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Injured Avatars: The Impact of Embodied Anatomies and Virtual Injuries on Well-being and Performance

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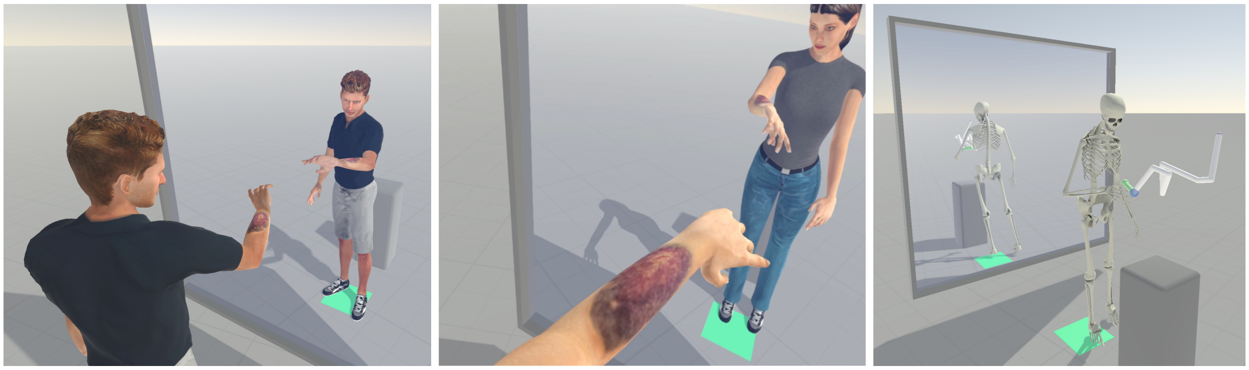

Fig. 1: To assess the impact of anatomical and injured avatars on well-being and performance, participants experienced four different avatars in a plain Virtual Reality environment. The left panel shows an injured human avatar. The middle panel illustrates how a participant experienced the avatar. After this embodiment induction, participants completed a line-following task located opposite the mirror to sample motor performance. The right panel shows a healthy skeleton avatar performing this task.

Abstract—Human cognition relies on embodiment as a fundamental mechanism. Virtual avatars allow users to experience the adaptation, control, and perceptual illusion of alternative bodies. Although virtual bodies have medical applications in motor rehabilitation and therapeutic interventions, their potential for learning anatomy and medical communication remains underexplored. For learners and patients, anatomy, procedures, and medical imaging can be abstract and difficult to grasp. Experiencing anatomies, injuries, and treatments virtually through one's own body could be a valuable tool for fostering understanding. This work investigates the impact of avatars displaying anatomy and injuries suitable for such medical simulations. We ran a user study utilizing a skeleton avatar and virtual injuries, comparing to a healthy human avatar as a baseline. We evaluate the influence on embodiment, well-being, and presence with self-report questionnaires, as well as motor performance via an arm movement task. Our results show that while both anatomical representation and injuries increase feelings of eeriness, there are no negative effects on embodiment, well-being, presence, or motor performance. These findings suggest that virtual representations of anatomy and injuries are suitable for medical visualizations targeting learning or communication without significantly affecting users' mental state or physical control within the simulation.

Index Terms—Virtual reality, Avatars, Virtual embodiment, Healthcare.

1 Introduction

Virtual reality (VR) allows for convincing illusions of embodying virtual avatars, virtual characters that are controlled by human movements [2]. Head-mounted display (HMD) driven experiences create the illusion of being in another place [56] and experiencing it through another body [54]. The flexibility of VR allows avatars to possess different properties from the physical bodies they replace. Users' acceptance and identification with their new avatar and its distinct characteristics enable research designs that were once challenging, if not impossible. Although the precise causes and interactions of the psychological effects in VR are still being investigated [64], embodiment and the associated mental and behavioral impacts have proven relevant across various domains, like learning empathy by inhabiting others' bodies [5]. Such studies have contributed to us gaining a deeper understanding of how the human brain and sense of self works [28], and many other medical use cases have emerged, like treating body dysmorphic disorder [62], anorexia [48], or pain relief [36]. Although VR can be a powerful tool for communicating medical contents to students and patients [46], not all medical applications have solid theoretical foundations or demonstrate superior results compared to traditional therapies [31]. Further utilizing embodied displays of anatomies, injuries, and potential treatments can make medical information discussions more comprehensible and therapies more impactful.

Previous research on embodiment explored how different avatars affect the user's experience, such as therapies that aim to improve a user's body condition or mindset [37]. Also, often the focus is on how a more abstract or simplified visualization influences the experience. Previous works have examined how avatars that have fewer fingers [60], translucent bodies [35], or detached hands [72] affect users' feeling of embodiment and immersion. Some works have investigated the impact of anatomically adjusted avatars or injuries [3]. However, there is a

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Fig. 2: Overview of the avatars used in our study. We use a healthy human (left) and skeleton avatar (center-left), for our *Avatar Type* condition. A human with a bruise (center-right), and a skeleton with a broken arm (right) are used for the *Injury* condition per *Avatar Type*. Depending on the users' handedness and gender, the avatar and injury location are adjusted.

gap in understanding one's response to seeing their body without skin or with injuries. Besides the effects on well-being, users of such a system could be affected by the Proteus effect [49], adapting their own behavior in a negative way to match the expected impacts of injuries or anatomical avatars.

Understanding the effects induced by avatars is important to investigate numerous potential benefits. Effective communication is crucial in communication with patients, as it affects patients' trust, care effectiveness and reduces anxiety [13]. While the challenges with medical communication are manifold due to the complexity, VR offers the opportunity to support and evolve it by providing immersive and interactive experiences. VR can assist both students and patients in comprehending abstract facts or technical terminology, for example through visual and more approachable explanations [41]. From the patient's perspective, VR could serve multiple functions. For instance, it could be used to illustrate a specific injury and proposed treatments, which could improve patient understanding and trust in the process, potentially leading to better health outcomes. In cases where an injury is not directly visible, providing a more profound understanding of what is happening and its implications might aid patient motivation and adherence to treatment plans. Further research into visualizing how the body is affected beneath the skin could help foster comprehension of the needs and limitations of those affected. Embodied learning could benefit medical education by providing interactive interfaces to explore anatomy and medical knowledge, fostering motivation and increasing learning efficiency. Similar works have already proven successful [6].

However, to utilize these benefits, we need to understand the risks they may pose. To minimize any negative impacts as much as possible, it's imperative to investigate using both mental and physical metrics to gauge effects. Leaving individuals feeling drained or overwhelmed after seeing anatomies and injuries could lead to demotivation and negatively affect outcomes. This is particularly important given that demographics such as patients and their family members are often already experiencing high levels of stress. High levels of eeriness in simulations have been linked to lower viewing duration and avoidance, possibly hampering comprehension [14]. Similarly, any adverse impact on motor controls would directly hinder exploration and possibly affect engagement. While medicine is the most directly relevant field for understanding how injured and anatomical avatars affect users, there are several other application areas, including gaming, where this understanding is vital. Therefore, it is crucial to expand our understanding of body illusions and their impact on users.

This work aims to provide insights on how a visually and interactively plausible, but potentially emotionally distressing and injured avatar influences the user. We investigate whether users can reach similar levels of embodiment with an anatomical avatar or injuries and evaluate their impact on well-being and motor function. To achieve this goal, we conduct a user study with 44 participants, comparing multiple avatars in a full body tracked setting. We utilize a skeletal model as an anatomical avatar (see Figs. 1 and 2), as used in medical training, and conditionally add an injury to the users' dominant hand's arm. These avatars are compared to nondescript human avatar used as a baseline. This experiment aids in bridging the knowledge gap regarding the use of realistically modified avatars, which could potentially evoke discomfort or unease. Gathering data on the impact of anatomical avatars and injuries on users' mental state and motor performance not only enhances our comprehension of our responses to various avatars but also paves the way for future applications, particularly in the realm of medical communication and education.

This study addresses two overarching research questions:

RQ1 How do anatomical avatars and virtual injuries affect participants' emotional state?

RQ2 How do anatomical avatars and virtual injuries affect participants' physical performance?

2 Related Work

Fully immersive VR using a HMD has gained significant popularity in psychological and medical applications, primarily due to its combination of flexibility, ease of use, and comparatively low cost. However, the efficacy of these applications depends on many factors and remains somewhat inconclusive at this time, as mixed results are common [16, 31, 36]. As our understanding of the factors at play increases and the inherent advantages become more apparent, we can expect beneficial applications to be refined and new ones to emerge. This work aims to broaden our understanding of using avatars for medical learning and communication by building on the following theoretical foundations.

2.1 Presence and Embodiment

Presence is often described as the extent of the subjective feeling of being present in a virtual environment [56, 58]. It serves as a way to compare virtual environments independently of the task at hand [64], although the exact definition and influence of variables such as place, plausibility [66], and coherence [10, 65] remain debated. The importance of believable visual and motion fidelity, combined with internal consistency and coherence, is crucial for eliciting emotional responses [24].

Taking inspiration from the prototypical rubber hand experiment [7], VR elevates the sense of embodiment seen there [68]. Embodiment is commonly understood as the perception of an alternative representation as one's own body, which is then processed accordingly [28]. Several factors contribute to the emergence of embodiment, including avatar appearance, ego perspective [26], and visuomotor synchrony between the avatar and the user's real body [19]. In this work, we use a virtual mirror to make this synchrony more apparent and provide users with a better view of their avatar. We measure embodiment using the Virtual Embodiment Questionnaire (VEQ) [54], which assesses three factors: body ownership, agency, and change. The level of embodiment affects emotional response, which, in turn, impacts the effectiveness of the

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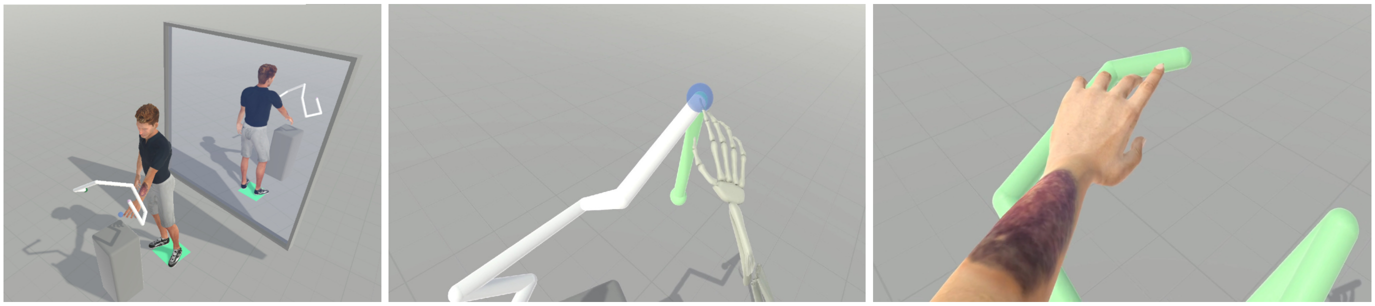

Fig. 3: Progress on the line-following task, displaying the status before (left), while (middle) and shortly after (right) tracing the line. Left is a third person perspective, middle and right panel show the task from a participants perspective, including visible injuries on the forearm. The blue sphere on the avatars dominant hand index finger indicates with which finger to follow the line.

application [20]. Therefore, it is crucial to maintain high visual [35, 60] and control fidelity [19], as they influence embodiment and ownership.

2.2 Avatars

The term "avatar" was adopted in the mid 1980s with HMDs-driven VR applications as key technology. It is described as a "perceptible digital representation, whose behaviors reflect those executed, typically in real time, by a specific human being" [2]. In case of VR simulations, this specific human being is the users wearing a HMD and controlling their virtual surrogates. However, a virtual experience can contain multiple avatars which are controlled by other (possibly remote) human users or algorithms (so-called "agents"). As explored in the previous section, the choice of the user's virtual avatar has a great impact on both of presence and embodiment. The shape and appearance, and the animation and behavioral fidelity of an avatar influences how we experience it inside a simulation. Furthermore, the level of control and fidelity we exert over the avatar has critical impact [12, 19]. Full body tracking with head, hands and feet was found to result in higher levels of embodiment and presence [17].

Besides effects caused by the embodiment itself, the Proteus effect might influence users' behavior [73]. It describes the phenomenon of people adapting their behavior and mindset towards the perceived characteristics of their virtual self-representation. The exact mechanisms that cause the effect are not fully clear, but a mixture of self-perception and schema activation seems likely [50, 51]. Some research might describe a similar or the same effect, without explicitly calling it Proteus effect [39]. Applications of the effect are manifold, including effects on physical performance [44, 45] and effects on mental well being [70]. In a meta-analysis, a small but relatively consistent effect was found [49]. The effect is more likely to be prominent with higher embodiment and self-identification [34], and people are more likely to adapt desirable characteristics [47]. Still, there have been indications of patients adapting their movement and hand usage behavior in response to having too little fingers on their virtual hand [29]. Feelings of uncanniness and eeriness can also be evoked by avatars. Known from research on humanoid robots with anthropomorphic characteristics, this phenomenon is also relevant for VR research. Eeriness can be caused by a multitude of stimuli, with face and voice distortion, morphing, realism, and motion manipulation being among the most influential factors [14]. Implications of eeriness include avoidance, lower viewing duration, and higher dislike frequency. However, the accuracy of some measurements is sometimes debatable [14].

In addition, there is research on effects caused by threats to the virtual avatar and body discontinuity. Users felt higher levels of ownership with connected than disconnected hands in static [42, 71] and dynamic situations [61]. However, threat response was similar independent of disconnection. Others found no impact on ownership in dynamic scenarios, but lower motor performance [9, 72]. Note that in these cases the disconnection is abstract (e.g. arm just cuts of or connected by thin thread), instead of presented as a result of injury. Furthermore, threat response studies were mainly concerned with the imminent response to a seen threat, not the effect of embodying an avatar with injury already present. An injured, static hand was found to cause increased pain sensitivity and feelings of unpleasantness compared to a baseline [40], indicating an effect on emotional and mental state. Other studies confirm a link between morphological changes and emotional response, with a moderating effect of sense of embodiment [38]. These works usually focus on pain response, without full body tracking and only show a hand, possibly resulting in overall lower levels of embodiment and resulting impact. One study found an injured avatar (not graphical, bandage vs. no bandage) to result in higher temporal demand compared to a healthy one [3], but no other changes.

2.3 Well-being

Vitality refers to the state of being strong, energetic, and full of life. The vitality scale is a questionnaire that captures the subjective feeling of vitality, suggesting that it reflects the well-being of the respondent [55]. It further captures negative influences, possibly exerted by "somatic factors such as physical symptoms and perceived body functioning." Additional studies have shown that higher vitality is associated with individuals feeling "more active, attentive, and productive; they are also better at maintaining effortful self-control and coping with stress" [4]. In another study, mild stress in VR did not lead to a reduction in the sense of agency and body ownership [69]. However, it is known that severe stress can generally lead to dissociative symptoms [57]. This demonstrates that different emotions and their intensity have varying, non-linear influences, including on embodiment and presence.

2.4 Educational and Clinical Usage

There are approaches that employ VR to train prospective doctors through interaction with virtual patients or by practicing decision making [22]. VR is also utilized in practitioner-patient communication, assisting in areas such as treatment visualization and patient information dissemination [1]. Using VR prior to surgery has been demonstrated to positively impact patients' objective knowledge without increasing anxiety [43]. Most of these implementations employ simple methods, such as mobile phone-based VR [41], and do not incorporate the virtual patient's body itself.

Augmented Reality "magic mirror" approaches enable users to experience anatomy on their own bodies, as their body is displayed on a screen [21, 33]. These approaches have demonstrated positive results in educational settings [6]. Features such as active exploration options and intuitive spatial understanding have been cited as helpful and could be preserved or even enhanced in VR scenarios. Generally, learning anatomy in VR is considered effective [15, 18], though users typically do not explore their own anatomy. Active engagement rather than passive observation has been shown to have a positive effect [25], and it is likely that additional benefits arise from implicit learning effects [67]. Therefore, exploring one's own anatomy in extension could facilitate better retention through tangibility.

VR has seen increased usage in clinical settings, both in physical [11] and mental healthcare [37].VR and embodiment have been proposed for empathy training, allowing users to take on the perspectives of others and experience sensations on their own bodies [5]. Similarly,

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there has been a call for more research into "embodied medicine" [53], applying VR, embodiment, and our improving understanding of related psychological effects to enhance healthcare. Utilizing virtual environments more and more, understanding how we react to different avatars and additional visualizations, such as injuries, will be critical moving forward.

2.5 Hypotheses

Based on the literature outlined above, we formulated four hypotheses to investigate the effects of medically relevant avatars in virtual environments. Insights derived from these hypotheses will help inform other projects when using such avatars. H1 through H3 relate to research question one, making more detailed assumptions about avatars' influences on mental state. H4 is a detailing of research question two, specifying physical impact. These hypotheses are discussed in detail in Sec. 5, where we also examine the influence of our interventions.

H1: The human avatar will elicit higher levels of virtual body ownership than the anatomical avatar. Since embodiment is directly linked to how much we identify with a given avatar, we hypothesize that a human avatar will result in higher levels of embodiment than a skeleton. Due to the limited literature on the effect of actual injuries compared to abstract changes, and considering our added injuries are rather mild, we make no predictions in this regard.

H2: Injuries will negatively affect participants' vitality. VR has been shown to effectively impact emotional states [52], with higher embodiment causing a greater effect [20]. We suspect that the presence of an injury may have a negative effect on well-being. Although the anatomical avatar may evoke an uneasy feeling, we generally do not expect it to impact well-being.

H3: Anatomical and injured avatars will cause higher levels of eeriness. Given the common association of skeletons with death and creepiness, we anticipate that using them as avatars will evoke higher levels of eeriness. Since uncanniness and eeriness can be triggered by threatening stimuli, distortions, disgust, and anomalies among other factors, we expect that the injury will also elicit high levels of eeriness.

H4: Injured avatars will negatively affect task performance. We assume that the Proteus effect may lead participants to move slower or more shakily in response to their injured avatar. Additionally, the injury itself could increase stress in participants, which can affect physiological responses [63].

3 Method

To test our hypotheses and investigate the research questions, we implemented a VR application in which the participants experienced different avatars and were asked to perform a 3D line-following task. The application allowed user embodiment with different avatar types and injuries.

3.1 Design

We used a counter-balanced 2 *(Avatar Type)* × 2 *(Injury)* within-subject (repeated measures) design for the experiment. Each factor had two levels. As shown in Fig. 2, *Avatar Type* was either a generic human or a skeleton anatomy. Depending on the gender and the handiness of the participants, each participant used a male or female avatar, each with and without a visible injury. The visual presentation of the *Injury* condition depended on the avatar. In the human avatar, the injury was shown as a severe bruise on the dominant forearm. In the skeleton avatar, the injury was shown as a fractured bone on the dominant forearm. As a dependent variable, we measured seven subjective scales and three objective measures.

3.2 Materials and Apparatus

3.2.1 Hardware and Implementation

The experiment was conducted using a VR-capable PC equipped with an Intel i9-10980XE processor, NVIDIA GeForce RTX 3090 GPU, and 128GB RAM. The experiment was developed in Unity 2021.3.15 with the OpenXR plugin 1.5.3. Participants used an HTC Vive Pro HMD with a 90 Hz refresh rate, 110 degrees horizontal field of view, and a resolution of 1440×1600 pixels per eye. The application ran at 90 Hz without frame drops. Participants wore three HTC Vive 3.0 Trackers attached to their pelvis and lower shins. The hands were tracked by Valve Index controllers, as depicted in Fig. 4. With these inputs, the avatar's position and pose were driven using the Final IK[1] package, version 2.2. By employing six tracking points, we aimed to provide high-fidelity motion tracking and full-body Inverse Kinematics (IK) without resorting to more invasive tracking suits or other complex setups

Fig. 4: Participants were wearing a HMD, Valve Index controllers, and three Vive Trackers, worn on the pelvis and each lower shin.

3.2.2 Avatars

For our study, we selected human and anatomical avatars, akin to the types users might engage within educational or medical scenarios. For the human avatars, we used rigged male and female characters created using Autodesk Character Generator[2]. For the anatomical representation, we chose a skeleton avatar, due to its visual distinctiveness from the human avatar, while still being easily identifiable as human, compared to for example a nervous system avatar. The base asset for the skeleton was sourced from the Unity asset store[3] and used for both male and female participants. The avatars where adapted and remodelled to include the bruise and fracture, respectively. Also, the avatars were adapted for both left and right handedness (i.e., displaying the injury on the dominant hand, see Fig. 2). All avatars were automatically calibrated and adjusted to match the users height. There were only one male and female representation, no further adjustments to fit the participants physical appearance were made.

3.2.3 Injuries

We opted to depict a bruised forearm for the human avatar and a fractured forearm bone for the skeleton, as illustrated in Fig. 2. These specific injury types were selected due to their moderate severity and ubiquity. We anticipated that such injuries, if experienced in reality, would affect arm mobility without inducing extreme repulsion in participants, given our lack of a baseline to gauge emotional responses. We

[1] http://root-motion.com/
[2] https://charactergenerator.autodesk.com/
[3] https://assetstore.unity.com/packages/3d/characters/creatures/rigged-skeleton-117134

derived the depiction of the bruise from photographs of the bruising commonly associated with broken arms. This choice ensured that both avatars demonstrated a comparable injury, reinforcing the experimental consistency. The injury location was chosen with considerations for both visibility and the potential impact on arm movements of users exploring an avatar and environment in VR. The positioning ensures that the injury is easily visible when looking at their own body within the virtual environment. Moreover, the forearm injury remains in at least the peripheral vision of participants while they undertake the line-following task, maintaining a constant reminder of the injury's presence.

3.2.4 Environment

We designed the surrounding environment as a low detail and plain virtual environment due to the unclear nature of a plausible setting for anatomical avatars and to minimize distractions. The environment is empty, except for a mirror, a pedestal on which the line-following task is displayed, and a green spot on the floor indicating where to stand. This type of environment was chosen to ensure that the user focuses on the avatar and to prevent biases caused by inconsistencies between the simulation and the avatar [30]. A third-person view of the virtual environment can be found in Fig. 1.

3.2.5 Line-Following Task

In addition to subjective measures obtained through questionnaires, we collected objective data using a physical task. This physical movement task aimed to help us understand how avatars can influence a user's control and ability to explore the virtual environment. Participants were asked to trace an angled line in 3D space with the tip of their index finger as quickly and accurately as possible. Upon displaying the path after the embodiment induction, a semi-transparent blue sphere appeared on the user's dominant hand's index fingertip, indicating how to follow the path. The paths were deterministically created based on a supplied seed value and followed a set of constraints to ensure comparability. Examples of this task can be seen in Fig. 1 and Fig. 3. All paths were of equal length (1.5m), did not include angles between segments smaller than 30 degrees, and had no intersections. Continuous data logging began when a participant touched the green-marked beginning of the line and ended when the rose-colored endpoint was reached. Progress along the path was visible, with traced segments turning green. We chose this task because it required quick and precise movements with the arm potentially showing the injury, and allowed for straightforward capture of speed as duration and precision as deviation from the displayed path. Moreover, the forearm remained in the subject's field of view during the task, ensuring visibility of the injury, if present.

3.3 Procedure

Participants initially received information about the experiment and provided written consent. They then responded to demographic questions, as well as Self Assessment Manikin (SAM) and motion sickness questionnaires. Subsequently, participants were equipped with the HTC Vive trackers, controllers, and the HMD, receiving assistance in adjusting them as needed. A brief acclimatization period, lasting no more than two minutes, was provided in the SteamVR home application, allowing participants to further fine-tune the headset for their comfort.

During the experiment, the participants went through four cycles of VR exposure, measurement, and relaxation, each corresponding to a different combination of independent variables. For each *Avatar Type* condition, the two *Injury* conditions were presented consecutively; for example, if the first round featured the injured skeleton avatar, the second round would include the healthy skeleton avatar. This structure resulted in eight potential sequences in which participants could encounter the four condition combinations. Participants were assigned to one of these eight sequences in a counterbalanced manner. Upon completing the fourth VR exposure and measurement round, the relaxation video was omitted as the experiment neared its conclusion. The entire experimental process took approximately one hour. A diagram illustrating the procedure can be found in Fig. 5.

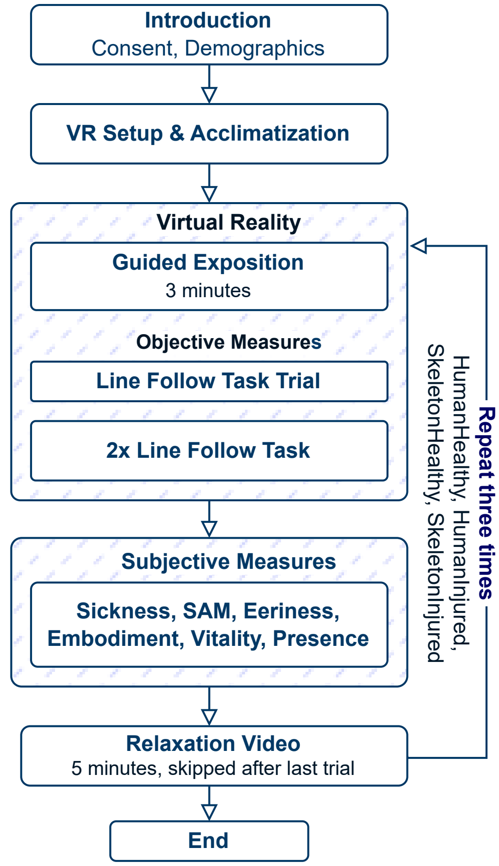

Fig. 5: User Study Procedure Diagram: The procedure begins with a welcoming phase, followed by participants completing initial questionnaires. They then experience four blocks of VR exposure, with subjective measures taken after each block. To facilitate relaxation between VR tasks, a nature video is played after the first three VR blocks.

In each condition, participants listened to three minutes of prerecorded audio instructions via the HMD's speakers. The instructions specified movements involving both hands and arms, as well as slight movement towards and away from the mirror. Additionally, the instructions prompted participants to examine their virtual body, particularly their hands and arms, ensuring they noticed the presence or absence of injuries. The instructions incorporated short pauses to allow participants to follow the instructions and experience their avatar. Following the embodiment induction phase and avatar exposure, participants were instructed to complete the line-following performance task (see Sec. 3.2.5). The task was presented behind the participants, opposite the mirror from the starting point (see Fig. 1). Participants traced a line using a blue-colored, semi-transparent sphere displayed on the tip of their dominant hand's index finger. Line creation adhered to a set of constraints to ensure comparability. The starting point of the line was marked in green, while the finish point was marked in rose. Each participant began with a warm-up round, followed by two logged rounds.See Fig. 3 for an overview.

After each VR exposure, participants completed digital questionnaires on a computer to assess subjective measures. Before starting the next trial, the participants watched a relaxation video on the same computer for five minutes. The video featured calm nature footage. After the video, the SAM scale was reassessed to measure the relaxation effect. Concluding the experiment, participants were asked for written qualitative feedback and were debriefed.

3.4 Participants

We recruited 44 participants from university courses and mailing lists, social media, and personal connections. Two participants had to be

	M_H	SE_H	M_S	SE_S	F	p	η_p^2
SAM							
Arousal§	2.56	.198	2.36	.190	.328	.570	.008
Valence§	7.05	.231	6.96	.245	3.06	.088	.070
Eeriness†	3.39	.157	4.40	.148	**27.79**	**<.001**	**.404**
VEQ							
Acceptance†	4.43	.204	4.48	.200	.450	.833	.001
Control†	5.65	.129	5.93	.104	**7.92**	**.007**	**.162**
Change†	3.44	.197	3.38	.236	.100	.754	.002
Vitality†	4.83	.146	4.97	.135	3.36	.074	.002
Presence							
Being There‡	1.21	.147	1.51	1.65	**4.23**	**.046**	**.094**
Realness‡	-.78	.142	-.74	.143	.153	.697	.004

Note. Scale widths as follows: $\S = 1-9$, $\dagger = 1-7$, $\ddagger = -3-3$
Note. Avatar types: H = Human, S = Skeleton

Table 1: Main effects of Avatar Type.

	M_H	SE_H	M_I	SE_I	F	p	η_p^2
SAM							
Arousal§	7.08	.235	6.92	.232	1.50	.227	.035
Valence§	2.42	.182	2.50	.207	.470	.497	.011
Eeriness†	3.64	.134	4.16	.129	**21.25**	**<.001**	**.341**
VEQ							
Acceptance†	4.46	.180	4.44	.178	.021	.887	.001
Control†	5.80	.109	5.80	.111	.002	.966	<.001
Change†	3.44	.207	3.38	.193	.390	.536	.009
Vitality†	4.91	.144	4.90	1.42	.006	.938	<.001
Presence							
Being There‡	1.42	.138	1.31	1.55	1.15	.291	.027
Realness‡	-.71	.138	-.80	.134	1.48	.231	.035

Note. Scale widths as follows: $\S = 1-9$, $\dagger = 1-7$, $\ddagger = -3-3$
Note. Avatar types: H = Healthy, I = Injured

Table 2: Main effects of Injury.

excluded (one dropped headset, one had technical issues) from the data. 24 (57%) were male, and 18 female. Participants were aged between 18 and 34, with a mean age of $M = 25.45$ ($SD = 3.17$). 27 preferred German as main language of the study, while 15 chose English, and 28 participants self-reported as "European" ethnicity, the rest as "other." 23 reported "Student" as main occupation, another 11 "PhD student," the remaining eight participants had varying occupations. Most participants had no previous experience with VR (29), another four tried it at some point in the past, while the remaining nine reported at least one hour of VR usage a week. Four (9.5%) were left-handed, no one had motor-impairments. None of the participants had any injuries on their arm, like the avatars in the experiment. In return for the participation, two 25 Euro gift vouchers were randomly awarded among the participants.

3.5 Measures

3.5.1 Subjective Measures

We assessed the impact of the independent variables (*Avatar Type* and *Injury*) on the dependent variables (well-being and motor performance) using seven scales or subscales. These are listed in the order they were presented in the experiment after VR exposure.

Fast Motion Sickness Scale (FMS) To examine motion sickness, we use the single question Fast Motion Sickness Scale (FMS) [27]. The scale ranged from 1, representing no discomfort, to 100, representing strong discomfort.

Self-Assessment Manikin (SAM) We used the arousal and valence subscales before and after each VR exposure to visually assess the self-reported affective experience [8]. Arousal represents the perceived degree of physiological activation by the participant. Valence indicates the degree of joy or discomfort experienced during the exposure.

Eeriness Eeriness was assessed using the subscale with the same name from the refined Uncanny Valley Effect scale [23]. This subscale consists of two parts, "eerie" and "spine-tingling," of which both were used.

Virtual Embodiment (VEQ) To determine the effect on embodiment, all three subscales "Acceptance," "Control," and "Change" of the VEQ [54] were used.

Vitality (SVS-G) We measured current subjective vitality using the five state-level items of the German adaption of the Subjective Vitality Scale, and their corresponding English variants [4].

Presence (IPQ) To measure the perceived presence in virtual reality, we used the G1 question *"In the computer generated world I had a sense of 'being there'"* and realness subscale of the igroup presence questionnaire (IPQ) [59].

3.5.2 Objective Measures

To evaluate the impact on physical performance, participants were required to complete one warm-up and two measured trials of a line-following task, as shown in Fig. 3 and Fig. 1. The task started when the green-marked starting point of the line was touched with the participant's dominant hand index finger and concluded when the final, pink-marked segment of the line was touched. For each trial, we recorded the completion time, mean squared distance to the nearest point on the line, and the standard deviation of the distance to the line.

4 Results

4.1 Analysis Strategy

The analyses were performed using SPSS Statistics 29. We evaluated our independent variables *Avatar Type* and *Injury* with regard to subjective measures main effects using two-way repeated measures ANOVAs with significance level set to 0.05. A two-way repeated-measures MANOVA was used to evaluate the objective measures. We evaluated all objective measures together in one procedure, as they belong to the same construct of impact on physical hand performance. Since there were only two levels per factor, we did not test for sphericity.

4.2 Subjective Measures

For eeriness, there was a statistically significant interaction between *Avatar Type* and *Injury*, $F(1,41) = 6.86$, $p = .012$, $\eta_p^2 = .143$. Analysis of the studentized residuals showed that there was normality, as assessed by the Shapiro-Wilk test of normality, and no outliers, as assessed by no studentized residuals greater than ± 3 standard deviations. Simple main effects reveal that with the human avatar type, eeriness was statistically significantly different in the non-injured trial ($M = 3.04$, $SD = 1.19$) compared to the injured trial ($M = 3.75, SD = 1.01$), $F(1,41) = 27.24$, $p =< .001$, $\eta_p^2 = .399$. With the skeleton avatar, eeriness was also statistically significantly different in the non-injured trial ($M = 4.24$, $SD = 1.03$) compared to the injured trial ($M = 4.57$, $SD = 1.08$), $F(1,41) = 6.08$, $p =< .001$, $\eta_p^2 = .129$. Comparing injuries, eeriness significantly differs between human compared to skeleton for a non-injured avatar, $F(1,41) = 30.93$, $p =< .001$, $\eta_p^2 = .430$. For injured avatars, eeriness also significantly differs between human compared to skeleton avatar, $F(1,41) = 17.85$, $p =< .001$, $\eta_p^2 = .303$. For reliability analysis, Cronbach's alpha was calculated to assess the internal consistency of the Eeriness subscale of the uncanny valley questionnaire, consisting of 9 questions. The scale had a high level of internal consistency in each condition, as determined by a Cronbach's alpha of $HumanHealthy = 0.869$, $HumanInjured = 0.921$, $SkeletonHealthy = 0.883$, $SkeletonInjured = 0.890$.

Additionally, we analyzed the Eeriness scale for only the subsets of participants that self-identified as European and Non-European. With

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only the European subset ($n = 28$), there is no interaction effect, but the main effect of *Avatar Type* ($F(1,27) = 46.82$, $p =< .001$, $\eta_p^2 = .634$) and *Injury* ($F(1,27) = 25.87$, $p =< .001$, $\eta_p^2 = .489$) show a significant statistical difference in eeriness. Analyzing the non-European group ($n = 14$) shows no statistically significant interaction or main effects. However, descriptive data such as means and standard deviations can be found in Fig. 6.

Means, standard errors, and main effects of all other subjective measures are listed in Tab. 1 for *Avatar Type* and in Tab. 2 for *Injury*. For *Avatar Type*, besides eeriness, there is a significant difference between *Control* and *Presence "being there"*, both higher for the Skeleton condition. Analyzing *Injury* does not reveal any other significances.

We applied a Pearson's product-moment correlations between some of our dependent variables to better understand their relationships. Since not all variables were normally distributed as assessed by Shapiro-Wilk's test ($p > .05$), we ran additional Spearman correlations, confirming our results.

There was no statistically significant correlation between eeriness and virtual body ownership (VEQ Acceptance subscale) for all conditions. Human Healthy $r(40) = .11, p = .476$; Human Injured $r(40) = .22, p = .155$; Skeleton Healthy $r(42) = -.11, p = .504$; Skeleton Injured $r(40) = .-.14, p = .368$. Overall, eeriness thus explained 2% of the variation in virtual body ownership, as assessed by averaged squared correlation coefficients. We further ran correlations for four conditions between virtual body ownership and the objective measures (duration, mean error, standard deviation). We found no statistically significant correlations between the respective values in every condition. Lastly, we analyzed correlations between virtual body ownership and vitality. There were no statistically significant correlations for the Human Injured, $r(40) = .30, p = .052$, Skeleton Healthy, $r(40) = .09, p = .575$, and Skeleton Injured, $r(40) = .26, p = .093$, conditions. There was a statistically significant, strong correlation between virtual body ownership and vitality in the Human Healthy condition combination, $r(40) = .60, p =< .001$, with virtual body ownership explaining 36% of the variation in vitality.

SAM arousal and Valence were also evaluated with a three way ANOVA, comparing pre and post exposure measurements for each condition. Valence did not show any statistically significant differences between pre and post measurements for *Avatar Type* and *Injury*. There was a significant main effect between measurements of Arousal before ($M = 7.81$, $SE = .198$) and after exposure ($M = 7.00$, $SE = .223$), $F(1,41) = 36.28$, $p =< .001$, $\eta_p^2 = .469$. There were no main or interaction effect of either *Avatar Type* and *Injury*.

In addition to condition based analysis, motion sickness was analysed over time using a one-way ANOVA. Sickness was asked for as a single question based on [27], with answers ranging between 0 (no sickness) to 100 (very high sickness). Sickness was measured after the demographics questionnaire, and after each VR exposure, resulting in 5 measurements. The scores varied slightly over time, from start ($M = 6.93$, $SD = 13.19$) over first ($M = 8.98$, $SD = 11.02$), second ($M = 8.38$, $SD = 11.91$) and third ($M = 8.93$, $SD = 12.20$) to fourth ($M = 8.31$, $SD = 10.88$) VR exposure measurement. Differences between these measurement points were not statistically significant, $F(2.49,46.13) = 1.23$, $p = .301$, $\eta_p^2 = .029$ (including a Greenhouse-Geisser correction). As there were two outliers that started with somewhat higher sickness scores, the same procedure was run with these participants removed. This test also did not reveal significant differences.

4.3 Objective Measures

The objective measures collected during the line-follow task were analyzed based on a two-way repeated measures MANOVA. The two independent variables were *Avatar Type* and *Injury*, the three dependent variables duration, mean error, and standard deviation. There were two trials we classified as outliers, since the participants did not touch the end point of the line follow task to end the recording, causing inflated measures. These two trials were removed from analysis. We found no multivariate outliers in the data, as assessed by Mahalanobis distance. There was no evidence of multicollinearity, as assessed by Pearson correlation ($|r| < 0.9$). There was no statistically significant interaction effect between *Avatar Type* and *Injury*, $F(3,37) = .759, p = .524, Wilks'\Lambda = .942, \eta_p^2 = .058$. There also was no statistically significant main effect of *Avatar Type*, $F(3,37) = .087, p = .967, Wilks'\Lambda = .993, \eta_p^2 = .007$, or *Injury*, $F(3,37) = .912, p = .445, Wilks'\Lambda = .931, \eta_p^2 = .069$, on the dependent variables.

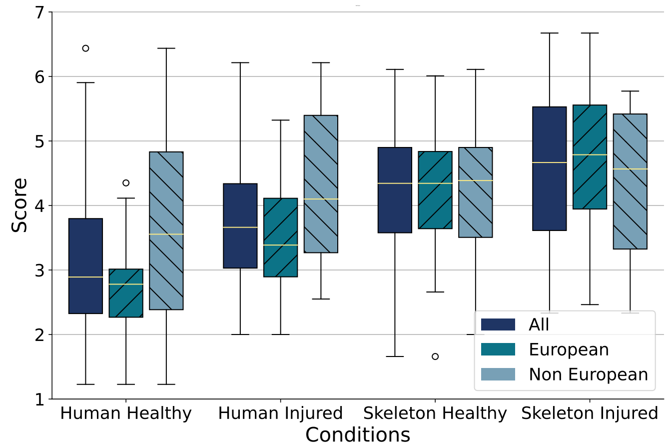

Fig. 6: Eeriness scores for all study participants, participants that identify as European participants and participants that do not. Eeriness is significantly higher with both the skeleton avatar type and the injury present for all participants and the European subgroup. No significant differences were found in the non-European subgroup.

We also analyzed the game duration results with a one-way repeated measures MANOVA with point in time as the independent variable. This is to analyze the learning effect over the trials as the experiment went on, independent of virtual avatar order. The results indicate a significant statistical main effect of time on the dependent variables, $F(9,31) = 6.17, p =< .001, Wilks'\Lambda = .358, \eta_p^2 = .642$. Follow up univariate tests revealed a statistically significant effect of time on duration ($M_0 = 7.02, SD_0 = 3.59$; $M_1 = 6.00, SD_1 = 3.12$; $M_2 = 5.70, SD_2 = 2.76$; $M_3 = 5.27, SD_3 = 2.54$), $F(1.57,61.17) = 16.27, p =< .001, \eta_p^2 = .294$. There was no statistically significant effect on mean error, $F(2.15,83.65) = 1.34, p = .267, \eta_p^2 = .033$, or standard deviation, $F(2.70,105.41) = 1.76, p = .165, \eta_p^2 = .043$.

4.4 Qualitative Comments

At the end of the experiment, participants were given the opportunity to provide general, negative, and positive feedback, which has been categorized here for clarity. Several comments noted that experiencing a virtual injury produced an interesting, somewhat uncomfortable bodily sensation that was independent of the avatar. Positive feedback mainly praised the experience of embodying a skeleton and the IK system, which allowed for smooth, intuitive full-body movement, even for novices. Conversely, negative feedback centered on minor tracking and IK inaccuracies, such as inaccurate inferred elbow rotation, incorrect foot grounding, and slightly offset hand angles. Some participants also expressed a desire for finger tracking, which was not included, or a more entertaining relaxation phase.

5 Discussion

In this section, we discuss how our research questions and hypotheses align with the results presented in the previous chapter. We subsequently elaborate other relevant findings and the results' applicability to medical communication.

5.1 Research Questions

Our research questions were to investigate the effects of anatomical avatars and virtual injuries on well-being and physical performance. Despite an increase in eeriness, we did not observe any negative effects

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of anatomical avatars and injuries on measures such as embodiment, vitality, SAM, or presence. This suggests a minimal impact on users' emotional states and well-being, indicating that eeriness can be present without further impairing the user. As eeriness has been linked with shorter viewing duration and disliking content, efforts should be made to minimize this effect, although complete avoidance may not be feasible due to its association with threats like injuries. Some significant differences exist in embodiment and presence subscales; however, these can be attributed to other factors such as avatar IK fidelity. Moreover, no effect was found on physical performance. Overall, these findings have positive implications for usability in applications, suggesting that avatars with potentially unsettling medical conditions can be used without adversely affecting users' mental states or engagement. These findings hold particular relevance for medical education and communication, where graphic representations of illnesses and anatomies are common. In addition to medical applications, our findings could extend to non-medical fields where developers might consider incorporating injuries into avatars to enhance detail and realism. For instance, in gaming, maintaining low impact on motor fidelity is crucial, or in training scenarios, where high user attention is required. We believe our results can provide valuable insights for these scenarios, contributing to more informed design decisions.

5.2 Hypotheses

H1: Our first hypothesis was that we would find higher levels of virtual body ownership with the human than the anatomical avatar. However, the results did not support this hypothesis. There was no significant effect of *Avatar Type* on the Acceptance subscale of the VEQ, which measures virtual body ownership. We had expected that the human avatar type would elicit higher levels of body ownership, as it more closely matches the user than the skeleton. A possible explanation for this finding is that the skeleton is still somewhat human-like, as all human bodies include a skeleton as part of their anatomy. Another possible factor is that both avatar types were not adjusted to match the user's physical appearance, and we had a diverse participant group. The skeleton might have matched everyone comparably well.

We also did not find any significant effect of *Avatar Type* on the Change subscale of the VEQ, which measures how much the user perceives changes in their virtual body. This is surprising, as both avatar types visibly changed quite a bit during the experiment. However, this result might be explained by looking at the four questions that make up this subscale. Out of these four questions, two ask about width and height of the avatar, which did not change in our experiment, as we adjusted all avatars to match the user's proportions.

Interestingly, we found a significant effect of *Avatar Type* on the Control subscale of the VEQ, which measures how much control the user feels over their virtual body. The skeleton avatar scored higher on this subscale than the human avatar. This could be due to participants being more sensitive to minor inaccuracies in angles and movement caused by tracking and inverse kinematics when embodying a human avatar. For a skeleton avatar, these inaccuracies might have been less noticeable due to lower familiarity with its appearance and movement.

Finally, we did not find any effect of *Injury* on any of the VEQ subscales. This means that seeing injuries on their virtual body did not affect participants' sense of ownership, change or control over it. This indicates the feasibility of using embodiment as a tool to aid explorability, interaction and personalization in medical use cases.

H2: Contrary to our expectation, we did not find any evidence to support our second hypothesis that injuries would negatively affect the participants' vitality. We assumed that seeing injuries on the virtual body would have a negative influence on the participants' mental state. Previous works have shown that injuries can cause psychological distress and lower vitality. Moreover, the skeleton itself is often associated with death or illness in popular culture and media. However, it is possible that the injury case was similar to the first hypothesis, where people did not fully embody the effect of mild injuries on their virtual body. Therefore, they did not experience any negative consequences on their well-being either. The absence of significant differences in SAM valence ratings across different avatars supports the vitality measures.

The absence of negative effects suggests that there were no adverse impacts on the participants' mental well-being. This is an important finding for both medical communication and learning. It indicates that using virtual bodies to represent anatomy and health issues does not increase stress or anxiety levels. Investigating whether there are no adverse influences when users actually have the injuries depicted on the avatar would be an important direction for future research to enable patient communication. Avatars could empower patients to better understand their condition and make informed decisions about their treatment options. For medical learning, it means that using virtual bodies to teach students about anatomy and injuries would not impair their attention or motivation.

H3: Our third hypothesis was confirmed by the results, revealing that both the anatomical skeleton and the presence of an injury significantly increased participants' perception of eeriness. This suggests that participants were not only aware of but also sensitive to the changes in the virtual body, particularly when injuries were visible. Eeriness was linked to users' reduced liking of the content and shorter viewing duration, among other factors [14]. Consequently, it would be beneficial to minimize eeriness. While it may be challenging to avoid eeriness entirely, as it can be caused by abnormal, distorted, or threatening humanoids, certain measures can be taken. Improving tracking and IK fidelity should help address motion distortions, which can cause increased eeriness. Moreover, personalized or more fitting avatars can result in lower eeriness, as indicated by the influence of participants' self-identified ethnicity on their perception of eeriness in addition to our manipulation of independent variables.

H4: Reviewing our fourth hypothesis, *Injured avatars will negatively affect task performance*, we found that our results do not support it. We hypothesized that the presence of an injury in the avatar would have a negative impact on the user's motor performance, based on the Proteus effect. We expected that users would be influenced by the injured avatar and behave more cautiously (slower) or less accurately in the tracing task. However, our results did not support this hypothesis and showed no significant difference in motor performance between injured and non-injured avatars. This finding supports the usability of injured avatars, as there is no indication than physical motion and accuracy are lowered while exploring the virtual setting.

There are multiple possible explanations for this finding. One explanation is that an injury is less of a cue that influences people attributed behaviors or perception, and more of a physical handicap that limits their abilities. As people are more likely to pick up desirable traits [47], there was some hurdle to adoption. Another factor might have been that the perceived permanence of the injury might have moderated the Proteus effect. Users might have assumed that the injury was temporary and did not affect their long-term identity or capabilities. Therefore, they might have ignored or dismissed it as irrelevant for their performance. A third explanation is that users might have been motivated by the game-like nature of the task and tried to be as fast and accurate as possible regardless of their avatar condition. The task instructions emphasized speed and accuracy as the main criteria for success, which could have overridden any potential influence of the avatar appearance. A different task design or instruction could reveal influences of the smaller effects size of the Proteus effect. A task that requires following a line without specifying speed or accuracy, or a proxy task that induces hand movements without being explicitly related to them could surface possibly results.

5.3 Applicability to Medical Communication

Evaluating these findings in their applicability to medical communication, we can see some indication that anatomical avatars are suitable for usage in VR scenarios involving individuals without medical training, without causing mental and physical drawbacks. Applicability to other avatars suitable for medical visualization, for example involving muscular or nervous systems, seems plausible. The same is true at least for mild injuries, however we can't extrapolate our results to other, more drastic injuries. Participants not identifying as European did rate our baseline human avatars more eerie than their European peers. We assume that this effect is due to the mismatch in appearance, and was independent of the effect of injury. An application aiming to utilize human avatars could further individualize the avatars to the user. There was, however, no significant relationship between eeriness and virtual body ownership. In turn, there was no significant effect of body ownership on motor performance. Since the strength of the Proteus effect is associated with body ownership levels, this finding suggests that participants were not negatively influenced, regardless of the avatar fit. Further supporting this assumption is the absence of a negative correlation between embodiment and subjective vitality. Furthermore, we can see in the SAM Arousal results, that a five minutes relaxation video phase reliably brought participants back to baseline arousal levels. This is in line with previous works, confirming the efficacy of nature based videos as a calming measure.

6 Limitations

Our study utilized mild injuries that may not accurately represent the experiences of avatars with more severe conditions. Further, users with real physical injuries, unlike our healthy participant group, could react differently to seeing their injuries on an avatar. Although it is unlikely that individuals with extreme injuries would participate in pre-operative educational sessions, such interventions might be employed in therapy, trauma reprocessing, or learning situations. Still, individuals who have previously experienced the type of injuries depicted on their avatar may react differently upon seeing these injuries reflected on their virtual selves, as compared to users who have never personally encountered such medical conditions. Our results demonstrated a significant effect of injury presence on perceived eeriness; more severe injuries could potentially have a stronger impact. For example, an amputation or a graphic, bloody injury might evoke a more intense response from participants, possibly leading to adverse effects on well-being and performance. While a bruise may not be a significant concern for most individuals, a severe injury causing intense pain, or an illness with potential long-term consequences, could be perceived differently. Nonetheless, the current study used relatively benign injuries and visualizations to establish a baseline. Further, some works analyzing adapted avatars see increased phantom pain in participants. This measure was deemed out of scope for this work, but could be explored deeper in line with different injuries.

The present study only included generic avatars, with varying resemblance to the user. While a diverse participant group is essential to generate more valid results, lower levels of identification could have influenced the results. Nonetheless, there was no statistically significant negative correlation between virtual body ownership as a proxy for identification with the avatar, and vitality as well as motor performance. This leads to the assumption, that our results should be valid for varying levels of identification with the avatar. Others have also found that in a more traditional third person game, self-similarity did not impact avatar injury response [32]. Basing the avatars virtual appearance on the user and the inclusion of real injuries in these very similar looking avatars could potentially enhance communication and empathy between healthcare providers and patients. However, it is unclear how such personalization would affect the impact on users mental state or physical performance.

Lastly, the skeleton avatar type used in the current study may be overloaded with pop culture connotations, influencing the perceived eeriness. The frequent usage of skeletons in media as something scary could have contributed to the participants' responses. Future studies could consider alternative avatars, like ones showing the muscular system, to further explore the relationship between anatomical avatars and perception.

7 Conclusion

Overall, the potential applications of anatomical and injured avatars in medical communication and education are promising. To our knowledge, this is the first study to examine the effects of anatomical avatars with virtual injuries on embodiment, presence, mental well-being and motor performance. The participants reported similar levels of embodiment and presence compared to a normal human avatar as baseline. Importantly, the use of injured avatars did not negatively impact participants' mental well-being or motor performance. This suggests that both anatomical and injured avatars have the potential to be used in medical communication and learning settings without adverse mental or physical effects, and warrant further investigation.

Future work could explore the impact of more severe injuries on avatar perception and their usability in medical communication and learning. These findings could pave the way for the development of immersive and explorable learning environments for students to better understand medical concepts. Moreover, the potential of this technology to aid patients in understanding their illnesses and upcoming procedures should be explored by testing with real patients. Conducting tests with patients who have experienced, or are currently dealing with, conditions similar to those portrayed on the avatar, could provide deeper insights into how these virtual representations influence behavior. The use of avatars that accurately depict a patient's injury or condition could enhance patient understanding and communication with healthcare providers, especially with further personalization and in the context of patient care.

Figure Credits

All images are original works of the authors.

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