitness	6.41	2.84	6.75	2.45	8.25	2.17	6.75	3.25	8.00	2.59	9.25	2.73
SPF - endurance	5.91	3.14	6.75	2.73	8.50	1.88	7.08	3.82	8.50	2.67	9.83	2.03
SPF - flexibility	6.66	3.72	7.00	2.82	8.33	1.49	5.41	3.67	6.58	3.42	7.66	3.36
SPF - strength	5.16	2.94	5.66	2.83	6.91	2.60	7.00	2.13	8.08	1.83	8.41	2.06
SPF - body composition	5.66	3.17	5.91	2.60	7.50	1.73	6.66	3.77	7.75	2.63	9.66	2.34

Table 1: Descriptive data showing the means (M) and standard deviations (SD) for each measure. For the sake of clarity, we did not provide any descriptive statistics for the time course of the HR and pedaling frequency per minute. The time course for both measures is shown in Figure 5 and Figure 6, respectively.

high-fives [56], exercise in a group [115], music [11, 19, 59, 80], television [94], biofeedback training [33] as well as mental imagery [39]. In sports psychology, mental imagery has proven to be an effective psychological tool to improve physical performance [69, 109, 116] and describes the self-visualization while exercising, e.g. visualizing oneself being motivated and engaged or with an enhanced physical appearance [90]. Transferring this idea to virtual avatars, VR supports the mental imagery process by vividly visualizing what it would be like to own a body with different degrees of athleticism during the actual exertion. As shown in the SPF scores, the participants attributed a high level of fitness and athleticism to the athletic avatars. Since self-confidence and self-efficacy were identified as one of the underlying mechanisms for the induced changes in physical performance and physiological responses through mental imagination [110], we hypothesize that the participants felt more confident in the athletic than in the medium and non-athletic avatar to be able to master the upcoming challenge and to perform well. This could, in turn, result in a lower stress level indicated by a decreased HR. Future investigations are needed to verify our assumption by assessing the participants’ confidence and self-efficacy as well as the degree of excitement during virtual embodiment. Furthermore, a visual comparison of the average HR across time suggests that the athletic avatars’ impact remained stable throughout the warm-up and exercise, but decreases during cool-down. Hence, future studies should focus on the time course of the Proteus effect and how this phenomenon evolves over time to understand how to harness the full potential of the effect.

Research in psychology also offers the attentional shift [60] caused by the avatars’ appearances as a potential explanation for the effects found in our study. Bigliassi et al. [12] showed, for example, that motivational audiovisual stimuli could affect the brain activity resulting in a decreased feeling of fatigue in the muscles. Researchers agree that a shift in attention from internal cues, e.g. HR or fatigue, to external cues, e.g. music or video, influences physiological responses to physical activity, e.g. attenuating stress and arousal [92, 94]. Although we did not specifically assess attention in terms of association and dissociation [60], the virtual body itself provided the main cues that could have been the focus of users’ attention. Considering the scores of the BRQ and the PIS, we induced the strongest body ownership in the athletic avatars with the highest score for similarity identification, indicating that the avatars with an athletic appearance are most akin to the participants’ physical body. The aforementioned theory of shifting attention would suggest that participants were distracted by the avatars with features and characteristics that deviated from their real physical body, potentially attenuating physiological responses such as the HR, which was not the case. We, however, found that participants’ had a lower HR in the avatar with an athletic appearance, that is why we assume that the shift in attention is not the driver for a decrease in the HR. To validate our assumption, future work could include measures of assessing the participants’ attentional focus while embodying virtual avatars with different attributes during physical exertion.

5.3 Pedaling Frequency

The Proteus effect suggests that the participants behave in accordance to the common expectations connected with the avatars’

Inferential Statistics

Measure	Body		Gender		Body × Gender		Time		Gender × Time	
	p	η_p^2	p	η_p^2	p	η_p^2	p	η_p^2	p	η_p^2
HR (time course)	<.001	.014	.004	.315	.052	.004	<.001	.591	<.001	.102
Average HR during exercise	.449	.035	.004	.315	.782	.011	-	-	-	-
Average HR during resting period	.273	.057	.105	.114	.251	.779	-	-	-	-
Pedaling Frequency (time course)	<.001	.010	.577	.014	<.001	.002	<.001	.110	.016	.025
Average Pedaling Frequency	.565	.025	.578	.014	.269	.058	-	-	-	-
Perceived Exertion	<.001	.715	.011	.259	.444	.036	-	-	-	-
Distance	.213	.067	.572	.014	.146	.083	-	-	-	-
BRQ - vrbody	<.001	.385	.243	.061	.191	.072	-	-	-	-
BRQ - mirror	.001	.248	.068	.143	.290	.054	-	-	-	-
BRQ - features	<.001	.554	.784	.003	.360	.045	-	-	-	-
BRQ - twobodies	.359	.045	.393	.033	.109	.095	-	-	-	-
BRQ - agency	.336	.048	.208	.070	.186	.073	-	-	-	-
Similarity Identification	<.001	.660	.929	.000	.363	.044	-	-	-	-
Wishful Identification	<.001	.761	.923	.000	.681	.017	-	-	-	-
Embodied Presence	.091	.103	.038	.180	.329	.049	-	-	-	-
SPF - fitness	<.001	.280	.394	.033	.512	.602	-	-	-	-
SPF - endurance	<.001	.334	.124	.103	.909	.004	-	-	-	-
SPF - flexibility	.001	.263	.447	.026	.827	.008	-	-	-	-
SPF - strength	.006	.202	.024	.210	.633	.020	-	-	-	-
SPF - body composition	<.001	.288	.116	.107	.667	.018	-	-	-	-

Table 2: Inferential statistics providing p-values and the corresponding effect sizes (η_p^2) for each measure. Only the HR and the pedaling frequency were statistically analyzed across time.

appearance. One might assume that the elicited behavioral changes due to the embodiment of the avatars affect the physiological responses while cycling in VR. Although we found changes in behavior with regard to the pedaling frequency induced by the avatars' athleticism, they cannot explain the differences in HR as there is no systematic effect of the athletic avatars that are in line with the HR across time. These unsystematic behavioral correlates support previous work showing that idealized avatars can either enhance or decrease the power output while cycling in a competitive VR exergame [54]. This is also in line with Peña and Kim [81] who showed that players of a tennis exergame can exhibit a decreased physical activity when they think that their avatar has either a physical advantage or a disadvantage over the opponents' virtual character. Hence, more research is needed to understand behavioral changes caused by an avatar's appearance in a sports context due to these ambiguous findings.

5.4 Body Ownership and BMI

We also found a relationship between the body ownership ratings and the perception of effort, the HR across time and the pedaling frequency. Additionally, there were correlations between the subscales of the user identification and the HR across time as well as the pedal frequency. Hence, we cannot rule out effects of the experienced body ownership and the identification with the avatars on physiological responses and behavioral changes. Considering the ratings of the BRQ, which were generally low for the male- and female-gendered non-athletic and medium avatars, the extent of the body ownership may partially explain the effects on the perception of effort and HR response. This is supported by findings from prior investigations showing that a user's physiological behavior is affected by the degree of full body ownership over virtual avatars.

Slater et al. [108], for example, found in a VR experiment that participants who embodied an avatar from 3PP had a lower HR in response to a virtual threat compared to when embodying an avatar from 1PP. Likewise, Bergström et al. [10] demonstrated that the HR and HR variability correlates with the strength of the experienced body ownership. The authors found that an uncomfortable body posture of an avatar increases the HR and that the rise in HR is associated with a higher level of body ownership. Due to these findings, we cannot definitely conclude that the effects arose as a function of the avatars' appearance. Additionally, previous work found that avatars with characteristics fundamentally different than one's own physical body can provide a novel experience increasing excitement and interest [7, 55]. Therefore, the non-athletic and medium avatar could trigger engagement and excitement resulting in arousal which raised the HR. Our results did not determine if the non-athletic and medium avatar increased or the athletic avatar decreased the HR. Consequently, more research is needed to explore the relationship between avatars which are associated with a high level of fitness and the induced physiological changes. As research suggests that the body ownership is a significant moderator of the Proteus effect [5], future work should aim to design appropriate avatars with characteristics representing the desired degrees of physical fitness without deteriorating the body ownership and agency. We hypothesize that such avatars can be achieved by enabling the users to customize the avatars' appearance during embodiment in VR based on predefined requirements.

We assume that a user's physical condition could also mediate the Proteus effect during exercise in VR. In line with Kocur et al. [49], who recommended to assess the BMI as an objective measure of one's physical condition, we analyzed the BMI as a potential moderator by including it as a covariate in our statistical analyses. However, we could not find any effects indicating a relationship between the psychophysiological effects of an avatar's appearance and the participant's BMI. This can be due to the fact that our participants had similar BMIs (M = 22.74, SD = 2.61). Nonetheless, we do not rule out that a user's physical condition and fitness mediates the Proteus effect during physical activity. Since we did not systematically controlled the BMI in our study, future work should investigate whether and to what extent one's physical condition and athleticism mediate avatars' effects during physical effort.

5.5 Adverse Effects and Risks

Regardless of whether the effects are caused by the extent of the perceived body ownership or the avatar's athletic appearance, the psychophysiological impact of avatars on users during physical exertion should be considered when designing avatars for VR exercise systems. As the perception of effort and HR are variables that represent the psychological and physiological response to physical effort, their manipulation can entail risks. Iodice et al. [43], for example, povided false acoustic HR feedback during cycling in a real-world experiment to modulate the perception of effort. Similar to an exteroceptive BOI as a misperception of a brain's body representation, the authors, therefore, induced an interoceptive illusion - a misperception of one's physiological state in terms of effort. The authors found that an increased HR feedback caused a higher perception of effort, so that the participants overestimated their perceived exertion. Interestingly, a decreased HR feedback did not result in a lower perception of effort. They argued that this asymmetry is due to a cautious risk-averse strategy, as underestimating the perceived exertion may mislead someone to exercise with an intensity that exceeds one's physical ability. Hence, innapropriate exercise intensities can, for example, increase the risk for injuries [97], sore muscles [22], overexertion[60], and reduce exercise adherence [57, 93, 97]. We, however, found a decreased perception of effort with a lower HR potentially due to the embodiment of an athletic avatar. Although the ratings of the Borg's RPE scale indicated that the perceived exertion was generally low with only a slight decrease in HR, the same exercise was perceived as less physically intense when embodied in an avatar whose appearance is connected with better physical abilities compared to the other avatars. Even if our findings seem promising to positively affect the user, the aforementioned adverse effects have to be kept in mind in the avatar creation process particularly regarding beginners of fitness programs and amateur athletes [36]. Consequently, our results need further investigation with a more diverse population considering potential negative effects caused by the embodiment of avatars to better understand the Proteus effect and, therefore, to gain knowledge that contributes to a more effective and particularly advantageous usage of avatars in VR exercise applications.

6 CONCLUSION

In this paper, we investigated the effects of an avatar's athletic appearance on the user's perception of effort and physiological response during physical activity. First, we systematically designed 32 avatars and conducted an initial study to determine the stimuli for our VR experiment. Afterwards, we conducted a study with 24 participants who embodied three avatars with different levels of athleticism while riding a stationary bicycle in VR. We found that the participants had a lower HR when embodying the athletic avatars compared to the non-athletic and medium avatars. We also observed a systematic relationship between an avatar's athletic appearance and the perception of effort. Participants embodied in the athletic avatars perceived the exercise as less physically strenuous than embodied in the non-athletic and medium avatars. Our results suggest that avatars which are associated with a high level of fitness can reduce a user's perception of effort and decrease the HR during physical activity in VR. While previous work showed that an avatar's appearance could positively affect the physical performance, we found that avatars can even affect physiological responses to effort. In line with related theories from sports psychology, we assume a boost in confidence due to the athletic avatars resulting in a decreased HR. These findings suggest that avatars may be a powerful tool to positively influence users during physical exertion. More research in a more controlled environment with a larger body of participants is required to confirm our findings, as they may pose a promising opportunity for designers and developers of VR exercise systems to make users perceive high-intensity exercises less physically strenuous, and, therefore, promote physical activity and foster exercise adherence. Future studies can build upon our work to explore the psychophysiological impact of avatars to gain a deeper understanding of the mechanisms underlying exercise performance in VR.

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