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Investigating the Impact of Customized Avatars and the Proteus Effect during Physical Exercise in Virtual Reality

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Abstract

Virtual reality (VR) allows to embody avatars. Coined the Proteus effect, an avatar's visual appearance can influence users' behavior and perception. Recent work suggests that athletic avatars decrease perceptual and physiological responses during VR exercise. However, such effects can fail to occur when users do not experience avatar ownership and identification. While customized avatars increase body ownership and identification, it is unclear whether they improve the Proteus effect. We conducted a study with 24 participants to determine the effects of athletic and non-athletic avatars that were either customized or randomly assigned. We developed a customization editor to allow creating customized avatars. We found that customized avatars reduced perceived exertion. We also found that athletic avatars decreased heart rate while holding weights, however, only when being customized. Results indicate that customized avatars can positively influence users during physical exertion. We discuss the utilization of avatar customization in VR exercise systems.

CCS Concepts

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

Keywords

virtual reality, body ownership, Proteus effect, virtual embodiment, avatars, customization

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1 Introduction

Physical inactivity has emerged as a global public health concern, contributing to various chronic diseases and overall deterioration of well-being [106]. Many people around the globe do not meet the recommended levels of physical activity and those who start exercising typically drop out within the first months [55, 59]. Leveraging immersive technology such as virtual reality (VR) has become a promising approach to tackle physical inactivity and increase exercise adherence [24, 110]. Therefore, immersive exercise systems and fitness applications received increased attention and aim to motivate people by eliciting enthusiasm during physical exertion and promoting a healthier lifestyle [40].

A crucial component of VR experiences is the *avatar*—the users' digital self-representation. Modern VR technology allows users to experience the avatar as their own body resulting in a phenomenon commonly known as the body ownership illusion (BOI) [41, 47]. This illusory sensation of embodying a virtual avatar is typically induced using motion capture so that users' motions are registered and transferred onto the avatar in real time [41, 90, 98]. When users move their limbs, the avatar's equivalent limbs mimic this motion creating the perceptual illusion of having a foreign body. As VR allows displaying the avatar in all possible ways, the user can, therefore, embody all imaginable appearances with different characteristics than the own body [44].

Interestingly, previous work found that the avatars' visual characteristics can change how users behave and perceive the surrounding environment [44, 108]. Yee and Bailenson [108] showed that users embodying attractive avatars behaved more confidently while talking to a confederate in VR. The authors termed this phenomenon the *Proteus effect.* This effect could also be evidenced during exergames. Peña and Kim [80] showed that users playing virtual tennis on a Wii Fit using a normal weight avatar were physically more active than when operating an avatar the authors dubbed obese. Similarly, Kocur et al. [48] revealed that muscular avatars can decrease the perception of effort during exercise in VR. As the perception of effort is a barrier to regular physical activity [65], these findings suggest that the avatars' appearance can be leveraged to make more effective immersive fitness applications [44]. However, there is empirical evidence that the Proteus effect can also fail to occur when neglecting important moderators [5, 49, 74].

Kocur et al. [49] found that athletic avatars do not necessarily affect the perception of effort and heart rate responses positively while cycling in VR. The authors argue that the users had a reduced body ownership and identification with the avatars that made the Proteus effect fail to occur. This is in line with Praetorius and Görlich [81] who assumes that the magnitude of the Proteus effect and whether this phenomenon occurs at all depends on the extent of the experienced body ownership and how strong users can identify with the avatars [81]. Banakou et al. [5], for example, found that the Proteus effect is extinguished when the avatar do not move in synchrony due to a reduced sensation of body ownership. To avoid that an avatar's effects fail to occur, it is important to find ways to increase the probability of successfully inducing the Proteus effect and amplify its magnitude by augmenting the sense of body ownership and identification with the avatars.

Prior research showed the benefits of allowing users to customize their avatars such as enhanced body ownership sensations [67]. Birk et al. [13], for example, found that customized avatars can increase avatar identification and intrinsic motivation while playing an infinite runner on a non-immersive display. Koulouris et al. [56] revealed that customized avatars enhanced user identification and exercise performance while cycling in a VR exergame. While these findings suggest that customized avatars contribute to a higher sense of identification and embodiment, it is still unknown whether they also result in an amplified Proteus effect. If customized avatars can increase the Proteus effect resulting in enhanced exercise performance and reduced perceptual and physiological responses to physical effort, designers and developers could allow users to customize their avatars instead of assigning predefined ones to leverage the Proteus effect and create more effective fitness applications.

In this paper, we conducted a study with 24 participants to determine the effects of avatars with two levels of athleticism that were either customized or randomly assigned. We measured the effects on participants' perceptual and physiological responses as well as their physical performance. To allow users to customize their avatars, we developed a VR customization editor. Hence, users embodied athletic and non-athletic avatars that were either customized or randomly assigned while performing physically demanding tasks. We found that athletic avatars significantly reduced the heart while holding weights, however, only when being customized. We also show that the athletic as well as the customized avatars decreased the perception of effort. The findings indicate that avatar customization can positively affect users' physical performance as well as perceptual and physiological responses during exercise. Results also suggest that avatar customization can augment the Proteus effect on physiological responses. We discuss our findings in the light of the Proteus effect and how they can be utilized for VR exercise and fitness applications. We also contribute with a VR customization editor that allows to create individualized avatars while embodying them.

2 Related Work

Our work builds on previous findings about the Proteus effect in physical settings and beyond. In the following, we first describe how users can experience the illusory sensation of embodying avatars. Afterward, we discuss work on the avatar customization and how it contributes to a closer avatar-user connection. Finally, we give an overview of the Proteus effect and its significant moderators.

2.1 Body Ownership Illusions

One remarkable capacity of the human brain lies in its ability to reconcile conflicting information from multiple senses, generating illusions that shape our perception of the world. This capability enables humans to interpret and experience their surroundings in ways that diverge from objective reality [41, 67].

Optical illusions fascinated humans since millenia. Aristotle already described that touching a small pea between two crossed fingers induced the tactile sensation of touching two different peas [2]. More recent perceptual illusions such as the Pinocchio illusion [58] or the popular rubber hand illusion (RHI) [17, 88] demonstrate how our brain can be tricked into perceiving other body parts or artificial limbs as our own. In the RHI, first demonstrated by Botvinick and Cohen [17], the act of simultaneously stroking one's actual hand while observing a rubber hand causes humans to accept the artificial limb as part of their own body. This phenomenon has been explained by an integration of information from different senses during a single event. Our brain unifies the information into a cohesive perception [27, 33].

Despite apparent conflicts between visual input (seeing the rubber hand being stroked), tactile sensations (feeling the stroking on one's actual hand), and proprioception (the awareness of the hand's position), the brain adeptly resolves these conflicts. The result is a coherent and robust perceptual experience [28]. Consequently, the brain produces the illusion of ownership over artificial limbs, such as a rubber hand or even entire bodies, a phenomenon commonly referred to as the BOI [41, 98].

Petkova and Ehrsson [79], for example, showed that by applying visuo-tactile synchrony — a synchrony between touch and vision — the perception of a body swap can be induced. This induction method was also used to create the sensation of embodying an empty space resulting in an out-of-body experience [26]. While these illusions are just few of many examples that were induced in the real world [41], VR has become a promising technology to create the feeling of embodying a computer-generated body.

VR enables the creation of perceptual experiences that are hardly feasible or even impossible to replicate in real-world environments. In VR, researchers can move beyond conventional visuo-tactile synchrony and explore alternative methods to induce bodily illusions. Utilizing tracking devices and advanced motion capture technologies, the movements of users can be accurately recorded and translated onto the virtual skeleton of an avatar, establishing a visuo-motor synchrony — a synchrony of movements between the physical body and the virtual representation. Sanchez-Vives et al. [93], for example, demonstrated the induction of a virtual RHI solely through visuo-motor synchrony, without the need for tactile stimulation. Participants in their experiment could move their actual hand and fingers, observing the virtual hand react synchronously.

Since then, there have been numerous manifestations of full-body illusions demonstrating that users could even accept virtual bodies with visual attributes significantly divergent from their own physical selves. Examples included avatars that indicated having a different gender [96, 98] or body composition [30, 39, 53, 71], a much younger appearance [5], an older appearance [7], or even a different skin color [6, 31].

2.2 Avatar Identification

Typically, game designers and researchers provide players with a virtual body using avatars — virtual characters that represent users in virtual worlds [8]. The term avatar is derived from the Hindu term "avatara" which refers to the descent of a deity on earth in terrestrial shapes [77]. According to Banks [8], in games users metaphorically descent into the virtual world by taking on digital bodies in terms of avatars. Hence, an avatar acts as the digital self-representation of players that is under their control during the game experience [44, 72].

Beside the perceived BOI, another important quality metric of the avatar experience is the sense of identification with the avatar. Van Looy et al. [102] postulates that avatar identification can be defined as a shift in self-perception that makes players consider their identity in the game as "I" and the virtual world as "where". Players, therefore, virtually turn into the avatar and experience in-game events as they were really happening to them [42]. In line with self-determination theory that is frequently used as a framework on how to design engaging games [13, 91], using avatars that players can identify with satisfies the need of relatedness, i.e., feeling connected to the avatar and others. Therefore, an increased avatar identification can result in a better overall game experience [10, 82], motivation [13], physical activity and arousal [85], as well as in-game performance [56, 84].

Van Looy et al. [102] subdivided avatar identification into three dimensions: similarity identification, wishful identification, and embodied presence. These dimensions are inspired by self-discrepancy theory [32] postulating that one's self-concept consists of different components: the actual self (i.e., traits that an individual believes to possess), the ideal self (i.e., traits that an individual ideally wants to possess), and the ought self (i.e., traits that an individual believes they ought to possess). To achieve a high degree of avatar identification, these different selves need to be considered in the avatar design process. The more similar the avatar is to their player, the better they can identify with the avatar resulting in a stronger bond between both [20]. Similarity does not necessarily refer to the visual appearance only but also includes personality, attitudes, and beliefs [20, 102]. Wishful identification refers to the ideal version of oneself with attributes that are desirable and players would typically like to possess in the real world [99]. Previous work found that players who embodied idealized avatars were more satisfied and connected with their virtual characters [25, 37]. Similar to BOI, embodied presence refers to the sense of being present in the virtual world while being embodied in the avatar [102].

To foster identification with avatars in games and offer a more inclusive experience, many video games (particularly role-playing games) allow users to individually customize their avatar and express themselves [100]. In *World of Warcraft* [15], for example, players can choose the appearance, skills, and traits of their virtual characters. Another popular example is the open-world role-playing game *Cyberpunk 2077* [18], where players can modify their avatar using an extensive and detailed customization editor. Prior research found that customized avatars enhance body ownership, identification, and the overall game experience [13, 87, 111]. Koulouris et al. [56] also showed that customized avatars reflecting a realistically better version of oneself improved physical performance while playing an exergame on a stationary bike. Interestingly, the authors showed that idealized avatars with characteristics that were non-achievable for the embodying users increased self-discrepancy resulting in deteriorating effects. While customization seems promising to increase body ownership and identification, the effects of customized avatars shown in previous work are not entirely understood.

Overall, designers aim at inducing a strong sense of body ownership and avatar identification to create vivid and embodied experiences in games and virtual worlds [44]. The experience of body ownership is rather driven by cognitive mechanisms processed in a bottom-up manner, i.e., the fusion of single incoming sensory information across different modalities [3, 28]. Avatar identification arises when top-down concepts related to the avatar fit the self-concepts of the player. Hence, identification is mainly driven by top-down mechanisms based on prior knowledge and experiences, e.g., stereotypes [29, 104]. However, the precise mechanisms underlying BOIs and identification are yet not fully clarified and require further investigations.

2.3 Proteus Effect

The Proteus effect, as revealed by Yee and Bailenson [108], refers to the phenomenon where users' perception and behavior in virtual environments are influenced by the appearance of their avatars. Yee and Bailenson [108] showed that users embodying attractive avatars exhibited increased confidence in social interactions compared to those with less attractive avatars. This effect stems from users associating stereotypical characteristics with their avatars' appearance, subsequently leading to changes in behavior, attitude, and perception [11, 44, 83, 109].

One plausible explanation for the Proteus effect draws on self-perception theory, suggesting that individuals modify their behavior and attitudes based on their self-perception [9]. Users adapt their behavior and attitudes in response to the characteristics, stereotypes, and features associated with their avatars' visual appearance. Numerous studies have demonstrated this phenomenon: older-looking avatars influencing walking speed [86], muscular avatars enhancing physical performance [46, 48], and a sweaty appearance could affect perceived exertion [45].

Several studies point to avatars influencing users' performance, with cognitive enhancements observed using an Einstein avatar [7, 52]. Improved physical performance was demonstrated in scenarios such as typing and weightlifting, where avatars with specific attributes positively impacted users' abilities [43, 46, 48]. Interestingly, the similarity between the user and avatar, rather than specific characteristics, has also been linked to enhanced physical activity [56, 69, 84].

A recent study by Kocur et al. [49] showed that the Proteus effect can fail to occur when certain conditions are not met. In a VR experiment, athletic avatars could not affect perception of effort and heart rate responses while cycling an ergometer bike [49]. The authors argue that a reduced experienced embodiment and identification with the avatars are responsible for the absence of the Proteus effect. This is in line with Osimo et al. [74] who showed that avatars have a stronger cognitive influence when their move synchronously with the users' motion compared to an asynchronous movement. Similarly, Banakou et al. [5] found that visuo-motor asynchrony can extinguish effects originated from the avatar's appearance. For this reason, Kocur et al. [51] proposed to investigate embodiment time as a moderator of the Proteus effect, as previous work found that the longer one embodies foreign limbs the higher the degree of perceived body ownership [101]. In this vein, Navarro et al. [69] revealed that avatars displaying the users' face have a stronger influence on users' physical performance while running on a treadmill compared to avatars having a stranger's face. While the results suggest that the Proteus effect could depend on the extent of avatar identification as well as experienced body ownership, a systematic investigation is still missing.

2.4 Summary

Previous research demonstrated a phenomenon known as the Proteus effect, which describes behavioral, perceptual, and attitudinal changes based on the avatars' visual appearance. Research found that muscular and athletic avatars can improve physical performance during physically demanding tasks in VR. However, such effects can fail to occur when users experience a reduced sense of body ownership and identification with the avatar. While customizing avatars is known to increase body ownership and identification, it is still unknown whether customized avatars indeed augment the Proteus effect. Consequently, the impact of customized avatars on the Proteus effect and users' perceptual and behavioral changes remains unclear.

3 Method

We conducted a study to examine the interplay between customized avatars and their athletic appearance. While previous work showed that generic athletic avatars can reduce physiological and perceptual responses [46, 48], we hypothesize that this effect can be enhanced when athletic avatars are customized instead of randomly assigned. We, therefore, aim to disentangle the perceptual and physiological effects of customized avatars and the effects of athletic avatars during physical exertion in VR. Consequently, participants embodied athletic and non-athletic avatars that were either customized by themselves or by another participant. Specifically, we explore how both customized and randomly assigned avatars, with either athletic or non-athletic appearances, affect physical performance, perceptual responses, and physiological reactions during exercise in VR. Additionally, body ownership, avatar identification, self-perceived fitness, and sense of presence are assessed to account for potential moderating factors [49, 81].

Based on the Proteus effect [46, 48, 109] and potential moderators such as body ownership and avatar identification [7, 81], the study therefore tested the following hypotheses:

- Hypothesis 1 (H1): Athletic avatars reduce the perception of effort and physiological responses, and improve physical performance during physical exercise in VR.
- Hypothesis 2 (H2): The effects of avatar customization and athleticism on perception of effort, physiological responses, and physical performance during physical exercise in VR interact. Specifically, we hypothesize that athletic avatars have a greater effect when being previously customized compared to randomly-assigned avatars.

3.1 Study Design

We investigate the effects of avatar customization and athleticism on physical performance as well as perceptual and physiological responses during exercise in VR. We conducted a study with two independent variables and followed the approach by Kocur et al. [48] by using a repeated-measures design to cancel out individual differences and reduce unsystematic variance. The first independent variable is CUSTOMIZATION with the two levels *customized* and *randomized*. The second independent variable is ATHLETICISM with two levels *athletic* and *non-athletic*. Participants therefore embodied customized and randomly assigned avatars with different levels of athleticism while performing physical exercises. To reduce order effects, we counterbalanced the order of the four conditions using a 4*4 Latin square.

3.2 Measures

We assessed the subjective perception of effort using the well-established Borg rating of perceived exertion (RPE) scale [16] while holding weights and performing biceps curls (see Fig. 1). We also continuously recorded the heart rate during the tasks and measured the physical performance by counting the number of curls. Another task was the reaction wall, where participants engaged in a reaction wall game that is frequently used as a playful way to train one's agility, speed, and coordination in a range of domains [35, 38, 61]. In this task that took 45 seconds, we used the number of correct hits to operationalize physical performance.

3.2.1 Perceived Exertion. We assessed the perceived exertion while participants were holding weights and during the biceps curls. The RPE scale was designed to increase linearly with exercise intensity and consists of 15 grades from 6 to 20. Every second grade is combined with a textual representation of the intensity, e.g. "7" stands for "very, very light" and "19" for "very, very hard" [16]. A rough estimation of the current heart rate can be calculated by multiplying each grade by 10, e.g., an intensity of 8 approximately matches a heart rate of 80.

3.2.2 Heart Rate. The heart rate is frequently used as a valid predictor for one's level of physical fitness [73]. We measured the HR using an optical HR monitor worn at the participant's forearm (Polar OH1, Polar Electro, Finland). We continuously assessed the HR while participants were holding weights and performing biceps curls.

3.2.3 Physical Performance. We assessed physical performance for the biceps curls and reaction wall game. For the biceps curls, we counted the number of curls throughout the duration of the task

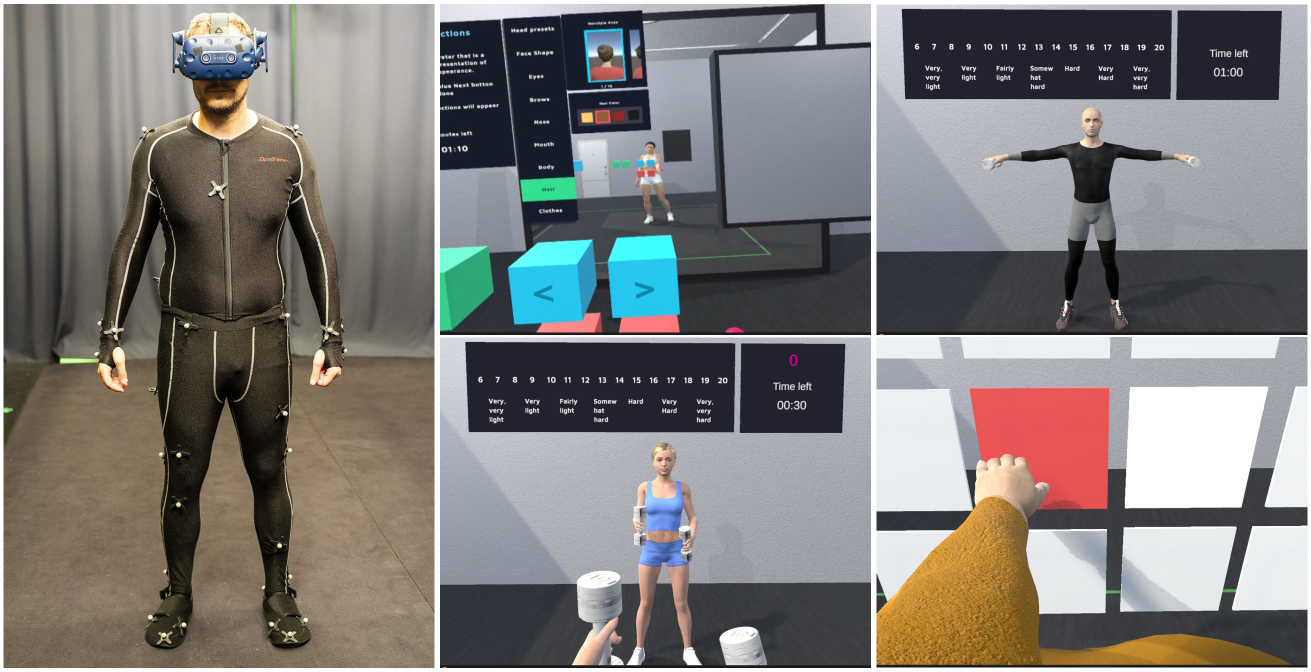

Figure 1: User wearing a motion capture suit (left), the VR customization editor (top middle), the athletic avatars while holding weights (top right) and performing biceps curls (bottom middle) in front of a virtual mirror, and a non-athletic avatar during the reaction wall game (bottom right).

(30 seconds). For the reaction wall game, we counted the number of hits throughout the duration of the task (45 seconds).

3.3 Control Measures

To account for potential moderating factors [49, 81], a set of subjective measures were taken. We assessed the sense of presence using Item G5 of the Igroup Presence Questionnaire (IPQ) ("In the computer generated world I had a sense of "being there) [94]. Self-assessment of personal fitness was obtained through the Self-Perceived Fitness Questionnaire (SPF) [23], and the degree of avatar embodiment was assessed using the Body Representation Questionnaire (BRQ) [7]. Furthermore, identification with the avatar was measured using the Player Identification Scale (PIS) [102].

3.3.1 Body Ownership. Body ownership refers to the sense of perceptually "inhabiting" an avatar. It describes how much users feel that the avatar is an extension of their own body or self in the virtual space [41, 97]. To quantify the induced body ownership, we used the BRQ [7] with the single-item subscales vrbody ("I felt that the virtual body I saw when looking down at myself was my own body"), mirror ("I felt that the virtual body I saw when looking at myself in the mirror was my own body"), features ("I felt that the virtual body resembled my own real body in terms of shape, skin tone or other visual features"), twobodies ("I felt as if I had two bodies"), and agency ("I felt that the movements of the virtual body were caused by my own movements").

3.3.2 Self-Perceived Fitness. Self-assessment of personal fitness was obtained through the SPF [23]. This questionnaire uses the subscales (scores range from 1 to 13) fitness, strength, body composition, endurance, and flexibility (see Table 1). We surveyed participants using the SPF before the VR experiment to determine how fit they perceived themselves, which served as the baseline. In addition, we also asked the participants to complete the SPF after completing the tasks while still embodying the respective avatar condition to learn how fit they perceived themselves during avatar embodiment. Fig. 8 shows the average Δ SPF total score indicating the resemblance of the avatars' perceived fitness and participants' actual perceived fitness.

3.3.3 Avatar Identification. While the concepts of body ownership and avatar identification are related, they involve distinct psychological and experiential processes. Avatar identification is the psychological process of connecting with or seeing the avatar as a representation of oneself. It describes how much an individual identifies with the avatar in terms of personality, values, goals, or narrative [13, 102]. In line with previous work [81], we also assessed the sense of identification with the avatar using the PIS [102]. This scale consists of the subdimensions embodied presence, similarity identification, and wishful identification.

3.3.4 Presence. In line with previous work [48, 86, 92], we determined how present participants felt in the virtual environment. As Schwind et al. [95] suggested that the IPQ [94] questionnaire best reflects the construct of presence, we used the item G1 "general presence" using a 7-point Likert scale.

3.4 Tasks

We used three different tasks using isometric (i.e., holding weights) and isotonic exercises (i.e., biceps curls), and exercises that rely on agility and coordination (i.e., reaction wall) to cover a broad range of different physical abilities. Building on prior research in sports physiology [14, 103] and avatar studies [46, 48], we aimed to minimize unsystematic variance by controlling the task order across conditions: reaction wall, biceps curls, and holding weights. While randomizing the task order would minimize order effects but instead introduce random variability, a fixed sequence ensured that any order effects, such as fatigue accumulation, were systematic and equally distributed across avatar conditions. This enables better control over their influence on the results [103].

3.4.1 Reaction Wall Task. The reaction wall is frequently used as a playful way to train one's agility, speed, and coordination in a range of domains [35, 38, 61]. In this task, participants were standing in front of a virtual wall consisting of a total of 16 fields that can light up. Once the participant initiated the game with the start button, one field lit up in red. Upon touching that field, another randomly selected field lit up. The game lasted for a total of 45 seconds, and the objective was to touch as many fields as possible within this time frame. The task required the participant to move quickly and coordinate their movements. We used the number of correct fields hit to operationalize physical performance in this task.

3.4.2 Biceps Curls. In the second task, participants had to perform biceps curls following the approach proposed by the American Alliance for Health, Physical Education, Recreation and Dance Functional Fitness Test [89]. The fitness test is suitable for all fitness levels and can be conducted without adjusting weights for each participant. Consequently, participants performed as many curls as possible in 30 seconds using 2 kg dumbbells. They were instructed to perform the curls only as fast as they could while still adhering to a correct execution. The exercise was explained before the experiment, and proper posture and execution were practiced with test weights. The experimenter observed the execution and corrected if necessary by verbal instructions. During the execution, participants maintained an upright posture with feet shoulder-width apart, holding the dumbbells at the sides of the body with slightly bent arms. Without moving the upper arms, the forearms were maximally bent upward over the elbow joint. The arms were then brought back to the starting position in a controlled manner [21]. We counted the number of curls to operationalize physical performance in this task.

3.4.3 Holding Weights. According to a standardized procedure [1, 68], participants held one weight of 1kg in each hand for 60 seconds in a position at 90 degrees of shoulder abduction in the scapular plane (see Fig. 1). During the task, participants were presented with the RPE scale using a virtual panel, which remained visible throughout the entire task. At the 20th, 40th, and 55th seconds, a red border appeared around the panel, and the participant verbally indicated their perceived effort by stating a number on the scale.

3.5 Participants

We recruited 24 participants (12 female and 12 male) through the mailing list of our institution and social networks. One additional participant (female) was only recruited to create the first set of customized avatars without taking part in the main study. Hence, the following information only refer to the 24 participants. Their age ranged from 20 to 34 years ($M = 26.13$, $SD = 3.58$). Twenty-two participants were right-handed, and two were left-handed. Regarding the VR experience, 82.6% of the participants indicated they had no prior experience with VR, and 17.4% reported playing VR games a few times a year. To assess the participants' level of fitness, we used the SPF questionnaire by Delignières et al. [23] as part of the demographics (see Table 1).

	Female (N=12)		Male (N=12)	
Scales of the SPF (min=1,max=13)	*M*	*SD*	*M*	*SD*
Fitness	7.75	2.26	6.75	2.52
Strength	8.00	2.04	8.33	1.49
Body Composition	7.75	1.28	7.41	1.97
Endurance	7.08	2.19	7.66	1.92
Flexibility	7.91	1.24	7.75	1.95

Table 1: Means (M) and standard deviations (SD) of the subscales of the SPF questionnaire by Delignières et al. [23] showing how participants assessed their personal fitness level.

39.1% of the participants reported never playing computer games, 26.1% played a few times a year, 8.7% played a few times a month, 13% played a few times a week, and 13% played daily. Seventeen participants wore contact lenses of had no visual impairment. Seven participants wore glasses. Four participants mentioned having previous upper extremity injuries, but all participants were healthy and pain-free at the time of the study. The body mass index (BMI) was within the normal range for 17 participants, ranging from 23.0 to 23.9. One participant had a low BMI of 17.9. Five participants had a slightly elevated BMI between 25.6 and 28.3, and one participant had an elevated BMI with a value of 32.

Participants were compensated with credit points for their study course. They were informed that they could withdraw or discontinue the experiment at any time without penalty.

3.6 Apparatus

We used an HTC Vive Pro HMD with a wireless adapter to allow participants moving freely within the VR area (see Fig. 1). The integrated Vive chaperone system rendered virtual lines when users approached the space boundaries preventing them to go beyond the defined VR area. The HMD has a wide horizontal field-of-view of 110° and a spatial resolution of 1440 × 1600 pixels per eye displayed at 90 fps. Participants perceived the virtual body and the surrounding environment from first-person perspective.

We induced body ownership and agency by visuomotor synchrony. Participants' real movements were captured with Optitrack motion capturing[1] and transferred onto the virtual skeleton of the avatar. To track participants' full-body motion, we employed a marker-based OptiTrack motion tracking system with twelve cameras (eight PRIME 13 and four PRIME 13W) and the Motive software (v. 2.1). The motion tracking software ran on a dedicated PC with Windows 10, Intel i7-8700, 26GB RAM, and a NVIDIA GeForce GTX

[1]https://optitrack.com/

1080 graphics card. We calibrated the OptiTrack system according to the manufacturer's specification.

Participants had to wear black marker suits (Optitrack Motion Capture Suit Classic[2]) available in different sizes (S, M, and L) with 49 passive markers. The OptiTrack system tracked participants' skeleton with 240 fps and was synchronized with the HMD's head tracking to avoid interference. Using UDP multicast the skeletons were streamed through a local 1000 Mbit network connection via the NatNet protocol to the PC (Windows 10, Intel i7-8750H, 16GB RAM, NVIDIA GeForce GTX 1060 graphics card) that ran the VR application and rendered the 3D scene.

3.6.1 Avatars. We used the Standard Genesis 8.1 Basic Male and Genesis 8.1 Basic Female characters from the 3D suite of DAZ Studio 4.20 as the basis for all avatars[3]. The bodies and clothing of the avatars can be adjusted using morph targets, e.g, body fat, muscularity, height, etc. For detailed facial adjustments, we used the DAZ extension 200 Plus Head and Face Morphs for Genesis 8 Male and Female[4]. The avatars and clothing were additionally post-processed in Blender 3.0[5], to align the morph targets of the clothes and bodies. To achieve better skin textures, the PreIntegratedSkinShader V2.0[6] was applied to the models. Various hairstyles were used from the Daz suite, and additional hairstyles were exported from various Mixamo[7] avatars.

3.6.2 VR Customization Editor. To compare the effects of customized avatars with avatars that were randomly assigned, an avatar creator was needed. Thus, we developed a customization editor that enables to adjust the avatar's appearance based on certain parameters, e.g., clothes, facial features, hair, and body composition. To ensure a high degree of body ownership, we developed the VR customization editor using Unity (v. 2020.3.21f1) to allow participants to customize their avatars while embodying them (see Fig. 1). Participants initially embodied a standard avatar fitting the specified gender which could be modified through a menu in the virtual space. There were two panels representing the user interface. The left panel allowed participants to navigate through categories that could be altered, e.g., body, face, or hair. In the right panel, individual parameters could be adjusted in detail. Navigation and control were done using 3D buttons and sliders, activated through virtual touch. All changes were transferred in real-time to the embodied avatar. In the virtual space, there were three mirrors allowing participants to view themselves from all angles.

We followed the approach by Koulouris et al. [56] to determine the avatars' characteristics that could be modified. During avatar creation, participants could choose from a total of 16 face templates, which could then be adjusted in detail. There were 20 facial details (eyes, eyebrows, nose, mouth, face shape) that could be customized. For the body, there were a total of 13 editing options regarding the categories muscularity, body fat, and height. The level of muscularity and body fat could be adjusted using morph targets[8][9] (ranging from 0 to 100%) that controlled the extent of fitness, weight, muscularity, body fat, fitness details such as definition, and the overall body mass. Participants could therefore extensively design the avatars' athleticism using sliders in the customization editor that controlled the morph targets' values. To reduce complexity and ensure realistic proportions, the morph targets controlled the entire body and not specific body parts. Fig. 2 shows examples of customized baseline, athletic, and non-athletic avatars.

An essential aspect of avatar creation was enabling adjustments to easily recognizable features such as hair, clothing, and body shape to facilitate identification with the avatar [25]. Therefore, participants could choose from 10 hairstyles (ranging from short to long as well as tied hair), different clothing items ranging from short to long attire with 5 types of pants (shorts, jeans, joggers, loose pants, leggings), 4 types of upper part clothing (tank top, jogging sweater, t-shirt, sweatshirt), and three types of shoes (unisex sneakers, basketball shoes, and casual everyday-shoes.) All items' colors as well as the colors of skin, hair, and eyes could be customized. First, participants were instructed to create an avatar that should best represent themselves and resemble the real appearance and their body shape as closely as possible. Based on this avatar, an athletic and non-athletic version were created and later embodied during the physical tasks (see Fig. 2).

3.7 Procedure

After arrival, we explained the study's procedure. Afterward, participants read and signed an informed consent form. Following that, a demographic questionnaire was filled out on a desktop computer, along with a questionnaire assessing their own fitness. The experimenter asked the participants if they were right- or left-handed, as the device for measuring heart rate was attached to the non-dominant arm.

Participants were briefed on the tasks and the RPE scale. The holding weight exercise and biceps curls were explained, and proper posture and execution were practiced with test weights. Afterwards, the user interface of the VR customization editor was explained. Participants then put on the motion capture suit, donned the VR headset, and adjusted its size fitting to their head. Once clothing and the headset were in place, participants performed a T-pose to calibrate the skeleton for the avatars.

The VR customization editor was launched and participants initially embodied a neutral base avatar corresponding to their stated gender. Alongside the user interface for avatar creation and mirrors, there was also a panel with instructions and a timer. Participants had a maximum of 20 minutes to create an avatar that best matched their real appearance. Starting from this avatar, they could create an athletic version with the instruction "Create an avatar that is a representation of your appearance after 1 year having a healthy and active lifestyle with regular exercise and a healthy diet," and a non-athletic version with the instruction "Create an avatar that is a representation of your appearance after 1 year having an unhealthy and inactive lifestyle with no exercise and an unhealthy diet". In

[2]https://optitrack.com/products/motion-capture-suits/
[3]https://www.daz3d.com/
[4]https://www.daz3d.com/200-plus-head-and-face-morphs-bundle-for-genesis-8-female-s-and-male-s
[5]https://www.blender.org/
[6]https://assetstore.unity.com/packages/vfx/shaders/pre-integrated-skin-shader-7238
[7]https://www.mixamo.com/
[8]https://www.daz3d.com/massive-morphs-for-genesis-8-male
[9]https://www.daz3d.com/massive-morphs-for-genesis-8-female-s

Figure 2: Examples of avatars with the baseline, athletic, and non-athletic version (from left to right). Participants had a maximum of 20 minutes to create an avatar that best matched their real appearance while doing sports. Starting from this avatar, they had additional five minutes to create an athletic version with the instruction "Create an avatar that is a representation of your appearance after 1 year having a healthy and active lifestyle with regular exercise and a healthy diet," and a non-athletic version with the instruction "Create an avatar that is a representation of your appearance after 1 year having an unhealthy and inactive lifestyle with no exercise and an unhealthy diet". Participants could customize a range of options ranging from different faces and facial details, body compositions using categories such as muscularity, body fat, and height, as well as different hair and sports clothes from long to short attire (see section 3.6.2)

total, participants had five minutes for creating the athletic and non-athletic versions.

After avatar creation, participants embodied the athletic and non-athletic avatars during the physical tasks. As we aimed to increase external validity, we did not use one generic avatar as the randomized avatar for all participants. Instead, they were assigned two avatars (one was athletic, one was non-athletic) created by the preceding participant. Thus, each participant embodied a total of four avatars. As the first participant also required two avatars that were not customized, an additional participant was recruited only for customizing an athletic and non-athletic avatar.

To allow the participant to become familiar with the virtual environment and the respective avatar condition, we included a short adaptation phase where participants could perceive themselves in a virtual mirror. Once ready, the participants could start the reaction wall game by pressing a virtual button. After 45 seconds, a notification appeared indicating that the task was completed. The experimenter paused the VR application and the screen faded to black. The experimenter then handed over the dumbbells to the participants and restarted the VR application to start the bicep curls task. The participants were asked if they were ready, and with a verbal signal from the experimenter, the task started. After 25 seconds, the RPE scale lit up in red, and the participant stated a number representing their perceived effort. The task concluded after 30 seconds, and a scale for weight assessment appeared.

Participants rated the perceived weight on the scale verbally from 0 (light) to 6 (heavy). Afterwards, the VR application was paused and the experimenter then handed dumbbells to the participant for the weight-holding task. After restarting the VR application, the experiment used a verbal signal to start the weight holding task. The participants were asked to hold the weights for 60 seconds and provide their perceived effort using the RPE scale after 20, 40, and 55 seconds. Following that, the weight of the dumbbell was subjectively assessed from 0 (light) to 6 (heavy). The experimenter removed the dumbbells and the participants were asked to complete the questionnaires in VR, i.e., BRQ, IPQ, PIS, and SPF. In line with Kocur et al. [46], we leveraged the time for completing the questionnaires as a resting period taking about 3 minutes per participant to reduce the heart rate before the next condition. Afterwards, the first condition was finished and the participant received a new avatar, repeating the procedure.

Once the tasks with all avatars were completed, participants could remove the VR headset and the motion capture suite. Finally, they filled out a questionnaire regarding their experience with the avatars and the experiment. Participants were debriefed and received credit points for their study course and as well as sweets for their participation. The entire study lasted approximately 90 minutes in total, with approximately 60 minutes spent in the virtual world.

4 Results

Our measures consisted of both parametric and non-parametric data. We conducted Shapiro-Wilk tests to assess normality for the perception of effort, physical performance, and all questionnaire

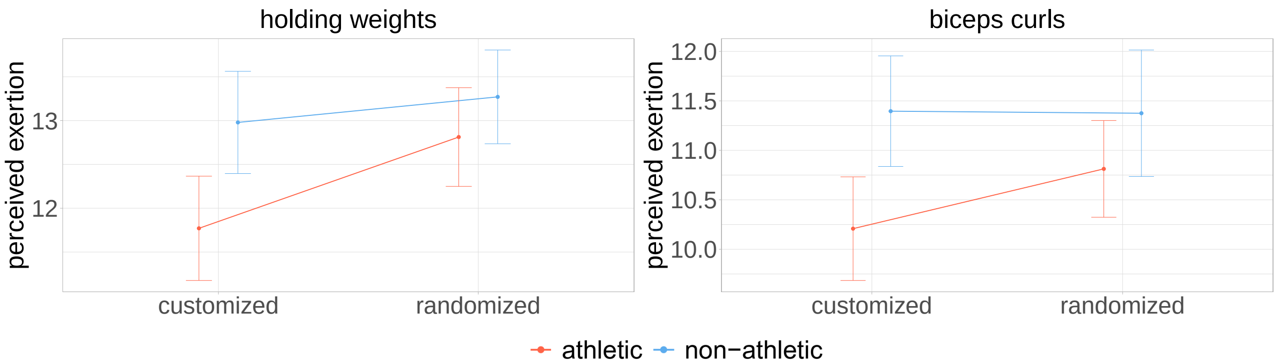

Figure 3: Average perceived exertion score while holding weights (left) and while performing biceps curls (right). Participants had a significantly lower perceived exertion while holding weights when embodying the customized avatar and the athletic avatar. Similarly, participants also had a significantly lower perception of effort while performing biceps curls when embodying the athletic avatar. The error bars represent the standard error of the means.

scores. For hypothesis testing involving non-parametric data, we used the Aligned Rank Transform (ART) package for R by Wobbrock et al. [107] to perform an ART analysis of variance (ANOVA). All analyses were performed at the participant level with the subject as a random factor. Table 3 shows a summary of the inferential statistics per measure and task.

To analyze the effects on perceived effort, we conducted a 2×2 repeated measures analysis of variance (RM-ANOVA) with Customization (*customized, randomized*) and Athleticism (*athletic, non-athletic*) as within-subject factors. The dependent variable was perceived exertion, measured on the RPE scale, ranging from 6 to 20. We used the same analysis framework for evaluating self-perceived fitness, avatar identification, experienced illusion of body ownership (IBO), and sense of presence. For the analysis of heart rate (HR) during the biceps curls, we conducted a $2 \times 2 \times 6$ RM-ANOVA with Customization (*customized, randomized*), Athleticism (*athletic, non-athletic*), and Time (*after 5, 10, 15, 20, 25, 30 seconds*) as within-subject factors. HR data were aggregated in 5-second intervals. In the analysis of HR while holding weights, Time included 12 levels, corresponding to measurements every 5 seconds for 60 seconds. The dependent variable was HR, measured in beats per minute (BPM).

4.1 Perceived Exertion

We performed statistical analyses to find out the effects of Avatar and Customization on the perception of effort for the tasks holding weights and biceps curls.

4.1.1 Holding Weights. A 2×2 RM-ANOVA revealed a significant main effect of Athleticism, $F(1, 23) = 4.663$, $p = .041$, $\eta_p^2 = .169$, and Customization, $F(1, 23) = 5.812$, $p = .024$, $\eta_p^2 = .202$, on perceived exertion during weight holding tasks. However, the interaction between Customization and Athleticism was not significant, $F(1, 23) = 2.545$, $p = .124$, $\eta_p^2 = .100$. Participants reported lower perceived effort when embodied in athletic avatars compared to non-athletic avatars and in customized avatars compared to randomized ones. Hence, we confirm H1 indicating that athletic avatars could reduce perception of effort. In addition, we also found that customization could also reduce perception of effort.

4.1.2 Biceps Curls. Similarly, a 2×2 RM-ANOVA for biceps curls revealed a significant effect of Athleticism, $F(1, 23) = 10.599$, $p = .003$, $\eta_p^2 = .315$, but no significant effect of Customization, $F(1, 23) = 0.576$, $p = .455$, $\eta_p^2 = .024$. There was also no significant interaction between Customization and Athleticism, $F(1, 23) = 1.501$, $p = .233$, $\eta_p^2 = .061$. Participants reported lower perceived exertion during biceps curls when embodied in athletic avatars compared to non-athletic avatars (see Fig. 3). Hence, these findings again confirm H1.

4.1.3 Correlation Analysis. To test whether there is a relationship between the perception of effort and the participants' self-perceived fitness (baseline, i.e., evaluated before avatar embodiment), we performed Pearson's correlation analyses of the total SPF score and the perception of effort while holding weights and during biceps curls. There was a significant negative correlation between the perception of effort and the self-perceived fitness while holding weights, $r(94) = -0.295, p = .003$. We also found a significant negative correlation between the perception of effort and the self-perceived fitness during biceps curls, $r(94) = -0.435, p < .001$. The negative correlation indicates that a higher self-perceived fitness tended to result in a lower perception of effort for both tasks.

4.2 Heart Rate

As we continuously recorded the HR while participants were holding the weights and performing the biceps curls, we report the inferential statistics per task. For both tasks, HR was determined every second over the duration of the task (60 seconds for holding weights and 30 seconds for biceps curls). The recorded data were then aggregated into 5-second intervals for both tasks, resulting in 12 aggregate HR values per participant for holding weights and 6 values for biceps curls. To control for individual differences in resting HR and eliminate potential confounding factors, we normalized the HR data by centering it at zero for each participant (subtracting the initial HR value from subsequent values). As previous work

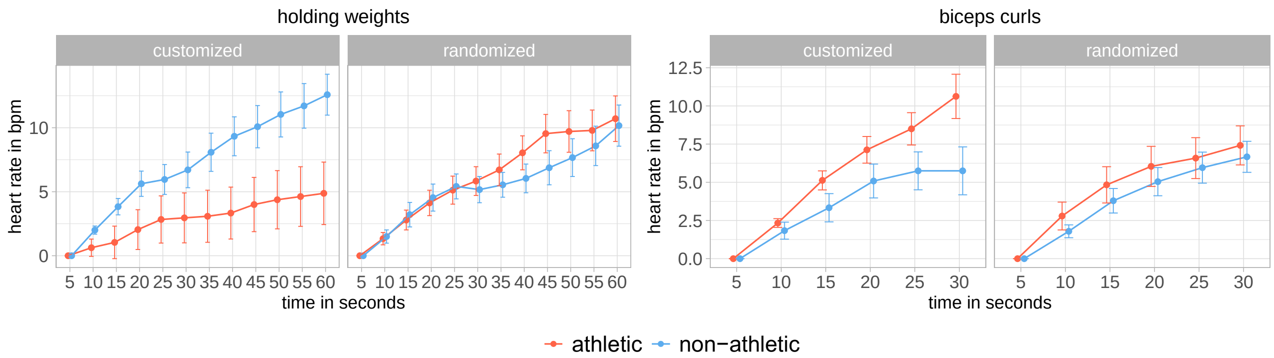

Figure 4: Average normalized heart rate centered at zero while holding weights (left) and performing biceps curls (right). Participants had a significantly reduced heart rate while holding weights when embodying the athletic avatar, however, when the avatar was previously customized. The error bars show the standard error of the means.

suggest that the Proteus effect is time-dependent [46], this allowed us to investigate how HR evolved over time and explore whether the effects caused by the independent variables differently evolve across time.

4.2.1 Holding Weights. A 2 × 2 × 12 RM-ANOVA was conducted to analyze the effects of Customization, Athleticism, and Time on the normalized HR while holding weights. The analysis revealed no significant main effect of Customization, $F(1, 23) = 0.311$, $p = .583$, $\eta_p^2 = .013$. However, there was a significant main effect of Athleticism, $F(1, 23) = 4.374$, $p = .048$, $\eta_p^2 = .160$, indicating that participants had a lower HR when embodying athletic avatars compared to non-athletic avatars. A significant main effect of Time was also observed, $F(1.71, 39.33) = 29.814$, $p < .001$, $\eta_p^2 = .565$, as well as a significant two-way interaction between Customization and Athleticism, $F(1, 23) = 5.214$, $p = .032$, $\eta_p^2 = .185$. Furthermore, a significant three-way interaction between Customization, Athleticism, and Time, $F(1.99, 45.82) = 3.471$, $p = .040$, $\eta_p^2 = .131$, was found. All other interactions were non-significant (all $p > .05$).

These results confirm H1 indicating that participants experienced a lower HR over time when embodying athletic avatars. In addition, H2 is also confirmed as the analysis showed a significant interaction effect of Customization and Athleticism indicating that the effects caused by the avatars' athleticism depended on if the avatars were being previously customized (see Fig. 4).

4.2.2 Biceps Curls. A 2 × 2 × 6 RM-ANOVA was conducted to analyze the effects of Customization, Athleticism, and Time on the normalized HR during biceps curls. The analysis revealed no significant main effect of Customization, $F(1, 23) = 0.366$, $p = .551$, $\eta_p^2 = .016$, or Athleticism, $F(1, 23) = 3.125$, $p = .090$, $\eta_p^2 = .120$. However, there was a significant main effect of Time, $F(1.67, 38.40) = 74.028$, $p < .001$, $\eta_p^2 = .763$, indicating a strong effect of time on HR during the task. All interaction effects were non-significant (all $p > .05$). These results suggest that participants' HR during biceps curls was significantly influenced by the passage of time but was not affected by the athletic appearance or the customization of the avatars (see Fig. 4). Consequently, H1 and H2 cannot be confirmed for biceps curls suggesting that avatars' physiological effects are task-specific.

4.2.3 Correlation Analysis. To test whether there is a relationship between the heart rate responses and the participants' self-perceived fitness (baseline, i.e., evaluated before avatar embodiment), we performed Pearson's correlation analyses of the total SPF score and the heart rate while holding weights and during biceps curls. There was a significant negative correlation between the heart rate and the self-perceived fitness while holding weights, $r(94) = -0.224, p = .029$. We also found a significant negative correlation between the heart rate and the self-perceived fitness during biceps curls, $r(94) = -0.240, p = .019$. The negative correlation indicates that a higher self-perceived fitness tended to result in a lower heart rate for both tasks.

4.3 Physical Performance

A 2 × 2 RM-ANOVA was conducted to analyze the effects of Customization and Athleticism on the number of hits during the reaction wall game. The analysis showed no significant main effect of Customization, $F(1, 23) = 4.103$, $p = .055$, $\eta_p^2 = .151$, or Athleticism, $F(1, 23) = 3.332$, $p = .081$, $\eta_p^2 = .127$. There was also no significant interaction between Customization and Athleticism, $F(1, 23) = 2.490$, $p = .128$, $\eta_p^2 = .098$. A 2 × 2 ART ANOVA was performed to analyze the number of biceps curls. The analysis revealed a significant main effect of Customization, $F(1, 23) = 5.806$, $p = .024$, $\eta_p^2 = .200$, indicating that participants executed more biceps curls while embodying customized avatars compared to randomized ones. However, there was no significant effect of Athleticism, $F(1, 23) = 3.575$, $p = .071$, $\eta_p^2 = .130$, and no significant interaction between Customization and Athleticism, $F(1, 23) = 0.020$, $p = .887$, $\eta_p^2 < .001$. These results suggest that participants performed more biceps curls when embodying customized avatars, regardless of their athleticism. Figure 5 shows the number of hits and biceps curls across the conditions. Hence, H1 and H2 cannot be confirmed for the amount of biceps curls and number of hits during the reaction wall game.

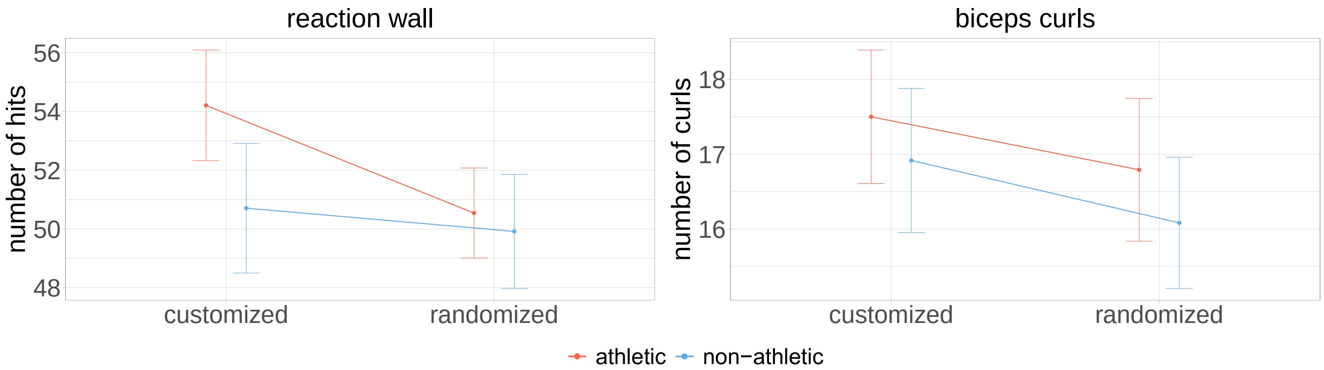

Figure 5: Mean number of hits for the reaction wall game (left) and the number of biceps curls (right). Participants performed significantly more biceps curls when embodying customized avatars, regardless of their athleticism. The error bars show the standard error of the means.

4.3.1 Correlation Analysis. To test whether there is a relationship between the physical performance and the participants' self-perceived fitness (baseline, i.e., evaluated before avatar embodiment), we performed Pearson's correlation analyses of the total SPF score and the performance during the reaction wall game and biceps curls. There was no significant correlation between the performance and the self-perceived fitness during biceps curls, $r(94) = -0.025, p = .810$. We also did find not a significant correlation between the performance and the self-perceived fitness during the reaction wall game, $r(94) = -0.107, p = .287$.

4.4 Control Measures

In the following, we report the statistical results of each control measure that was used to account for potential moderators proposed by previous work [49, 81]. The summary of the statistical analysis of each control measure can be found in Table 2.

4.4.1 Body Ownership. We performed 2×2 ART RM-ANOVAs on each dimension of the BRQ (vrbody, twobodies, mirror, features, and agency) to analyze the effects of Customization, Athleticism, and their interaction. The results indicate that participants experienced higher body ownership when embodying the customized avatars compared to the randomized ones, as well as when embodying the athletic avatars compared to the non-athletic avatars. Figure 6 shows the average scores for each dimension of the BRQ across conditions.

4.4.2 Avatar Identification. We conducted 2×2 ART RM-ANOVAs on each dimension of the PIS (embodied presence, similarity identification, and wishful identification) to analyze the effects of Customization and Athleticism. The results suggest that participants experienced a higher sense of identification with the customized avatars compared to the randomized ones, as well as with the athletic avatars compared to the non-athletic ones. Figure 7 shows the average scores of each dimension of the PIS for each condition.

4.4.3 Self-Perceived Fitness. We conducted a 2×2 RM-ANOVA on the total score of the SPF to analyze the effects of Customization and Athleticism. The results suggest that participants perceived higher fitness when embodying customized and athletic avatars, but this was independent of any interaction between customization and athleticism. Figure 8 shows the average overall scores of self-perceived fitness across conditions relative to participants' actual perceived fitness.

4.4.4 Presence. We conducted a 2×2 ART RM-ANOVA to analyze the effects of Customization and Athleticism on the general presence measured by the IPQ. The results indicate that participants did not experience a significant difference in their sense of presence while embodying the respective avatars. Figure 8 shows the average overall presence scores per condition.

5 Discussion

The quantitative results of our study revealed that customized and athletic avatars can decrease the perception of effort while exercising in VR. Participants had a lower perception of effort while holding weights when embodying the customized avatars compared to the randomly assigned ones. In line with previous work on the Proteus effect [46, 48], we also showed that participants had a lower perceived exertion when embodying the athletic avatar compared to the non-athletic version. As indicated by the significant Customization × Athleticism interaction, our results even show that athletic avatars reduced the heart rate over time while holding weights, however, only when being customized. This implies that customizing avatars can influence the effects by an avatar's athleticism on physiological responses to physical effort. In addition, participants executed more biceps curls while embodying the customized compared to the randomized avatars.

Considering the Proteus effect, we could show that participants had a lower perception of effort while embodying athletic avatars during biceps curls and when holding weights. While not significant, we can observe the trend that the impact of athletic avatars on perceived exertion appear larger when the avatars were customized (see Fig. 3). In line with the perception of effort, we could show a dependency between customization and athleticism on heart rate while holding weights (see Fig. 4). We would expect that the customized athletic avatars resulted in the best while the customized non-athletic avatars in the worst performance as well as perceptual and physiological responses. We, however, found

	Customization			Athleticism			Customization × Athleticism		
Questionnaire Items	$F(1, 23)$	**p**	η_p^2	$F(1, 23)$	p	η_p^2	$F(1, 23)$	**p**	η_p^2
BRQ: vrbody	11.478	.002	.33	6.609	.017	.22	5.789	.025	.20
BRQ: twobodies	.482	.494	.02	.043	.837	.002	.549	.466	.02
BRQ: mirror	8.330	.008	.27	11.996	.002	.34	4.289	.049	.16
BRQ: features	16.796	<.001	.42	29.820	<.001	.56	4.196	.052	.15
BRQ: agency	.033	.858	.001	4.648	.042	.17	2.090	.161	.08
PIS: embodied presence	32.402	<.001	.58	18.451	<.001	.45	8.887	.007	.28
PIS: similarity identification	36.296	<.001	.61	48.181	<.001	.68	20.644	<.001	.47
PIS: wishful identification	13.590	.001	.37	178.379	<.001	.89	38.454	<.001	.63
SPF: total score	8.204	.009	.263	7.501	.012	.246	0.657	.420	.03
IPQ: general presence	1.712	.203	.07	0.177	.677	.007	3.096	.091	.12

Table 2: Inferential statistics for all control measures assessing body ownership (BRQ), avatar identification (PIS), self-perceived fitness (SPF), and presence (IPQ).

that customization influences the most measures irrespective of the avatars' athleticism. Consequently, our findings suggest that whether customization increases avatars' effects could depend on the task at hand. Holding weights is an isometric exercise, while biceps curls are an isotonic exercise, and these different types of exercises may have varying susceptibility to the Proteus effect. Understanding how the effectiveness of the Proteus effect changes across different types of tasks is a promising direction for future research.

We rule out effects of fatigue and exhaustion as an causal explanation for the variance in physiological and perceptual responses between the avatars. We employed a repeated-measures design to minimize unsystematic variance arising from individual differences. To mitigate order effects, we counterbalanced the conditions across participants. Furthermore, task durations were controlled and held consistent across participants to ensure that all participants had an equal amount of time for each task. As participants completed the same sequence of tasks regardless of the avatar they embodied, any fatigue experienced would affect each avatar condition systematically. Thus, the significant differences in heart rate and perceptual responses we observed cannot be attributed to fatigue, as such effects would not explain the variation between avatar conditions.

Furthermore, we also ensured that the participants had a workload that was within the aerobic threshold of 75% maximum HR [76] per avatar condition by using physical tasks with a light to moderate intensity to minimize effects of fatigue and avoid the lactate turn point [46, 76]. This is also represented by participants' perceived exertion that ranged from 10 to 13 which is considered light to moderate [16] (see Fig. 3). Hence, our findings indicate that, although later tasks (e.g., holding weights) or conditions may have led to higher levels of exhaustion, the effects of the avatars were sufficiently robust to remain detectable.

5.1 Perception of Effort and Physical Performance

In line with previous findings [46, 48], we found that an avatar's appearance can affect the perception of effort during physically demanding tasks. Customized avatars resulted in a generally lower perception of effort compared to randomly assigned ones. While previous work found that an avatar's level of athleticism [46, 48] or the sweaty appearance [45] has an effect on perceptual responses, our findings show that customization has also an effect while exercising in VR.

In contrast to the assumption that customizing avatars could increase the Proteus effect, we could not find a higher perception of effort when embodying customized avatars with a non-athletic appearance compared to randomly assigned ones when holding weights. We assume that customizing an avatar that reflects the user irrespective of the athleticism increases attachment and motivation. Hence, we hypothesize that participants were more attached to the outcome and their performance regarding the perception of effort when embodying customized avatars and, in turn, rated lower scores than when embodying the randomly assigned avatars. These findings are in line with the subjective ratings of experienced embodiment and user identification showing higher similarity and embodied presence ratings (see Fig. 7) and generally higher embodiment scores across dimensions (see Fig. 6).

Previous work found that muscular avatars can increase physical performance in terms of a higher grip strength [48]. While we also found effects of athletic avatars, they could not be observed for all tasks (see Table 3). Kocur et al. [50], for example, argued that the Proteus effect occurs for a range of activities such as virtually rowing. Our study, however, adds that for some tasks avatars' effects seem to be more effective than for others. While previous work revealed that the Proteus effect is avatar-specific, e.g., users tend not to behave in line with undesired attributes such as narcissism [36], our work suggests that the Proteus effect can also be task-specific. Hence, future studies should investigate what tasks benefit more or less from the avatars' appearance to learn more about the phenomenon's effectivity and its utilization.

In addition, we show that customized avatars can also improve performance in terms of a higher numbers of biceps curls. As customized avatars can positively influence users across different physically demanding tasks, we recommend enabling users to customize avatars in immersive fitness applications. While customization options in popular exergames, e.g., *RingFit* [70], are still limited [22],

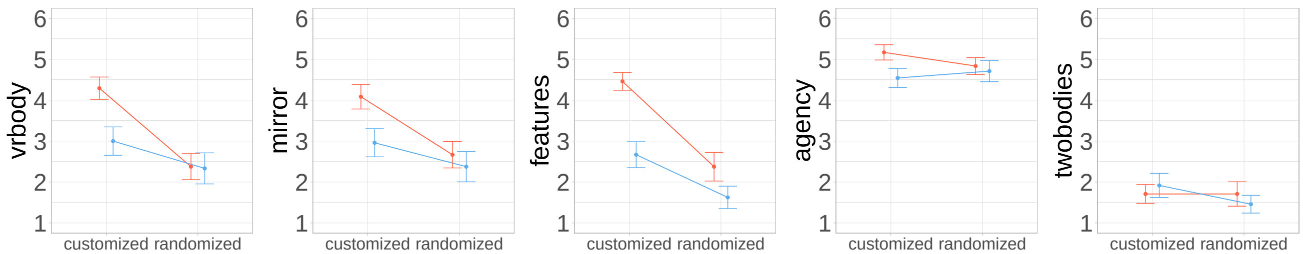

Figure 6: Mean BRQ questionnaire scores for each subdimension (vrbody, mirror, features, agency, and twobodies). Error bars show the standard error of the means.

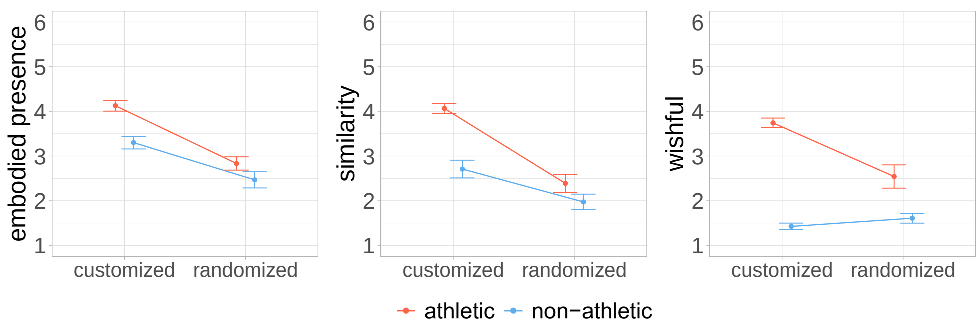

Figure 7: Mean PIS questionnaire scores for each subdimension (embodied presence, similarity identification, and wishful identification). Error bars show the standard error of the means.

future work should further investigate how more extensive customization features and also the level of athleticism can contribute to a lower perception of effort.

While previous work has already shown that customized avatars can improve motivation [12] and performance in exergames [22, 56, 60], our work is the first that systematically disentangled the effects caused by customization and the Proteus effect. The effects of customization suggest that the Proteus effect may thus operate through mechanisms of self-identification and perceived control, rather than just mimicking the avatar's characteristics. Hence, this supports the notion that perceptual and behavioral changes are triggered by changes in self-perception [9] rather than priming effects [4, 83]. This shifts the focus from the avatar's external traits to the user's internal connection with the avatar [11]. Users' perceptual responses and performance is therefore closely tied to the psychological connection with their avatar rather than just its visual attributes. This suggests that instead of solely focusing on traits such as athleticism and muscularity, future work should explore to leverage traits that resonate with users' self-concept and increase the psychological connection with the avatar [34], e.g., using 3D-scanned avatars that align with users' physical appearance [105]. This is in line with Clark [19], who argues that stereotypical appearances can be effective, however, could further reinforce stereotypical thinking. The main effect of customization regardless of the avatars' athleticism suggests that designers could consider focusing on user-avatar similarity instead of only stereotypical appearances such as athleticism.

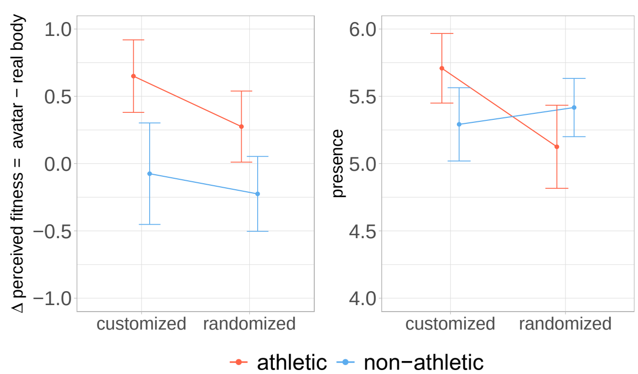

Figure 8: Left: Average Δ self-perceived fitness scores of each subdimension (fitness, strength, body composition, flexibility, endurance) showing the resemblance of the avatars' perceived fitness and participants' actual perceived fitness (positive = avatar is perceived more fit, 0 = equal perceived fitness of avatars and participants, negative = avatar is perceived less fit). Right: average score of the general presence of the IPQ (right). Error bars show the standard error of the means.

► Customized avatars can reduce the perception of effort and improve physical performance irrespective of the avatars' athleticism.

5.2 Heart Rate

Kocur et al. [46] showed that athletic avatars reduced heart rate while cycling an ergometer in VR. We extend previous work by showing that athletic avatars reduced heart rate responses while holding weights, however, only when being customized. Previous work explained that the effects on heart rate could originate from the different levels of experienced embodiment and identification rather than from the visual athleticism of avatars [46, 50]. Accordingly, Navarro et al. [69] also showed that user-avatar similarity influenced cardiac frequency while walking on a treadmill. As we found that the experienced embodiment and identification is higher on average for the customized avatars compared to the randomly assigned ones, our results suggest that body ownership and avatar identification augmented the effects caused by the avatars' appearance. Accordingly, participants perceived the customized athletic avatars as more fit than the randomized athletic avatars relative to their actual fitness level (see Fig. 8). This indicates that avatars that were personally created by users were attributed with higher physical abilities than randomized ones and can, therefore, explain the effects caused by customization. Consistent with the ratings of wishful identification (see Fig. 7), participants created a more idealized version of themselves when customizing the athletic avatar, indicating a successful manipulation check. These findings imply that customizing avatars with idealized physical characteristics can augment the physiological effects originating from the Proteus effect due to the avatars' athletic appearance. Besides, correlation analyses suggest that a higher self-perceived fitness resulted in a lower reduced heart rate. Future work could systematically analyze how metrics that objectively quantify participants' athleticism, e.g., using a cooper test to determine physical fitness [64], influence the Proteus effect.

Interestingly, the descriptive statistics suggest that the heart rate while embodying athletic avatars is higher compared to non-athletic avatars during biceps curls. In line with Kocur and Schwind [54], we assume that avatars do not directly control physiological measures such as heart rate, but induce a behavioral change and depend on the physiological activity. In our study, avatars increased heart rate when power and speed are required (e.g., while performing biceps curls) and decrease heart rate when endurance is required (e.g., while holding weights), suggesting a cognitive mapping and an underlying mechanism that controls body functions via motor control (e.g., through breathing) [54].

In a different context, Slater et al. [97] revealed that participants who embodied an avatar from a third-person perspective had a lower heart rate response to a virtual threat compared to a first-person perspective. Furthermore, it seems also plausible that avatars with visual attributes that fundamentally differ from the real self can also influence physiological responses due to novelty effects [57]. As the randomly assigned avatars were created by other participants with characteristics deviating from the self, embodying them could create a novel and interesting experience raising the heart rate. Hence, we assume that customization is the driving factor for physiological responses due to avatar embodiment.

► Athletic avatars can reduce heart rate responses while holding weights, however, only when being customized.

5.3 Design Considerations

Our findings consolidate previous work [46, 48, 50, 78] indicating that designers and researchers of VR exercise applications can use athletic avatars to improve participants' perception of effort. Athletic avatars can be effective in fitness-oriented applications, where embodying a muscular, capable character aligns with the physical effort and achievement goals of the application. As the perception of effort is a barrier to regular physical activity [66], making exercise feel less intense without changing the actual intensity can contribute to more effective exergames [65]. Hence, athletic avatars can inspire players to push themselves further due to a reduced perceived exertion by reinforcing a sense of athleticism and competence [62, 63].

Our study also revealed that physiological effects caused by the Proteus effect can be enhanced using customized avatars with an athletic appearance. However, we found that the heart rate responses could only be influenced while holding weights — an isometric exercise involving the static contraction of a muscle without any active repetitive movement. While Kocur et al. [46] revealed that utilizing an avatar's athleticism can be advantageous for users while cycling, we show that when athleticism and customization are combined during isometric exercises, the exercise benefits can be even more impactful. A lower heart rate response can help prevent premature fatigue and enhance exercise enjoyment, potentially making it easier for users to adhere to long-term fitness routines [66]. For beginners, for example, reducing heart rate responses can lower the risk of overexertion, ensuring safety and comfort, and make exercise a more appealing and mentally beneficial experience [16, 75].

Besides utilization, it is important to know how an avatar's appearance affect the basal HR from a research perspective. If psychophysiological effects due to the embodiment of athletic and customized avatars occur, the avatar, therefore, has to be considered in the experimental design process. While more research is required to better understand avatars' effects with a broader range of activities, we propose to consider customization options in immersive exergames or fitness applications to enhance avatar identification and embodiment, with the goal to augment the Proteus effect.

5.4 Limitations and Future Work

Even though our immersive customization editor was equipped with many options to personalize the avatars, commercial customization editors offer more options for individualization. While the results indicate that our options were sufficient to induce different degrees of body ownership and identification, they do not encompass the full range of possible avatar customization, e.g., to study behavioral traits or more nuanced personality traits.

Additionally, the study focused solely on short-term physiological and perceptual responses during exercise in VR. The long-term effects of using customized avatars, including potential behavioral changes or sustained modifications in physical activity levels, were

Measures	Tasks	Customization			Athleticism			Customization × Athleticism		
		$F(1, 23)$	p	η_p^2	$F(1, 23)$	p	η_p^2	$F(1, 23)$	p	η_p^2
Perceived Effort	Holding Weights	5.812	**.024**	.202	4.663	**.041**	.169	2.545	.124	.100
	Biceps Curls	0.576	.455	.024	10.599	**.003**	.315	1.501	.233	.061
Heart Rate	Holding Weights	0.311	.583	.013	4.374	**.048**	.160	5.214	**.032**	.185
	Biceps Curls	0.366	.551	.016	3.125	.090	.120	0.423	.522	.018
Performance	Biceps Curls	5.806	**.024**	.200	3.575	.071	.130	0.020	.887	<.001
	Reaction Wall	4.103	.055	.151	3.332	.081	.127	2.490	.128	.098

Table 3: Summary of the inferential statistics providing p-values and the corresponding effect sizes (η_p^2) for each measure and task. Building on prior research, we hypothesized that athletic avatars would lead to a reduced perception of effort [45, 48] and lower heart rate responses [46, 50] (H1). Additionally, we hypothesized an interaction effect between customization and avatar athleticism on the measures due to body ownership and avatar identification as moderators of the Proteus effect [7, 46, 81](H2). We confirm H1 for the perception of effort during holding weights and biceps curls, as well as for the heart rate while holding weights. We also confirm H2 for heart rate responses while holding weights.

not assessed. Future research should explore these long-term impacts to provide a more comprehensive understanding of how avatar customization can be optimized for VR exercise applications. In addition, a more diverse participant pool with different characteristics, e.g., different levels of athleticism, could provide valuable insights into possible moderators of the Proteus effect. Furthermore, we focused on avatars with realistically enhanced abilities, e.g., after one year of a healthy diet. However, our study did not investigate how customizing avatars with super abilities, e.g., Superman, influence perceptual and physiological responses.

Our findings indicate that customizing avatars can influence the heart rate while exercising. On the one hand, a reduced heart rate can be interpreted as positive when considering it as a physiological reaction to a decreased perception of effort. In this case, using customization options in VR exercise applications can be seen as beneficial for players. However, an elevated heart could also be interpreted as positive when considering it as a measure for physical activity [69]. In this case, randomly assigned avatars could cause participants to be more physically active, burn more calories, and put more effort into the task even if at an unconscious level. As both options appear plausible, future work should further investigate physiological changes caused by avatars during physically demanding activities to derive conclusive guidelines how to utilize avatar customization and the Proteus effect for VR exercise systems.

Another potential limitation is the consistency of the observed effects of avatars' athleticism and customization across different tasks. While we could demonstrate significant effects for some tasks, such as reduced heart rate caused by athletic avatars for holding weights but not for biceps curls, these effects were not observed uniformly across all task types. These findings may indicate a potential lack of generalizability of the Proteus effect suggesting that the influence of avatar athleticism and customization may depend on specific task characteristics. While we aimed to explore different physical tasks to cover a broad range of physical abilities, i.e., a reaction time task (reaction wall game), an isometric task (holding weights) as well as an isotonic task (biceps curls), there is still a range of activities that need to be analyzed to learn about the generalization of the Proteus effect. These findings emphasize the need for further research to explore the underlying mechanisms driving these task-specific effects and to better understand how the Proteus effect can consistently influence performance and perception across a broader range of activities [50].

The experiment and the tasks introduced some accumulation of fatigue due to physical activity. Hence, the effects caused by customization or avatar athleticism could be influenced by the task sequence. It is therefore still unclear if and how the Proteus effect is affected by the physical workload users are experiencing during avatar embodiment. Consequently, future work could systematically explore the robustness and effect size of avatars' effects at different levels of exhaustion and fatigue.

6 Conclusion

In this paper, we investigate the effects of customized and randomly assigned avatars on users' physical performance as well as perceptual and physiological responses during physically demanding tasks in VR. We developed an immersive VR customization editor allowing to create individualized avatars while embodying them. We then conducted a controlled experiment with 24 participants who played a reaction wall task, performed biceps curls, and held weights while embodying athletic or non-athletic avatars that were either customized or randomly assigned. We found that embodying athletic avatars resulted in lower heart rates while holding weights, however, only when they were customized. Additionally, customized and athletic avatars resulted in a lower perception of effort while holding weights. In addition, customized avatars increased the number of performed curls irrespective of the avatars' athleticism.

Overall, we showed that customized avatars can positively affect users' perception of effort, heart rate, and physical performance to physical effort. We also replicated findings from previous work indicating that athletic avatars can decrease perception of effort during physically demanding tasks. Hence, our paper extends prior research about the Proteus effect by showing that not only athletic avatars but also customized avatars can be beneficial for users' physical performance while exercising. In addition, results also indicate that customizing avatars can increase the Proteus effect on physiological responses while holding weights. While we could find the Proteus effect for some tasks, e.g., a reduced heart rate caused by athletic avatars for holding weights but not for biceps curls, our results may suggest a lack of generalizability of the Proteus effect indicating that this phenomenon depends on the task. This contradicts prior research postulating that avatars' effects during physical activity translate to a range of activities and adds a new perspective on the Proteus effect and its effectivity for certain tasks. Future studies can build upon our work to explore further aspects such as long-term effects or behavioral changes across different activities to deepen our understanding of avatars' effects.

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