Physiological and Perceptual Effects of Avatars' Muscularity while Rowing in Virtual Reality

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ABSTRACT

Virtual reality enables embodying different avatars. Coined the Proteus effect, previous work found that the visual characteristics of an avatar can cause behavioral, attitudinal, and perceptual effects. Recent work suggests that avatars' muscularity can even have physiological effects while cycling in virtual reality. As the effects have not been replicated it is, however, unclear how robust they are and if effects are limited to specific activities, such as cycling. Therefore, we conducted a study to understand if avatars' muscularity also causes physiological and perceptual effects for other tasks and if the effects can be replicated. 16 participants embodied a muscular and a non-muscular avatar while rowing on an indoor rower. We found that over time participants' heart rates increased significantly slower when embodying a muscular avatar compared to a non-muscular avatar. While not significant, descriptive statistics suggest the same trend for perceived exertion. Overall, the results confirm previous findings and support the conclusion that avatars can cause physiological effects for a range of physical activities.

CCS CONCEPTS

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

KEYWORDS

Proteus effect, virtual reality, avatar, heart rate, muscularity

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1 INTRODUCTION

In recent years, using virtual reality (VR) for physical exercises received increased attention. Immersive exergames or fitness applications such as Beat Saber [5] gained popularity and have been rated as one of the best games for VR [44]. This suggests that users are willing to physically exert themselves while being immersed in virtual worlds. Previous work showed that exercising in VR can increase physical activity, motivation, and exercise adherence [16, 36, 43]. Consequently, VR is a promising technology to promote physical activity and create effective exercise environments [9].

Researchers and designers of VR exercise applications can use avatars—virtual characters that represent the user in computer-generated environments—to create embodied experiences and enable intuitive interaction. In 2007, Yee and Bailenson [64] revealed that the visual appearance of avatars can cause users to change their behavior. This phenomenon was termed the *Proteus effect*. The authors showed, for example, that attractive or tall avatars can enhance users' self-confidence while being immersed in VR resulting in behavioral changes such as increased extraversion or aggressive bargaining [64, 65]. Since these seminal experiments, the Proteus effect has been reported in a variety of different contexts [12, 28, 48, 49].

Recent work documented that avatars can influence users' perceptual responses during physical exercise. Kocur et al. [31] showed that muscular avatars reduced the perception of effort while holding weights for a certain amount of time. In another study, Kocur et al. [25] revealed that sweaty avatars can also decrease the perception of effort while cycling. There is also empirical evidence suggesting that athletic avatars might even reduce users' heart rate while cycling [27]. These findings suggest that avatars can be harnessed to make users perceive exercises and workouts less intense while the actual workload remains the same [42]. For designers and developers of immersive exercise systems, such findings are promising as they suggest that avatars can be used as a tool to create more effective exercise environments.

Indoor rowing is an effective and popular full-body exercise performed at gyms [53, 62]. Recently, multiple rowing VR exergames and fitness applications have been developed (e.g., [47, 58, 63]). As rowing is a highly intense and physically demanding activity, such applications could also benefit from high-performing avatars to reduce perceptual and physiological responses. Furthermore, users can constantly perceive most of their virtual bodies while rowing due to the seating position and body posture in an indoor rowing device. This could possibly amplify a muscular avatar's effects. However, it is currently unknown whether such effects also occur in other types of exercise. To date, effects on perceived exertion have mainly been shown for tasks such as holding weights [31, 38, 39] or cycling on a stationary bike [25, 32]. As rowing is different from cycling and other types of exercises regarding the execution, involved body parts and muscle groups, physiological responses, and energy expenditure [1, 40, 41], it is unclear if effects on perceived exertion can also be found for virtual rowing. Effects of avatars' muscularity on physiological responses, such as heart rate, have only been found in a single study [27] which could not be replicated [32]. Thus, it is also unclear how robust physiological Proteus effects are.

In this paper, we investigate the effects of an avatar's muscular appearance on heart rate and perceived exertion during indoor rowing. We aimed to replicate findings from previous work [27, 31] to explore whether the Proteus effect is limited to specific activities or also translates to other types of exercises such as rowing. We conducted a study with 16 participants who embodied muscular and non-muscular avatars while rowing in VR. We found that over time participants' heart rates increased significantly slower while being embodied in a muscular compared to a non-muscular avatar. While not significant, the same trend can be observed for perceived exertion. We conclude that the Proteus effect translates to rowing in VR and affects physiological across a range of activities. We discuss the results and propose research directions for future work.

2 RELATED WORK

Our work builds on previous work about the Proteus effect caused by an avatar's stereotypical appearance. In the following, we discuss work on avatars in VR and how they can be used to create a sense of embodying them. Finally, we give an overview of the Proteus effect and how this phenomenon can be induced by an avatar's athletic appearance during physical exertion.

2.1 Avatars in Virtual Reality

Steuer defined VR as a real or simulated environment in which a perceiver experiences telepresence [60]. Virtual bodies are commonly used to represent the user in virtual environments and are typically called avatars—after the Sanskrit word for "descent" [15]. Previous work showed that a first-person perspective—perceiving the virtual world through the eyes of the avatar—in combination with congruent visual-motor synchrony can create such strong cues that users have the feeling of embodying these avatars and accepting them as their own body [22]. Thus, extending Steuer's definition [60], VR does not only enable perceiving a different world but also experiencing the world through a different body.

A virtual representation of users is fundamentally important in human-computer interaction as through them users feel represented and in control over their actions executed in the virtual environment [30, 37, 57]. Interestingly, VR enables the creation of perceptual experiences that are hardly feasible to create in the real world. Using tracking devices the movements of users can be accurately recorded and transferred onto the avatar. This visuo-motor synchrony—a synchrony of movements between the physical body and the virtual representation—can create a sensation of embodying the avatar [22, 33]. Sanchez-Vives et al. [52], for example, demonstrated how users can experience a virtual hand as their own hand through visuo-motor synchrony. In this experiment, participants could move their real hand and fingers and observe the virtual hand reacting synchronously. There is further evidence that users can experience full-body illusions even accepting virtual bodies with characteristics that differ from their own physical selves. For example, previous work revealed that users perceived avatars that indicated having a different gender [56, 59] or body composition [21, 24, 26, 31, 35, 46], a much younger appearance [2], an older appearance [4, 34], or even a different skin color [3, 19], and superhuman appearances [29] as their own body in VR.

2.2 The Proteus Effect

Interestingly, the virtual embodiment of avatars can induce behavioral, perceptual, and attitudinal changes. Yee and Bailenson [64] found that the avatar is not only useful to enhance the VR experience but can also change users' behavior and perception [65]. They term this effect the Proteus effect after the Greek God Proteus who is notable for being the origin of the adjective "protean"—the ability to take on many different self-representations [23, 64]. One explanation for the Proteus effect is self-perception theory postulating that people observe themselves from an imaginary third-person perspective similarly to an external observer [7]. This allows to interpret the own behavior and attitudes that cause us to act in a certain way. Transferring this idea to the Proteus effect, Yee and Bailenson [64] revealed that attractive avatars increased users' confidence during a VR dialogue. As attractiveness is connected with an increased self-confidence and extraversion, users behaved conform to the avatars' appearance.

Results of an increasing body of work, including studies on the effects of sexualized avatars [17], non-creative avatars [14], and attractive avatars [66], have been ascribed to the Proteus effect. Reviewing work on the Proteus effect in virtual environments and video games, Praetorius and Görlich [48] suggest that self-similarity enhances the effect, undesirable characteristics of the avatar can reduce the effect, and that the sense of presence and embodiment is particularly important. A meta-analysis of the Proteus effect by Ratan et al. [49], considering 46 quantitative experimental studies, concluded that the Proteus effect is a reliable phenomenon, with a small-but-approaching-medium effect size. While Clark [12] concludes that effects are smaller than indicated and suggests alternative explanations, Beyea et al. [8] conducting yet another meta-analysis of the Proteus effect found stronger effect sizes for studies conducted in VR. When initially coining the term Proteus effect, Yee and Bailenson [64, 65] only considered behavioral effects. In line with this initial understanding, most work on the Proteus effect investigated effects on behavior and attitudes [49].

2.3 The Proteus Effect During Physical Exertion

Recent works investigated the Proteus effect in physical contexts. In a recent study by Lin et al. [39], it was observed that the presence of abdominal muscles on avatars had an impact on the exercise

Figure 1: The female-gendered and male-gendered non-muscular avatars (left) as well as the female-gendered and male-gendered muscular avatars (right). The four avatars are adapted from the work by Kocur et al. [27].

behavior of users. Specifically, participants embodying avatars characterized by a "six-pack" exhibited lower levels of physical activity compared to those embodying avatars without pronounced abdominal muscles. The authors hypothesized that users perceived themselves as already being in good physical shape while embodying a muscular avatar. Consequently, they felt less compelled to engage in rigorous exercise. These findings are in line with Lin and Wu [38], who manipulated the age of avatars. The authors showed that embodying avatars of a younger age heightened the perceived exertion during exercise sessions.

Similarly, Czub and Janeta [13] conducted a comparative analysis between a VR environment, where participants executed biceps curls while embodying athletic avatars, and a non-VR setting. Results indicated that participants completed more repetitions in VR. These outcomes corroborate those of Matsangidou et al. [43], who documented lower perceived pain levels during biceps curls performed in VR compared to a real-world setting. As behavior and perception can consciously be influenced, previous work also studied physiological effects [18, 25, 27]. Results by Kocur et al. [27], studying the effects of avatars' athleticism while cycling, suggest that athleticism has a significant and systematic effect on heart rate and perceived exertion. Another study, also by Kocur et al. [25], investigating the effects of sweating avatars while cycling, however, revealed effects on perceived exertion but not on heart rate. Additionally, a recent study by Kocur et al. [32] could not show the Proteus effect while cycling a stationary bike using athletic and non-athletic avatars. Hence, further investigations are required to gain a better understand about physiological effects of avatars on users.

2.4 Summary

In conclusion, in VR, we can embody avatars, which we accept as our own body [22]. Embodying stereotypical avatars can induce what has been coined the Proteus effect [64, 65]. A large body of work supports the conclusion that embodying avatars with stereotypical characteristics can cause changes in behavior and attitude [8, 49]. Previous work also suggests physiological Proteus effects while cycling with different avatars [27] but failed to replicate them [25, 32]. Thus, it is unclear how robust physiological Proteus effects are and if effects are limited to specific activities, such as cycling.

3 METHODS

We conducted a controlled experiment to understand if the effects of avatars' muscularity on heart rate are robust and can be determined for tasks beyond cycling.

3.1 Study Design

To investigate the effects of avatars' muscularity, we conducted a controlled experiment with the one independent variable muscularity (non-muscular and muscular). We used a within-subjects design to cancel out individual differences between participants.

Participants embodied either a non-muscular or a muscular avatar of their identified gender (see Figure 1). To be consistent with previous work, we adapted the approach used by Kocur et al. [27] to create the four avatars. Also in line with previous work (e.g. [25]), we measured three dependent variables. We measured participants' heart rate to determine physiological effects, perceived exertion to determine perceptual effects, and presence to determine if the avatars affect how immersed participants were.

3.2 Apparatus

We developed an apparatus that enabled participants to row on an indoor rower in real life while transferring their movement to rowing a single scull in virtual reality.

3.2.1 Real-Life Setup. The aim was to recreate a realistic rowing experience called sculling. While sculling the rower is sitting with the back to the travel direction having an oar in each hand. The thrust is generated through the whole body by extension of the legs,

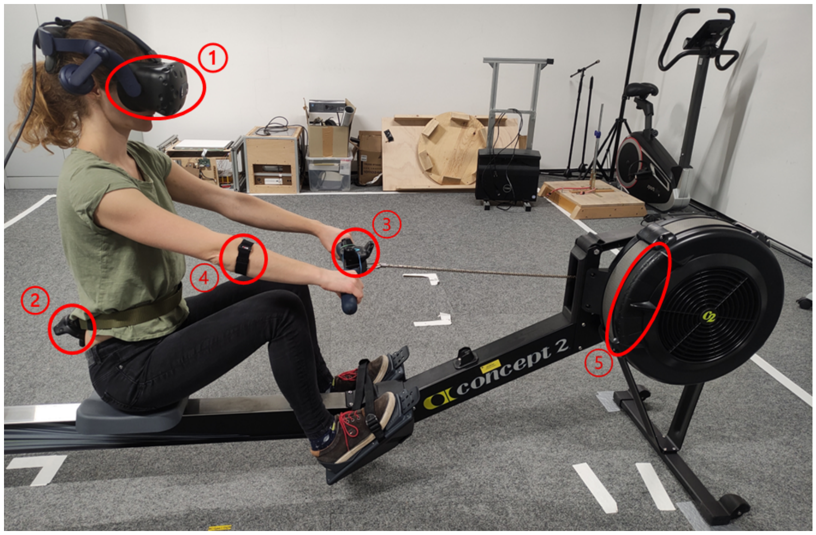

Figure 2: A participant on the Rower Model D by Concept2 outfitted with (1) HTC Vive Pro 2, (2) Vive Tracker 2.0 on the hip, (3) Vive Tracker 2.0 on the hand grip, (4) Polar OH1 HR sensor, (5) the mechanical resistance setting of the rowing machine.

straightening of the back, and pulling with the arms. Rowing is considered relatively safe to practice due to the steady motion and distribution of the load on the whole body. We used the Model D[1] indoor rower by Concept2. The Model D has been used worldwide for home-based training, official competitions, and performance assessment in sports and science [61] (see Fig. 3). It enables manual adjustment of the indoor rower's pull resistance from 1 to 10 using a mechanical lever.

Participants were equipped with an HTC VIVE Pro 2 head-mounted display (HMD) to ensure a high-resolution visual presentation of the scene. The HMD naturally provided the position of the participants' heads. To further track participants' position and movements we attached a HTC Vive Tracker 2.0 to their lower back and another HTC Vive Tracker 2.0 to the Model D's hand grip. Participants' feet rested on the Model D's feet rest.

3.2.2 *Virtual Setup.* We used Unity (ver. 2020.3.13f1) to design and implement the virtual environment. We used the commercially available 3D model by machine_men[2] as a basis for the single rowing scull. The 3D model is highly realistic and advertised as usable in broadcast, high-res film close-ups, and advertising. We converted the model using the FBX Converter tool by Autodesk and flipped the textures' normals in Blender. We also separated the meshes of the seat and oars from the main model to animate them. Additionally, we adjusted the scull's scale and its position to match the scale and position of the real world. Thereby, the range of movement by the seat in the virtual world matches the range of motion of the real seat, allowing to achieve perfect synchronicity. The origins of the oars were moved to the rigging points so that the oar rotate around this point.

We used the two HTC Vive Tracker 2.0 attached to the lower back and the hand grip, in addition to the HMD, to track the movement of the participants. We animated the avatars using the inverse kinematics (IK) script of the Final IK package by RootMotion[3]. We used the stationary position of the feet, the position of the head, tracked by the HMD, the position of the hands, tracked by the Vive sensor attached to the hand grip, and the position of the hip, tracked by the second Vive sensor as anchor points for the IK. Altogether, this allowed a fluid and realistic animation of the avatar.

We aimed to keep the surroundings of the rowing scull simple but realistic to simultaneously avoid distractions and achieve a high level of realism. Therefore, we used a water plane that mimics open water. We used a water shader[4] to display realistically animated water. To realize an initial embodiment phase we placed a mirror in front of the rowing scull at its start position. Therefore, we used a plane object and linked the outwards-facing camera object as the rendering texture.

3.3 Measures

We determined participants' cardiac frequency while rowing on the indoor rower to determine physiological effects. In line with previous work on the Proteus effect (e.g. [25, 31, 45]), we measured participants' heart rates throughout the embodiment phase and the 8 minutes exercise. We used an optical Polar OH1 HR sensor by Polar Electro, which has previously been validated for moderate- and high-intensity physical activities [20], placed on the left or right arm. The sensor was paired with a smartphone via Bluetooth for real-time data recording and the data sets were exported via the Polar Flow app. We aggregated the raw heart rate data over two-minute intervals to reduce noise, resulting in data points for the embodiment phase and while rowing for 2 minutes, 4 minutes, 6 minutes, and 8 minutes.

[1]Modell D Indoor Rower https://www.concept2.com/service/indoor-rowers/model-d
[2]Single Rowing Sculls by machine_men: https://www.turbosquid.com/3d-models/single-rowing-sculls-c4d/1023066
[3]Final IK by RootMotion: https://assetstore.unity.com/packages/tools/animation/final-ik-14290
[4]Simple Water Shader URP by IgniteCoders: https://assetstore.unity.com/packages/2d/textures-materials/water/simple-water-shader-urp-191449

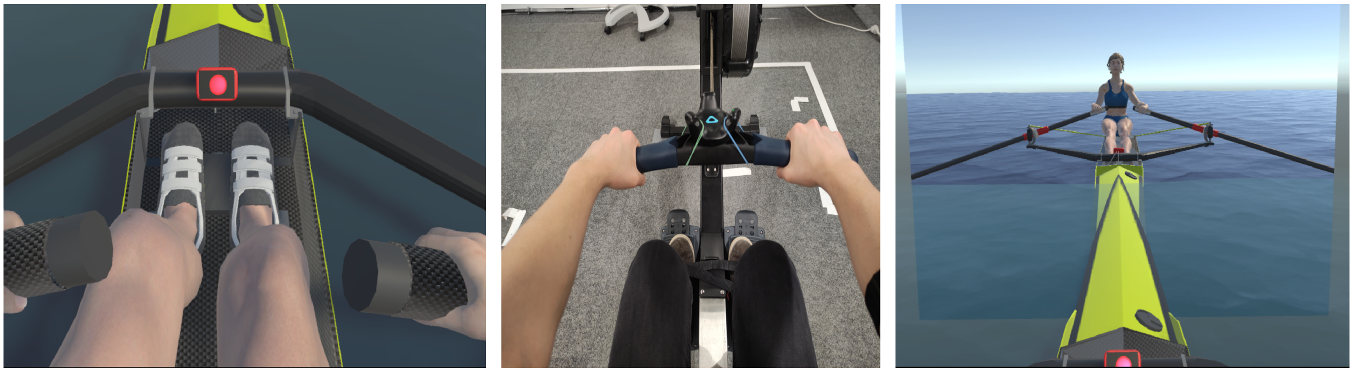

Figure 3: From left to right: in-application first-person-view of hands and legs, real-world first-person-view of hands and legs, in-application first-person-view during priming with mirror in front.

We measured participants' perceived exertion to determine perceptual effects. In line with previous work on the Proteus effect (e.g. [25, 31, 39]), participants were shown the psychophysical Borg's RPE scale [10] after the embodiment phase and after rowing for 2 minutes, 4 minutes, 6 minutes, and 8 minutes. Participants orally communicated the value that best represented their perception of effort. The RPE scale was designed to increase linearly with physical exercise intensity ranging from 6 (no exertion) to 20 (maximal exertion). The scale is designed to estimate the current HR by multiplying each value by 10, so an intensity of 15, for example, approximately matches an HR of 150 [10].

How present participants feel in the virtual environment could act as a moderator for the Proteus effect [51] or as a confounder. Thus, in line with previous work [34, 50, 51], we determined how present participants feel in the virtual environment for both conditions. We used the iGroup presence questionnaire (IPQ) [54] as suggested by Schwind et al. [55], who assume that the IPQ questionnaire best reflects the construct of presence. Participants filled out the 13 items of the IPQ questionnaire outside of VR after each condition.

3.4 Procedure and Task

After welcoming the participants, we explained the procedure of the study. After receiving informed consent, we collected demographic information. Afterward, we attached the Polar OH1 HR sensor to the participant's arm and one of the Vive trackers to the lower back. As males have, on average, a higher skeletal muscle mass and are, on average taller, we adjusted the resistance of the indoor rower according to the participants' gender. We set the resistance to 5 of 10 for male participants and 3 of 10 for female participants, to prevent over-straining or injury by providing a relatively low level of resistance for both genders. If the participants were inexperienced with the use of an indoor rower, we gave them a short demonstration of the correct technique.

After sitting down on the indoor rower and setting up the HMD, participants were immersed in the virtual scene in front of the mirror for two minutes. This was followed by rowing for a total of eight minutes at a fixed pace of 22 strokes per minute. We ensured that participants are able to maintain a steady pace by virtually attaching a rhythmically blinking light to the scull (see Figure 3). The light was blinking with a frequency of 22 blinks per minute, representing the desired speed. We asked participants to orally provide their perceived exertion every two minutes. After rowing for eight minutes, we asked participants to take off the HMD, fill out the IPQ questionnaire, and take a break for 5 minutes. Afterward, they continued with the second condition. We alternated the order of the conditions to avoid sequence effects.

3.5 Participants

We recruited 16 participants through mailing lists and personal contacts for the study. 8 participants identified as male and 8 participants identified as female. They were between 18 and 32 years old (M=25.25, SD=3.71). 4 participants were compensated with credit points for their degree program.

4 RESULTS

In the following, we report the analysis of participants' heart rates, the perceived exertion they experienced, and the presence they perceived. To investigate the effects of the independent variable muscularity on the participants' HR response and perception of effort, we analyzed the time course of both measures across the entire exercise using two-minute intervals. Hence, we included the factor time (5 levels with a 2 minutes interval) in the statistical analysis.

4.1 Heart Rate

We analyzed the effect of muscularity and time on participants' heart rates. Mauchly's test indicates that the sphericity assumption was violated for time ($p<0.001$) and muscles*time ($p<0.001$). Therefore, we used the Greenhouse-Geisser correction to adjust the degrees of freedom. A two-way repeated measures ANOVA revealed a significant effect of time ($F(1.301, 19.517)=26.000$, $p<0.001$), no significant effect of muscularity ($F(1,15)=0.485$), $p=0.497$), and a significant muscles*time interaction effect ($F(1.844, 27.660)=3.928$ $p=0.034$). Thus, over time, participants' heart rate was significantly affected by the embodied avatar. Figure 4 shows participants' heart rates over time for the two conditions.

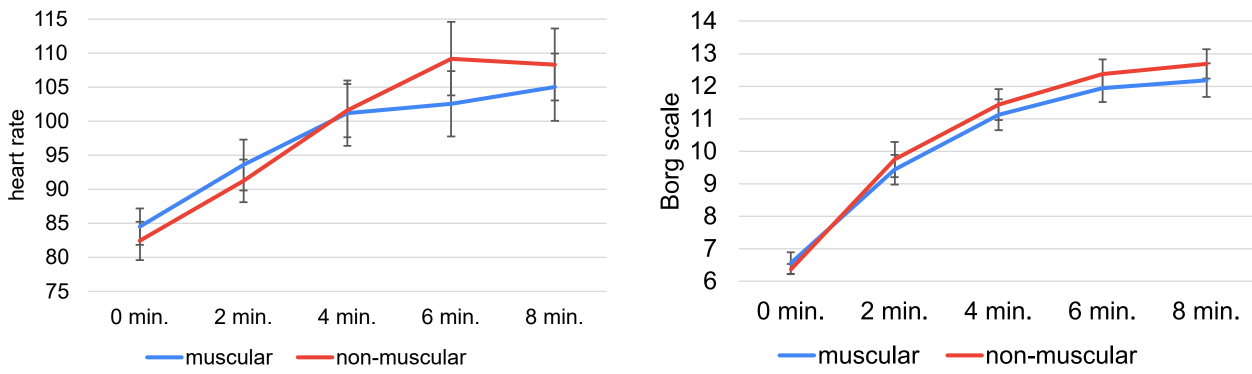

Figure 4: Participants' heart rate at the start and throughout the eight minutes exercise for the two conditions (left) and participants perceived exertion at the start and throughout the eight minutes exercise for the two conditions (right). Error bars show the standard error.

4.2 Perceived Exertion

We analyzed the effect of muscularity and time on the perceived exertion experienced by participants and measured using the Borg scale. Mauchly's test indicates that the sphericity assumption was violated for time ($p<0.001$) and muscles*time ($p<0.001$). Therefore, we used the Greenhouse-Geisser correction to adjust the degrees of freedom. A two-way repeated measures ANOVA revealed a significant effect of time ($F(2.215, 33.219)=85.447$, $p<0.001$), no significant effect of muscularity ($F(1,15)=0.692$), $p=0.419$), and no significant muscles*time interaction effect ($F(2.350, 72.050)=0.489$, $p=0.597$). Thus, participants' perceived exertion was significantly affected by time but not by muscularity or the interaction of time and muscularity. Figure 4 shows participants' perceived exertion over time for the two conditions.

4.3 Presence

We analyzed the effect of muscularity on the three subscales of the IPQ. A one-way repeated measures ANOVA revealed no significant effect on spatial presence ($F(1,15)=0.046$, $p=0.833$), involvement ($F(1,15)=1.209$, $p=0.289$), or realism ($F(1,15)=1.947$, $p=0.180$). Thus, muscularity had no significant effect on any of the IPQ's three subscales. Figure 5 shows the three subscales of the IPQ for the two conditions.

5 DISCUSSION

We conducted a study to understand if the muscularity of the embodied avatar has significant physiological and perceptual effects. Participants were rowing on an indoor rower while virtually being in a single scull and embodying either a muscular or a non-muscular avatar. We found that over time, participants' heart rate was significantly affected by the embodied avatar. Embodying a muscular avatar, participants' heart rate increased slower compared to embodying a non-muscular avatar. While the effect is not significant, we observed a similar trend for the perceived exertion participants experienced. We found no effect of avatars' muscularity on the presence they experienced.

The results are in line with previous work which revealed an effect of athleticism on heart rate while cycling in VR [27]. As we found no effect of muscularity on presence, we assume that the effect on the heart rate was indeed caused by muscularity and not by other aspects of the avatar design. In contrast to previous work [25, 27, 31], our analysis revealed no effect on perceived exertion. Our descriptive results, however, suggest the same trend as found by previous work.

One possible explanation for physiological changes could originate from behavioral adaptations caused by the avatars' appearance. In line with the Proteus effect, the athletic avatar could change the body posture or the stroke while rowing. This could change the effectiveness of rowing and, in turn, the physiological responses in terms of cardiac frequency. Findings from sport physiology, for example, show that the body position and rowing technique affects power output as well as physiological responses [6]. Hence, the athletic avatar could possibly make participants row more efficiently. However, as all participants were inexperienced with rowing, we do not argue that the athletic avatar improved participants' rowing technique. Instead, we assume that participants adapted their body posture or stroke in a more "athletic" and "dynamic" way. As we did not measure such behavioral adaptations such as body posture and stroke efficiency, future work should further explore the cause of physiological changes due to the avatars' appearance originating from variations in the technique.

The study's main limitation is the comparatively low number of participants, potentially resulting in limited statistical power. We increased the study's statistical power by using a repeated measures design, canceling out individual differences. We adjusted the difficulty of the task to participants' gender to reduce differences between participants. In addition, we only compared two levels of muscularity to reduce the number of conditions. We still assume that statistical power was limited and potentially the reason why no effect on perceived exertion was observed. Future work should further explore the Proteus effect with a larger sample size and a control condition serving as a baseline using an avatar with average muscularity. In this vein, other factors such as familiarity with VR,

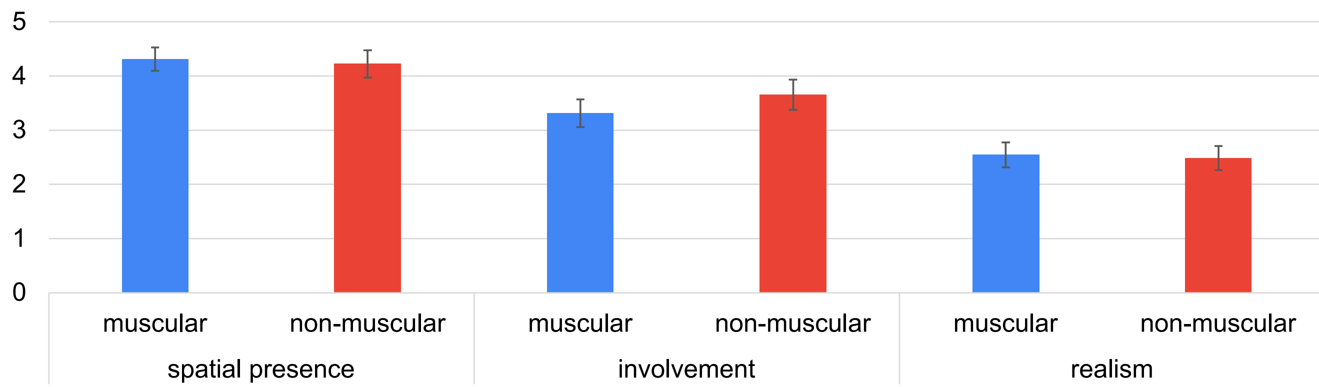

Figure 5: The three subscales of the IPQ for the two conditions. Error bars show the standard error.

and psychological factors such as motivation and competitiveness should be explored to learn about potential moderators.

Overall, we can conclude that not only the Proteus effect, in general, is a robust effect [8, 49] but that effects on physiological responses, in our case the heart rate, are also robust and replicable. There are multiple directions for practical applications and future work regarding this effect. An obvious avenue is considering avatars' muscularity in virtual training applications and virtual competitions. Using muscular avatars could increase the effectiveness of training. Using them in virtual competitions, however, could result in a new form of e-doping, extending, hacks and taking performance-enhancing substances, considered by previous work [11, 42]. The most pressing direction for future work is investigating repeated exposure and long-term effects not only for physiological effects but for the Proteus effect in general. For a short-term embodiment, we see a gradual increase of the Proteus effect. We assume that over longer people will adapt if they embody an avatar for a longer duration resulting in the Proteus effect fading away. While this in itself has to be investigated, it would also be interesting to understand how and why the effect developed over time.

6 CONCLUSION

In this paper, we investigate the effects of athletic and non-athletic avatars on users' perceptual and physiological responses during physical exercise. We conducted a controlled experiment with 16 participants who were indoor rowing in VR while embodying athletic or non-athletic avatars. We found that embodying an athletic avatar resulted in a lower increase of participants' heart rate compared to the non-athletic version. As the sense of presence was not influenced by the avatars, we argue that the effects on heart rate were caused by the avatars' muscularity and not other experiential characteristics. Hence, our paper extends prior research about the Proteus effect by showing that athletic avatars can not only be beneficial for cycling but also for rowing. Future studies can use and extend our work to explore the underlying mechanisms for physiological changes caused by the Proteus effect.

REFERENCES

[1] Todd A Astorino, Chandler Oriente, Jill Peterson, Giannina Alberto, Erica Elena Castillo, Ulices Vasquez-Soto, Esmerelda Ibarra, Victoria Guise, Ivan Castaneda, Joel R Marroquin, Rachel Dargis, and Jacob S Thum. 2021. Higher Peak Fat Oxidation During Rowing vs. Cycling in Active Men and Women. *The Journal of Strength & Conditioning Research* 35 (2021). Issue 1. https://journals.lww.com/nsca-jscr/Fulltext/2021/01000/Higher_Peak_Fat_Oxidation_During_Rowing_vs_.2.aspx

[2] Domna Banakou, Raphaela Groten, and Mel Slater. 2013. Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. *Proceedings of the National Academy of Sciences* 110, 31 (2013), 12846–12851. https://doi.org/10.1073/pnas.1306779110 arXiv:https://www.pnas.org/doi/pdf/10.1073/pnas.1306779110

[3] Domna Banakou, Parasuram D Hanumanthu, and Mel Slater. 2016. Virtual embodiment of white people in a black virtual body leads to a sustained reduction in their implicit racial bias. *Frontiers in human neuroscience* (2016), 601.

[4] Domna Banakou, Sameer Kishore, and Mel Slater. 2018. Virtually Being Einstein Results in an Improvement in Cognitive Task Performance and a Decrease in Age Bias. *Frontiers in Psychology* 9 (2018). https://doi.org/10.3389/fpsyg.2018.00917

[5] Beat Games. 2019. Beat Saber. Game [PC, PS, Meta Quest]. Beat Games, Czech Republic.

[6] Gordon Bell, Jack Bennett, William Reynolds, Daniel Syrotuik, and Pierre Gervais. 2013. A Physiological and Kinematic Comparison of two Different Lean Back Positions During Stationary Rowing on a Concept II Machine. *J Hum Kinet* 37 (July 2013), 99–108.

[7] Daryl J. Bem. 1972. Self-Perception Theory. *Advances in Experimental Social Psychology* 6 (1972), 1–62. https://doi.org/10.1016/S0065-2601(08)60024-6

[8] David Beyea, Rabindra (Robby) Ratan, Yiming (Skylar) Lei, Hanjie Liu, Gabriel E. Hales, and Chaeyun Lim. 2023. A New Meta-Analysis of the Proteus Effect: Studies in VR Find Stronger Effect Sizes. *PRESENCE: Virtual and Augmented Reality* (07 2023), 1–30. https://doi.org/10.1162/pres_a_00392

[9] Samantha Bond, Deepika R. Laddu, Cemal Ozemek, Carl J Lavie, and Ross Arena. 2021. Exergaming and Virtual Reality for Health: Implications for Cardiac Rehabilitation. *Current Problems in Cardiology* 46, 3 (2021), 100472. https://doi.org/10.1016/j.cpcardiol.2019.100472

[10] GA Borg. 1982. Psychophysical bases of perceived exertion. *Medicine and science in sports and exercise* 14, 5 (1982), 377—381. http://europepmc.org/abstract/MED/7154893

[11] Subhrajit Chanda, Shaun Star, et al. 2021. Contouring E-doping: A menace to sportsmanship in E-sports. *Turkish Online Journal of Qualitative Inquiry* 12, 8 (2021), 966–981.

[12] Oliver Clark. 2020. How to kill a Greek God-A review, critique, and meta-analysis of 14 years of Proteus effect research. (2020).

[13] Marcin Czub and Paweł Janeta. 2021. Exercise in Virtual Reality With a Muscular Avatar Influences Performance on a Weightlifting Exercise. *Cyberpsychology: Journal of Psychosocial Research on Cyberspace* 15, 10 (2021), 1–16. https://doi.org/10.5817/CP2021-3-10

[14] Alwin de Rooij, Sarah van der Land, and Shelly van Erp. 2017. The Creative Proteus Effect: How Self-Similarity, Embodiment, and Priming of Creative Stereotypes with Avatars Influences Creative Ideation. In *Proceedings of the 2017 ACM SIGCHI Conference on Creativity and Cognition* (Singapore, Singapore) *(C&C '17)*. Association for Computing Machinery, New York, NY, USA, 232–236. https://doi.org/10.1145/3059454.3078856

[15] Denise Doyle. 2009. The body of the avatar: rethinking the mind-body relationship in virtual worlds. *Journal of Gaming & Virtual Worlds* 1, 2 (2009), 131–141. https://doi.org/10.1386/jgvw.1.2.131/1

[16] Samantha Finkelstein, Andrea Nickel, Zachary Lipps, Tiffany Barnes, and Zachary Wartell. 2011. Astrojumper: Motivating Exercise with an Immersive Virtual Reality Exergame. *PRESENCE: Virtual and Augmented Reality* 20 (2011), 78–92. Issue 1. https://doi.org/10.1162/PRES

[17] Jesse Fox, Jeremy N. Bailenson, and Liz Tricase. 2013. The embodiment of sexualized virtual selves: The Proteus effect and experiences of self-objectification via avatars. *Computers in Human Behavior* 29, 3 (2013), 930–938. https://doi.org/10.1016/j.chb.2012.12.027

[18] David Halbhuber, Martin Kocur, Alexander Kalus, Kevin Angermeyer, Valentin Schwind, and Niels Henze. 2023. Understanding the Effects of Perceived Avatar Appearance on Latency Sensitivity in Full-Body Motion-Tracked Virtual Reality. In *Proceedings of Mensch Und Computer 2023 (MuC '23)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3603555.3603580

[19] Beatrice S. Hasler, Bernhard Spanlang, and Mel Slater. 2017. Virtual Race Transformation Reverses Racial Ingroup Bias. *PLoS ONE* 12, 4 (2017), 1–20. https://doi.org/10.1371/journal.pone.0174965

[20] Imali T. Hettiarachchi, Samer Hanoun, Darius Nahavandi, and Saeid Nahavandi. 2019. Validation of Polar OH1 optical heart rate sensor for moderate and high intensity physical activities. *PLOS ONE* 14, 5 (05 2019), 1–13. https://doi.org/10.1371/journal.pone.0217288

[21] Alexander Kalus, Martin Kocur, Johannes Klein, Manuel Mayer, and Niels Henze. 2023. PumpVR: Rendering the Weight of Objects and Avatars through Liquid Mass Transfer in Virtual Reality. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 263, 13 pages. https://doi.org/10.1145/3544548.3581172

[22] Konstantina Kilteni, Antonella Maselli, Konrad P. Kording, and Mel Slater. 2015. Over my fake body: body ownership illusions for studying the multisensory basis of own-body perception. *Frontiers in Human Neuroscience* 9 (2015). https://doi.org/10.3389/fnhum.2015.00141

[23] Martin Kocur. 2022. Utilizing the Proteus Effect to Improve Performance Using Avatars in Virtual Reality. https://epub.uni-regensburg.de/52677/

[24] Martin Kocur. 2023. Towards Investigating the Effects of Athletic Avatars and Room Size on Time Perception. Mensch und Computer 2023 - Workshopband. https://doi.org/10.18420/muc2023-mci-ws05-425

[25] Martin Kocur, Johanna Bogon, Manuel Mayer, Miriam Witte, Amelie Karber, Niels Henze, and Valentin Schwind. 2022. Sweating Avatars Decrease Perceived Exertion and Increase Perceived Endurance While Cycling in Virtual Reality. In *Proceedings of the 28th ACM Symposium on Virtual Reality Software and Technology* (Tsukuba, Japan) *(VRST '22)*. Association for Computing Machinery, New York, NY, USA, Article 29, 12 pages. https://doi.org/10.1145/3562939.3565628

[26] Martin Kocur, Sarah Graf, and Valentin Schwind. 2020. The Impact of Missing Fingers in Virtual Reality. In *Proceedings of the 26th ACM Symposium on Virtual Reality Software and Technology* (Virtual Event, Canada) *(VRST '20)*. Association for Computing Machinery, New York, NY, USA, Article 4, 5 pages. https://doi.org/10.1145/3385956.3418973

[27] Martin Kocur, Florian Habler, Valentin Schwind, Paweł W. Woźniak, Christian Wolff, and Niels Henze. 2021. Physiological and Perceptual Responses to Athletic Avatars While Cycling in Virtual Reality. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 519, 18 pages. https://doi.org/10.1145/3411764.3445160

[28] Martin Kocur, Niels Henze, and Valentin Schwind. 2021. The Extent of the Proteus Effect as a Behavioral Measure for Assessing User Experience in Virtual Reality. In *CHI 2021 - Workshop on Evaluating User Experiences in Mixed Reality*. 1–3. https://epub.uni-regensburg.de/45543/

[29] Martin Kocur, Lukas Jackermeier, Valentin Schwind, and Niels Henze. 2023. The Effects of Avatar and Environment on Thermal Perception and Skin Temperature in Virtual Reality. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 231, 15 pages. https://doi.org/10.1145/3544548.3580668

[30] Martin Kocur, Alexander Kalus, Johanna Bogon, Niels Henze, Christian Wolff, and Valentin Schwind. 2022. The Rubber Hand Illusion in Virtual Reality and the Real World - Comparable but Different. In *Proceedings of the 28th ACM Symposium on Virtual Reality Software and Technology (VRST '22)*. Association for Computing Machinery, New York, NY, USA, Article 31, 12 pages. https://doi.org/10.1145/3562939.3565614

[31] Martin Kocur, Melanie Kloss, Valentin Schwind, Christian Wolff, and Niels Henze. 2020. Flexing Muscles in Virtual Reality: Effects of Avatars' Muscular Appearance on Physical Performance. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (Virtual Event, Canada) *(CHI PLAY '20)*. Association for Computing Machinery, New York, NY, USA, 193–205. https://doi.org/10.1145/3410404.3414261

[32] Martin Kocur, Manuel Mayer, Amelie Karber, Miriam Witte, Niels Henze, and Johanna Bogon. 2023. The Absence of Athletic Avatars' Effects on Physiological and Perceptual Responses while Cycling in Virtual Reality. In *Proceedings of the 22nd International Conference on Mobile and Ubiquitous Multimedia (MUM '23)*. Association for Computing Machinery, New York, NY, USA, 366–376. https://doi.org/10.1145/3626705.3627769

[33] Martin Kocur, Daniel Roth, and Valentin Schwind. 2020. Towards an Investigation of Embodiment Time in Virtual Reality. Mensch und Computer 2020 - Workshopband. https://doi.org/10.18420/muc2020-ws134-339

[34] Martin Kocur, Philipp Schauhuber, Valentin Schwind, Christian Wolff, and Niels Henze. 2020. The Effects of Self- and External Perception of Avatars on Cognitive Task Performance in Virtual Reality. In *Proceedings of the 26th ACM Symposium on Virtual Reality Software and Technology* (Virtual Event, Canada) *(VRST '20)*. Association for Computing Machinery, New York, NY, USA, Article 27, 11 pages. https://doi.org/10.1145/3385956.3418969

[35] Martin Kocur, Valentin Schwind, and Niels Henze. 2019. Utilizing the Proteus Effect to Improve Interactions using Full-Body Avatars in Virtual Reality. Mensch und Computer 2019 - Workshopband. https://doi.org/10.18420/muc2019-ws-584

[36] Lisbeth H. Larsen, Lone Schou, Henrik Hautop Lund, and Henning Langberg. 2013. The Physical Effect of Exergames in Healthy Elderly—A Systematic Review. *Games for Health Journal* 2, 4 (2013), 205–212. https://doi.org/10.1089/g4h.2013.0036 arXiv:https://doi.org/10.1089/g4h.2013.0036 PMID: 26192224.

[37] Hannah Limerick, David Coyle, and James W. Moore. 2014. The experience of agency in human-computer interactions: a review. *Frontiers in Human Neuroscience* 8 (2014). https://doi.org/10.3389/fnhum.2014.00643

[38] Jih-Hsuan Tammy Lin and Dai-Yun Wu. 2021. Exercising With Embodied Young Avatars: How Young vs. Older Avatars in Virtual Reality Affect Perceived Exertion and Physical Activity Among Male and Female Elderly Individuals. *Frontiers in psychology* 12 (2021). https://doi.org/10.3389/fpsyg.2021.693545

[39] Jih-Hsuan Tammy Lin, Dai-Yun Wu, and Ji-Wei Yang. 2021. Exercising With a Six Pack in Virtual Reality: Examining the Proteus Effect of Avatar Body Shape and Sex on Self-Efficacy for Core-Muscle Exercise, Self-Concept of Body Shape, and Actual Physical Activity. *Frontiers in Psychology* 12 (2021). https://doi.org/10.3389/fpsyg.2021.693543

[40] Joshua R. Lindenthaler, Anthony J. Rice, Nathan G. Versey, Andrew J. McKune, and Marijke Welvaert. 2018. Differences in Physiological Responses During Rowing and Cycle Ergometry in Elite Male Rowers. *Frontiers in Physiology* 9 (2018). https://doi.org/10.3389/fphys.2018.01010

[41] Donald A. Mahler, Bruce E. Andrea, and Joseph L. Ward. 1987. Comparison of Exercise Performance on Rowing and Cycle Ergometers. *Research Quarterly for Exercise and Sport* 58, 1 (1987), 41–46. https://doi.org/10.1080/02701367.1987.10605418

[42] Samuele Marcora. 2016. Can Doping be a Good Thing? Using Psychoactive Drugs to Facilitate Physical Activity Behaviour. , 5 pages. Issue 1. https://doi.org/10.1007/s40279-015-0412-x

[43] Maria Matsangidou, Chee Siang Ang, Alexis R. Mauger, Jittrapol Intarasirisawat, Boris Otkhmezuri, and Marios N. Avraamides. 2019. Is your virtual self as sensational as your real? Virtual Reality: The effect of body consciousness on the experience of exercise sensations. *Psychology of Sport and Exercise* 41 (2019), 218–224. Issue March. https://doi.org/10.1016/j.psychsport.2018.07.004

[44] Vivek Nair, Viktor Radulov, and James F. O'Brien. 2023. Results of the 2023 Census of Beat Saber Users: Virtual Reality Gaming Population Insights and Factors Affecting Virtual Reality E-Sports Performance. arXiv:2305.14320 [cs.HC]

[45] Jessica Navarro, Jorge Peña, Ausias Cebolla, and Rosa Baños. 2022. Can Avatar Appearance Influence Physical Activity? User-Avatar Similarity and Proteus Effects on Cardiac Frequency and Step Counts. *Health Communication* 37, 2 (2022), 222–229. https://doi.org/10.1080/10410236.2020.1834194 PMID: 33054371.

[46] Jean-Marie Normand, Elias Giannopoulos, Bernhard Spanlang, and Mel Slater. 2011. Multisensory Stimulation Can Induce an Illusion of Larger Belly Size in Immersive Virtual Reality. *PLoS ONE* 6, 1 (2011), 1–11. https://doi.org/10.1371/journal.pone.0016128

[47] Brett J. Parton and David L. Neumann. 2019. The effects of competitiveness and challenge level on virtual reality rowing performance. *Psychology of Sport and Exercise* 41 (2019), 191–199. https://doi.org/10.1016/j.psychsport.2018.06.010

[48] Anna Samira Praetorius and Daniel Görlich. 2020. How Avatars Influence User Behavior: A Review on the Proteus Effect in Virtual Environments and Video Games. In *Proceedings of the 15th International Conference on the Foundations of Digital Games* (Bugibba, Malta) *(FDG '20)*. Association for Computing Machinery, New York, NY, USA, Article 49, 9 pages. https://doi.org/10.1145/3402942.3403019

[49] Rabindra Ratan, David Beyea, Benjamin J. Li, and Luis Graciano. 2020. Avatar characteristics induce users' behavioral conformity with small-to-medium effect sizes: a meta-analysis of the proteus effect. *Media Psychology* 23, 5 (2020), 651–675. https://doi.org/10.1080/15213269.2019.1623698 arXiv:https://doi.org/10.1080/15213269.2019.1623698

[50] René Reinhard, Khyati Girish Shah, Corinna A. Faust-Christmann, and Thomas Lachmann. 2020. Acting your avatar's age: effects of virtual reality avatar embodiment on real life walking speed. *Media Psychology* 23, 2 (2020), 293–315. https://doi.org/10.1080/15213269.2019.1598435

[51] Nouran Sadek, Passant Elagroudy, Ali Khalil, and Slim Abdennadher. 2022. The Superhero Pose: Enhancing Physical Performance in Exergames by Embodying Celebrity Avatars in Virtual Reality. In *Nordic Human-Computer Interaction Conference* (Aarhus, Denmark) *(NordiCHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 1, 11 pages. https://doi.org/10.1145/3546155.3546707

[52] Maria V. Sanchez-Vives, Bernhard Spanlang, Antonio Frisoli, Massimo Bergamasco, and Mel Slater. 2010. Virtual hand illusion induced by visuomotor correlations. *PLoS ONE* 5, 4 (2010), 1–6. https://doi.org/10.1371/journal.pone.0010381

[53] Bonita Sawatzky, Brandon Herrington, Kevin Choi, W Ben Mortenson, Jaimie Borisoff, Carolyn Sparrey, and James J Laskin. 2022. Acute physiological comparison of sub-maximal exercise on a novel adapted rowing machine and arm crank ergometry in people with a spinal cord injury. *Spinal Cord* 60 (2022), 694–700. Issue 8. https://doi.org/10.1038/s41393-022-00757-2

[54] Thomas W Schubert. 2003. The sense of presence in virtual environments: A three-component scale measuring spatial presence, involvement, and realness. *Z. für Medienpsychologie* 15, 2 (2003), 69–71.

[55] Valentin Schwind, Pascal Knierim, Nico Haas, and Niels Henze. 2019. Using Presence Questionnaires in Virtual Reality. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300590

[56] Valentin Schwind, Pascal Knierim, Cagri Tasci, Patrick Franczak, Nico Haas, and Niels Henze. 2017. "These Are Not My Hands!": Effect of Gender on the Perception of Avatar Hands in Virtual Reality. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. ACM, New York, NY, USA, 1577–1582. https://doi.org/10.1145/3025453.3025602 Honorable Mention Award.

[57] Sofia Seinfeld, Tiare Feuchtner, Antonella Maselli, and Jörg Müller. 2021. User Representations in Human-Computer Interaction. *Human–Computer Interaction* 36, 5-6 (2021), 400–438. https://doi.org/10.1080/07370024.2020.1724790

[58] Nur Aqilah Shoib, Mohd Shahrizal Sunar, Nurshamine Nazira Mohd Nor, Azizul Azman, Mohd Najeb Jamaludin, and Hadafi Fitri Mohd Latip. 2020. Rowing Simulation using Rower Machine in Virtual Reality. In *2020 6th International Conference on Interactive Digital Media (ICIDM)*. 1–6. https://doi.org/10.1109/ICIDM51048.2020.9339603

[59] Mel Slater, Bernhard Spanlang, Maria V. Sanchez-Vives, and Olaf Blanke. 2010. First Person Experience of Body Transfer in Virtual Reality. *PLoS ONE* 5, 5 (2010), 1–9. https://doi.org/10.1371/journal.pone.0010564

[60] Jonathan Steuer, Frank Biocca, Mark R Levy, et al. 1995. Defining virtual reality: Dimensions determining telepresence. *Communication in the age of virtual reality* 33 (1995), 37–39.

[61] Gunnar Treff, Lennart Mentz, Benjamin Mayer, Kay Winkert, Thomas Engleder, and Jürgen M. Steinacker. 2022. Initial Evaluation of the Concept-2 Rowing Ergometer's Accuracy Using a Motorized Test Rig. *Frontiers in Sports and Active Living* 3 (2022). https://doi.org/10.3389/fspor.2021.801617

[62] Katharina Trompeter, Jeronimo Weerts, Daniela Fett, Ali Firouzabadi, Kai Heinrich, Hendrik Schmidt, Gert-Peter Brüggemann, and Petra Platen. 2021. Spinal and Pelvic Kinematics During Prolonged Rowing on an Ergometer vs. Indoor Tank Rowing. *The Journal of Strength & Conditioning Research* 35, 9 (2021). https://journals.lww.com/nsca-jscr/fulltext/2021/09000/spinal_and_pelvic_kinematics_during_prolonged.40.aspx

[63] Robby van Delden, Sascha Bergsma, Koen Vogel, Dees Postma, Randy Klaassen, and Dennis Reidsma. 2020. VR4VRT: Virtual Reality for Virtual Rowing Training. In *Extended Abstracts of the 2020 Annual Symposium on Computer-Human Interaction in Play* (Virtual Event, Canada) *(CHI PLAY '20)*. Association for Computing Machinery, New York, NY, USA, 388–392. https://doi.org/10.1145/3383668.3419865

[64] Nick Yee and Jeremy Bailenson. 2007. The Proteus Effect: The Effect of Transformed Self-Representation on Behavior. *Human Communication Research* 33, 3 (2007), 271–290. https://doi.org/10.1111/j.1468-2958.2007.00299.x

[65] Nick Yee and Jeremy N. Bailenson. 2009. The Difference Between Being and Seeing: The Relative Contribution of Self-Perception and Priming to Behavioral Changes via Digital Self-Representation. *Media Psychology* 12, 2 (2009), 195–209. https://doi.org/10.1080/15213260902849943

[66] Bian Yulong, Han Lei, Zhou Chao, Chen Yingmin, and Gao Fengqiang. 2015. The Proteus Effect in Virtual Reality Social Environments: Influence of Situation and Shyness. *Acta Psychologica Sinica* 47, 3, Article 363 (2015), 363-374 pages.