Sweating Avatars Decrease Perceived Exertion and Increase Perceived Endurance while Cycling in Virtual Reality

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ABSTRACT

Avatars are used to represent users in virtual reality (VR) and create embodied experiences. Previous work showed that avatars' stereotypical appearance can affect users' physical performance and perceived exertion while exercising in VR. Although sweating is a natural human response to physical effort, surprisingly little is known about the effects of sweating avatars on users. Therefore, we conducted a study with 24 participants to explore the effects of sweating avatars while cycling in VR. We found that visualizing sweat decreases the perceived exertion and increases perceived endurance. Thus, users feel less exerted while embodying sweating avatars. We conclude that sweating avatars contribute to more effective exergames and fitness applications.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; • **Applied computing →** *Computer games*; • **Computing methodologies → Virtual reality**.

KEYWORDS

avatars, Proteus effect, exergames, virtual reality, body ownership, perception of effort, sweating

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1 INTRODUCTION

Recently, the popularity and interest in VR technology to create health-related fitness applications increased [23]. Researchers and developers of immersive exergames recognized their potential as effective health interventions to engage people and promote physical activity [3, 23, 35, 65, 91]. The combination of entertainment and fun with physical effort and activity has been successfully applied to increase motivation and engagement during exertion [79], enhance exercise performance [67] and physical fitness [61, 62], and increase adherence to physical activity [81]. Research also found that VR exercise systems can reduce users' perception of effort [65, 103], which is considered a barrier to regular physical activity [63]. As previous work showed that a decreased perceived exertion could increase exercise tolerance and contribute to exercise adherence [74], systematically reducing the perception of effort is a valuable endeavor for creating more effective exergames and fitness applications.

To create natural and embodied experiences and elicit the sense of having an own body in VR, designers and developers typically use avatars—virtual characters that represent the user in virtual worlds. In recent years, research found that users can even have the feeling of embodying avatars and accept them as their "new" body in VR [41]. When users perceive the virtual environment (VE) from a first-person perspective using a head-mounted display (HMD) and look down at their own physical body, they see the virtual avatar's body spatially replacing their real one [89]. Additionally, motion capture technology is used to track users' movements and map them onto the avatar's pose in real-time. As a result, the corresponding avatars' limbs temporally and spatially move in synchrony when users move their limbs. This visual and proprioceptive stimulation of the perceptual apparatus can cause users to experience a body ownership illusion—an illusory perception that a foreign or artificial body is the own one [41, 64].

Interestingly, the embodiment of avatars with stereotypical characteristics can even change users' behavior, attitude, and perception—a phenomenon known as the Proteus effect [100, 101]. Kocur et al. [49], for example, found that the embodiment of muscular avatars increased users' grip strength and reduced their perceived exertion while holding weights. Similarly, Kocur et al. [46] revealed that users who embodied an athletic avatar had a lower perceived exertion and heart rate (HR) response while cycling in VR than those who embodied a non-athletic avatar. These results suggest that the embodiment of an avatar with an appearance users can identify with and associated with enhanced physical abilities can positively affect them during exertion.

From a human-computer interaction (HCI) perspective, such findings are promising as they imply that avatars can be leveraged to influence users during physically demanding tasks positively. Hence, it is vital to learn more about such effects and understand how to design an avatar's visual characteristics that make users perceive physical exertion less intense without decreasing the actual workload. While avatars with salient features that are associated with widely known stereotypes are known to affect users during effort, e.g., a very high amount of body fat [46, 75, 77] or muscularity [49, 54], only little is known about other attributes that can be harnessed to improve perceptual and physiological responses to physical exertion.

A natural human response to physical exertion is sweating. As exercise elevates the body temperature, the autonomic nervous system sends signals to the sweat glands to start secreting sweat and cool the body [55, 88]. Hence, thermal sweating mechanisms balance the body temperature by counteracting the rise caused by exercising [6]. In popular sports video games, e.g., NBA 2K22 [1], FIFA 22 [30], or UFC 4 [31], sweat effects are designed on avatars' skin and clothes to create realistic sports simulations. In addition, sweating is also used as a game design element to inform players about the virtual characters' level of fatigue. However, it is currently unknown how visualized sweat effects on avatars affect users while embodying them in an immersive VE. On the one hand, avatars' sweating could contribute to a more realistic experience during physical exercise in VR. However, on the other hand, sweating could also be associated with physical exertion and fatigue. That is why users could connect the avatar with fatigue and strenuous labor, which, in turn, could result in adverse effects on users, such as an increased perception of effort and elevated physiological responses. Therefore, it is crucial to find out how sweating avatars affect users while exercising in VR.

In this paper, we investigate whether an avatar's sweaty appearance affects users' perceived exertion and their sweating and HR response while cycling in VR. Hence, we conducted a study with 24 participants who cycled an ergometer following a standardized protocol while embodying a sweaty and non-sweaty avatar. We found that participants had a lower perceived exertion while embodying the sweaty avatar than the non-sweaty avatar. We also found that users' perceived endurance was rated higher in the sweaty than in the non-sweaty avatar. We argue that sweat effects on avatars should be visualized during physical activity in VR as they positively affect users' perceptual responses to physical effort and contribute to a more realistic and natural VR experience.

2 RELATED WORK

Our work is based on a growing body of empirical studies showing effects of avatars on users in VR. In the following, we first present investigations of the Proteus effect in VEs. Afterward, we provide an overview of research on the impact of avatars on users in immersive exergames and fitness applications. Eventually, we outline games using virtual characters that respond to physical exertion by visualizing sweat or other behavioral characteristics associated with fatigue and effort.

2.1 Proteus Effect

Previous work demonstrated that embodying avatars with salient characteristics can change users' behavior, attitude, and perception due to their stereotypical assessments. Yee and Bailenson [101] found that users behaved more confidently when embodying an attractive avatar compared to a non-attractive avatar. Similarly, the authors showed that users negotiated more aggressively when embodying tall avatars compared to smaller ones. As attractiveness and height are associated with self-confidence and extraversion, users adapted their behavior to act in accordance with the common expectations connected with the avatars' appearance. In allusion to the Greek God Proteus who could instantly change his shape into any possible appearance, this phenomenon was coined the Proteus effect [100, 102]. Since the demonstration of this phenomenon, the Proteus effect has been shown in a variety of different contexts [44, 82], e.g., cognitive performance [9, 51, 83], aggressive behavior [4], implicit racial bias [8], food choice [85], creative ideation [32], or walking speed [50, 84].

The Proteus effect is frequently explained by self-perception theory that postulates that people observe themselves from an imaginary third-person perspective to infer their attitudes, emotions, and internal states [12]. It is deemed natural that we analyze our own behavior to understand the drivers for our actions in a similar way we observe others to derive their intentions and feelings. Valins [96], for example, showed that participants' who were told that their HR had increased while watching photographs of people, subsequently rated them as more attractive. As an increased HR can be interpreted as a sign for emotional arousal in such a scenario, the participants inferred that the people on the photograph had caused their HR to elevate due to their attractiveness.

Similar mechanisms occur during the Proteus effect. Kilteni et al. [40], for example, showed that light-skinned participants who embodied a dark-skinned avatar more actively and rhythmically played a hand drum compared to light-skinned avatars. As the stereotype of dark-skinned people being more rhythmic than light-skinned people was activated by the avatar's appearance, the users' accordingly changed their behavior and showed increased movements patterns while drumming [40].

Overall, results from previous work indicate that users assess the avatar's appearance during embodiment and, therefore, behave in accordance with the expected behavior. From an HCI perspective, this phenomenon is promising as it can be leveraged using avatars with certain characteristics to change users' behavior and experience while interacting with VEs and make them perform better than they would in other avatars [52, 53].

2.2 Avatars' Effects in Exergames and VR Exercises

The Proteus effect could also be demonstrated during physical exertion. Li et al. [58] documented that overweight children who played Wii Fit [72] with a "normal" avatar were more motivated and performed better than when playing with an overweight avatar. Navarro et al. [70] showed that participants who watched an avatar wearing sports clothes and being textured with the participants' face were more physically active while running compared to avatars equipped with formal dresses and a stranger's face. Peña and Kim [75] showed increased physical activity of female players who controlled a casual avatar in a virtual tennis game compared to an avatar the authors termed "obese".

Similarly, Peña et al. [77] replicated the findings with male participants and presented two hypotheses: the "take it easy" and the "give up" assumptions. The former postulates that players are less physically active when they believe they have an advantage over the opponent, whereas the latter describes a reduced activity when they think they have a disadvantage. Similar findings were reported by Keenaghan et al. [37], who showed that cycling against a virtual character representing an idealized self negatively affects users' physical performance. As the authors found that competing against a character with slightly enhanced athleticism can boost performance, they argue that self-discrepancy elicited by the deviation of the actual self and a non-achievable idealized version causes participants to perform worse.

Another study showed that avatars with pronounced abdominal muscles reduced physical activity compared to "normal" avatars [59]. The authors hypothesized that users believed they do not need to exercise with the same effort while embodying the avatar with a "six-pack", as it already represents a high level of athleticism and an idealized body shape [59]. However, Kocur et al. [49] showed that muscular avatars boosted physical performance in terms of a higher grip strength and reduced perception of effort while holding weights. Additionally, Kocur et al. [46] revealed that athletic avatars can even reduce HR responses while cycling. The authors showed that participants had a lower HR while embodying athletic avatars compared to medium and non-athletic avatars. These findings demonstrate the astonishing psychophysiological impact of avatars on users, as they show that the Proteus effect not only affects users' behavior and attitude, but also their physiological responses.

2.3 Game Characters' Responses to Physical Exertion

Popular sports video games, e.g., NBA 2K22 [1], FIFA 22 [30], or UFC 4 [31], typically license real sports organizations and their athletes to create realistic sports simulations. Therefore, the virtual athletes simulate real life personalities and their attributes are implemented according to the abilities and special skills of the real professional athletes. Common ratings such as speed, body height, agility, and also stamina and fatigue are used to determine the virtual athletes' abilities [2]. Character designers, therefore, aim at creating athletes that realistically respond to physical exertion. They can sweat, breathe heavily and their performance decreases when they reach a certain state of fatigue. To create credible animations, designers also apply principles from human emotion recognition [66] and locomotion [95], such as stereotypical body language [86], to equip virtual athletes with non-verbal cues implicitly communicating with players.

Certain behavioral poses that are associated with physical fatigue or a high amount of sweat on their skin or jerseys are used as game design elements to inform players about the athletes' current physical state. Hence, players, for example, can adapt their strategy by substituting one athlete for another to enable rest and repletion of energy. In addition, stamina bars are used as part of a user interface [36] to provide more salient cues about the avatars' physical exertion. In non-sports games, such as the AAA titles The Last of Us Part II [69] or Uncharted 4: A Thief's End [68], realistic character animations and designs are used to display high levels of strain in certain situations., e.g., sweaty skin, exhausted gait, tired facial expressions, or increased respiration.

While research provides recommendations on how to design virtual characters' emotions in games [14, 90] or cartoons [94], surprisingly little is known about the effects of avatars' responses to physical exertion on users of VR applications. Basori and Qasim [10] analyzed different techniques of designing sweat during facial animations to generate expressions that display fear and anger. They showed that visualizing sweat using textures and particles can create realistic sweating animations. Other researchers simulated physical properties of water drops to create credible tear and sweating animations [25, 97]. de Melo and Gratch [25] designed different emotional expressions of virtual faces using tears to display sadness and sweat to display fear. The authors showed that visualizing sweat and tears improves identification of the underlying emotions of the virtual human. However, they focused on sweating elicited by emotional stress instead of thermoregulation. Weyrich et al. [98] analyzed real faces under certain conditions, e.g., high environmental temperature, to generate a model for realistic skin reflectance. Kider et al. [39] developed a fatigue model based on motion and biosignal data (e.g., HR or galvanic skin response) to display exhaustion effects on virtual characters by adding sweat, breathing deformation, flushing, and panting. Although related work provides knowledge about how to design exhaustion and fatigue on virtual characters, the effects on users in VR while embodying them are yet unknown.

2.4 Summary

Related work found that avatars with stereotypical characteristics that are connected with high physical abilities can enhance performance and reduce perceived exertion during physical effort in immersive exergames or fitness applications. Typically, the avatars' salient morphological characteristics are changed to induce the Proteus effect, such as body fat or muscularity. However, a strong deviation from the avatars' and users' attributes can result in adverse effects [45], e.g., self-discrepancy [37] or "take it easy" and "give up" hypothesis [59, 77]. Hence, more subtle changes without manipulating body structures could be promising to induce the Proteus effect avoiding a strong discrepancy between the users' self and the avatar. However, there is currently little known about other attributes that could be leveraged to create more effective avatars in VR exercise systems. Although sweating is a natural human response and is frequently visualized on avatars to create a realistic game experience, research has neglected to investigate sweating effects of avatars on users while embodying them during physical exertion [48]. Hence, it is currently unknown whether and how visualizing sweat on avatars affects users during VR exercise.

3 METHOD

To learn about the impact of a sweating avatar on users during physical exertion, participants were asked to ride a stationary bicycle ergometer using a standardized exercise protocol [73]. We assessed the perception of effort, sweating response, HR, and pedaling frequency. We replicated the study by Kocur et al. [46], however, instead of systematically manipulating the athletic appearance of the avatars, we used constantly athletic avatars with a sweaty and non-sweaty appearance.

3.1 Study Design

We conducted a study using a within-subjects design with the one independent variable Appearance with the two levels *sweaty* and *non-sweaty*. Consequently, participants embodied avatars of their identified gender with a *sweaty* and *non-sweaty* appearance. The *sweaty* avatars had sweaty clothes as well as sweaty skin and hair. To gain first insight into the effects of avatars' sweat on users, we used static sweating using textures, i.e., the *sweaty* avatars were sweating from the beginning and the amount of sweat remained constant throughout the exercise. In contrast, the *non-sweaty* avatars' clothes, skin, and hair were not sweaty throughout the exercise. To reduce order effects, we counterbalanced the order of the avatars.

3.2 Measures

To determine the effects of the independent variable, we took a number of objective and subjective measures. We repetitively assessed the perceived exertion using the Rating of Perceived Exertion (RPE) scale [17] while cycling a bicycle ergometer. In line with techniques from sports medicine, we determined participants' sweating rate using absorbent dressings attached on the skin to analyze participants' sweating response as an indicator for physical activity and effort [5, 29]. Additionally, we continuously measured the HR and the pedaling frequency. We also surveyed participants after each condition using the self-perceived fitness (SPF) questionnaire [27], the Body Representation Questionnaire (BRQ) [7, 9] for assessing the experienced body ownership of the avatars, and the Player Identification Scale (PIS) [60] to quantify the embodied presence and identification with the *sweaty* and *non-sweaty* avatars. As simulator sickness is known to cause increased physiological responses (e.g., increased sweating rate or HR), we also administered the Virtual Reality Sickness Questionnaire (VRSQ) using the items sweating, nausea, general discomfort, stomach awareness, and increased salivation [42] to control for potential effects caused by the VR exposition.

3.2.1 Perceived Exertion. We used a well-established experimental procedure in sports and clinical settings to assess the perceived exertion [99]. We asked participants to report their perception of effort while cycling using the RPE scale developed by Gunnar Borg [15, 17]. After 4:30, 9:30, 14:30, and 19:30 minutes, we showed a virtual scale within the VE that ranged from 6 (no exertion) to 20 (maximal exertion). Participants were then asked to rate the perceived exertion by assigning a number to how exerted they felt and verbally communicating it to the experimenter. Due to the correlation between the perception of effort and the HR response to physical exertion [15, 18, 38], the scale was originally designed to approximately estimate the current HR by multiplying each value by 10. For example, if participants report an intensity of 13, their HR is supposed to be approximately 130 [17].

3.2.2 Self-Perceived Fitness. We administered a version of the self-appraisal questionnaire from Borg and Skinner [16] adapted by Delignières et al. [27] to quantify the SPF while embodying the *sweaty* and *non-sweaty* avatar. The authors created a questionnaire with the five dimensions endurance, strength, flexibility, body composition, and fitness rated on a 13-point scale [27].

3.2.3 Sweating Rate. As previous work found that avatars can decrease HR while cycling [46], we added the sweating rate as a dependent variable to further explore participants' physiological responses during exertion. We used a gravimetric technique using absorbent dressings to collect sweat directly from the skin. We attached non-sterile cohesive dressings onto the skin surface of the right forearm. Participants' sweating rate was determined from the weight change of the dressings. Therefore, we scaled a dressing *before* cycling to assess the baseline weight and immediately *after* cycling in each condition to determine the weight after the dressing has absorbed sweat. We used a new dressing after each condition. To calculate the weight difference between the dressings, we subtracted the weight *before* the avatar condition (pre) from the weight *after* the avatar condition (post): $\Delta wt = wt(post) - wt(pre)$. A larger difference indicates a higher sweating rate due to a larger amount of sweat absorbed by the dressings.

3.2.4 Heart Rate. As previous work found that the optical HR sensor Polar OH1 (Polar Electro, Finland) can be used as a valid measure of HR in laboratory settings [34], we employed this sensor and attached it onto participants' left arm to continuously assess the HR during the cycling exercise.

3.2.5 Pedaling Frequency. We measured the pedaling frequency to analyze the rate at which participants turned the pedals and control for behavioral changes induced by the avatars' sweaty appearance. We, therefore, attached a cadence sensor (Polar Cadence Sensor Bluetooth Smart, Polar Electro, Finland) onto the right pedal of the ergometer to continuously measure the pedaling frequency during the cycling exercise.

3.2.6 Body Ownership. Participants answered the BRQ [7, 9] to assess the experienced body ownership of the avatars. The BRQ consists of five single-item subscales: vrbody ("I felt that the virtual body I saw when looking down at myself was my own body"),

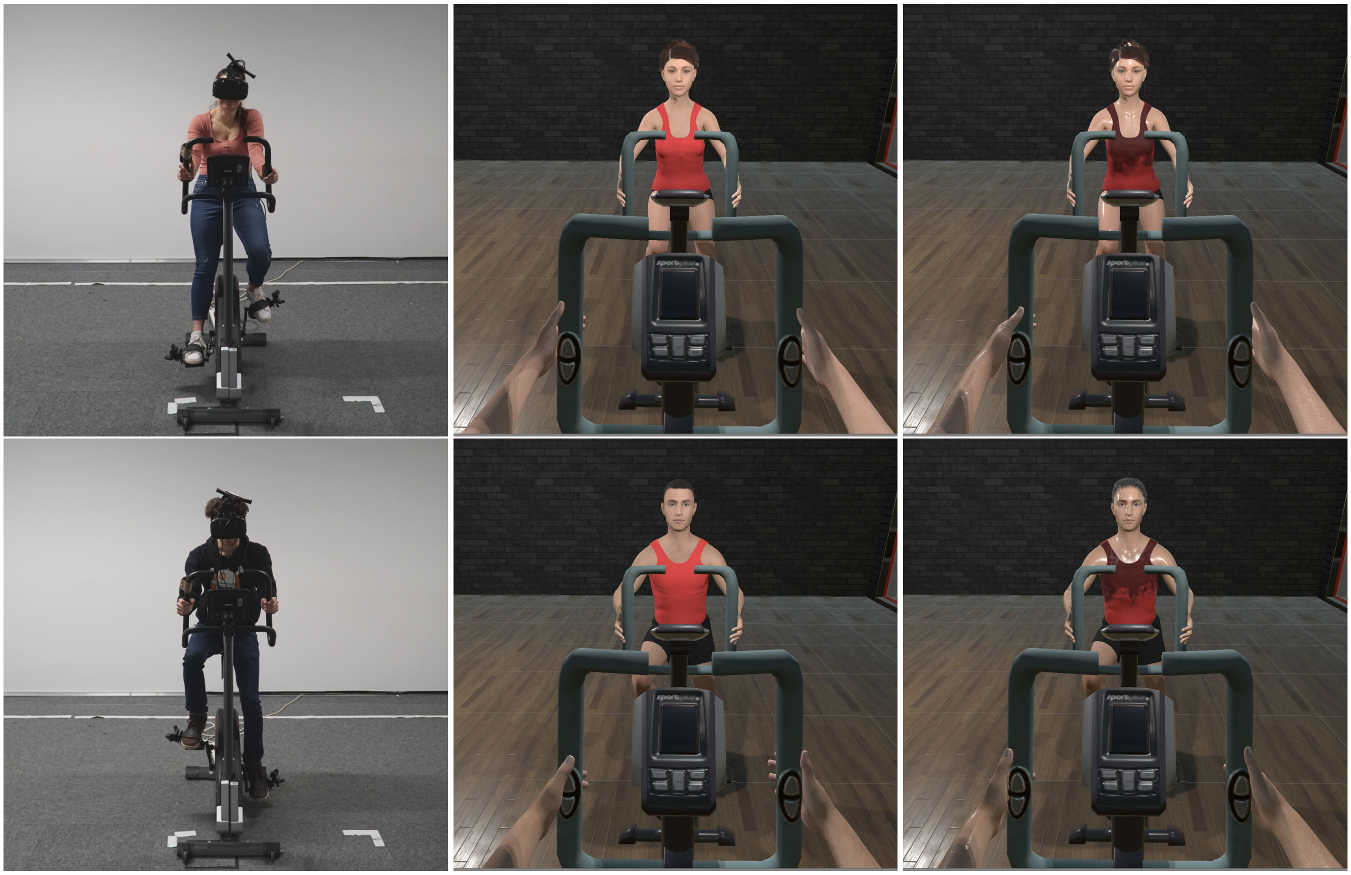

Figure 1: The real world (left) and the virtual scene consisting of the non-sweaty (left) and sweaty (right) avatars on a stationary bicycle.

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").

3.2.7 Avatar Identification. As users' identification with avatars can moderate an avatar's behavioral and perceptual impact [80], we assessed the user identification using the three subscales of similarity identification, wishful identification and embodied presence from the PIS [60]. The items consist of a 5-point Likert scale from 1 ("strongly disagree") to 5 ("strongly agree").

3.3 Apparatus

We designed two male and two female avatars using Daz3D (v. 4.12) with different levels of sweat (see Figure 1). To achieve a high sense of ownership of the avatars, we used the athletic avatars created by Kocur et al. [46] that were rated with the highest scores in terms of perceived body ownership and user identification in their study. We created the sweaty avatars by designing roughness maps for the skin and colored diffuse maps for the clothes using the painting software Substance Painter (v. 2019.3.3). In line with de Melo and Gratch [25], we simulated material properties of water using textures with high specular and low diffuse values in the sweating area on the face to create static beads of sweat. We designed wet hair using 3D-models and textures with a high level of smoothness. We used the game engine Unity3D (v. 2019.3.13f1) to develop the VR application. To allow the participants to constantly perceive their virtual body while cycling, we placed a virtual mirror in a simple VE consisting of a fitness room with dark walls and a virtual replica of the stationary bicycle.

The participants cycled on an electromagnetically braked bicycle ergometer (SportPlus Ergometer, Latupo GmbH, Germany) in our VR laboratory. To ensure a speed-independent workload for all participants, we used the watt mode so that the ergometer dynamically adjusted resistance based on a given watt value. We used two HTC Vive trackers and attached them to each pedal using cable ties to track and transfer the pedal motion onto the virtual replica of the ergometer in VR. We used an HTC Vive HMD (High Tech Computer Corporation, Taoyuan, Taiwan) with a wide horizontal field-of-view of 100° and a spatial resolution of 1080 × 1,200 pixels per eye displayed at 90 frames per second. In addition, the HMD was equipped with a wireless adapter to reduce the number of wires and increase safety.

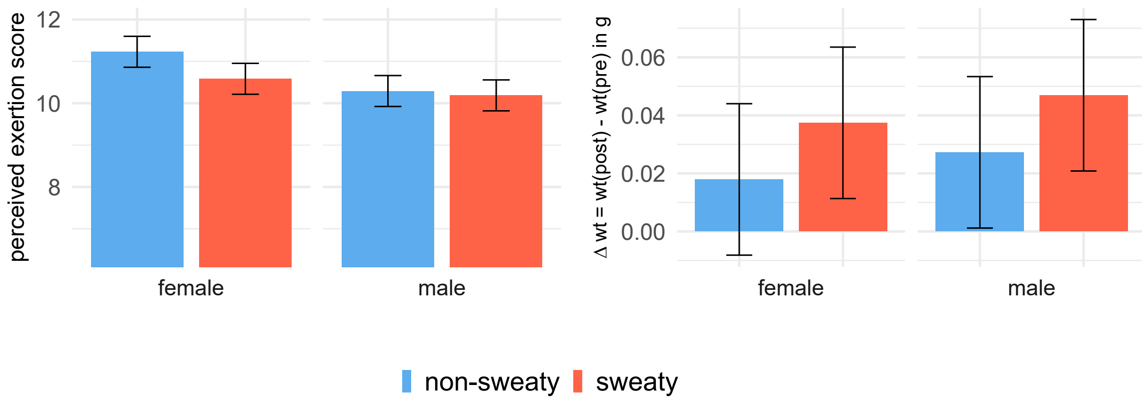

Figure 2: Mean scores of the perceived exertion while cycling (left) and the sweating rate determined by the average weight difference in g (wt) between the dressings *before* (pre) and *after* (post) the respective avatar condition (right). Error bars show the 95% confidence interval of paired differences for the comparison of the *sweaty* and *non-sweaty* avatar condition, calculated separately for each Gender [78].

The participants perceived the VE and their virtual body from first-person perspective so that they experienced their physical body to be spatially replaced by the avatar's body. When the participants looked down at their own body or in the virtual mirror while riding the ergometer, they saw the virtual body cycling instead. We used real-time inverse kinematics[1] to make the avatar mimic the participants' pedaling motion. We used an Android smartphone (Samsung Galaxy Note 9) running the Cyclemeter app compatible with the Polar HR and cadence sensor to measure the participants' HR and pedaling frequency. The VR application ran on a desktop computer (Windows 10, Intel i7-8750H, 16GB RAM, NVIDIA GeForce GTX 1060 graphics card).

3.4 Participants

As Kocur et al. [46] were able to detect small to medium effects of an avatar's athletic appearance on users' physiological and perceptual responses with a sample size of 24 using a within-subjects design, we accordingly recruited 24 participants (12 female, 12 male) through our university's mailing list and public forums. On average, participants were 24.0 years old (SD = 7.3) ranging from 18 to 58. We calculated the individual Body Mass Index (BMI) using the participants' body weight and height (M = 25.1, SD = 7.0). Twenty-three participants were students and were compensated with credit points for their study course. One participant was a technician. One participant stated to play VR games a few times per week, six participants a few times per year, and 17 participants never play VR games. This study was approved by the local ethics committee.

3.5 Procedure

After welcoming the participants, they were asked to sign an informed consent form and answer questions about demographic data, SPF, and familiarity with VR technology. We then briefly introduced VR so that they could get familiar with the equipment. Afterward, we attached the HR sensors onto the participants' left forearm and the absorbent patches onto the right forearm. The participants then sat on the bike and were supported with putting on the HMD. We also adjusted the height of the ergometer's seat to allow participants to sit in a comfortable position with their knees slightly bent when the pedals were at the bottom position. The participants were asked to hold the handlebars while cycling as we only tracked the pedals and used inverse kinematics to animate the legs and the upper body.

After starting the VR application, participants embodied the avatar of the first condition (either the *sweaty* or *non-sweaty* version). We followed a standardized exercise protocol [73] starting with a five-minute warm-up phase using a low-intensity load of 40 watts. After five minutes, we started the exercise phase at 50 watts and increased the workload by 10 watts every minute. After 10 stages, a five-minute cool-down phase with a constant workload of 40 watts was included to allow participants actively recovering from the exercise. Participants were cycling for 20 minutes in each condition with the same exercise intensity for both avatars. After the cycling exercise, we helped participants with taking off the HMD and asked them to get off the ergometer to complete the questionnaires on a desktop computer. Afterward, the next condition started using the respective avatar. We did not inform the participants about their performance and the measurements. On average, the study took 60 minutes per participant in total.

4 RESULTS

Our measures consist of parametric data. Shapiro-Wilk tests for normality and a visual inspection of histograms were used to test the assumption of normal distribution for parametric data. As the HR and sweating response is a ratio-scaled measurement, we assume a normal distribution of the data. We used a two-way analysis of variance (ANOVA) with Gender as between-subjects variable and Appearance as within-subjects variable for hypothesis testing.

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

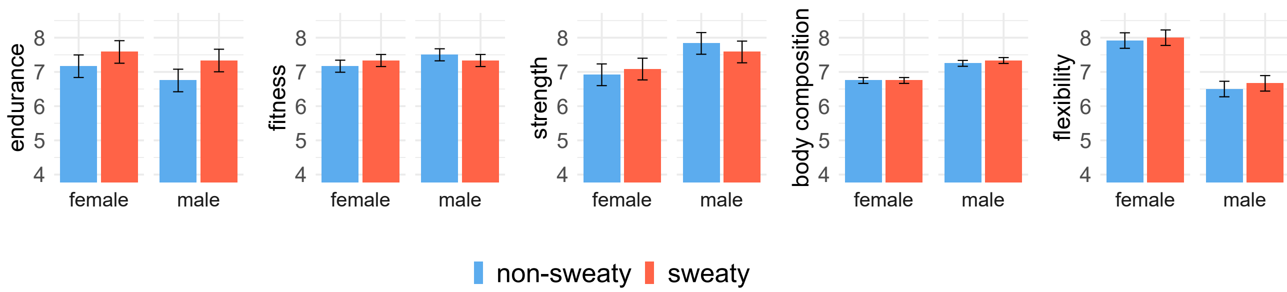

Figure 3: Mean SPF questionnaire scores for each subdimension (endurance, fitness, strength, body composition, flexibility). Error bars show the 95% confidence interval of paired differences for the comparison of the *sweaty* and *non-sweaty* avatar condition, calculated separately for each Gender [78].

4.1 Perceived Exertion

A 2(Appearance: *sweaty* vs. *non-sweaty*) × 2(Gender: *female* vs. *male*) ANOVA revealed a significant main effect of Appearance, $F(1, 22) = 4.68$, $p = .042$, $\eta_p^2 = .18$, on the perceived exertion. The main effect of Gender, $F(1, 22) = 1.53$, $p = .229$, $\eta_p^2 = .07$, and the interaction effect of Appearance × Gender, $F(1, 22) = 2.44$, $p = .132$, $\eta_p^2 = .10$, were not significant. Hence, participants' perception of effort was generally lower during the cycling exercise while embodying the *sweaty* avatar compared to the *non-sweaty* avatar (*female*: 11.2 vs. 10.6, *male*: 10.3 vs 10.2). Figure 2 depicts the mean values of the perceived exertion.

4.1.1 Correlation Analysis of the Perceived Exertion and the Dimensions of the BRQ. To test whether there is a relationship between the perceived exertion and participants' identification with the avatars, we computed a Pearson correlation coefficient for the perceived exertion and the dimensions of the BRQ for the *non-sweaty* and *sweaty* avatars. We did not find a significant correlation between the perceived exertion and the dimensions of the BRQ for the *sweaty* and *non-sweaty* avatars (all $p > .05$) indicating that participants' perception of effort was not affected by the experienced embodiment of the avatars.

4.1.2 Correlation Analysis of the Perceived Exertion and the Dimensions of the PIS. To test whether there is a relationship between the perceived exertion and participants' identification with the avatars, we computed a Pearson correlation coefficient for the perceived exertion and the dimensions of the PIS for the *non-sweaty* and *sweaty* avatars. We found a significant negative correlation between the perceived exertion and the dimension embodied presence, $r(22) = -.50$, $p = .013$, for the *non-sweaty* avatars. There was no other significant correlation between the perceived exertion and the dimensions of the PIS for the *non-sweaty* and *sweaty* avatars (all $p > .05$). Hence, results indicate that participants had a lower perceived exertion when feeling more present "within" the *non-sweaty* avatar (e.g., "I feel like I am inside my character" or "In the game, it is as I become one with my character"). However, this was not the case for the *sweaty* avatars indicating that the sense of embodied presence did not affect the decreased perceived exertion caused by the avatars' sweaty appearance.

4.1.3 Correlation Analysis of the Perceived Exertion and the Dimensions of the SPF questionnaire. To test whether there is a relationship between the perceived exertion and participants' perceived fitness of the avatars, we computed a Pearson correlation coefficient for the perceived exertion and the dimensions of the SPF questionnaire for the *non-sweaty* and *sweaty* avatars. We did not find a significant correlation between the perceived exertion and the dimensions of the SPF questionnaire for the *sweaty* and *non-sweaty* avatars (all $p > .05$).

4.2 Self-Perceived Fitness

We performed 2(Appearance: *sweaty* vs. *non-sweaty*) × 2(Gender: *female* vs. *male*) ANOVAs on each dimension of the SPF questionnaire. We found a significant main effect of Appearance, $F(1, 22) = 9.54$, $p = .005$, $\eta_p^2 = .30$, on the dimension endurance. The main effect of Gender, $F(1, 22) = 0.18$, $p = .679$, $\eta_p^2 = .01$, and the interaction effect of Appearance × Gender, $F(1, 22) = 0.26$, $p = .612$, $\eta_p^2 = .01$, were not significant.

We did not find a significant main effect of Appearance, $F(1, 22) = 0.00$, $p = 1.0$, $\eta_p^2 < .01$, and of Gender, $F(1, 22) = 0.38$, $p = .846$, $\eta_p^2 < .01$, on the dimension fitness. However, there was a significant interaction effect of Appearance × Gender, $F(1, 22) = 4.40$, $p = .048$, $\eta_p^2 = .17$. All other dimensions were non-significant (all $p > .05$). Figure 3 depicts the average scores of the dimensions of the SPF questionnaire.

Results indicate that participants perceived the *sweaty* avatars' endurance higher compared to the *non-sweaty* avatars. Additionally, the female-gendered *sweaty* avatar's fitness was rated higher than the non-sweaty avatar's. However, this was not the case for the male-gendered *sweaty* avatar whose fitness was rated lower compared to the *non-sweaty* avatar.

4.3 Sweating Rate

We performed a 2(Appearance: *sweaty* vs. *non-sweaty*) × 2(Gender: *female* vs. *male*) ANOVA on participants' sweating rate while riding the stationary bicycle. There was no significant effect of Appearance, $F(1, 22) = 2.30$, $p = .143$, $\eta_p^2 = .09$, of Gender, $F(1, 22) = 0.32$, $p = .578$, $\eta_p^2 = .01$, and no interaction effect of Appearance × Gender, $F(1, 22) = 0.00$, $p = .994$, $\eta_p^2 < .01$.

Although visual inspection of the mean sweating rates (see Figure 2) descriptively denotes a systematic difference between conditions with higher values for the *sweaty* avatars compared to the *non-sweaty* avatars, theses differences were not statistically significant. We calculated a post-hoc power analysis (G*Power 3.1.9.4) by converting the effect size $\eta_p^2 = .09$ into Cohen's f (Cohen's $f = .31$) using the formula provided by Kim [43] for the factor Appearance. The analysis revealed a power of only 66% to find a medium effect based on a correlation between the sweating rate of *sweaty* and *non-sweaty* avatars of $r = .26$ using our sample size of $N = 24$. This indicates that the statistical power was not sufficient to find significant differences between the *sweaty* and *non-sweaty* avatar. An a priori power analysis revealed that to detect an effect of size Cohen's $f = .31$ and a desired level of $\alpha = .05$, a minimum sample size of $N = 34$ is necessary to reach a power of 80%.

4.4 Heart Rate

In line with Northridge et al. [73], we analyzed the time course of the HR response by calculating 1-minute time intervals and aggregating the data per minute. We, therefore, included the factor Time with 20 levels (from 1 min to 20 min) in the statistical analyses. We performed a 2(Appearance: *sweaty* vs. *non-sweaty*) × 2(Gender: *female* vs. *male*) × 20(Time: 1 vs. 2 vs. 3 vs... 20) ANOVA to evaluate the HR response over the course of time. We found a significant main effect of Gender, $F(1, 22) = 4.71$, $p = .041$, $\eta_p^2 = .18$, and of Time, $F(19, 418) = 69.98$, $p < .001$, $\eta_p^2 = .76$. However, we did not find a significant effect of Appearance, $F(1, 22) = 0.15$, $p = .704$, $\eta_p^2 = .01$. We also found a significant interaction effect of Gender × Time, $F(19, 418) = 2.08$, $p = .005$, $\eta_p^2 = .09$. All other interaction effects were not significant (all $p > .05$). Results indicate that female participants had a higher HR response than male participants and that the HR increased over time regardless of the avatar.

4.5 Pedaling Frequency

We performed a 2(Appearance: *sweaty* vs. *non-sweaty*) × 2(Gender: *female* vs. *male*) ANOVA on the pedaling frequency. We did not find significant effects of Appearance, $F(1, 22) = 0.11$, $p = .741$, $\eta_p^2 < .01$, of Gender, $F(1, 22) = 0.67$, $p = .422$, $\eta_p^2 = .03$, and no interaction effect of Appearance × Gender, $F(1, 22) = 0.01$, $p = .918$, $\eta_p^2 < .01$. Hence, participants' pedaling frequency was not affected by the avatars' sweaty appearance.

4.6 Body Ownership, Avatar Identification, and Simulator Sickness

We performed 2(Appearance: *sweaty* vs. *non-sweaty*) × 2(Gender: *female* vs. *male*) ANOVAs on each dimension of the BRQ, PIS, and VRSQ. We did not find any significant effects on the dimensions of the questionnaires (all $p > .05$). Hence, participants' experienced body ownership, avatar identification, and simulator sickness was not affected by the avatars' sweaty appearance. As the simulator sickness ratings were generally low for all avatars (*female*: $M = 0.6$, $SD = 0.4$, *male*: $M = 0.7$, $SD = 0.4$), our VR applications caused none to only slight symptoms of simulator sickness.

5 DISCUSSION

The present findings show that avatars with a sweaty appearance can reduce perceived exertion while cycling in VR. Users who embodied sweaty avatars perceived the task as less intense and strenuous compared to non-sweaty avatars. Our results consolidate the findings from previous work demonstrating the positive impact of avatars during physical exertion in VR [24, 46, 49].

5.1 Effects on Perception of Effort and Perceived Endurance

At first glance, one might assume that the sweaty appearance of an avatar could be connected with physical fatigue and a high exertion and, therefore, could prime users resulting in an increased perception of effort. Interestingly, it was the opposite. We explain the findings using the Proteus effect [100] that describes behavioral, attitudinal, and perceptual changes caused by users' connected associations with the embodied avatar's appearance. We argue that participants associated the avatar's sweaty appearance with higher physical abilities than avatars who were not sweating.

Research from physiology found that athletes generally sweat more and at an earlier stage than non-athletes, as athletes usually have a higher muscle mass, and their body adapts to regular physical activity by producing more sweat and even changing its composition [11, 19, 57]. Furthermore, sweaty bodies and clothes are typically part of sport environments such as gyms. Hence, participants possibly associated the sweaty avatars with sports and fitness. Therefore, sweating during exertion could instead be a sign of increased physical abilities and not a lower level of athleticism. This assumption is confirmed by the dimension endurance of the SPF questionnaire showing that participants attributed a significantly higher level of endurance to the sweaty avatar.

We assume that the sweaty appearance combined with the task at hand caused participants to interpret that the avatar is physically active and regularly exposed to endurance exercises. As the avatar elicits expectations of what it would be like to own a body with such characteristics, they attributed a higher endurance to themselves. According to self-perception theory [12], the change in self-perception due to the sweaty avatar causes participants to perceive an increased endurance and raises the expectation to perform better at cycling than they would in the non-sweaty avatar. In line with a perception-behavior process [21, 56], the primed associations with the sweaty avatars, i.e., people with a higher endurance perform better at endurance exercises such as cycling, made participants perceive the workout as less intense and strenuous than when embodying a non-sweaty avatar. This explanation is in line with previous work showing a systematic reduction of perceived exertion while embodying avatars associated with high physical abilities, e.g., muscular [49] or athletic [46] avatars.

While the Proteus effect seems plausible, we cannot rule out other explanations. As we only induced a relatively low body ownership (e.g., for the dimension *vrbody* "I felt that the virtual body I saw when looking down at myself was my own body", ranging from 1 to 7, $M = 2.58$, $SD = 1.23$, average of all avatar conditions), participants could perceive the embodied avatar as a different "person" rather then being themselves. This dissociation could even be reinforced when the participants were less sweating than the avatar. Due to the presence of another "person" sweating during physical exertion and being more tired than the participants might cause them to feel less tired and perceive the exercise less intense.

As we used a within-subjects design, participants could compare the avatar that they were currently embodying (either sweaty or non-sweaty) against the previous version (either sweaty or non-sweaty). While this study design simulates a realistic use case scenario in immersive exergames, where the user is able to freely select different avatars [20, 92], it also highlights the differences between the versions of the avatar possibly resulting in amplified effects. Thus, future studies should also investigate the impact of avatars in a between-subjects design to isolate the effects from other psychological phenomena [22], e.g., priming [76], competition [54, 77], or confirmation bias [71]. Due to such possible alternative explanations, more work is needed to clarify the underlying mechanisms for an optimized utilization of such effects. Qualitative methods such as post-experience interviews could be used to find out more about the participants' perception of the used avatars and what associations are activated while embodying them.

Our data do not show any significant effects on users' sweating. While the visual comparison of the means shows a systematic sweating rate for the sweaty and non-sweaty avatars (see Figure 2), inferential statistics revealed no significant effects. As participants performed the exercise two times in succession using the respective avatars, participants' amount of produced sweat differed between the first and second conditions regardless of the avatar. Hence, we assume that order effects increased the unsystematic variance making it difficult to find a significant difference between conditions. As this measure was of exploratory nature to learn more about physiological responses to exertion while embodying different avatars, future work should, therefore, evaluate users' sweating response with a larger body of participants while controlling for individual sweating characteristics. Other exercises different than cycling, e.g., during bicep curls [24, 65], jogging [33], or workouts such as knee lifts or arm waves [59, 93], could provide additional insights.

5.2 Implications and Future Work

Such findings are promising for designers and developers of VR exergames and fitness applications as they show that visualizing sweat on avatars can have positive effects on users during physical exertion. As we systematically decreased the perception of effort while cycling in VR, sweaty avatars turned out to be promising for creating more effective exercise applications. On average, Kocur et al. [46, 49] reduced the perception of effort by approximately 1 point on the 6-20 scores of the RPE scale using muscular or athletic avatars. We were able to reduce the perception of effort by approximately 0.6 points for the female avatars and 0.1 for the male avatars (*female*: 11.2 vs. 10.6, *male*: 10.3 vs 10.2). The average differences between the sweaty and non-sweaty avatars suggest that the effects of female avatars were larger than the effects of male avatars. Although results imply that sweating can elicit the Proteus effect, the magnitude of the impact on users during physical exertion seems to be smaller than effects caused by morphological changes of avatars, e.g., a high muscle mass. As we could not replicate findings on users' HR responses, this could be a reason why the HR remained unaffected across the cycling exercise. Future studies could analyze whether adding sweat to avatars with different levels of athleticism can even reinforce, dampen, or reverse the effects on users, e.g., non-athletic avatars are attributed with higher endurance abilities due to sweating [46].

Interestingly, prior investigations found that caffeine can also decrease the perception of effort by 1 point on the RPE scale [28]. Therefore, athletes frequently consume caffeine before workouts to boost their performance and reduce the perceived exertion [26, 63]. Although the psychoactive effects of caffeine and the psychological effects caused by changes in self-perception cannot be equated, we argue that future work should further analyze the promising potential of avatars on users while exercising in VR to learn whether avatars' appearance can cause similar effects as caffeine. Finding out the magnitude of avatars' effects on the perception of effort and whether users can benefit from such effects in the long term is of particular interest.

As sweating is a natural human response, we argue that avatars should be equipped with sweating mechanisms to create a realistic and lifelike VR experience. As designers and developers aim at creating credible visuals, it is crucial to use anthropomorphic characters that accurately mimic human responses [87]. In line with Bohil et al. [13], who stated that the "ultimate goal of designers and users of VR environments is a computer-generated simulation that is indistinguishable to the user from its real-world equivalent", we hypothesize that designing sweat on avatars in appropriate situations, e.g., physical exercise can contribute to a more natural and improved experience [47]. As we created avatars with either a sweaty or non-sweaty appearance to gain first insights into the effects on users, future work should further elaborate on more natural sweating responses, e.g., visualizing an increase of sweating over time [25]. This could result in a more natural and realistic experience amplifying the effects on users while exercising in VR.

6 CONCLUSION

In this paper, we investigated the effects of sweating avatars while cycling in VR. Therefore, we conducted a VR experiment using a standardized bicycle protocol with 24 participants who rode an ergometer bike while embodying a sweaty and non-sweaty avatar. We found that participants had a lower perceived exertion when embodying the sweaty avatar compared to the non-sweaty avatar. Hence, participants embodied in the sweaty avatars felt less exerted and perceived the bicycle exercise less strenuous. Additionally, we found that sweating avatars increased participants' perceived endurance as they associated the sweaty avatar with enhanced endurance abilities. These findings suggest that visualizing sweat on avatars can positively influence users during physical exertion in VR. Our work shows that sweating avatars can contribute to more effective VR exergames and fitness applications.

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