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The Effects of Avatar and Environment Design on Embodiment, Presence, Activation, and Task Load in a Virtual Reality Exercise Application

Andrea Bartl*
HCI Group
University of Würzburg

Christian Merz†
HCI Group
University of Würzburg

Daniel Roth‡
HEX Lab
FAU Erlangen-Nürnberg

Marc Erich Latoschik§
HCI Group
University of Würzburg

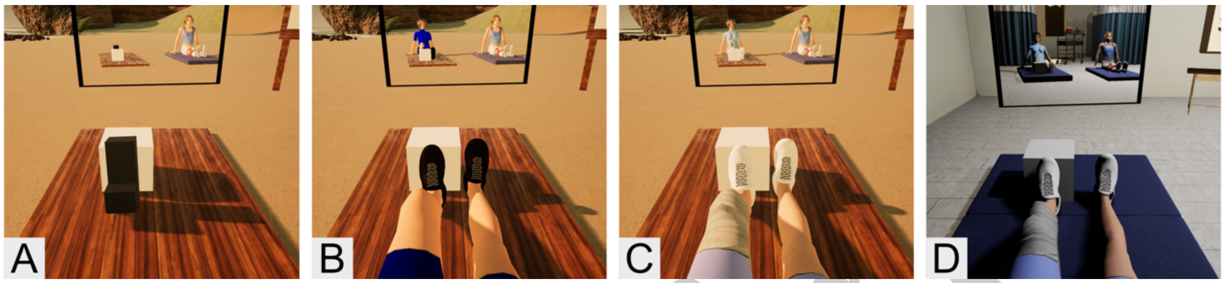


Figure 1: User perspective in the VR exercise application. (A-D) show a subset of the study conditions. (A) Partial body on beach, (B) Healthy avatar on beach (congruent), (C) Injured avatar on beach (incongruent), and (D) Injured avatar in hospital (congruent).

Abstract

The development of embodied Virtual Reality (VR) systems involves multiple central design choices. These design choices affect the user perception and therefore require thorough consideration. This article reports on two user studies investigating the influence of common design choices on relevant intermediate factors (sense of embodiment, presence, motivation, activation, and task load) in a VR application for physical exercises. The first study manipulated the avatar fidelity (abstract, partial body vs. anthropomorphic, full-body) and the environment (with vs. without mirror). The second study manipulated the avatar type (healthy vs. injured) and the environment type (beach vs. hospital) and, hence, the avatar-environment congruence. The full-body avatar significantly increased the sense of embodiment and decreased mental demand. Interestingly, the mirror did not influence the dependent variables. The injured avatar significantly increased the temporal demand. The beach environment significantly reduced the tense activation. On the beach, participants felt more present in the incongruent condition embodying the injured avatar.

Index Terms: Human-centered computing—Empirical studies in HCI; Human-centered computing—User studies; Human-centered computing—Virtual reality

1 Introduction

Virtual Reality (VR) systems are increasingly used in various application areas, e.g., education, entertainment, therapy, and many more. The design of a VR application influences intermediate factors that lead to a VR system achieving (or preventing) a particular desired goal in a particular use case. For example, high levels of immersion (design choice) are known to influence the feeling of presence (intermediate factor) [53, 55], which in turn is believed to impact learning outcomes (goal) [15, 39].

*e-mail: andrea.bartl@uni-wuerzburg.de
†e-mail: christian.merz@uni-wuerzburg.de
‡e-mail: d.roth@fau.de
§e-mail: marc.latoschik@uni-wuerzburg.de

The design space of VR systems is markedly large. Developers can choose from almost unlimited variations of virtual environments, user representations (avatars), and supported interactions. Each design decision may (and often will) affect multiple intermediate factors of VR experiences. However, the intended influence of the design choices on the intermediate factors is frequently merely assumed in practice. A typical use case for VR exercise applications is VR rehabilitation. Here, for example, a common assumption is that the plain utilization of VR as a very first general design choice increases motivation and hence positively influences the rehabilitation outcome [20]. Yet, many efficacy studies fail to demonstrate the theoretically predicted superiority of VR systems in physical rehabilitation for both neurological conditions [18, 34] and orthopedic conditions [69]. Here, VR systems are often applied without sound justification for the specific design choices. In order to maximize the potential of VR systems to achieve general and application-specific goals, it is necessary to explore the impact of specific design choices on use case-relevant intermediate factors.

Contribution: We developed an immersive VR application for physical exercises targeting the lower body as applicable in VR rehabilitation and other VR exercise applications. In two user studies, we explored the effects of central design choices of embodied VR experiences (avatar and environment) on important intermediate factors (sense of embodiment, presence, motivation, activation, and task load). Due to the plethora of possible design choices, we did this with convenience samples. This is necessary to form valid hypotheses for future research with specific user groups, e.g., patients requiring rehabilitation, that are justifiable ethically and in terms of increased effort. We present and discuss the results of both studies. Our work contributes to the basic research regarding the design of applications for embodied VR experiences.

2 Related Work

This work focuses on the design of fully-immersive VR systems for physical exercises targeting the lower body. Such VR systems have been attributed with many beneficial properties. Especially in the context of physical rehabilitation, when compared to conventional therapy, VR systems supposedly enhance cognitive and physical realism and increase excitement [20]. Therefore, it is plausible to claim that VR therapy should actually work better than conventional therapy regarding the application-specific goals. Surprisingly, studies with patients often fail to prove this superiority [18, 34, 69]. Articles regarding VR applications for orthopedic rehabilitation often report using a particular system without analyzing the relation between specific design choices and the intermediate factors involved (see review articles [5, 16, 69]). System descriptions are sometimes superficial and usually lack in-depth justifications for design decisions. Many of the utilized systems are low immersive off-the-shelf applications not tailored to the use case. This could be one reason why the predicted superiority of VR technology can rarely be proven.

In the following, we will discuss relevant intermediate factors for VR exercise systems and address essential design choices. Based on the presented literature, we derive our research questions.

2.1 Intermediate Factors

Two prominent intermediate factors are directly connected to the virtual environment and the user representation. The subjective feeling of being present in the virtual environment (*presence*) [53] and the extent to which users process a virtual body as if it was their own body (*sense of embodiment*) [26]. While these are more general VR-related intermediate factors relevant for almost all use cases, other more use case-specific factors exist.

First, it requires *motivation* to perform physical exercises. Motivation is particularly important in physical rehabilitation, where the rehabilitation's success depends on patient compliance and motivation to exercise at home [64]. Here, the user's current *activation* is of great importance. After surgery, patients face a greater risk of feeling frustrated and bored [8] which can reduce patient engagement with the often repetitive exercises [19]. Lastly, to avoid unnecessary risk of injury due to accidental overloading of the user, it is crucial to know the influence of the applied design choices on *task load*.

2.2 Design Choices

There are countless design decisions to be made for a VR exercise application, e.g., the exercise selection, analysis, and control, feedback mechanisms, the virtual exercise environment, the user representation, and many more. In fully immersive VR, head-mounted displays commonly occlude the user's view of the own body as well as the real world. Moreover, physical exercises relate directly to a person's body. Therefore, two fundamental design choices for embodied VR systems in general and especially for VR exercise systems are the user representation, aka their avatar, and the environment.

2.2.1 Avatars

Avatars are virtual surrogates of users in virtual worlds, driven by their human behavior [3]. Regarding their design, we distinguish between avatar fidelity and avatar type.

Avatar Fidelity Avatar fidelity (sometimes referred to as avatar realism) can be differentiated into multiple categories, e.g., behavioral realism and appearance realism [12, 50]. Behavioral realism requires motion tracking and its mapping to avatar motion. The simplest, low fidelity method, common in consumer hard- and software, is only to track the head and hands and use partial representations, e.g., abstract shapes or floating hands. Sophisticated and thereby usually high-cost full-body tracking systems achieve the highest avatar fidelity, incorporating facial expressions, gaze tracking, and gestures [47]. In between are solutions that visualize not only hands and head but also other body parts using additional single tracking points, e.g., the feet, up to solutions that calculate a full-body representation via inverse kinematics [49].

The sense of embodiment can emerge for low and high fidelity avatars [6, 13, 21, 52]. However, it seems weaker with floating body parts than when they are connected [52]. Following the model proposed by Latoschik and Wienrich [33], missing body parts could lead to incongruence at the cognitive or perceptual layer, thus reducing plausibility and thereby impacting various intermediate factors. Additionally, a full body provides more information on visuomotor synchronicity, potentially increasing agency [11, 23, 30] which fosters the sense of embodiment [26]. In previous experiments, an increased sense of agency also increased virtual presence [24] thereby potentially facilitating various other intermediate factors, e.g., motivation in physical exercises [9, 38]. Representing the users' movements with a high fidelity avatar might also support observational learning in exercising [61, 63]. However, to enable at-home training, tracking equipment has to be affordable, transportable, and easy to set up [31]. In physical rehabilitation, injured persons may be limited in motion and sensitive to touch. Therefore, the tracking equipment needs to be easy to put on and as little invasive as possible, e.g., like previously proposed systems for homework monitoring using various sensors above or below the injured knee [1, 2, 42].

Avatar Type Avatars are also distinguishable by what we describe here as avatar type. The avatar type's primary determiner is the avatar's appearance. In contrast to avatar fidelity, an avatar type is categorical rather than a bipolar spectrum. Avatar types may be differentiated on a single or multiple appearance dimensions or attributes. Such categories are, for example, the fit of a representation to a specific task such as drumming [25] or planning and problem-solving [4]. Through their respective external characteristics, avatar types represent specific roles and create preconceptions in users.

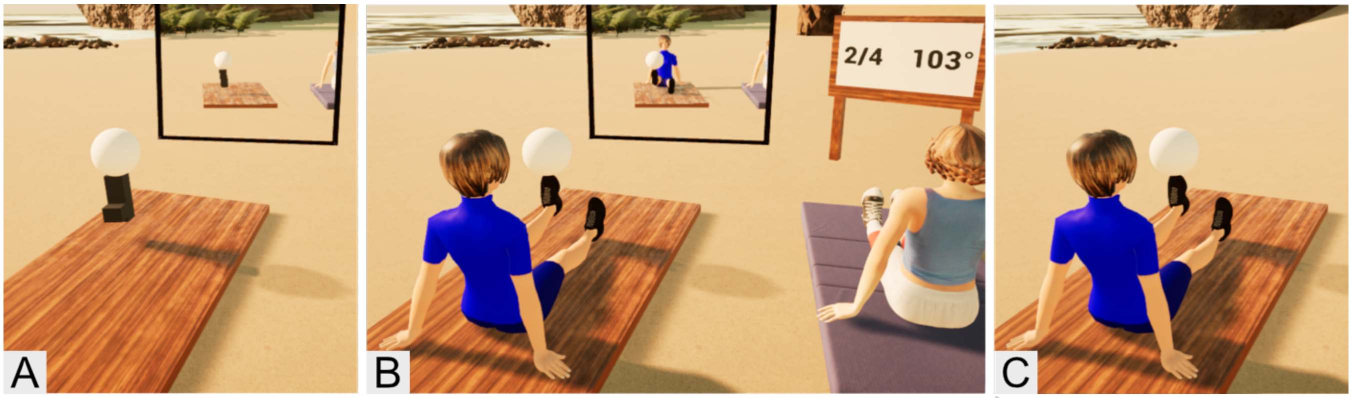
In this regard, the *proteus effect* [66, 67] describes the phenomenon that the avatar's appearance influences users' attitudes and behavior depending on their stereotypical beliefs about the avatar. Therefore, the avatar type seems promising for influencing intermediate factors through deliberate design choices. A large body of studies exists that explore the effects of different avatar types on general or application-specific goals in the context of physical exercises, e.g., physical performance [29, 35, 36] or physical activity [43, 44]. Regarding the intermediate factors, Kocur et al. [28] found that athletic avatars potentially decrease the perceived exertion, indicating the avatar type's potential influence on the perceived task load. Additionally, Li et al. [35] found that a normal-weight self-avatar increased motivation in obese children while playing an exergame with the Nintendo Wii. This suggests an influence of the avatar type on motivating and activating factors.

2.2.2 Virtual Environments

We distinguish between the effect of specific objects in the environment and the type of environment conveying a certain atmosphere.

Environment Objects For physical exercises, mirrors are often used to provide additional visual feedback, allowing users to observe, control, and correct their movements from a third-person perspective. Virtual mirrors are also common in research targeting embodied virtual experiences, e.g., [14, 22, 48, 60]. Here, they are typically believed to strengthen the connection with one's avatar, potentially facilitating the sense of embodiment. Past research suggests that both continuous and interrupted viewing of one's avatar in a virtual mirror can induce a sense of embodiment [22]. However, the influence of the virtual mirror on most intermediate factors is yet unclear.

Environment Type Studies suggest that different types of virtual environments elicit different emotions [10, 46] similar to real environments. Wang et al. [62] showed that VR environments affect the psychological state of users by successfully reducing stress using virtual environments featuring nature scenes. Other work implies that more emotionally charged environments increase presence [46] independent of the emotional valence [24]. However, the influence of the environment type is often ignored in studies that investigate the impact of VR, for example, on application-specific goals. Especially in use cases where the transition from low-immersive to high-immersive systems is just beginning, e.g., in VR knee rehabilitation where existing reviews [5, 16, 69] do not report any studies investigating the influence of the virtual exercise environment.



Three of the four conditions of Study 1: (A) Partial body with abstract foot visualization only (between-factor) with mirror (within-factor), (B) anthropomorphic, full-body avatar with mirror, (C) full-body avatar without mirror. The fourth condition was the partial body without a mirror.

2.3 Research Questions

Based on the presented literature, we now derive our research questions for investigating the influence of central design choices regarding the avatar and the environment.

$RQ_{AvatarFidelity}$ Different levels of avatar fidelity require different hardware and software solutions, resulting in different system complexity and costs. While more complex systems enable high avatar fidelity, they are often not realistically usable in exercise use cases. Especially not for at-home training, where equipment needs to be affordable and easy to put on [31]. It is, therefore, necessary to investigate the influence of different levels of avatar fidelity that are still realistically achievable with common consumer VR solutions. Understanding their impact ultimately helps to choose appropriate solutions for the application-specific goals at hand. Thus, our first research question is the following: **How do different levels of avatar fidelity influence intermediate factors when exercising?**

RQ_{Mirror} We have identified mirrors as a prominent object in many virtual environments, e.g., in VR exercise systems and embodied VR research. A common assumption is that mirrors enhance the sense of embodiment [22] and support exercise execution in general. Due to its frequent use, it is necessary to understand the mirror's influence on relevant intermediate factors to understand how to use it effectively. Hence, our second research question reads as follows: **How does a virtual mirror influence intermediate factors when exercising?**

$RQ_{AvatarType}$ Research on the *proteus effect* [66, 67] suggests that the avatar's appearance can be explicitly used to foster certain behaviors. An obvious design choice is to select the avatar in congruence with the intended use case, with the external appearance already conveying use case-specific roles and assumptions. This is also in line with an online study by Praetorius et al. [45] that suggests that users prefer different avatar types depending on the context of use. However, it is first necessary to know how this context-congruent choice affects the use case-relevant intermediate factors. This leads to our third research question: **How do different avatar types influence intermediate factors when exercising?**

$RQ_{EnvironmentType}$ Virtual environments potentially influence users similarly to the real world [10, 46]. Thus, the choice of the virtual environment is a central design decision. However, similar to the avatar type, the choice seems more obvious for some virtual environments than others. Hence, the virtual environment is often chosen in congruence with the use case at hand. Therefore, our last research question targets the influence of different environment types: **How do different environment types influence intermediate factors when exercising?**

3 Study 1

The first user study examined $RQ_{AvatarFidelity}$ and RQ_{Mirror}. The institution's responsible ethics committee approved the study.

3.1 Design

The study followed a 2×2 mixed-design with two independent variables (IVs): *avatar fidelity* and *mirror*. As a between-subjects factor, we examined differences in participants' experience when exercising embodied in avatars with different levels of avatar fidelity ($RQ_{AvatarFidelity}$). We chose to compare two different levels of fidelity that are both still achievable with consumer-grade hard- and software. Specifically, we compared an abstract, partial body representation to an anthropomorphic, full-body representation. This IV was the between-factor to avoid carry-over effects because past research implies that the influence of the own representation persists beyond the exposure, potentially influencing subsequent interactions [68]. As a within-factor, participants performed the exercises once with and once without the support of a virtual mirror (RQ_{Mirror}). Sect. 2.2.2 shows the VR system within the conditions of Study 1.

3.2 Apparatus and Material

This section describes the methods of Study 1.

3.2.1 VR Exercise Application

We implemented a VR application for physical exercises targeting the lower body. Implementation included multiple feedback loops with a sports orthopedist. Our application is called iLAST which stands for **i**mmersive **L**eg Coordination **A**nd **S**trength **T**herapy.

Training Setup Users exercise sitting on a mat. In VR, the user's avatar sits on a virtual mat. Fig. 1 shows the user's first-person view. In front of them is a virtual mirror. Next to the mirror is a sign showing the required and completed number of repetitions and the position of the user's leg, represented by an angle. To the right of the user's avatar sits a female virtual coach who wears sports clothes. Before the first performance of an exercise, she explains and demonstrates the required movement. During the exercise, the coach silently repeats the movement alongside the user while looking forward. Between exercises, she announces that the user has time to rest and gives instructions to move on with the subsequent exercise when the break is over. We ensured that participants did not focus primarily on the coach while exercising by analyzing the movement data after the study.

Exercises iLAST includes two movement exercises inspired by rehabilitation exercises for the knee: 1) *Leg Raises* are a typical exercise prescribed after anterior cruciate ligament surgery. The exercise strengthens the quadriceps muscles, which are essential

Figure 2: A user performing Leg Raises (left) and Knee Extensions (right). Trackers were located on the user's back, hands, and feet.

for walking again after surgery. In iLAST, users move a ball up and down by raising the extended leg (see Sect. 2.2.2). 2) *Knee Extensions* help to regain mobility after surgery and aim to restore the ability to straighten the knee. Users pull a box towards them by bending the knee and pulling the heel towards the body center. Then they push the box away by slowly extending the leg until it is stretched out again (see Fig. 1). Fig. 2 shows both exercises from a third-person perspective in reality. Users receive visual feedback to guarantee correct execution. For this purpose, the exercise objects (ball or box) turn green and pulse once at the lower and upper end of the predefined range of motion. The exercise object is white when the leg position is inside the range and turns red when it is outside.

3.2.2 Independent Variable Manipulation

For the anthropomorphic, full-body representation, we used the avatars provided by iKinema Orion. We adjusted their textures so that the clothes looked like sportswear. Male participants controlled a male, female participants a female avatar. For the abstract, partial body condition, a block at the left foot position replaced the full-body avatars (see Sect. 2.2.2). We visualized only one foot because this was the only body part directly involved in object interaction during the exercises, giving enough feedback for proper execution. We chose the abstract block instead of a realistic human foot or shoe to avoid strong emotional responses due to eeriness. Existing research implies that missing body parts potentially have a more detrimental effect on the user experience when their visualization is realistic than abstract [51]. We implemented the virtual mirror for the second IV using the planar reflection of the Unreal Engine.

3.2.3 Hard- and Software

We implemented iLAST using Unreal Engine 4.17. To represent the user's movements in the virtual environment, we used iKinema Orion (v. Runtime 0.93). It uses six tracking points and inverse kinematics to simulate full-body tracking. We tracked the user's movements using the HTC Vive Pro and five additional VIVE trackers (v. 1.0) on the participants' hands, feet, and lower back. Fig. 2 shows the tracker placement on a user. Although the lower fidelity condition technically requires less hardware, we used the same tracking system for both conditions to avoid confounds. iKinema Orion scales the avatar's size during calibration. No further adjustments to the participant's body proportions were performed. Before conducting the studies, we tested the system with various persons to rule out potential confounds from different body proportions. During the studies, we used the integrated headphones of the HTC Vive Pro. The application ran on a VR-capable PC consisting of an Intel Xeon E3-1230 v5, an Nvidia GeForce GTX 980 Ti, and 16 GB RAM.

3.2.4 Measurements

We assessed participants' subjective experiences using the online questionnaire tool Limesurvey. To measure the users' *sense of embodiment* we used the Virtual Embodiment Questionnaire [48]. It consists of three subscales measuring agency, body ownership, and the perceived change of the own body schema. We selected this questionnaire because, unlike other embodiment questionnaires, it contains the *change* subscale, which is thought to be partly responsible for the occurrence of the Proteus effect [48]. With the Presence Questionnaire [65] we measured participants' *presence-related subjective responses* to our VR system. The questionnaire described by Li et al. [35] was used to assess the *general exercise motivation*. To measure the *current activation level* of the participants, we used the short form of the Activation-Deactivation Adjective Check-List (AD-ACL) [58, 59]. The checklist has two dimensions: energetic activation (sleepy vs. awake) and tense activation (calm vs. nervous). We assessed the *task load* using the raw version of the NASA Task Load Index [17]. It assesses the mental, physical, and temporal demand, perceived effort, performance, and frustration.

As additional control variables, we assessed *VR sickness* [27] and *exercise duration*. For the exercise duration, we logged each exercise's start and end times. We built mean values over the individual runs for each exercise type within an experimental block. We also logged *positional data* of the VR equipment. All participants filled in a *demographic questionnaire* assessing age, biological sex, occupation, highest educational attainment, language skills, visual and hearing impairments, gaming habits in hours per day, VR experience in total hours, and the sports activity level in hours per week.

3.3 Procedure

First, the participants filled out a consent form and pre-questionnaires (*VR sickness*) and received an introduction to the study setting. The experimenter told them to imagine they had a torn anterior cruciate ligament in their left knee followed by surgery and would now have to perform rehabilitation exercises in VR. The experimenter helped equip the participants with the trackers and completed the calibration for motion tracking. At the beginning of the VR exposure phase, the virtual coach explained the Leg Raises exercise, which the participants performed four times, followed by 30 seconds of rest. The participants repeated this exercise once. Next, the coach explained the Knee Extension exercise, which the participants performed eight times, followed by 30 seconds of rest. The participants repeated this exercise twice. After the exercises, the participants answered the main questionnaires (*embodiment, presence, motivation, activation, task load*) on a laptop. They repeated

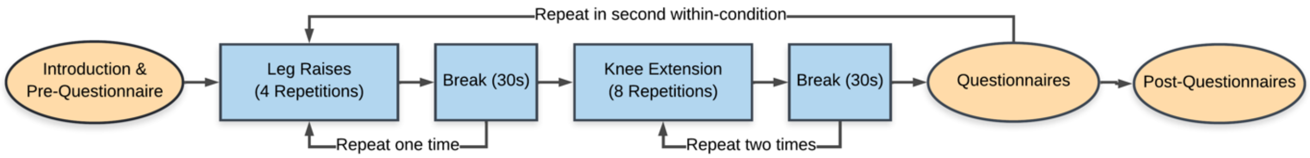


Figure 3: Procedure of the two user studies.

the training in the other within-factor condition. We randomized the order of conditions. At the end, they filled out a post-questionnaire (*VR sickness and demography*). Finally, the experimenter thanked the participants and bid them farewell. Fig. 3 shows the procedure of the experiment.

3.4 Participants

All participants were students that received credit points necessary for gaining their bachelor's degree. Each student could only participate in one of the studies to avoid learning or carry-over effects. For Study 1, we recruited $N = 84$ participants. We excluded $n = 5$ participants due to technical problems, i.e., tracking failures that disrupted the exercises and $n = 2$ participants because they corrected their visual impairment during the experiment insufficiently. The resulting sample of $N = 77$ participants was $M = 20.74$ ($SD = 2.06$) years old. 70.1 % were female, 29.9 % were male. Half of the sample exercised with the partial body ($n = 38$), the other half exercised with the full body ($n = 39$). In the partial-body group, 71.1 % were female; in the full-body group, 69.2 % were female; the remaining percentage in both groups reported being male. We found no significant association between the condition and the participants' activity level, $\chi^2(2) = 3.65$, $p = .168$, as well as their prior VR experience, $\chi^2(4) = 1.35$, $p = .874$. In both groups, about 50 % stated to do 0 to 3 hours of sports every week. More than a third had less than 1 hour of VR experience and about 70 % had 5 hours of prior VR experience at a maximum in both groups.

3.5 Results Study 1

We performed the analysis using IBM SPSS Statistics 26 and R 3.6.3. The initial analysis of the data revealed several violations of the normality and variance homogeneity assumptions. Therefore, we calculated robust mixed ANOVAs using the bwtrim() function of the R package WRS2 [37]. This function uses 20 % trimmed means. All reported means (M) and standard deviations (SD) are trimmed values. As an effect size, we calculated partial eta-squared η_p^2.

3.5.1 Dependent Variables

Fig. 4 shows the significant results of Study 1. We found no significant main effect of the avatar fidelity on body ownership. There was, however, a significant main effect on agency, $Q_A(1, 36.27) = 5.18$, $p = .029$, $\eta_p^2 = .020$. Agency was higher for the full body ($M = 6.25$, $SD = 0.33$) compared to the partial body ($M = 5.82$, $SD = 0.45$). Analysis of the perceived change also revealed a significant main effect, $Q_A(1, 43.66) = 49.41$, $p < .001$, $\eta_p^2 = .210$. The perceived change of the own body schema was stronger with the full body ($M = 3.84$, $SD = 0.82$) than with the partial body ($M = 1.59$, $SD = 0.55$). There was no significant main effect of the mirror and no significant interaction on body ownership, agency, and change.

The avatar fidelity had a significant main effect on the mental demand, $Q_A(1, 33.10) = 9.93$, $p = .003$, $\eta_p^2 = .050$. Participants felt the task to be less mentally demanding when being embodied with a full-body avatar ($M = 7.81$, $SD = 3.56$) compared to a partial body ($M = 14.67$, $SD = 6.62$). The other task load subscales (physical and temporal demand, effort, performance, and frustration) were

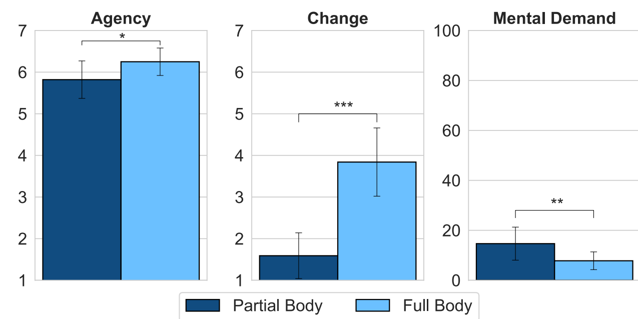


Figure 4: Main effects of avatar fidelity. Error bars show standard deviations. $^{*} < .05$, $^{**} < .01$, $^{***} < .001$

also lower for the full-body condition. However, these differences did not reach significance. The mirror did not significantly impact the perceived task load.

Neither the avatar fidelity nor the mirror significantly influenced the feeling of presence, motivation, or activation. Regarding the perceived presence, we found two tendencies ($p < .080$). Ratings were higher for the full body ($M = 5.43$, $SD = 0.33$) than for the partial body ($M = 5.11$, $SD = 0.33$) and higher with the mirror ($M = 5.33$, $SD = 0.29$) than without the mirror ($M = 5.20$, $SD = 0.41$). The motivation tended ($p = .050$) to be higher without ($M = 4.33$, $SD = 0.22$) than with the mirror ($M = 4.27$, $SD = 0.27$). We found no interaction effects.

3.5.2 Control Variables

VR sickness ratings were low across conditions, ranging between 5 and 12 on a scale from 1 to 100. We found a tendency ($p = .050$) for an increase between the measurement before ($M = 6.68$, $SD = 3.07$) and after the experiment ($M = 8.97$, $SD = 4.90$). We believe this to be uncritical because the values were overall low, the experimenters did not detect any signs of VR sickness in the participants, and the participants did not complain of severe symptoms. There was no significant main effect of the experimental group (full-body vs. partial body) and no interaction regarding VR sickness. We found no significant effects of both IVs on the duration of both exercises.

3.6 Discussion Study 1

The avatar fidelity (abstract, partial vs. anthropomorphic, full-body avatar) influenced the sense of embodiment and the mental demand during the exercises ($RQ_{AvatarFidelity}$). Overall, participants accepted both levels of avatar fidelity as virtual bodies (body ownership), and both caused a high level of agency, which is in line with Gonçalves et al. [13]. However, similar to Seinfeld et al. [52], we found that the full-body avatar induced a significantly higher feeling of agency. An obvious explanation is visuomotor synchronicity, which strongly facilitates agency [23, 26, 30]. The full body provides more information about the synchronicity between the participants' movements and the avatar. The full-body avatar also significantly increased the perceived change of the own body schema. Although

Figure 5: Manipulation of Study 2. Top: Avatar types (between-factor). Bottom: environment types (within-factor).

the partial body is technically a more significant deviation from the own body, it does not seem to affect the own body schema as much as the full avatar. The full body offers more visual features for direct comparison with the user's real body. Users may remain more connected to their own body when most of the virtual body is invisible. An increase in the perceived change of the own body schema is promising when aiming to exploit the proteus effect [48, 66, 67]. The higher sense of embodiment potentially also explains the tendency of higher presence with the full-body avatar [11].

Lastly, all task load measures were lower with the full-body avatar, significantly so for mental demand. This suggests that the full-body avatar helps users understand the exercises and better coordinate their movements. The full-body avatar is more congruent with our real-world expectations than the partial body [33]. It provides holistic visual feedback on all moving body parts during the motion sequence, thus reducing the mental demand. This is partially in line with Steed et al. [57] who found a positive influence of a full-body avatar on cognitive load when compared to having no avatar.

The availability of a virtual mirror did not influence the intermediate factors during the exercises significantly (RQ_{Mirror}). This is especially surprising for the sense of embodiment. Virtual mirrors are often used to induce, strengthen, or generally investigate the sense of embodiment [14, 22, 48, 60]. They potentially reinforce the awareness of visuomotor synchronicity and allow for additional visual feedback. There were only two non-significant tendencies regarding the mirror: Presence was higher, and motivation was lower with the mirror than without it. This conflicts with existing literature that has associated increased presence with increased motivation [9, 38] and needs further investigation. There are two possible explanations for the limited influence of the mirror in our study. Firstly, we placed the virtual mirror inside the participants' field of view but did not explicitly ask them to look at their reflections during the experiment. Secondly, it was sufficient for participants to focus directly on their bodies and the exercise object to perform the movements correctly. This alone creates a sense of embodiment. Exercises requiring participants to observe their reflection, e.g., to check their posture, may increase the mirror's effect on the user.

4 Study 2

The second study investigates $RQ_{AvatarType}$ and $RQ_{EnvironmentType}$ and was approved by the institution's responsible ethics committee.

4.1 Design

In analogy to Study 1, Study 2 followed a 2×2 mixed-design with two independent variables: *avatar type* and *environment type*. As a between-factor, we manipulated the avatar type ($RQ_{AvatarType}$) to avoid carry-over effects that have been observed in existing research on the proteus effect [68]. We chose an injured-looking avatar inspired by the use case of VR rehabilitation and compared it with an athletic, healthy-looking avatar similar to the presented works that already tried to leverage the *proteus effect* for physical exercise [28].

As a within-factor, we changed the type of virtual environment ($RQ_{EnvironmentType}$). In analogy with the avatar type, we chose one relaxing, pleasant beach environment in congruence with the healthy avatar; and one more stressful, unpleasant hospital environment in congruence with the injured-looking avatar. Participants exercised once in each environment. Fig. 5 shows the IVs of Study 2.

4.2 Apparatus and Material

Study 2 used the apparatus, materials, and procedure of Study 1 (see Sect. 3.2), with differences only in the manipulation of the IVs.

4.2.1 Independent Variable Manipulation

The healthy avatar type wore typical sports clothes with dark blue shorts, a bright blue t-shirt, and black sports shoes. In contrast, the clothes of the injured avatar were pale to simulate typical plain hospital clothes. The injured avatar also had a bandage on their left knee. Bandages are common in a therapy context but are also used in other exercise situations. However, the bandage most often indicates a physiological problem in both situations. In addition to the bandage, the injured avatar's skin tone was lighter to simulate less perfused skin, which can be a consequence of surgery [41].

We created two very distinct environments to create very different atmospheres. On the virtual beach, there were palm trees, bushes, stones, and the sea. Wang et al. [62] report that natural environments potentially relieve stress, especially when they include water. Wave and bird sounds as acoustic stimuli enhanced the immersion. The hospital room featured typical equipment such as beds, medicines, and cabinets. Instead of a wooden sign, a monitor displayed the knee angle and the number of repetitions. Typical sounds reinforced the hospital atmosphere, e.g., murmuring or door noises. The environment was inspired by a realistic situation of newly operated patients. After surgery, patients stay in the hospital for a few days and already begin rehabilitation.

4.3 Participants

For Study 2, we recruited $N = 78$ participants. We excluded $n = 2$ participants due to technical problems and $n = 2$ because their visual impairment was corrected insufficiently. The remaining $N = 74$ participants were on average $M = 20.96$ ($SD = 1.60$) years old. 62.16 % were female, 37.84 % were male. Half of the participants embodied the healthy avatar; the other half embodied the injured one. 51.4 % of the healthy avatar group and 73 % of the injured avatar group were female, with the remaining percentage being male. We found no significant association between the condition and the participants' activity level, $\chi^2(2) = 3.26$, $p = .230$, as well as their prior VR experience, $\chi^2(4) = 4.18$, $p = .401$. In both groups, more than 50 % did 0 to 3 hours of sports per week, and about 70 % had 5 hours of prior VR experience at a maximum.

4.4 Results Study 2

We can assume homogeneity of variances for all variables according to the Levene tests we performed. However, we found some violations of the normality assumption. Therefore, in analogy to Study 1, we performed robust mixed ANOVAs in R. All reported means (M) and standard deviations (SD) are trimmed values.

4.4.1 Dependent Variables

Fig. 6 shows all significant results of Study 2. The avatar type significantly impacted the temporal demand, $Q_A(1, 37.38) = 4.80$, $p = .035$, $\eta_p^2 = .004$. Participants rated it higher with the injured avatar ($M = 11.09$, $SD = 5.47$) compared to the healthy avatar ($M = 6.85$, $SD = 3.22$). We found no significant effect of the avatar type on the other task load subscales. The environment type did not significantly impact the task load. However, all task load subscales but the mental demand showed lower scores for the beach than for the hospital. There were no interaction effects.

The avatar type had no significant main effect on the energetic and tense activation. The energetic activation was also similar in both environments. However, we found a significant main effect of the environment type on the tense activation, $Q_B(1, 43.71) = 4.99$, $p = .031$, $\eta_p^2 = .002$. Tense activation was lower on the beach ($M = 16.59$, $SD = 1.80$) compared to the hospital environment ($M = 17.41$, $SD = 2.05$). All interactions were non-significant.

The avatar type had no significant main effect on the subjective feeling of presence and neither had the environment type. However, we found a significant interaction between the avatar type and the environment type, $Q_AB(1, 40.85) = 4.80$, $p = .034$, $\eta_p^2 = .002$. At the beach, participants felt more present when embodying the injured avatar ($M = 5.34$, $SD = 0.34$) compared to the healthy avatar ($M = 5.17$, $SD = 0.26$), while in the hospital the difference was smaller between the healthy avatar ($M = 5.25$, $SD = 0.2$) and the injured avatar ($M = 5.22$, $SD = 0.37$).

We found no significant effects regarding the sense of embodiment and motivation. There was, however, a tendency for an interaction effect ($p = .089$). On the beach, the healthy avatar ($M = 4.30$, $SD = 0.29$) led to more motivation than the injured one ($M = 4.19$, $SD = 0.35$), whereas the motivation was similar in the hospital for the healthy avatar ($M = 4.23$, $SD = 0.36$) and the injured avatar ($M = 4.20$, $SD = 0.32$).

4.4.2 Control Variables

We found no significant effects regarding the control variables.

Figure 6: Significant effects of Study 2. Error bars display standard deviations. $^* < .05$

4.5 Discussion Study 2

The avatar type (healthy vs. injured) influenced the temporal demand during the exercise ($RQ_{AvatarType}$). The injured avatar increased perceived temporal demand compared to the healthy avatar. The temporal demand subscale of the NASA TLX measures the perceived time pressure. The experimental procedure did not impose any external time pressure. All participants had to perform the same number of repetitions without any time limit, and we found no significant difference in exercise duration between conditions. Based on the proteus effect [66, 67], there are several explanations for the impact on temporal demand: Firstly, the injured avatar potentially caused a feeling of being limited by the injury, which made the execution more cumbersome and thus produced more time pressure. Secondly, the healthy avatar gave participants a healthy and athletic feeling, making them feel more up to the task and less time-pressured. Lastly, a combination of both explanations is possible. Interestingly, the higher perceived time pressure did not result in a significant difference in exercise duration. It may be that – again following the proteus effect – participants with the injured avatar would have been slower, but the time pressure made them move just as fast as participants with the healthy avatar. In general, the difference between avatar types regarding perceived time pressure is in line with prior work on the proteus effect that found positive influences of athletic avatars in VR exercise systems [28]. However, since the avatar type alone only affected temporal demand in our study, we assume that our manipulation has not yet utilized the proteus effect to its full potential.

The different environment types influenced the participants' activation ($RQ_{EnvironmentType}$). We chose two very different environments (stressful, negative hospital vs. relaxing, positive beach) to investigate the impact of the environment type on the users during the exercises. While participants were similarly present in both environments and felt similarly energetic, they felt less tense on the beach. First, this is in line with research showing that the environment type influences user perception [24, 46] and generally confirms our manipulation. Secondly, it emphasizes that carefully choosing the environment for a specific use case is crucial. Some use cases may already cause stress and negative emotions, like rehabilitation after an injury. Here, a relaxing beach environment might be beneficial, while in other use cases, e.g., exposure therapy, the goal may be to induce stress deliberately. However, our results did not reveal any other effects of the environment type alone. In our experiment, the environment was not directly linked to the content of the exercise. This was a conscious decision to keep the exercises constant across conditions. Nevertheless, we could already detect an influence of the environment type. The influence of the environment might become more substantial if users interact with objects that are contextually embedded in the environment. For example, when users move a coconut instead of a neutral ball on the beach.

We found a significant interaction between the avatar type and the environment type on presence. Surprisingly, the injured avatar created the highest feeling of presence on the beach, while presence was similar for both types in the hospital. That means that the less congruent avatar-environment combination increased the participants' presence. It is possible that participants did not associate the bandage with an injury-related limitation as much as anticipated and therefore did not perceive the injured avatar as incongruent with the beach. However, Latoschik et al. [32] found a similar effect of an incongruent virtual avatar crowd with varying avatar types (human and artificial). Here, the incongruence increased the perceived possibility to interact. These findings are also in line with Brübach et al. [7] who found that breaks in plausibility do not necessarily disturb the feeling of presence. Based on the model of Latoschik and Wienrich [33], they assume that we are much more capable of accepting incongruence at the cognitive layer than at the sensory or perceptual layer. However, we did not only find no break but an increase. One possible explanation would be that the incongruent combination increased attention and interest due to unexpectedness. Attention is a key component in some definitions of presence [53]. Lastly, we found a non-significant tendency for an interaction on motivation. The more congruent combination of the healthy avatar with the beach environment tended to increase motivation, while ratings were similar for both avatars in the hospital. This follows a more expected direction, in which the combination of positive characteristics increases motivation. The significant interaction on presence favoring the incongruent combination (injured on beach), and the interaction tendency regarding motivation favoring a congruent combination (healthy on beach) further emphasize the importance of design choices, not only in isolation but also in combination.

5 Implications

Regarding **avatar fidelity**, our results are in favor of the full-body avatar for our VR exercise system. Firstly, the increased feeling of agency is in line with prior works [52] and promising for observational learning [61,63] in which neurophysiological mechanisms are stimulated by observing one's or others' movements. Secondly, the increased feeling of change of the own body implies that full-body avatars might be more suitable when aiming at the proteus effect in an exercise context [48,66,67]. Finally, the full-body avatar reduced the mental demand. This is promising since high mental demand can lead to incorrect exercise execution and frustration [70].

We found no strong arguments for or against the use of a **virtual mirror** in our VR exercise system. This is surprising and contradictory to the assumption that virtual mirrors foster the sense of embodiment [22] and generally aid in exercise execution.

Regarding the **avatar type**, the injured avatar increased the perceived time pressure compared to the healthy one. Perceived time pressure can lead to incorrect exercise execution [56]. However, it may also motivate users as long as it is kept within reason.

In our study, the relaxing, pleasant **environment type** contributed to the well-being of users. This can become especially beneficial in situations involving vulnerable groups. For example, patients who have undergone orthopedic surgery are often confronted with negative feelings that potentially reduce motivation to exercise [8].

Surprisingly, the incongruent combination of the injured avatar on the beach increased presence. This finding adds to existing work investigating (avatar) plausibility in virtual environments [33,40,54]. Further, it emphasizes the importance of the investigation of design choices not only in isolation but also in combination.

6 Limitations and Future Work

Except for the effect on change, effect sizes and differences between means were small for all significant results. We suspect that our manipulation was too subtle. Gamification potentially distracts participants from their bodies, leading their focus more on the exercise.

Our choice of avatar type was very specific. The injured avatar might elicit more user-to-avatar congruence in injured users. Since our sample was healthy, potentially higher congruence with the healthy avatar is a possible confounding factor. However, the body ownership scores do not suggest large differences between avatar types. Overall, avatar personalization potentially intensifies emotional reactions [60] bearing additional potential for future work that should investigate user-avatar congruence as well as other (in)congruent avatar-environment combinations in more detail to better understand its influence on intermediate factors.

More women than men participated in both of our studies. Additionally, the distribution across conditions was unequal. Robust t-tests revealed that men felt a stronger agency with the partial body and no mirror than women did. In the partial body condition with a mirror, women felt more tense activation than men. With the healthy-looking avatar at the beach, men felt more physical demand than women. While gender differences were not the focus of this work, future research should look at this more closely to determine if certain design choices cause different reactions in different genders.

Lastly, for use cases such as VR rehabilitation, it is crucial to consider whether user group characteristics have an additional impact on our results. For example, users of VR rehabilitation applications might have either physical limitations due to an orthopedic condition, mental limitations due to neurological conditions, or both. For the healthy participants in our sample, the exercises we chose were on the simple side regarding task load. Injured persons might perceive the task load as higher, and activation levels and motivation might initially differ, possibly allowing for more significant effects.

7 Conclusion

In two user studies, we explored the influence of prominent design choices on intermediate factors in a VR exercise system. Specifically, we investigated the influence of different levels of avatar fidelity (abstract, partial vs. anthropomorphic, full-body), the availability of a mirror (with vs. without), the avatar type (healthy vs. injured), and the environment type (beach vs. hospital) on the sense of embodiment, presence, motivation, activation, and task load. For this purpose, we developed iLAST, an immersive VR application targeting physical exercises for the lower body. We found that a full-body avatar significantly increased agency and change factors and significantly decreased mental demand compared to a partial representation which confirms prior work on embodied VR experiences. Surprisingly, a virtual mirror's existence did not significantly impact the dependent variables. In line with the proteus effect, an injured-looking avatar significantly increased perceived temporal demand compared to a healthy one. Tense activation was significantly lower when exercising in a beach environment compared to a hospital environment. Additionally, participants felt more present at the beach when embodying the injured avatar, i.e., in an incongruent avatar-environment condition. Our results are a first step in the direction of design guidelines that will help to make informed design decisions in the future. This is essential to realize the full potential of VR systems for achieving general human-centered design goals or application-specific goals, e.g., in the context of efficacy studies. Future work should explore more of these design decisions in various other use cases to ultimately clarify how individual design decisions affect important intermediate factors in embodied VR experiences.

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