The Absence of Athletic Avatars' Effects on Physiological and Perceptual Responses while Cycling in Virtual Reality

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ABSTRACT

Virtual reality (VR) allows to embody avatars—the digital self-representation of the user. An avatar's appearance can change users' perception and behavior—a phenomenon known as the Proteus effect. Previous work found that athletic avatars can reduce heart rate and perceived exertion during physical effort. Although these findings are promising to create more effective VR exercises, they have not been replicated yet. Hence, the reliability and consistency of such effects is unknown. Therefore, we conducted a study with 32 participants to investigate physiological and perceptual effects of athletic avatars while cycling in VR following a standardized exercise protocol. We could not find effects of the avatars' athletic appearance on heart rate, perceived exertion, and imagined velocity. Our findings indicate that athletic avatars do not necessarily affect users during physical exertion. We discuss potential factors that can cause the Proteus effect fail to occur.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; *Haptic devices*; • **Applied computing → Computer games**.

KEYWORDS

avatars, Proteus effect, virtual reality, cycling, physical performance, body ownership

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1 INTRODUCTION

In recent years, the popularity and interest of health-related applications and exercise systems has grown. Researchers and developers of exergames [69] or immersive fitness applications [1] leveraged computer-generated sports environments to promote physical activity [47]. In immersive VR applications, e.g., FitXR [19], users perceive the virtual environment from a first-person perspective while their motions are registered by controllers and transmitted as user input during workouts in VR. Consequently, VR induces the illusion of being transported to another place while physically exercising so that the virtual performance correlates with the users' actual physical effort and activity. The combination of entertainment and novelty provided by digital technology (such as VR) with physical effort and activity has been successfully applied to increase motivation and engagement during exercise [55], enhance physical performance [49], and reduce perceived exertion [71].

A crucial component of an immersive and embodied experience is the avatar—the digital self-representation of the user [32]. Previous work found that a first-person perspective in combination with motion capture—registering the users' motion and transferring them onto the avatar—can create such strong cues that users can experience the avatar as their own body [29]. This illusory sensation of embodying an artificial body is known as the body ownership illusion (BOI) [28, 67]. Interestingly, research found that the BOI over avatars with certain visual appearances can change users' behavior and perception [76]. Yee and Bailenson [76] showed that while embodying attractive avatars increased self-confidence in a VR dialogue, the embodiment of tall avatars caused more aggressive bargaining behavior. Such changes are attributed to the Proteus effect [59, 76, 77]. The Proteus effect describes that users conform in behavior and attitude to their avatars' visual characteristics based on the stereotypical associations connected with the appearance [77].

There are also first manifestations of the Proteus effect during physical effort. Kocur et al. [38], for example, revealed that muscular avatars can decrease the perception of effort while holding weights. Another study indicated that athletic avatars can even decrease heart rate while cycling in VR [34]. These findings suggest that the

Proteus effect can not only influence users' perception and behavior [22], but also their physiological responses to physical effort. The Proteus effect opens up new possibilities for designers and researchers of immersive exercise systems. Systematically regulating users' responses to physical exercise allows to make exercise feel less strenuous without decreasing the actual intensity. On the one hand, avatars could, therefore, serve as a promising tool to enhance performance and increase exercise adherence [32]. On the other hand, such effects could entail risks as they could also have adverse consequences, such as overexertion [45], sore muscles [15], and an increased risk for injuries [34]. Hence, it is required to replicate the findings to learn more about the Proteus effect during exercise and understand how reliable and robust this phenomenon is. This is crucial for designers and creators of immersive exercise systems as they need to know how and whether an avatar's appearance can be leveraged to positively affect users during exertion. However, studies replicating the Proteus effect during physical exercise are scarce. Therefore, the reliability and robustness of avatar-induced physiological and perceptual effects during exertion is unclear.

In this paper, we investigated the impact of an avatar's athletic appearance on imagined physical performance, perception of effort, and heart rate responses while cycling an ergometer in VR. We, therefore, intended to replicate findings from previous work [34, 38] to learn how reliable and robust these findings are. We conducted a study with 32 participants who embodied athletic and non-athletic avatars during virtual cycling. We found that the avatars' athletic appearance had no effects on users' imagined physical performance, perception of effort, and heart rate responses. Hence, we were not able to replicate findings from previous work. We argue that the Proteus effect cannot be simply triggered using stereotypical avatars without considering users' characteristics and predispositions. We discuss potential factors that can cause the Proteus effect fail to occur.

2 RELATED WORK

In this section we discuss previous work investigating the perception of avatars in VR and the resulting effects on the user. Research around embodied cognition theories linked to body representation and body-related information is presented.

2.1 Body Ownership Illusions

The users' sensation of embodying the avatar and experience of control over the actions in the virtual environment are important factors for achieving a natural and vivid VR experience [42, 65, 66]. Hence, designers and researchers of VR applications aim to create a sense of body ownership of the avatar, which is an important component of any VR experience [29, 64]. Having an avatar in VR, for example, can increase the sense of presence and enhance depth perception [6, 70].

Such BOIs can be induced by using tracking devices to synchronize the movement of the avatar to the body movement of the user. One of the first manifestations of BOIs were shown in the real world inducing ownership sensations over an artificial rubber hand [12]. Another work by Kokkinara and Slater [40] focused on the ownership of a virtual leg by synchronously touching users' real leg while seeing the touch on the virtual leg. BOIs can be so intense that user can experience avatar embodiment even if the virtual appearance doesn't match the physical of the user [4, 25].

2.2 Embodied Cognition

The term embodied cognition describes that our perception and behavior depends on the characteristics of our own body [2]. There are multiple embodied cognition theories which emphasize the relation of body related information and representation with cognitive processes [18, 23, 74].

In recent years, multiple studies investigated embodied cognition approaches by manipulating body parts or other visual features. Linkenauger et al. [46] used an illusion of having smaller or larger body parts by using magnifying goggles, which resulted in a change of size perception regarding graspable objects. Similar effects can be seen in full body illusions in VR [3, 73]. The perception about the environment is influenced by the associated effort and possibilities connected with the own body and abilities. One example was shown by Kirsch and Kunde [30] who placed objects within reach for the user together with an either strong or weak counterforce. Results indicate that a stronger counterforce caused larger perceived distances of the objects. A similar effect could be seen with carrying a backpack and the estimation of the slope of hills [9] or the distance towards a target [57].

Tosi et al. [72] used a full body illusion to lengthen the legs of the user while doing an imaginary walking task towards a target, which resulted in an imagined quicker walk with longer legs. This study highlights the potential of inducing an illusion of the virtual body and the effects on users' perception. Different research also suggests that BOIs can induce physiological changes such as effects on skin temperature [36, 37]. Overall, these studies indicate that the way humans perceive and behave is directly connected to the own body. Hence, embodied cognition could be a theoretical framework to explain the Proteus effect.

2.3 Proteus Effect

The avatars' appearance can affect users' perception and behavior in the virtual world—a phenomenon known as the Proteus effect [76]. One of the first studies showing the Proteus Effect was done by Yee and Bailenson [76], who documented that users who embodied attractive avatars interacted with more confidence in social settings than with less attractive avatars. The Proteus effect originates from users' perception of the avatars' stereotypical appearance. While users' embody an avatar with certain visual characteristics, the concepts associated with the avatars' appearance are primed resulting in changes of behavior, attitude, and perception [38, 59, 77].

One possible explanation for this phenomenon is self-perception theory, indicating that people alter their behavior and attitude due to the perception of their own self [7]. Applying this idea to the Proteus effect, users change their behavior and attitude based on characteristics, stereotypes and features connected with the avatars visual appearance. This phenomenon was evidenced in multiple studies: Older looking avatars affect walking speed [61], muscular avatars enhance physical performance [38], athletic avatars as well as sweaty looking avatars reduce perceived exertion [33, 34], and dark-skinned avatars reduce racial bias [4, 20].

Further studies showed that embodying dark skinned avatars as a light skinned participant resulted in more active and rhythmically playing a drum compared to a light skinned avatar [27]. Similar could be observed by Yang et al. [75] in a non-immersive game as dark-skinned avatars were played more aggressively than light-skinned ones [75]. Furthermore, playing as an heroic avatar, Peña et al. [54] reported a more prosocial behavior.

Various studies suggest that avatars have an impact on users' performance. Some studies indicate that an improved cognitive performance can be induced using an Einstein avatar [5, 39]. Previous work also found enhancements in physical performance. Experienced typists can nearly match their typing speed outside of VR by using virtual hands on a keyboard in a typing scenario, as demonstrated by Knierim et al. [31]. Kocur et al. [38] demonstrated that physical performance can be improved in an isometric weightlifting scenario by using muscular avatars [38]. A similar outcome was observed by Otono et al. [53] when an AR overlay of the avatar was placed on the user's body. Although both studies employed muscular avatars to influence performance, Navarro et al. [51] demonstrated that physical activity can also be improved by a high user-avatar similarity [51].

2.4 Summary

Previous research demonstrated a strong association between the user's avatar in a virtual environment and their attitude, behaviour, and physical performance, which is known as the Proteus effect. Previous work found that muscular and athletic avatars can improve physical performance while cycling in VR. To be able to leverage an avatars' appearance during physical exercise in VR, it is crucial to know how robust and reliable this phenomenon is. However, such findings could not be replicated yet. Consequently, the consistency and reliability of the Proteus effect during physical exertion in VR is unclear.

3 METHODS

We investigated whether the avatars' athletic appearance can affect physiological responses to physical effort and imagined physical performance. Participants embodied two avatars of their identified gender with different athletic appearances. With each of the avatar, they had to complete tasks in different virtual environments. While we aimed to investigate the impact of an avatar's athletic appearance on imagined physical performance, i.e. the imagined velocity in a cycling imagery task, we also intended to replicate findings from previous work [34, 38] demonstrating effects of the avatars athletic appearance on user's perceived exertion and heart rate responses during real cycling on an ergometer. Hence, we explored the reliability and robustness of the Proteus effect during physical exertion in VR.

3.1 Study Design

We conducted a controlled experiment using a within-subjects design with independent variable avatar consisting of two levels athletic and non-athletic. To rule out any sequence effects, we counterbalanced the order of conditions. Hence, participants embodied avatars of their identified gender with a different athletic appearance (see Figure 1).

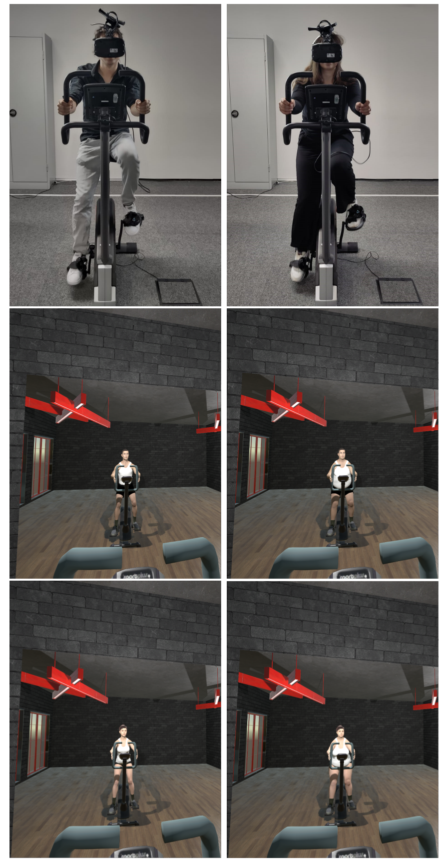

Figure 1: Participants were cycling an ergometer in the real world using an HMD (top). They embodied an athletic (left) or non-athletic (right) avatar of their identified gender while cycling in front of a virtual mirror.

3.2 Measures

We took multiple objective and subjective measures to assess the effects of the independent variable. While the participants were riding a stationary bicycle, we assessed the perceived exertion using the Borg's Rating of Perceived Exertion (RPE) scale [10]. We also measured the heart rate to assess physiological responses while cycling using an optical heart rate sensor (Polar OH1, Polar Electro, Finland) worn at the forearm. Moreover, we measured participants' imaginary velocity in the respective avatar condition to determine perceptual changes caused by the avatars' athletic appearance.

We also asked participants to complete questionnaires after each condition such as the self-perceived fitness (SPF) questionnaire [16] and the body representation questionnaire (BRQ) [3, 5] for quantifying the experienced body ownership. For the SPF questionnaire, we used a version of the self-appraisal questionnaire from Borg et al. [11], adapted by Delignières et al. [17], with the five dimensions endurance, strength, flexibility, body composition, and fitness, rated on a 13-point scale. The BRQ consisted of five 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") rated on a 5-point scale.

3.3 Tasks

In this study, we asked the participants to perform two tasks to explore the avatars' effects on different measures.

3.3.1 Ergometer cycling task. In the *ergometer cycling task*, participants were in the *studio scene* and had to cycle for 20 minutes on the ergometer while being embodied by one of the avatars. Based on a standardized protocol [34, 52], it started with a five-minute warm-up phase (minutes 1-5) in which the participants had to cycle slowly at a constant low-intensity load of 40 watts. In the exercise phase (minutes 6-15), the ergometer was set at 50 watts at the beginning and increased by 10 watts every minute until a workload of 140 watts was reached. The task finished with a five-minute cool-down phase (minutes 16-20) with a constant workload of 40 watts. To assess the perceived exertion during stationary bicycle riding, we applied an experimental procedure used by previous work [33, 34]. At four specific time points within the 20-minute cycling task (4:45, 9:45, 14:45, and 19:45 minutes), the participants were presented with a visual representation of the Borg's RPE scale ranging from 6 (no exertion) to 20 (maximum exertion) [10]. Participants verbally expressed the value that most accurately represented their perceived exertion. Throughout the *ergometer cycling task*, we additionally measured participants' heart rate.

3.3.2 Cycling imagery task. Inspired by Tosi et al. [72], we used a cycling imagery task to assess how the embodiment of avatars with different athletic appearances changes imaginary velocity. This task allows to determine the impact of avatars on users' perception. In the *cycling imagery task*, participants were asked to imagine that they were cycling along a road and to produce the time it takes to imaginarily cycle a given distance. One trial of this task is illustrated in Figure 3. A trial of the *cycling imagery task* started with displaying the *street scene* with a finish line at one of four distances (36, 54, 72 or 90 metres based on the game engine's metric system, see Figure 2).

After three seconds, a starting line appeared in the scene. The participants were instructed to produce their imagined cycling time by pressing the mouse button twice, which was attached on the ergometer's handle. The first press indicated the start of cycling and the second press indicated the timepoint when the participant imaginarily crossed the finishing line. After the first button press, a text prompt appeared in the scene with the word "STARTED" in green. After the second button press the word "STOPPED" in red appeared in the scene for three seconds. Lastly, the starting and finishing line disappeared for three seconds and the next trial started. The *cycling imagery task* comprised four blocks consisting of eight trials with each distance occurring twice in random order. In sum, each participant completed 32 trials. To ensure that participants still were embodying the respective avatar when performing the *cycling imagery task*, we included embodiment phases between the blocks of this task. During the embodiment phases, participants were in the *studio scene* and had to cycle for one minute with a constant workload of 50 watts.

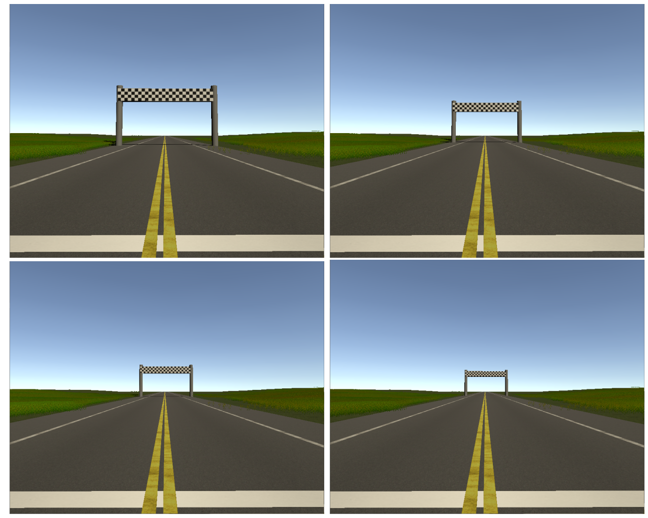

Figure 2: *Street scene* with four different distances (36, 54, 72, 90) as used in the cycling imagery task

3.4 Apparatus

In this study, participants performed tasks in VR scenes while seated on a bicycle ergometer. The bicycle ergometer (SportPlus Ergometer, Latupo GmbH, Germany) was equipped with electromagnetical brakes and was standing in the middle of our VR laboratory. During the cycling tasks the ergometer's "watt mode" was used, which dynamically adjusts the resistance to a specified watt value. Consequently, participants experienced a physical workload that remained consistent regardless of their speed. To capture cycling movements of the participants, HTC Vive trackers were affixed to each pedal. To present the VR application and track head movements of the participants, we used an HTC Vive head-mounted display (HMD) with a wide horizontal field-of-view of 100° and a spatial resolution of 1080 × 1200 pixels per eye displayed at 90 frames per second. A Polar OH1 optical sensor and a Polar V650 cadence sensor in combination with the Polar Beat app running on an Android smartphone were used to measure the heart rate and pedaling frequency of the participants in the *ergometer cycling task*. Responses in the *cycling imagery task* were given by pressing the button of a standard mouse that was attached to the handle of the ergometer.

The avatar models were designed using Daz 3D. We used two male and two female avatars with different athletic appearances (see Figure 1). These avatars shared an identical skeleton structure with matching bone configurations. In line with Kocur et al. [34], the non-athletic versions of the avatars were adjusted to a bulkiness level of 66% and the athletic versions of the avatars to a bulkiness level of 0%. The gender of the avatars was chosen based on the self-identified gender of the participants.

The VR application was built using Unity 2019.3.13f1 along with SteamVR and the Final IK toolkit. Participants experienced the

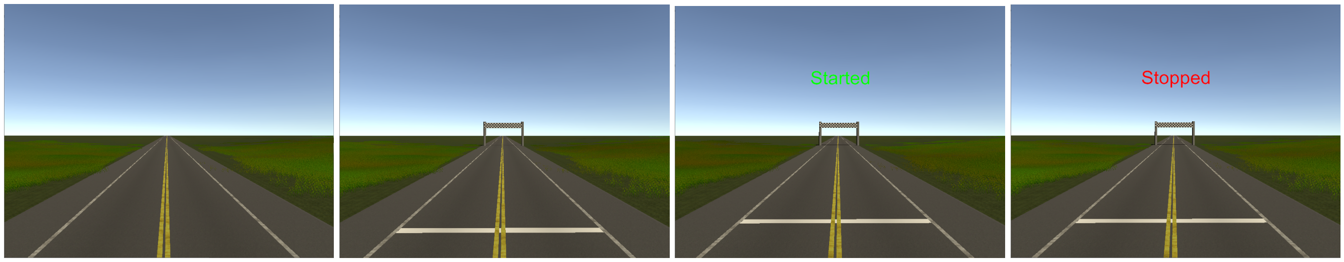

Figure 3: Different states of the *cycling imagery task*. First an empty street was shown. After 3 seconds a start line and goal at a specific distance (36, 54, 72, 90) appeared indicating the participants that they can start to imagine cycling towards the goal. Once they pressed the button, a green "Started" appeared over the target. Once they pressed the button again, the green changed to a red "Stopped" for 3 seconds. Afterwards the task started from the beginning.

virtual scenes and their virtual representations (the avatar) through a first-person perspective. The Final IK toolkit was employed to synchronize the avatars' motions with the user's movements, which were tracked by the HMD and the tracker attached to the pedals of the ergometer.

We used two different virtual scenes in the study. The *studio scene* was used for the *ergometer cycling task* and the embodiment phase to foster the experienced sense of embodiment. To allow the participants to focus on their virtual body during cycling, the *studio scene* consisted of a simple dark-walled room, a stationary virtual ergometer, and a mirror with stereoscopic reflections (see Figure 1). The virtual mirror was placed into the scene to enable participants to constantly perceive their virtual body while cycling on the ergometer. The *street scene* was used for assessing imagined velocity in the *cycling imagery task*. In this scene, participants viewed a street with a starting line and a distant finish line from first-person perspective without seeing an avatar (see Figure 2). The distance between the starting line and the finish line could vary between four different distances (36, 54, 72 or 90 metres, see Figure 2). When switching between scenes, the scene faded to black and then faded to the new scene.

3.5 Participants

We recruited 32 participants (mean = 25.2, sd = 6.6, 16 male and 16 female) from our university using mailings lists and public forums. Their age ranged from 21 to 37, as well as one participant aged 59. Additionally to demographics we asked for their experience regarding VR environments and if they have any uncorrected vision. The participants were healthy starting the study and reported no pain before, during or after study. We informed each participant that they could withdraw or discontinue from the study at any point without penalty especially with symptoms like VR-sickness in mind [13].

3.6 Procedure

At the beginning, we welcomed the participants and asked about their health conditions. If there were no health problems, participants read and signed an informed consent form and completed a demographic questionnaire and the SPF questionnaire. Prior to the start of the experiment, participants were provided with a separate room in our laboratory where they could change into sportswear if desired. They were then given a brief introduction to VR and had the opportunity to familiarise themselves with the VR equipment. We then attached the optical heart rate (HR) sensor to the participants' forearm. We asked the participants to sit on the bicycle ergometer and assisted them in putting on the HMD to ensure a good fit. We then calibrated the interpupillary distance to optimize visual clarity. The seat height of the ergometer was then adjusted so that the participants' knees were slightly bent when the pedals were in their lowest position. As soon as the participants entered the VR environment, we started the *studio scene* and embodied the participants with the avatar of the first avatar condition. The participants then started with the *ergometer cycling task* (see 3.3.1). After the cool-down phase of this task, the scene faded to black and then switched to the *street scene*. The participant then completed the *cycling imagery task* (see 3.3.2). After completing this task, the participants removed the HMD and completed both the BRQ and the SPF questionnaire. After answering both questionnaires, the whole procedure was repeated in the next avatar condition. The order of avatar conditions was counterbalanced across participants using a Latin square.

Table 1: Statistics of the 2 x 4 x 2 ANOVA on imagined velocity

Effect	DF_n	DF_d	F	p	η_p^2	ε
Avatar Condition (A)	1	30	0.05	.470	.018	
Distance (D)	1.46	43.92	9.52	< .001	.241	.488
Gender (G)	1	30	0.54	.470	.018	
A x D	3	90	0.50	.684	.016	
A x G	1	30	< 0.01	.985	< .001	
D x G	1.46	43.92	0.34	.647	.011	.488
A x D x G	3	90	0.80	.497	.026	

4 RESULTS

In the following, we report the statistical analysis of the taken measures such as the perceived exertion, imagined velocity, heart rate response, as well as experienced embodiment and fitness.

Data were analysed in R (version 4.2.3, [58]) using mixed ANOVAs and *t*-tests (R package *rstatix* version 0.7.2; [26]). Effects with violations of sphericity were Greenhouse-Geisser corrected and are reported with corresponding ε estimates. To further describe potential null effects, we additionally conducted Bayesian *t*-tests for

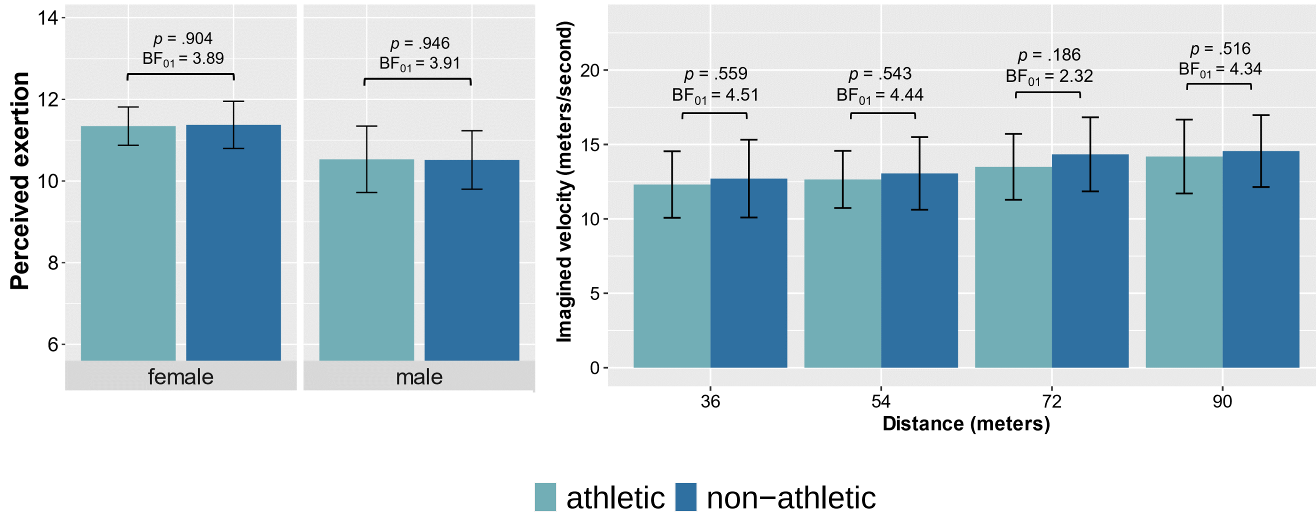

Figure 4: Mean scores of the perceived exertion while cycling in the respective avatar condition (left). Mean imagined velocity as a function of distance and avatar condition (right). Error bars show the 95% confidence interval of the means.

each pairwise comparison using default prior scales provided by the *BayesFactor* R package (version 0.9.12-4.4, [50]; see also [62]).

For analyzing the effect of the avatar conditions on perceived exertion, we used a 2 x 2 mixed design with avatar condition (athletic, non-athletic) as the within-subject factor. To control for gender differences, we additionally included gender (female, male) as a between-subject factor. Dependent variable was perceived exertion ranging from 6 to 20 using the RPE scale. We used the same design and analysis for determining the effects of the avatar on the self-perceived fitness and experienced body ownership.

For analyzing the effect of the avatar conditions on imagined velocity, we used a 2×4×2 mixed design. Within-subject factors were avatar condition (athletic, non-athletic) and distance (36, 54, 72, 90). To control for gender differences, we additionally included gender (female, male) as a between-subject factor. Dependent variable was imagined velocity in meters/second, calculated as the respective distance divided by the produced time in the cycling imagery task.

For analyzing the effect of the avatar conditions on heart rate responses, we used a 2 x 2 x 20 mixed design with avatar condition (athletic, non-athletic) and time condition (minute 1 to 20) as the within-subject factors. To control for gender differences, we additionally included gender (female, male) as a between-subject factor. Dependent variable was the heart rate in beats per minute.

4.1 Perceived Exertion

Perceived exertion as a function of the avatar condition is illustrated in Figure 4. The results of the 2 × 2 mixed ANOVA with avatar condition as within-subject factor and gender as control between-subject factor on perceived exertion showed no significant main effect for avatar, $F(1, 30) = 0.002$, $p = .964$, $\eta_p^2 < .001$. There was a significant main effect for gender, $F(1, 30) = 4.342$, $p = .046$, $\eta_p^2 = .126$, indicating that the perceived exertion was higher for female participants compared to male participants.

To obtain more information about the relevant non-significant main effect of avatar condition on perceived exertion, we conducted a Bayesian *t*-test on the perceived exertion averaged for female and male participants. A Bayes factor of $BF_{01} = 5.29$ indicated that the data are 5.29 times more likely under the null hypothesis that postulates identical perceived exertion between avatar conditions than under the alternative hypothesis that postulates a difference between perceived exertion between conditions. We additionally provide *p*-values and Bayes factors of this comparison for each gender separately in Figure 4.

4.2 Imagined Velocity

Practice trials were excluded from the analysis. Furthermore, to control for outliers, we excluded trials with extremely high velocities (> 200 m/s, 0.7% of all trials) and all trials with velocities that deviated more than two standard deviations from the individual condition mean (3.12% of all trials). Consequently, a total of 96.5% of all experimental trials were included in the analysis of imagined velocity.

Imagined velocities as a function of distance and avatar condition are illustrated in Figure 4. The results of the 2 × 4 × 2 mixed ANOVA with avatar condition and distance as within-subject factors and gender as control between-subject factor on imagined velocity are listed in Table 1. Our analysis revealed a significant main effect for distance, $F(1.46, 43.92) = 9.52$, $p = < .001$, $\eta_p^2 = .25$, $\varepsilon = .488$, indicating faster velocities at higher distances (see Figure 4). The main effect for avatar condition was not significant $F(1, 30) = 0.76$, $p = .389$, $\eta_p^2 = .025$. All other effects were also not significant (see Table 1). To obtain more information about the relevant non-significant main effect of avatar condition on imagined velocity, we conducted a Bayesian *t*-test on the imagined velocity averaged over distances. A Bayes factor of $BF_{01} = 3.68$ indicated that the data are 3.68 times more likely under the null hypothesis that postulates identical imagined velocities between avatar conditions than under the alternative

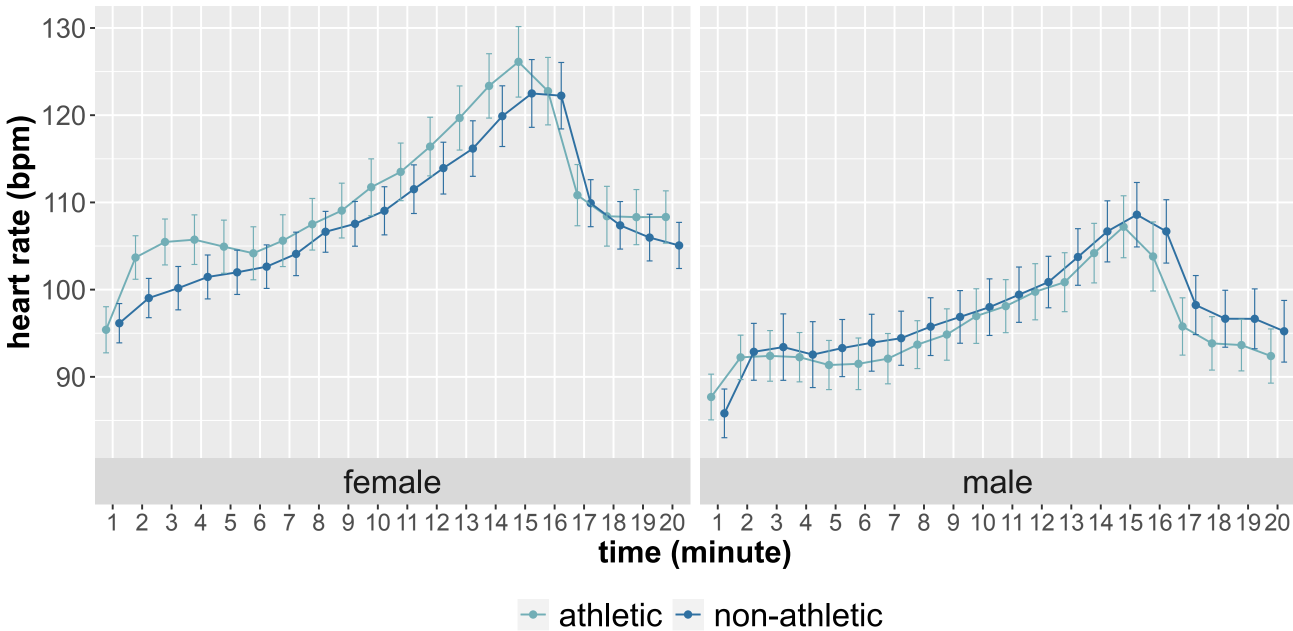

Figure 5: Mean heart rate response over time while cycling in the respective avatar condition. Error bars show the 95% confidence interval of the means.

hypothesis that postulates a difference between imagined velocities between conditions. We additionally provide *p*-values and Bayes factors of this comparison for each distance separately in Figure 4.

4.3 Heart Rate

Due to data loss, we excluded two participants from the analysis. Hence, a total of 30 participants was included in the statistical analysis. The results of the 2 x 2 x 20 mixed ANOVA revealed a significant main effect of gender, $F(1, 28) = 10.19$, $p = .003$, $\eta_p^2 = .267$, and of time, $F(2.42, 67.88) = 88.39$, $p = < .001$, $\eta_p^2 = .759$. However, there was no significant effect of avatar, $F(1, 28) = 0.082$, $p = .078$, $\eta_p^2 = .003$. We also found a significant interaction effect of gender x time, $F(2.42, 67.88) = 3.03$, $p = < .045$, $\eta_p^2 = .098$. All other interaction effects were not significant (all $p > .05$). The results indicate that participants' heart rate increased over time due to the higher workload and that female participants had a generally higher heart rate response. Figure 5 shows the average heart rate responses over time.

4.4 Body Ownership

We separately analyzed each dimension of the BRQ vrbody, mirror, features, agency, and twobodies using a 2 x 2 mixed ANOVA. The results revealed a significant main effect of avatar on the dimension vrbody, $F(1, 30) = 19.143$, $p < .001$, $\eta_p^2 = .390$. There was no significant effect of gender, $F(1, 30) = 0.320$, $p = .576$, $\eta_p^2 = .011$, and no significant interaction effect of avatar x gender, $F(1, 30) = 1.115$, $p = .299$, $\eta_p^2 = .036$.

We found a significant main effect of avatar on the dimension mirror, $F(1, 30) = 13.556$, $p < .001$, $\eta_p^2 = .311$. There was no significant effect of gender, $F(1, 30) = 0.667$, $p = .421$, $\eta_p^2 = .022$, and no significant interaction effect of avatar x gender, $F(1, 30) = 0.080$, $p = .779$, $\eta_p^2 = .003$.

We found a significant main effect of avatar on the dimension features, $F(1, 30) = 34.091$, $p < .001$, $\eta_p^2 = .532$. There was no significant effect of gender, $F(1, 30) = 0.086$, $p = .772$, $\eta_p^2 = .003$. There was a significant interaction effect of avatar x gender, $F(1, 30) = 5.455$, $p = .026$, $\eta_p^2 = .154$.

We did not find any significant effects on the dimensions agency and twobodies (all $p > .05$).

4.5 Self-Perceived Fitness

We separately analyzed each dimension of the SPF questionnaire fitness, endurance, strength, flexibility, and body composition using a 2 x 2 mixed ANOVA.

We could not find any significant effects for the dimensions fitness, endurance, strength, and body composition (all $p > .05$). However, there was a significant main effect of avatar on flexibility, $F(1, 30) = 4.303$, $p = .047$, $\eta_p^2 = .125$. There was no significant effect of gender, $F(1, 30) = 1.399$, $p = .246$, $\eta_p^2 = .045$, and no significant interaction effect of avatar x gender, $F(1, 30) = 0.120$, $p = .732$, $\eta_p^2 = .004$.

5 DISCUSSION

The findings indicate that the Proteus effect did not occur in the present study. Bayesian *t*-tests even revealed that the imagined

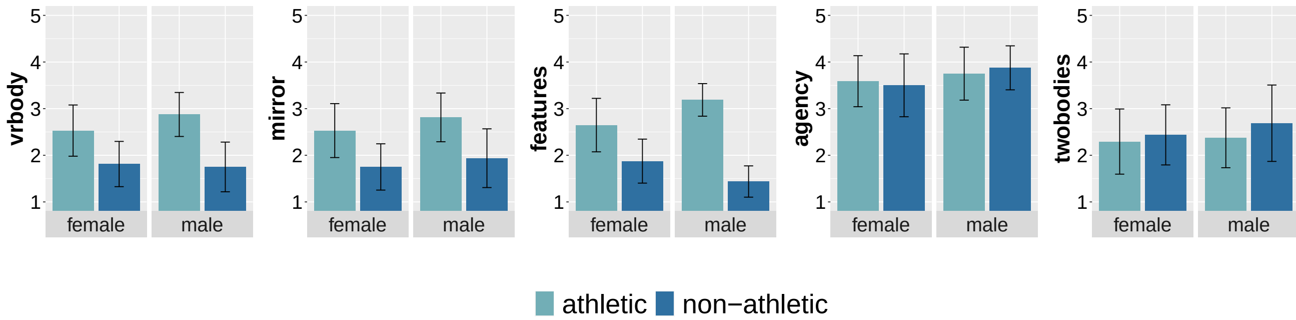

Figure 6: Mean BRQ questionnaire scores for each subdimension (vrbody, mirror, features, agency, and twobodies). Error bars show the 95% confidence interval of the means.

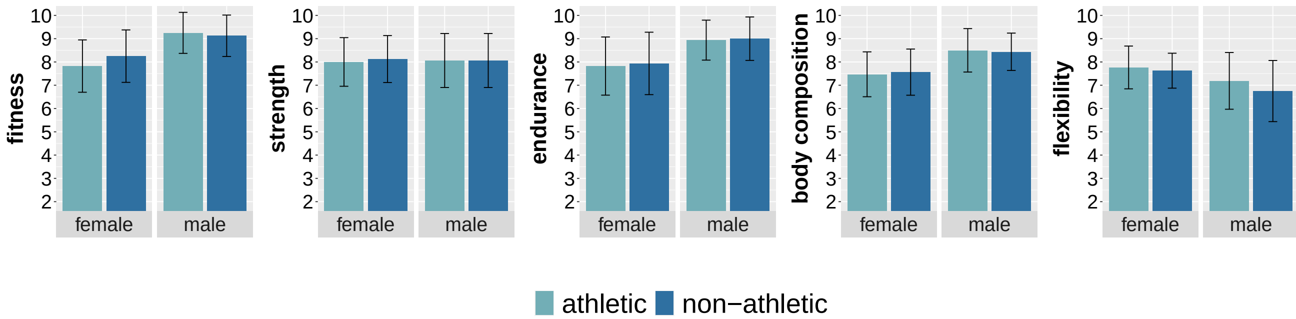

Figure 7: Mean SPF questionnaire scores for each subdimension (fitness, strength, endurance, body composition, flexibility). Error bars show the 95% confidence interval of the means.

velocity and perception of effort are more likely identical for the avatar conditions. However, previous work found that muscular and athletic avatars can affect users' perceptual and physiological responses to physical effort [34, 38]. Similarly, Kocur et al. [33] revealed that sweaty avatars can also decrease the perception of effort during exercise. These effects can be explained using the same underlying mechanisms: The visual appearance of the avatar is associated with characteristics that are connected to enhanced physical abilities, i.e., muscularity and increased sweating responses are typically linked with athleticism that, in turn, affects users' perceptual and physiological reactions during exercise [32, 35]. However, we could not show comparable or similar effects in our study. Consequently, it seems that the mechanisms responsible for the Proteus effect did not apply. These findings are in line with recent work reporting inconsistent effects of athletic and muscular avatars during physical exertion [33, 43, 44]. Avatar creators and designers of immersive exercise systems should be aware that athletic avatars do not necessarily result in a reduced perceived exertion of heart rate responses during physical tasks. In the following, we discuss potential factors that could be responsible for the Proteus effect fail to occur and propose approaches for avoiding them.

5.1 Perceived Athleticism of the Avatars

As we equipped the avatars with the same characteristics as Kocur et al. [34], we can dismiss that differences in the avatar design can be responsible for not being able to induce the Proteus effect. However, one possible explanation why the Proteus effect failed to occur can be participants' individual characteristics and how they perceived the avatars. Kocur [32] postulates that "every user is unique" and that the process of stereotyping can be highly individual. While we used a similar population regarding the demographics compared to Kocur et al. [33, 34, 38], we can still not dismiss that the associations connected with the avatar's appearance differed.

We could not find significant differences of the perceived fitness, strength, and endurance between the athletic and non-athletic avatars. Consequently, we assume that the visual characteristics of both versions did not trigger the expected associations such as athleticism and high physical abilities while embodying the athletic avatar. The absence of such associations could, in turn, cause the anticipated physiological and perceptual responses fail to occur. Furthermore, McCain et al. [48] found that undesirable traits represented by the avatars, such as narcissism associated with a Kim Kardashian avatar can be a barrier to the Proteus effect as users defy to behave in line with negative concepts. While we do not assume that the avatars were negatively perceived, we cannot dismiss that participants unconsciously refused to conform to the avatar.

Overall, we argue that it is therefore necessary to involve potential users early into the design process of the avatars. Future work could create a set of different avatars and let users rate their perceived athleticism while embodying them in VR to get a first understanding about the avatars' associated characteristics. Another option could be character customization [41]. Participants could create their own avatar using visual traits that they individually connect with enhanced physical abilities.

5.2 Experienced Body Ownership

While the sense of agency was relatively high indicating that the technical setup and motion capture adequately transferred users' motion onto the avatar with a low latency, participants still rated their experienced body ownership as low (see Figure 6). Consequently, it is possible that the intensity of the body ownership sensation was not sufficient and, in turn, they did not experience any perceptual effects such as an increased or reduced imagined velocity. As prior work showed that body ownership and avatar identification is a significant moderator of the Proteus effect [32, 34, 56], an inhibited sensation of embodying the avatar could cause behavioral and perceptual changes fail to occur.

Increasing the experienced body ownership by more realistic avatars or avatars with visual traits that are more similar to the participants' actual body could raise the magnitude of the Proteus effect. In line with the "mirror paradigm" [24, 68], we placed a virtual mirror in front of the participants to allow them to constantly perceive their virtual body while cycling. While the "mirror paradigm" is mainly applicable for indoor environments, mirror-like reflections in natural settings are very scarce. Consequently, mirrors are rather inappropriate for natural outdoor VR experiences. For this reason, future work should investigate other possibilities to facilitate the sense of embodiment, e.g., leveraging natural reflections of objects or using tasks where important body parts need to be visible while performing them [32]. Moreover, during the imagined velocity task, participants did not embody the avatar while assessing the anticipated velocity. Constantly embodying the avatar could also help to increase the avatars' impact during the task.

5.3 Magnitude of the Proteus Effect during Physical Exertion

Ratan et al. [59] documented in a meta analysis that the magnitude of the Proteus effect is on average "small to medium". In a more recent analysis, Beyea et al. [8] reported that the strength of this phenomenon is larger in immersive VR than in non-immersive environments. As we embodied participants in the respective avatar in an immersive virtual environment, we increased the probability of revealing perceptual and physiological changes. However, we still could not find any effects originating from the avatars' appearance. Even if the Proteus effect appears to be a reliable and robust phenomenon with several studies demonstrating its impact, Clark [14] postulates that its general effect size is smaller than expected. In line with this assumption, we argue that the magnitude of the Proteus effect highly depends on the context.

This phenomenon was evidenced in a variety of different behavioral and performance-related outcomes, e.g., cognitive performance [60], creativity [21], or food choice [63]. Although we can attribute behavioral, perceptual, and performance-related changes caused by the visual appearance of avatars to the Proteus effect, we argue that the effect of influencing cognitive performance, creativity, or food choice is different from the effect of changing physical performance. In other words: it is hardly possible to compare the Proteus effect and its occurrences in all the variety of contexts and outcomes due to its diversity. Hence, we argue that because the Proteus effect has a general effect size from small to medium, does not mean that this phenomenon has the same magnitude during physically demanding tasks. Each setting has its own underlying principles and moderators, e.g., increased fatigue during physical exertion or hunger during food choice. Hence, we suggest that future work should analyze the magnitude of this phenomenon within the specific context to gain a deeper understanding about its consistency and reliability specifically for VR exercise systems.

6 CONCLUSION

In this paper, we investigated whether an avatar's athletic appearance can affect perceptual and physiological responses while cycling an ergometer bike. We aimed to replicate findings from previous work to determine the reliability and consistency of the Proteus effect during physicial exertion. However, we could not find effects of the avatar on participants' imagined velocity, perception of effort, and heart rate. We even found that imagined velocity and perceived exertion are more likely the same for athletic and non-athletic avatars. Consequently, our results do not support a reliable and consistent Proteus effect during physical exertion. We argue that the successful induction of Proteus effect depends on a variety of factors such as users' individual characteristics, the associations with the avatars' appearance, and the extent of the experienced body ownership. Future work should further analyze this phenomenon using different populations to learn more about requirements that have to be met for the Proteus effect to occur.

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