frontiers | Frontiers in Virtual Reality

TYPE Original Research
PUBLISHED 25 March 2024
DOI 10.3389/frvir.2024.1251564

OPEN ACCESS

EDITED BY
Ali Arya,
Carleton University, Canada

REVIEWED BY
Adam Drogemuller,
University of South Australia, Australia
Michel Guerraz,
Université Savoie Mont Blanc, France

*CORRESPONDENCE
Christopher You,
✉ christopheryou@ufl.edu

RECEIVED 01 July 2023
ACCEPTED 21 February 2024
PUBLISHED 25 March 2024

CITATION
You C, Peck T, Stuart J, Gomes de Siqueira A and Lok B (2024), What my bias meant for my embodiment: an investigation on virtual embodiment in desktop-based virtual reality. *Front. Virtual Real.* 5:1251564.
doi: 10.3389/frvir.2024.1251564

What my bias meant for my embodiment: an investigation on virtual embodiment in desktop-based virtual reality

Christopher You[1]*, Tabitha Peck[2], Jacob Stuart[3], Alexandre Gomes de Siqueira[3] and Benjamin Lok[1]

[1]Virtual Experiences Research Group, Department of Computer and Information Science and Engineering, University of Florida, Gainesville, FL, United States, [2]Davidson Research in Virtual Environments Lab, Davidson College, Mathematics and Computer Science Department, Davidson, NC, United States, [3]University of Florida, Gainesville, FL, United States

The immersion of virtual reality (VR) can impact user perceptions in numerous forms, even racial bias and embodied experiences. These effects are often limited to head-mounted displays (HMDs) and other immersive technologies that may not be inclusive to the general population. This paper investigates racial bias and embodiment on a less immersive but more accessible medium: desktop VR. A population of participants (n = 158) participated in a desktop simulation where they embodied a virtual avatar and interacted with virtual humans to determine if desktop embodiment is induced and if there is a resulting effect on racial bias. Our results indicate that desktop embodiment can be induced at low levels, as measured by an embodiment questionnaire. Furthermore, one's implicit bias may actually influence embodiment, and the experience and perceptions of a desktop VR simulation can be improved through embodied avatars. We discuss these findings and their implications in the context of stereotype activation and existing literature in embodiment.

KEYWORDS

embodiment, desktop virtual reality, bias, avatar, virtual reality, stereotype

1 Introduction

Racial bias and discrimination continue to manifest themselves within society, impacting people in their communities and neighborhoods (Correll et al., 2007; Stewart et al., 2009), workplaces (Ziegert and Hanges, 2005), and even schools (Capers IV et al., 2017). For instance, implicit racial bias has been found to impair the degree of healthcare received by minorities (Hoffman et al., 2016). Physicians have been found to perceive the pain of Black patients as less severe than the pain of White patients (Staton et al., 2007; Mathur et al., 2014). In turn, Black patients often receive less pain medication in comparison to White patients with the same condition or pain (Cleeland et al., 1997; Anderson et al., 2009; Hoffman et al., 2016). This implicit bias is actively perceived by Black patients, causing them to feel less confident in recommended treatments (Penner et al., 2016).

Confronting this racial bias directly would be ideal; however, approaching people regarding their racial bias can generate adverse effects (Devine et al., 1991; Czopp and Monteith, 2003). Instead, some suggest that subtle approaches to address racial bias can be more effective (Dovidio and Gaertner, 1986). Rather than being explicit with the takeaway message, less direct, embedded exposures to race and positive themes may generate more impact on one's racial prejudices (Kaufman et al., 2016). Video games and serious games have been leveraged for this purpose in recent literature as they afford a level of immersion that allows for identification with characters to shift self-perceptions (Hefner et al., 2007). In particular, the immersive nature of virtual reality (VR) has been demonstrated to mitigate implicit bias of outgroups (Peck et al., 2013; Banakou et al., 2018; Chowdhury and Quarles, 2021), improve perceptions of self-image (Davis and Chansiri, 2019), and even improve cognitive performance (Banakou et al., 2018). Concurrently, VR also maintains itself as an entertaining form of media and enhances user experiences within the virtual environment (Monteiro et al., 2018; Shu et al., 2019).

These effects are typically afforded through the embodiment of a virtual avatar via a head-mounted display (HMD). However, in using immersive HMD-based technologies, delivering the described experiences can become challenging when considering scale, cost, and accessibility. Spanlang et al. (2014) described a non-commodity standard embodiment rig consisting of an HMD, numerous retro-reflective markers, haptic feedback devices, audio devices, and additional equipment to gather metrics. One may employ less restricting, alternative solutions such as inverse kinematics (Parger et al., 2018) with handheld controllers and an HMD (Lougiakis et al., 2020). Yet, HMDs alone still face their own set of complications: a general lack of availability in comparison to laptops, computers, or phones, discomfort, simulator sickness (Kolasinski, 1995), and even the inability to safely share and distribute HMDs due to sanitary concerns, as experienced during COVID-19 (Estrada and Prasolova-Førland, 2021). Although embodiment in VR can impact one's own implicit biases and perceptions and provide immersive experiences, there is a need to investigate embodiment on more accessible and available media in order to reach a larger population. To the best of our knowledge, little work has explored embodiment in non-HMD contexts, and even fewer have done so in the realm of bias reduction.

The aim of this work is two-fold: (1) to investigate the usage of a more accessible and inclusive platform to facilitate embodiment and (2) to build upon the ongoing investigation of VR as a medium to impact racial bias. We address the following research questions (RQs) on a desktop virtual environment (desktop-based VR):

- **RQ1.** Can embodiment be induced on desktop-based VR as measured via a standard embodiment questionnaire?
- **RQ2.** Can desktop embodiment be used to reduce racial bias as measured via an implicit association test?

To investigate these questions, we created an embodiment simulation allowing users to embody one of the four avatars in their desktop virtual environment. We conducted a remote between-subjects user study that had 158 participants interact with a virtual environment by a proxy of their avatar and measured the resulting level of embodiment and implicit racial bias.

Our findings suggest that embodiment can be induced and measured on desktop-based VR via traditional embodiment questionnaires. This embodiment does not appear to impact racial bias as seen in previous studies, but one's implicit racial bias may play a significant role in their level of embodiment in Black and White avatars. Additionally, greater embodiment elicits favorable responses toward in-game aspects of the simulation, improving user perceptions of the virtual experience. The present research contributes toward the development of impactful VR and Human-Computer Interaction applications that can be employed with greater inclusivity. We demonstrate that it is possible for one to leverage desktop virtual environments for immersive experiences while also reaffirming investigation toward the confrontation of complex social issues through serious games and inclusive platforms.

2 Related works

Previous work has studied the effects that avatars have on the user in their virtual environments and real-life attitudes. These effects can be heightened when an avatar is embodied by the user in a sense of agency, self-location, and ownership over the avatar. Embodiment is largely unexplored on desktop-based VR; thus, we discuss embodiment and avatar identity in the context of desktop-based VR, drawing parallels to existing literature.

2.1 Avatars and identities

Avatars are graphical representations of the user in a virtual environment (Fox and Ahn, 2013). Avatars are used in virtual environments to facilitate interaction and provide identity to users in their virtual environment (Taylor, 1999). Most commonly, avatars are used in video games or virtual worlds (Smith, 2006), building engagement and eliciting a sense of being within the virtual environment. Additionally, avatars allow users to "become someone else," giving users the ability to take on different identities (Taylor, 2002; Yee, 2006). When users identify with the avatar that they embody, attitude and perceptional change can occur (Yee, 2006; Yee et al., 2009). Yee and Bailenson (2007) and Yee et al. (2009) described this as the *Proteus* effect, as people tend to take on the persona of the avatar that they identify as. The authors found that users display more extraverted or confident behaviors in their virtual environment when adopting the identity of an attractive avatar. Other studies have found respective changes in attitudes when users adopt the identity of a child (Banakou et al., 2013; Tajadura-Jiménez et al., 2017). Users embodying a child overestimated the size of objects in their virtual environment. Similarly, embodying and identifying with an avatar belonging to that of a genius lead to better performance in cognitive tasks (Banakou et al., 2018).

As in the case of previous work (Banakou et al., 2013; 2018; Peck et al., 2013; Tajadura-Jiménez et al., 2017), a strong level of identification with the avatar can occur even when the avatar is visually dissimilar to the user. In fact, many times users may opt for avatars that are visually dissimilar to themselves, such as in the case of Second Life, a game where users could adopt an alternative identity through avatars designed by themselves. This phenomenon, called wishful identification (Hoffner, 1996; Hoffner and Buchanan, 2005), causes users to wish to be a version of themselves that they currently are not. In video games, this phenomenon can be quite salient: players were found to create avatars that resemble who they wished to be, rather than who they actually were (Bessière et al., 2007). Thus, creating an identity with an avatar is not only feasible but almost desired as people have preconceived notions about how they wish to be represented. On a similar vein, Peck et al. (2013) found that when White participants embodied a Black avatar, they still felt that the avatars were the representative of themselves despite being visually dissimilar. In doing so, pro-White bias was decreased for those participants as they embodied a Black avatar (Groom et al., 2009; Peck et al., 2013). Hamilton-Giachritsis et al. (2018) described this resulting effect through the lens of perspective-taking. Participants were able to naturally "see things from a different perspective" in their virtual environment. Because of this, changes in their own implicit attitudes were evident in the real world, even lasting up to several weeks after the intervention (Banakou et al., 2016).

In sum, self-identification with an avatar is valuable primarily for two reasons in the scope of our work with desktop-based VR: (1) when users are provided an avatar, they can become immersed to a greater degree through the afforded interaction; (2) the adopted identity of their avatar can instigate the real-world social change.

2.2 Embodiment

The term embodiment has been used in numerous contexts due to its multidisciplinary nature. For instance, in robotics, embodiment refers to the way in which artificial intelligence possesses a physical form (Foster, 2007; Holz et al., 2009). In virtual agents, embodiment can refer to an embodied conversational agent, or a virtual agent that possesses a virtual form (Cassell et al., 1999). However, in terms of virtual avatars, embodiment refers to the self-possession of the virtual avatar. Embodiment is traditionally defined by three senses: self-location, agency, and ownership (Kilteni et al., 2012).

Previously, it was described that when a user identifies with an avatar that they embody, the resulting attitude changes within the user can become salient. Thus, according to Kilteni et al. (2012), to embody an avatar, at least one of the three senses must be present in a minimal intensity. When all three senses are maximized, a user is said to experience a full sense of embodiment over their avatar. However, the three senses of embodiment interact with each other in diverse ways, with varying levels of importance. For instance, previous literature has hinted toward the idea that self-location could be the most dominant sense of embodiment (Blanke and Metzinger, 2009; Lenggenhager et al., 2009). Conversely, ownership has been argued to be unnecessary in the contribution to embodiment (De Vignemont, 2011). Previous work is conflicting in terms of the relationships and correlations between the senses (Tsakiris et al., 2007; Yuan and Steed, 2010; Rosa et al., 2019). In short, Kilteni et al. (2012) concluded that the relationship between the senses is generally unknown in terms of whether improvements on one can inhibit another. Based on this, it appears that the present quantity of each sense and their importance can vary depending on the context. This would suggest that embodiment on a desktop environment can be produced even with minimal intensities of certain senses of embodiment.

2.2.1 Embodiment in HMD-based VR

Maximizing the sense of embodiment is achievable when using a well-optimized HMD-based VR system. Because one's physical body coincides with their sense of self-location (Lenggenhager et al., 2009), self-location can be simple to achieve in HMD-based VR as the avatar's virtual body is placed where the user's physical body would exist. Additionally, the sense of agency is afforded in these VR systems as controllers, and other tracking devices allow for greater control over the movement of the avatar. Finally, the sense of ownership is achieved when the virtual body is perceived as truly that of the user's (i.e., sensations experienced by the user occur within the virtual avatar's body (Kilteni et al., 2012). Ultimately then, these senses of embodiment can be induced both naturally and often with ease by utilizing current HMD-based VR techniques. Given that these technologies are often not necessarily available in everyday commodities, our work aims to observe how embodiment occurs within desktop-based VR.

2.2.2 Embodiment in desktop-based VR

There has been little work investigating embodiment in desktop-based VR (Yuan and Steed, 2010; Kokkinara et al., 2015; Tham et al., 2018). However, Ash (2016) measured embodiment on a monitor-based display (Xbox 360) with a four-question questionnaire and found that identification with the avatar was more salient with those who experienced greater levels of embodiment. However, bias change was not measured; instead, the use of stereotypes and aggression was observed. Beltran et al. (2021) measured a bias change in their desktop virtual environment, but the embodiment measured in their study was more akin to that of avatar self-identification, and the embodiment questionnaires used were not validated. To the best of our knowledge, Ash's and Beltran et al.'s works are of the few studies attempting to measure embodiment in any capacity without an HMD. Because the validated measurements of embodiment have been developed since (with consideration toward the senses of embodiment described previously), it is important to evaluate embodiment in its present through this work.

Similar work has also likened embodiment on desktop-based VR to presence, or more specifically, self-presence (Biocca, 1997; Lee, 2004). Presence refers to the sensation of being within another environment from where the physical body is (Slater and Usoh, 1993). According to Biocca (1997), self-presence is the sense of presence but in terms of self—the users' mental model of themselves within their virtual environment. Self-presence appears to be a close comparison to embodiment on desktop-based VR. In fact, Biocca adds that self-presence itself is essentially the sense of embodiment. Self-presence, according to Biocca, functions in two ways: (1) the real-world self feels present with the avatar (virtual) self and (2) the avatar can affect the perception of the real-world self (Biocca, 1997; Behm-Morawitz, 2013). These ideas bear striking resemblance to the ideas of embodiment and avatar identification presented previously. However, the understanding of self-presence and embodiment has been changed and refined over time. Rather than "equal" to embodiment, self-presence has been posed as only a higher-level perspective of the sense of ownership in embodiment (Kilteni et al., 2012; Ratan, 2013; Rosa et al., 2019). Thus, we reason that self-presence does not fully encapsulate the senses of embodiment in its entirety. Our work therefore aims to explore how the sense of embodiment, rather than self-presence, occurs in desktop-based VR.

2.3 Immersive experiences in desktop-based VR

Although the embodiment of an avatar and bias change have been largely unexplored on desktop-based VR, there has been similar work in terms of creating VR applications that can be reached by a greater population. For example, Olson et al. (2020) created Passage Home, a game that challenges users to think critically in the light of racial accusations. The game was designed for HMD-based VR but was ported over to a web browser-based system due to the COVID-19 pandemic, allowing users to access the platform remotely. Users embodied a virtual avatar, and it was found that ethnic identity and racial attitudes affected their perception of the in-game characters. Although this study did not measure embodiment, it worked toward creating empowering social experiences for a greater population. Jarrell et al. (2021) had participants play as a virtual character in a 2D virtual environment, where player identification was measured. The results demonstrated that bias toward racially diverse profiles was affected based on the assigned avatar. Flavián et al. (2021) observed embodiment on a smartphone, desktop, and HMD, demonstrating that embodiment could be observed in varying levels of degrees (high-HMD, medium-smartphone, and low-desktop) and that the level of embodiment scaled up with the technology (i.e., low to high). However, this embodiment slightly differs from our definition, in that it focused on technological embodiment which attempts to measure the extent that a mode of technology allows one to interact, perceive, and interpret their environment (Flavián et al., 2019). However, Flavian et al.‘s work maintains some similar properties to our definition of embodiment and immersion and attempts to bridge the gap in creating readily accessible modalities of interaction to varying populations. Additionally, other work advocates that the experiences afforded by VR should be not only accessible in terms of availability to a larger population but also accessible in terms of usability (e.g., disability-friendly design) (Wobbrock et al., 2018; Mott et al., 2019). The technologies needed to utilize these immersive experiences can be impeding in terms of cost, convenience, and even motor function.

3 Materials and methods

3.1 Overview

As numerous factors, such as the environment, context, avatar design, and interactions, are all conducive to creating identity and embodiment, we provide the rationale for our system design. In short, we created a virtual environment based on the Peck et al. (2013) embodiment study and measured the resulting embodiment and bias change after using the desktop-based VR system.

3.2 System context

As a key component of embodiment is also creating an identity with the virtual avatar, we provided additional context to the participant to provide motivation for existing within the virtual environment. At the time that this study was run, a university building was being constructed for students on campus. Thus, we utilized this opportunity and advertised this study as a “virtual tour” of the constructed building to be. This worked well as the nature of the study, measuring bias change, needed to be hidden from participants. To further facilitate the virtual tour, the layout of the virtual environment was that of a university building, containing a lobby, front desk, classrooms, study spaces, and a student lounge. Although other studies such as the work by Ash (2016) have explored more active environments, in order to use this study as a baseline for future desktop embodiment, we opted for a simpler environment. In doing so, we remain consistent with the fundamental work in embodiment with HMD-based VR created by Peck et al. (2013).

The simulation was created within Unity. In order to aid participants in creating an identity with their embodied avatar, the study made use of virtual humans, which are agents that aim to look and interact like real humans (Swartout et al., 2006). As an avatar refers to the participant’s virtual representation, virtual humans will refer to other characters inside the environment. Virtual humans served as guides that participants interacted with during their “virtual tour.” All virtual humans and avatars were created using AutodeskÂ® Character Generator. The appearances of both the avatars and virtual humans were designed in a university-appropriate attire (e.g., full-length pants and shirt). The designs of the avatars and virtual humans were pilot-tested to ensure the skin tones were identifiable. The virtual characters’ appearances were pilot-tested with a subset of the target population. If a character’s appearance, clothing choices, or animations seemed abnormal or distracting, they were removed or modified to not impact the study. For instance, a number of comments during pilot tests suggested that one of the avatar’s hairstyles did not fit their demographic and was thus adjusted. To ensure equal exposure to both skin tones, we created a black virtual human for each white virtual human within the virtual environment. White and black avatars and virtual humans were designed to look nearly identical to each other except in terms of skin tone, eye color, or minor appearance changes in Character Generator, and all skin tones were chosen from Character Generator defaults. Body shape and size were consistent throughout all characters of the same gender. Finally, hairstyles were chosen such that they could be used across each gender (Figure 1). The decisions in character appearance can be limiting; however, the design makes sense when considering that factors such as varying levels of avatar attractiveness can affect the perception of the avatar (Behrend et al., 2012).

3.3 System design

To better describe our design, we preface this section with the prior work completed by Peck et al. (2013). The experience described by Peck et al. consisted of two phases: an embodiment phase and an approach phase. The embodiment phase aimed to induce embodiment through visuotactile stimulation and virtual mirrors. The approach phase sought to expose participants to other virtual humans of light and dark skin tone. In all, 12 (six light and six dark) non-verbal virtual humans walked past the avatar in the virtual environment. Thus, our work consisted of exploration and approach phases. Because an embodiment phase through

FIGURE 1
White, Black, and Alien avatars with their male and female counterparts. The None condition is not displayed as no avatar was present.

visuotactile stimulation is not applicable to desktop embodiment, the exploration phases were added to allow users to freely explore their virtual environment, interact with virtual humans, and complete "virtual tour objectives." The approach phase remained similar; participants were affixed in front of a virtual mirror and were approached by 12 virtual humans that interacted with the participant by either walking past or talking to the participant.

Although gender and intersectionality effects are important to investigate, this study is an investigation on the racial bias component. Thus, to control such effects (Lopez et al., 2019), we matched the gender of the participant, avatar, and virtual humans. Two simulation versions existed: a simulation with a male-only avatar and virtual humans and a simulation with a female-only avatar and virtual humans. Participants who identified as men participated in the male-only simulation, and participants who identified as women participated in the female-only simulation. Participants who identified as non-binary or preferred to self-describe a non-binary gender were randomly assigned one of the conditions.

Since not all aspects of HMD-based embodiment can be ported to a remote desktop-based VR experience (e.g., visuotactile stimulation), we attempt to provide some extension to Peck et al.'s phases, making the simulation more applicable for desktop-based VR. These extensions included control over the character via a keyboard and mouse, interactable gestures such as looking at the avatar's wrist, interactions with the virtual humans, and interactions during the approach phase (Figure 2). Additionally, we added task-based gamifications to provide participants a more immersive experience (Zichermann and Cunningham, 2011) (Figure 2).

3.4 Experiment

We conducted a user study with the proposed system with undergraduates at the University of Florida. Participants completed a pre-survey which contained demographic questions and the Implicit Association Test (IAT) (Greenwald et al., 1998). They

10.3389/frvir.2024.1251564

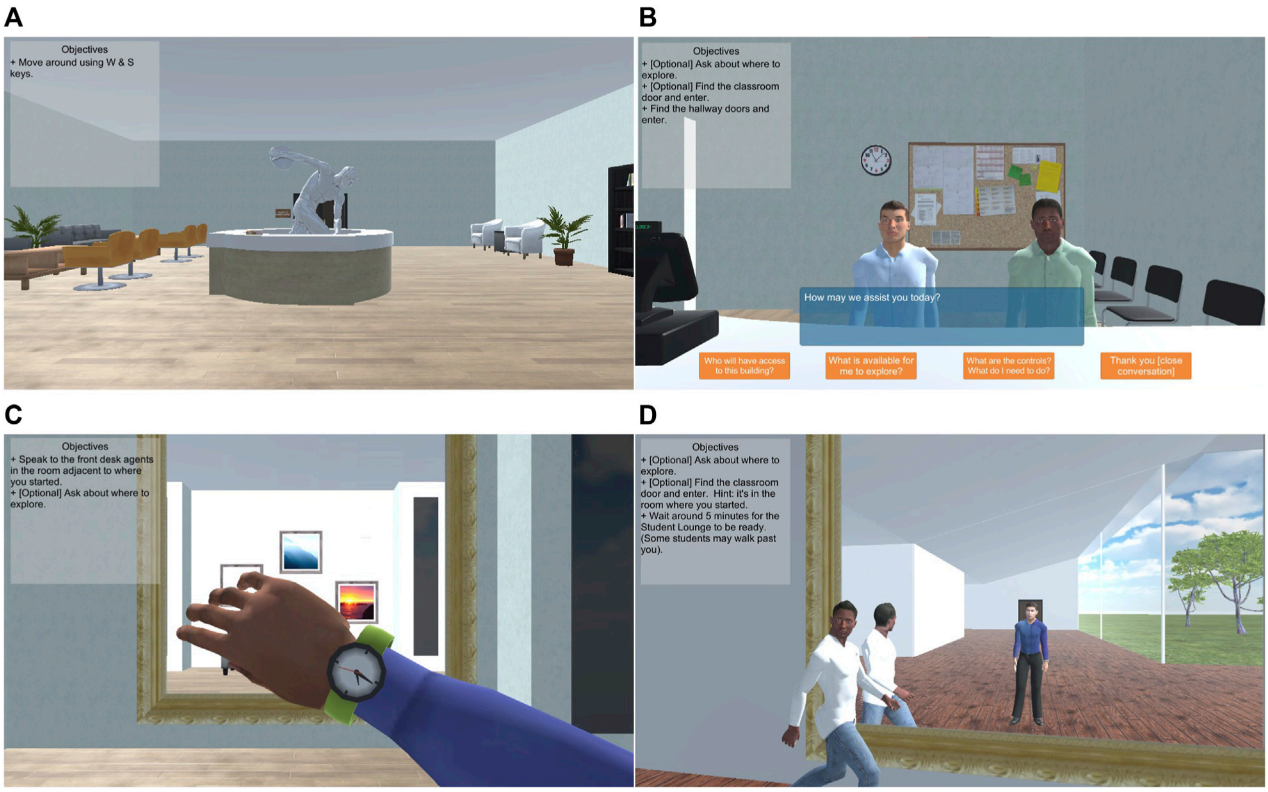

FIGURE 2
(A) Top left. Lobby where players started. **(B) Top right**. Players were able to interact with virtual humans. There were an equal number of white and black virtual humans in each phase and interaction. **(C) Bottom left**. Pictured is a participant interacting with their hand. We subtly introduce the avatar's skin tone in this interaction. **(D)**. **Bottom right**. Approach phase: Each virtual human turned their head to look directly at the participant as they walked past or stopped to interact.

were then invited to watch the tutorial video prior to participating in the simulation. The tutorial video portrayed a virtual assistant that explained the purpose of the simulation and basic controls. The nature of the study required deception, so the purpose of the simulation was framed as a virtual tour with objectives to complete. Participants then participated in the simulation. This experiment used a between-participant design with one independent variable, skin tone, with four levels (*White*, *Black*, *Alien*, and *None*). Participants were randomly assigned to one of these four conditions and embodied the assigned avatar in their virtual environment. Intersectional effects between race and gender pose an interesting research direction; however, since this work aims to isolate effects on racial biases, the gender of the avatar was matched to the participant's self-identified gender (except in the None condition, where no avatar was present). During the experiment, participants were directed to complete a set of objectives to complete the study. These objectives were displayed on the top left of their interface and directed participants to speak to the virtual humans, explore different areas of the tour, and interact with their avatar. To conclude the study, participants must follow the objective that led them to the *approach phase*, where 12 virtual humans interacted and walked by the participants' avatar before the participant was allowed to enter the final room of the tour. Immediately after the completion of the simulation, user logs were uploaded, and a second IAT was completed. A post-survey was deployed regarding embodiment and other questionnaires. Following the completion of the study, participants were awarded credit in their university courses.

The study was deployed remotely as motivated by our need for greater access and inclusivity. All participants completed the study on their own devices. Participants self-reported monitor display size. The average monitor display size was (M = 19.6″, SD = 7.40″), with the median and mode both being 15.6". To control for varying graphical capabilities of devices, all participants completed the simulation in the same quality settings (low) offered by Unity. Within the participants' virtual environment, data such as time in session, completed tasks, and player movement were recorded to validate study completion and unintended behaviors.

3.5 Participants

This study was reviewed and approved by the University of Florida Institutional Review Board (IRB). All participants provided their written informed consent to participate in this study. A total of 186 participants completed this IRB-approved study. Of the 186 participants, 18 were filtered out due to issues with the simulation's deployment for Mac users, causing these participants to complete parts of the study multiple times (n = 168). The issue was rectified shortly after launch, and the remaining participants on

TABLE 1 IAT's definition along with its uses as a pre-IAT and post-IAT in this experiment is described. Difference between the post- and pre-IAT measures the change in IAT scores concluding the experiment.

IAT	The racial implicit association test is a timed assessment on one's ability to match positive and negative words with black and white faces. The IAT score may quantify one's implicit bias
Pre-IAT	The pre-IAT is defined as one's IAT score measured before the experiment
Post-IAT	The post-IAT is defined as one's IAT score measured after the experiment

a Mac device reported no issues. The time to complete the experiment for 10 of the remaining participants was more than 1.5 times the inter-quartile range of time to complete the experiment so they were removed from analysis. Of the (n = 158) participants included in the analysis, age ranged from 18 to 47 years (M = 21.29 and SD = 4.73). Racial identity included 54% White, 3% Black, and the remaining 43% of participants identified as either Asian, Hispanic, or other/mixed races. In total, 30% of participants identified as women, 66% as men, and the remaining 4% as non-binary or self-described. Participants completing each condition include None, 37; Alien, 44; Black, 38; and White, 39.

3.6 Measures

The following measures were used to investigate our research questions and related variables:

Demographics questionnaire. Participants answered questions regarding their age, gender identity, and race. Participants also answered a single question to provide the size of their monitor in inches.

Racial bias measures. Participants were tasked with completing IAT immediately before and after the virtual simulation. The IAT attempts to measure implicit bias by requiring quick categorization of dark-skinned and light-skinned faces with positive and negative words (Greenwald et al., 1998). For this, a racial IAT was created in Qualtrics through iatgen using the skin tone racial bias figures from the Harvard IAT (Greenwald et al., 2003; Carpenter et al., 2019). The racial IAT captures bias on a scale of either pro-White or pro-Black bias. Although race extends beyond a binary simplification of White and Black, this IAT is utilized in this work due to the precedent of prior work (Peck et al., 2013; Lopez et al., 2019) and ability to act as a comparable baseline for future work in bias mitigation in desktop-based VR. Positive IAT scores indicate a favorable bias toward light-skinned individuals. Negative IAT scores indicate a favorable bias toward dark-skinned individuals in this arrangement. Pre- and post-IAT were calculated before and immediately after the experiment, respectively (Table 1). Explicit racial bias was also measured through the Modern Racism Scale (McConahay, 1986).

The avatar embodiment questionnaire. Participants completed the avatar embodiment questionnaire (AEQ) in the post-survey after the second IAT. Designed by Peck and Gonzalez-Franco (2021) for HMD-based VR, the AEQ consists of 16 scorable 7-point scale questions designed to measure embodiment. However, the final three questions were not applicable for our simulation and were not recorded, as directed by AEQ. AEQ was chosen as it is the most up-to-date measure of embodiment at the time of conducting this study and captures the traditional senses of self-location, agency, and ownership within its embodiment sub-measures: appearance, response, ownership, and multi-sensory.

Perceptions of virtual experience. During the post-survey, participants also answered questions regarding their perceptions of the virtual experience (Table 2). The role of these questions was two-fold: (1) to distract participants from the true nature of the study and (2) to examine user sentiments toward the virtual tour and features of the virtual experience.

4 Results

4.1 Questionnaire validation

Replicating Peck and Gonzalez-Franco (2021), the None condition was removed when considering embodiment since there was no self-avatar to embody. The four sub-measurements of embodiment each had acceptable or better reliability: appearance, $\alpha = .80$; response, $\alpha = .74$; ownership, $\alpha = .78$; except for multi-sensory, $\alpha = .62$ that had questionable reliability (Gliem and Gliem, 2003). All questions had above the recommended .3 corrected item-total correlation suggesting that questions need not be removed from any sub-measure (Field et al., 2012).

The experience questions had low-reliability, $\alpha = .57$; however, P2 and P5 questions had a corrected item-total correlation well below the recommended .3. Once removed, reliability was in an acceptable range, $\alpha = .69$.

4.2 IAT

No differences in pre-IAT scores were found between avatar conditions, $F(3, 154) = .06$, $p = .98$, $\eta^2 = .001$. A change in pre- and post-IAT scores was evaluated with a 4 (avatar condition: White, Black, Alien, and None) × 2 (IAT: pre and post) ANOVA with condition as a between-participant variable and IAT as a within-participant variable. A significant IAT main effect was found, $F(1, 154) = 4.45$, $p = .037$, $\eta^2 = .008$. All participants showed a smaller pro-White bias in the post-IAT ($M = .49$, $SE = .03$) compared to the pre-IAT ($M = .56$, $SE = .03$). No other significant main effects or interactions were found.

4.3 Avatar embodiment

The effects of the avatar condition on each embodiment sub-measure were evaluated using multiple regressions. Hierarchical models were built for each embodiment sub-measure by adding avatar condition and pre-IAT scores. The None condition was removed from embodiment questionnaire analysis since measuring embodiment without an avatar is irrelevant. *Post hoc* analysis was performed with a comparison of simple slopes at *mean* ± σ defined as low (.13), medium (.56), and high (.98) values of pre-IAT scores.

The ownership and multi-sensory sub-measures did not produce significant models and are not discussed in detail below.

TABLE 2 Questions used to gauge the perceptions of virtual tour and experience. Although they served to distract participants, the results of these questions were analyzed within the multiple regression model (Figure 5).

ID	Perceptions of virtual experience—individual questions
P1	The virtual tour of the building helped me get a general picture of the future student spaces
P2	The virtual humans (the other avatars) were informative
P3	I became nervous when the virtual humans approached me
P4	I am looking forward to using the future building
P5	I wanted to say hello to the virtual humans as they walked past
P6	I believe virtual human guided tours are a good feature for future virtual tours

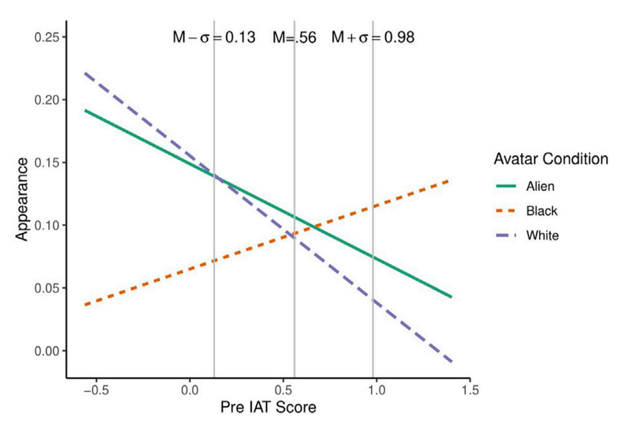

FIGURE 3
Line graph of appearance by pre-IAT scores for each avatar condition (Alien: solid green, Black: short-dash orange, and White: long-dash purple). Vertical lines indicate the pre-IAT score *mean* ± *σ*.

TABLE 3 Multiple regression models for the appearance embodiment measure with β (*standard error*).

	Model 1	Model 2
Intercept	0.10 (0.01)***	0.12 (0.02)***
Alien	−0.01 (0.02)	0.00 (0.03)
Black	0.00 (0.02)	0.07 (0.03)*
Pre-IAT	—	−0.05 (0.02)*
Alien: pre-IAT	—	−0.03 (0.04)
Black: pre-IAT	—	−0.12 (0.04)**
R^2	0.01	0.11
Adj. R^2	−0.01	0.07
Num. obs	121	121

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

TABLE 4 Multiple regression model for the response with β (*standard error*).

	Model 1	Model 2
Intercept	0.07 (0.01)***	0.08 (0.01)***
Alien	0.01 (0.02)	0.02 (0.02)
Black	−0.01 (0.02)	0.05 (0.02)*
Pre-IAT	—	−0.02 (0.02)
Alien: pre-IAT	—	−0.01 (0.04)
Black: pre-IAT	—	−0.11 (0.03)**
R^2	0.01	0.09
Adj. R^2	−0.01	0.05
Num. obs	121	121

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

4.3.1 Appearance

Adding pre-IAT significantly improved model fit, over avatar condition alone, F (3, 115) = 4.52, p = .005. The model steps, including the final model (F (5, 115) = 2.85, p = .02, R^2 = .11), can be seen in Table 3.

The significant main effects of Black and pre-IAT were found. These are quantified by the significant higher-order Black × pre-IAT interaction, t (115) = −3.00, p = .003, r = .27 (Figure 3). *Post hoc* analysis was performed comparing the White and Black conditions. Significant differences were found between the White and Black conditions at both the low pre-IAT scores, t (115) = 1.98, p = .05, r = .18, and the high pre-IAT score, t (115) = −2.15, p = .03, r = .20. With low pre-IAT scores, participants in the Black condition had significantly lower appearance scores (M = .07, SE = .024) compared to those in the White condition (M = .14, SE = .025). However, at high pre-IAT scores, participants in the Black condition had significantly higher appearance scores (M = .11, SE = .025) compared to those in the White condition (M = .04, SE = .024).

4.3.2 Response

Similar to the appearance sub-measure, adding pre-IAT to the response model significantly improved model fit, over avatar condition alone, F (3, 115) = 3.64, p = .01. The model steps, including the final model (F (5, 115) = 2.37, p = .04, R^2 = .09), can be seen in Table 4.

The significant main effects of Black were found. This was quantified by the significant higher-order Black × pre-IAT interaction, t (115) = −3.15, p = .002, r = .28 (Figure 4). *Post hoc* analysis was performed between the White and Black conditions. Significant differences were found between the White and Black conditions at the low pre-IAT scores, t (115)2.03, p = .04, r = .19, but not at the high pre-IAT scores, t (115) = −1.91, p = .06, r = .18. With low pre-IAT scores, participants in the Black condition had significantly lower response scores (M = .04, SE = .02) compared to those in the White condition (M = .10, SE = .02).

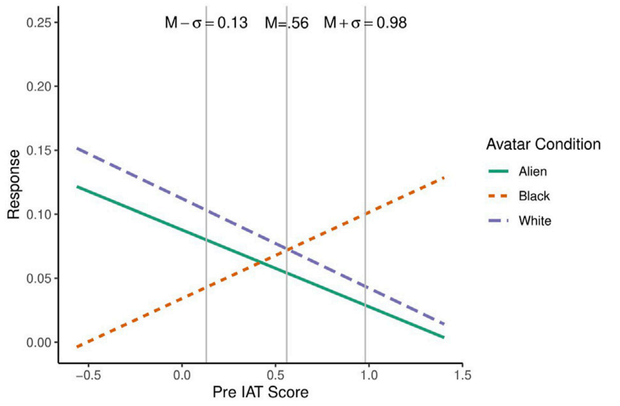

FIGURE 4
Line graph of response by pre-IAT scores for each avatar condition (Alien: solid green, Black: short-dash orange, and White: long-dash purple). Vertical lines indicate the pre-IAT score *mean* ± *σ*.

4.4 Perceptions of virtual experience

The effects of embodiment sub-measures and avatar condition on experience were evaluated using multiple regressions. Hierarchical models were built for experience by adding an embodiment sub-measure and avatar condition. The None condition was again removed from the analysis.

The appearance and response sub-measures did not produce significant models and are not discussed in detail below.

4.4.1 Ownership

When considering the effect of ownership on perceptions of virtual experience, adding the avatar condition did not improve the model and was therefore not included. The final model ($F(1, 119) = 9.35$, $p = .003$, $R^2 = .07$) can be seen in Table 5. Ownership significantly predicted perceptions of virtual experience, $\beta = .26$, $p = .003$.

4.4.2 Multi-sensory

When considering the effect of multi-sensory on perceptions of virtual experience, the avatar condition did not improve the model and was not included. The final model ($F(1, 119) = 6.63$, $p = .01$, $R^2 = .05$) can be seen in Table 6. Multi-sensory significantly predicted perceptions of virtual experience, $\beta = .20$, $p = .01$. See Figure 5 for the linear model concerning Ownership and Multi-sensory.

TABLE 5 Multiple regression model for ownership on the perceptions of virtual experience with β (*standard error*).

	Model 1
Intercept	0.75 (0.02)***
Ownership	0.26 (0.08)**
R^2	0.07
Adj. R^2	0.07
Num. obs	121

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

TABLE 6 Multiple regression model for multi-sensory on the perceptions of virtual experience with β (*standard error*).

	Model 1
Intercept	0.75 (0.02)***
Multi-sensory	0.20 (0.08)*
R^2	0.05
Adj. R^2	0.04
Num. obs	121

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

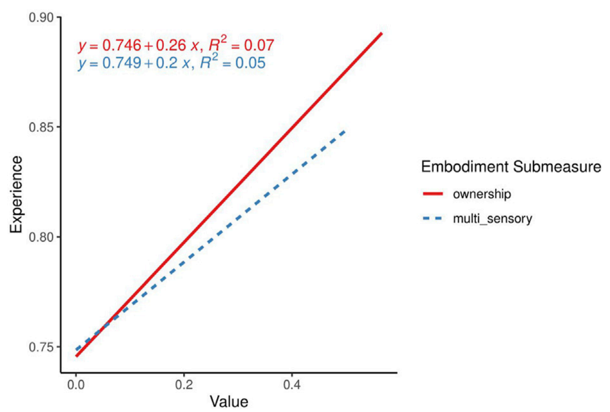

FIGURE 5
Linear models with equations and R^2 of experience by an embodiment sub-measure value (ownership: top solid red; multi-sensory: bottom short-dash blue). Experience refers to perceptions of virtual experience.

5 Discussion

This paper demonstrates that desktop embodiment can be induced and measured using standard embodiment questionnaires. The aspects of desktop embodiment also correlated with the positive perceptions of the virtual experience. However, the findings imply that desktop embodiment does not reduce implicit racial bias. Peculiarly, participants' biases toward an outgroup were positively correlated with the aspects of their embodiment of an avatar belonging to that outgroup. In this section, we discuss the original research questions and these auxiliary findings regarding desktop embodiment.

5.1 RQ1: Can embodiment be induced on desktop-based VR as measured via a standard embodiment questionnaire?

Regarding RQ1, embodiment was induced at low levels on a desktop virtual environment. This is demonstrated by the reliability obtained for AEQ and its sub-measurements, as well as the sub-measurement's ability to predict the perceptions of the virtual experience. To the best of the authors' knowledge, this paper is one of the first to utilize a validated avatar embodiment questionnaire to measure embodiment on the desktop in the context of racial bias. During analysis, the None condition's scores were unable to be analyzed in several instances as it was difficult to ascertain from what perspective participants were answering. This procedure was shown in previous literature where participants with no avatar still scored similar levels of embodiment (likely by answering from some proxy) (Lugrin et al., 2018; Peck and Tutar, 2020). Thus, analysis on embodiment in the None condition could not be compared, but non-embodiment results from this control condition were utilized in other analyses.

This induction of embodiment at a low level may further be evidenced by participants' perceptions of the virtual experience. The aspects of embodiment, specifically in the ownership and multisensory sub-measures, predicted the perceptions of virtual experience measure. This measure gauged participants on the helpfulness of the simulation as a virtual tour, usage of virtual humans in the simulation, and sentiments regarding the future usage of the actual building as a result of the virtual tour. The results imply that even partial or low embodiment may factor into a user's outlook on the virtual experience. Thus, without regard to racial bias change, virtual embodiment on desktop-based VR may be beneficial in other capacities. This would echo literature in traditional VR research demonstrating that embodiment has numerous positive effects [e.g., experience (Kim et al., 2014), improved self-image (Davis and Chansiri, 2019), and improved cognitive performance (Banakou et al., 2018)] and showcases that desktop embodiment has a potential practical merit.

Replicating the senses of self-location and ownership can be challenging with any desktop-based simulation. Participants will always be able to see their physical limbs, so the sense of embodiment can be hampered. As a result, embodiment scores are expected to be lower compared to those of HMD-based embodiment. However, Kilteni et al. (2012) theorized that even in such scenarios, each sense of embodiment can still be achieved. This is not unprecedented, as numerous studies have observed the effects of a third-person embodiment (Debarba et al., 2015; Galvan Debarba et al., 2017; Gorisse et al., 2017). Although self-location and ownership often have lower scores in third-person, it is evident that a sense of embodiment is achieved regardless. Despite the limitations of desktop-based VR, the proper design of virtual simulations can result in a sense of embodiment for users.

5.2 RQ2: Can desktop embodiment be used to reduce racial bias?

Desktop embodiment scores appear to have little effect on participants' implicit bias as measured by IAT. A significant reduction in IAT scores was observed in the post-IAT compared to the pre-IAT across all conditions. However, this is more likely due to learning effects from IAT as IAT was taken multiple times in a short period (Greenwald et al., 1998; Karpinski, 2004). Traditional VR research has observed racial bias change primarily in the context of more immersive scenarios (Peck et al., 2013; Banakou et al., 2016; Hasler et al., 2017). Our work differentiates from this prior work by investigating embodied effects on racial bias in a less immersive scenario. Thus, we hypothesize that to induce psychological change within a participant, greater levels of embodiment and avatar identification are necessary.

Interestingly, pre-IAT correlated with the aspects of their embodiment. These correlations were exhibited in the appearance and response sub-measures. Participants exhibiting lower pro-White bias also had lower embodiment measures of appearance and response. In the case of response, higher pro-White bias scores also correlated with a higher response. This implies that pre-existing biases from real life may factor into the embodiment of a virtual avatar.

One theory as to why pre-existing biases may impact embodiment is that the change in race was simply made salient to the user, increasing their attention to their avatar. However, a potentially more concerning possibility is that the presence of a Black avatar activated stereotypes within participants with a higher pro-White bias. The stereotype activation in turn caused embodied effects that directly increased embodiment. Stereotype activation is the triggering of stereotypes as a result of exposure to specific traits of a social group (e.g., race, gender, and age) (Bargh et al., 1996). The activation of these stereotypes is known to trigger action schemas within participants which cause them to implicitly embody aspects of the social group (Bargh et al., 1996; Niedenthal et al., 2005). As the detection of race and activation of stereotypes happen almost immediately when looking at someone (Bargh et al., 1996), it is likely a stereotype activation that occurred immediately for participants with higher pro-White bias when they viewed their Black self-avatar. As a result of the internally activated stereotypes, participants in this study may have experienced embodiment effects that increased their overall sense of embodiment (Bargh et al., 1996; Niedenthal et al., 2005). Furthermore, the perceptions of the avatar in relation to the self may play a role in the degree of embodiment achieved. Ratan (2019a; b) proposed that users may consider the avatar a self-representation, a social other, a utility, or a blend of the three. One's behavior when embodying an avatar may change depending on how the user perceives the avatar. If a user perceives the avatar as a utility or a social other, they may act as though they are using a tool or character rather than a virtual representation of themselves, altering the perceived embodiment. How the avatar's characteristics are perceived may impact the behavior in the simulation (Beaudoin et al., 2020). Thus, priming the avatar's race in coordination with how the users perceive themselves within the avatar can lead to a deviant behavior. It may be necessary to provide the desired *context* to the user on how the avatar should be utilized within theories such as Ratan's Self-Other-Utility framework (Ratan, 2019a; b).

This change in behavior deviant to oneself and conformed to that of the embodied persona has been demonstrated in previous psychology (Bargh et al., 1996; Dijksterhuis and Van Knippenberg, 2000; Kawakami et al., 2002) and VR literature (Reinhard et al., 2020). For instance, Bargh et al. (1996) primed participants with words relating to features of the elderly (e.g., Florida, bingo). The resulting embodied effect caused participants to subconsciously move more slowly when walking (mimicking elderly behavior) in comparison to a control group. The posed theory [later established by Niedenthal et al. (2005)] discusses how the priming of stereotypical words can activate the described action schemas. Such effects may be measured in future work to detect a change in behavior (perhaps similarly to previous VR stereotype work

(Hasler et al., 2017; Peck et al., 2018; 2020; Chang et al., 2019)). Therefore, there is a need to better understand how pre-existing biases and embodiment work in tandem. Although embodiment can reinforce positive behaviors, we should also be wary of the potential negative stereotypes that can result. Groom et al. (2009) described how inaccurate embodiment may simply illustrate the differences between the participant and the outgroup avatar's appearance and prime stereotypes instead of minimizing racial bias. Attempting to reduce implicit bias purely through the embodiment of a specific skin-toned avatar should be considered an oversimplification of what race entails. Lopez et al. (2019) and Banakou et al. (2020) added that reducing bias toward discriminated groups with VR is far more complex than simply embodying an avatar. Thus, although the premise of racial bias mitigation through VR is novel and worthwhile, we advise deeper consideration in approaching the topic.

This work utilized a pre–post-IAT measurement similarly performed in prior literature in the VR/HCI community (Peck et al., 2013; Banakou et al., 2016). We opted for this methodology to allow this work to remain comparable to other works performed in the VR/HCI community. However, this measurement method differs from methods used in psychology. The psychology field altogether avoids the use of multiple IATs by using a singular control group that takes the IAT without partaking in the intervention and a second group that experiences the intervention and takes IAT immediately after (Greenwald et al., 2003; Lai et al., 2014; FitzGerald et al., 2019; Whitford and Emerson, 2019). This methodology is performed in an attempt to prevent IAT learning effects. In the future, the VR/HCI community may benefit from a similar approach to the IAT as the psychology community. Even better, for more accurate indications of real-world bias, future work should continue to make use of alternative methods to evaluate the real-world outcomes of bias-reducing interventions (Peck et al., 2021a).

5.3 Growing needs in investigating societal biases in virtual reality

As VR becomes a growing medium to address real-world challenges such as racial bias, we note a number of challenges for the next chapter of this collective investigation. The large body of literature in this domain has limited its research to White and Black biases (Peck et al., 2013; Banakou et al., 2016). As seen in this study, only half the population consisted of White or Black participants. Viewing race in these binary terms will be a limiting factor for studies moving forward, especially considering that a large number of participants also had multiple race identities. This study aimed to study race as the primary variable to investigate as a baseline for future work. However, this required the design of the avatars to be limited to male and female (able-bodied) avatars with a similar body type. Not only is this a limiting view on both gender, but also it can reinforce biases and stereotypes (Brahnam and De Angeli, 2012; Silvervarg et al., 2012). Participants with non-binary gender identities were allowed to participate in our study; however, it was not possible to guarantee that an avatar that matched their gender identity was provided. Therefore, data from non-binary participants had to be excluded from this article. Simply excluding valuable data are neither sustainable for future work nor ideal. Thus, as our understanding of societal biases continues to evolve, there exists a need to evolve our study designs cooperatively. Works such as those proposed by Peck et al. (2021b) and Chowdhury and Quarles (2021) have begun to address the need to build VR applications more inclusively, and we echo these calls.

6 Limitations and future work

Beyond the IAT's limitations, our study's usage of IAT was also susceptible to learning effects as participants took the IAT immediately before and after the simulation. However, our simulation did not significantly decrease implicit bias for any specific condition in comparison to another, and we do not believe this was an issue. Additionally, only 3% of our population was Black/African-American. Although this is not representative of the target population, studies suggest that pro-White bias is more prevalent than pro-Black bias (Ahadinezhad et al., 2021). As a result, studying bias in our population addresses our RQs while also observing bias in populations that are not typically included in prior embodiment work (e.g., Asian or Hispanic populations); however, future work would benefit from a more representative population. Gender and intersectional effects may also need to be determined in future work (Jarrell et al., 2021).

Future work should also identify ways in which desktop-based embodiment can be improved. One limiting factor in this study was that participants experienced frustration during the simulation. This frustration may have impacted embodiment through diminished experience and immersion (Nylund and Landfors, 2015). During our approach phase, participants could not move their avatar and were made stationary to allow the virtual humans to walk past and interact with the participant. Despite providing a virtual tour-related justification for this interaction, many participants indicated frustration with the duration of the interaction and did not understand why this step was even necessary. Thus, more consideration may be necessary to design embodied experiences for a desktop experience. Cleverly designing in-simulation interactions may foster a more embodying experience as well, which could then potentially illustrate desired psychological effects. Finally, we conclude with a call for deeper consideration when developing embodied experiences to mitigate social biases as discussed in our work. In turn, future work can measure the presence of stereotype activation and how it may affect embodied users.

7 Conclusion

By embodying participants in the four types of avatars (Black, White, Alien, and None), we sought to determine if embodiment on a desktop environment could be induced and measured. In turn, we aimed to determine if the induced embodiment could reduce pro-White implicit racial bias. The results indicated that embodiment can be induced and measured using validated embodiment questionnaires. However, the intervention did not significantly change racial bias. We provide evidence that racial bias may actually play a role in a user's sense of embodiment by reinforcing racial stereotypes. Additionally, desktop embodiment correlates with positive perceptions of their virtual experience. This work investigates embodiment in less immersive platforms while reinforcing the study of VR, HCI, and serious games for social good. Future work will continue to investigate how to provide embodied experiences in less immersive platforms while accounting for the impact these experiences may have on user's perceptions, psychology, and bias.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the University of Florida Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

CY conducted the user study, carried out the data analysis with TP, and wrote the manuscript in consultation with all others. All authors contributed to the article and approved the submitted version.

Acknowledgments

The authors would like to thank the members of the Virtual Experiences Research Group for their help in providing feedback.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Ahadinezhad, B., Khosravizadeh, O., Maleki, A., and Hashtroodi, A. (2021). Implicit racial bias among medical graduates and students by an iat measure: a systematic review and meta-analysis. *Ir. J. Med. Sci.* 191 (1971), 1941–1949. doi:10.1007/s11845-021-02756-3

Anderson, K. O., Green, C. R., and Payne, R. (2009). Racial and ethnic disparities in pain: causes and consequences of unequal care. *J. pain* 10, 1187–1204. doi:10.1016/j.jpain.2009.10.002

Ash, E. (2016). Priming or proteus effect? examining the effects of avatar race on in-game behavior and post-play aggressive cognition and affect in video games. *Games Cult.* 11, 422–440. doi:10.1177/1555412014568870

Banakou, D., Beacco, A., Neyret, S., Blasco-Oliver, M., Seinfeld, S., Slater, M., et al. (2020). Virtual body ownership and its consequences for implicit racial bias are dependent on social context. *R. Soc. Open Sci.* 7, 201848. doi:10.1098/rsos.201848

Banakou, D., Groten, R., and Slater, M. (2013). Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. *Proc. Natl. Acad. Sci.* 110, 12846–12851. doi:10.1073/pnas.1306779110

Banakou, D., Hanumanthu, P. D., and Slater, M. (2016). Virtual embodiment of white people in a black virtual body leads to a sustained reduction in their implicit racial bias. *Front. Hum. Neurosci.* 10, 601. doi:10.3389/fnhum.2016.00601

Banakou, D., Kishore, S., and Slater, M. (2018). Virtually being einstein results in an improvement in cognitive task performance and a decrease in age bias. *Front. Psychol.* 9, 917. doi:10.3389/fpsyg.2018.00917

Bargh, J. A., Chen, M., and Burrows, L. (1996). Automaticity of social behavior: direct effects of trait construct and stereotype activation on action. *J. personality Soc. Psychol.* 71, 230–244. doi:10.1037//0022-3514.71.2.230

Beaudoin, M., Barra, J., Dupraz, L., Mollier-Sabet, P., and Guerraz, M. (2020). The impact of embodying an "elderly" body avatar on motor imagery. *Exp. Brain Res.* 238, 1467–1478. doi:10.1007/s00221-020-05828-5

Behm-Morawitz, E. (2013). Mirrored selves: the influence of self-presence in a virtual world on health, appearance, and well-being. *Comput. Hum. Behav.* 29, 119–128. doi:10.1016/j.chb.2012.07.023

Behrend, T., Toaddy, S., Thompson, L. F., and Sharek, D. J. (2012). The effects of avatar appearance on interviewer ratings in virtual employment interviews. *Comput. Hum. Behav.* 28, 2128–2133. doi:10.1016/j.chb.2012.06.017

Beltran, K., Rowland, C., Hashemi, N., Nguyen, A., Harrison, L., Engle, S., et al. (2021). "Reducing implicit gender bias using a virtual workplace environment," in *Extended a bstracts of the 2021 CHI conference on human factors in computing systems*, 1–7.

Bessière, K., Seay, A. F., and Kiesler, S. (2007). The ideal elf: identity exploration in world of warcraft. *Cyberpsychology Behav.* 10, 530–535. doi:10.1089/cpb.2007.9994

Biocca, F. (1997). The cyborg's dilemma: progressive embodiment in virtual environments. *J. computer-mediated Commun.* 3, 0. doi:10.1111/j.1083-6101.1997.tb00070.x

Blanke, O., and Metzinger, T. (2009). Full-body illusions and minimal phenomenal selfhood. *Trends cognitive Sci.* 13, 7–13. doi:10.1016/j.tics.2008.10.003

Brahnam, S., and De Angeli, A. (2012). Gender affordances of conversational agents. *Interact. Comput.* 24, 139–153. doi:10.1016/j.intcom.2012.05.001

Capers IV, Q., Clinchot, D., McDougle, L., and Greenwald, A. G. (2017). Implicit racial bias in medical school admissions. *Acad. Med.* 92, 365–369. doi:10.1097/acm.0000000000001388

Carpenter, T. P., Pogacar, R., Pullig, C., Kouril, M., Aguilar, S., LaBouff, J., et al. (2019). Survey-software implicit association tests: a methodological and empirical analysis. *Behav. Res. methods* 51, 2194–2208. doi:10.3758/s13428-019-01293-3

Cassell, J., Bickmore, T., Billinghurst, M., Campbell, L., Chang, K., Vilhjálmsson, H., et al. (1999). "Embodiment in conversational interfaces: rea," in *Proceedings of the SIGCHI conference on human factors in computing systems*, 520–527.

Chang, F., Luo, M., Walton, G., Aguilar, L., and Bailenson, J. (2019). Stereotype threat in virtual learning environments: effects of avatar gender and sexist behavior on women's math learning outcomes. *Cyberpsychology, Behav. Soc. Netw.* 22, 634–640. doi:10.1089/cyber.2019.0106

Chowdhury, T. I., and Quarles, J. (2021). A wheelchair locomotion interface in a vr disability simulation reduces implicit bias. *IEEE Trans. Vis. Comput. Graph.* 28, 4658–4670. doi:10.1109/tvcg.2021.3099115

Cleeland, C. S., Gonin, R., Baez, L., Loehrer, P., and Pandya, K. J. (1997). Pain and treatment of pain in minority patients with cancer: the eastern cooperative oncology group minority outpatient pain study. *Ann. Intern. Med.* 127, 813–816. doi:10.7326/0003-4819-127-9-199711010-00006

Correll, J., Park, B., Judd, C. M., Wittenbrink, B., Sadler, M. S., and Keesee, T. (2007). Across the thin blue line: police officers and racial bias in the decision to shoot. *J. personality Soc. Psychol.* 92, 1006–1023. doi:10.1037/0022-3514.92.6.1006

Czopp, A. M., and Monteith, M. J. (2003). Confronting prejudice (literally): reactions to confrontations of racial and gender bias. *Personality Soc. Psychol. Bull.* 29, 532–544. doi:10.1177/0146167202250923

Davis, D. Z., and Chansiri, K. (2019). Digital identities–overcoming visual bias through virtual embodiment. *Inf. Commun. Soc.* 22, 491–505. doi:10.1080/1369118x.2018.1548631

Debarba, H. G., Molla, E., Herbelin, B., and Boulic, R. (2015). "Characterizing embodied interaction in first and third person perspective viewpoints," in *2015 IEEE symposium on 3D user interfaces (3DUI)* (IEEE), 67–72.

De Vignemont, F. (2011). Embodiment, ownership and disownership. *Conscious. cognition* 20, 82–93. doi:10.1016/j.concog.2010.09.004

Devine, P. G., Monteith, M. J., Zuwerink, J. R., and Elliot, A. J. (1991). Prejudice with and without compunction. *J. Personality Soc. Psychol.* 60, 817–830. doi:10.1037//0022-3514.60.6.817

Dijksterhuis, A., and Van Knippenberg, A. (2000). Behavioral indecision: effects of self-focus on automatic behavior. *Soc. Cogn.* 18, 55–74. doi:10.1521/soco.2000.18.1.55

Dovidio, J. F., and Gaertner, S. L. (1986). *Prejudice, discrimination, and racism*. Academic Press.

Estrada, J. G., and Prasolova-Førland, E. (2021). Running an xr lab in the context of covid-19 pandemic: lessons learned from a Norwegian university. *Educ. Inf. Technol.*, 1–17. doi:10.1007/s10639-021-10446-x

Field, A., Field, Z., Miles, J. F. Z, and Miles, J. (2012). *Discovering statistics using R*. Sage publications.

FitzGerald, C., Martin, A., Berner, D., and Hurst, S. (2019). Interventions designed to reduce implicit prejudices and implicit stereotypes in real world contexts: a systematic review. *BMC Psychol.* 7, 29–12. doi:10.1186/s40359-019-0299-7

Flavián, C., Ibáñez-Sánchez, S., and Orús, C. (2019). Integrating virtual reality devices into the body: effects of technological embodiment on customer engagement and behavioral intentions toward the destination. *J. Travel and Tour. Mark.* 36, 847–863. doi:10.1080/10548408.2019.1618781

Flavián, C., Ibáñez-Sánchez, S., and Orús, C. (2021). Impacts of technological embodiment through virtual reality on potential guests' emotions and engagement. *J. Hosp. Mark. Manag.* 30, 1–20. doi:10.1080/19368623.2020.1770146

Foster, M. E. (2007). "Enhancing human-computer interaction with embodied conversational agents," in *International conference on universal access in human-computer interaction* (Springer), 828–837.

Fox, J., and Ahn, S. J. (2013). "Avatars: portraying, exploring, and changing online and offline identities," in *Handbook of research on technoself: identity in a technological society* (IGI Global), 255–271. doi:10.4018/978-1-4666-2211-1.ch014

Galvan Debarba, H., Bovet, S., Salomon, R., Blanke, O., Herbelin, B., and Boulic, R. (2017). Characterizing first and third person viewpoints and their alternation for embodied interaction in virtual reality. *PloS one* 12, e0190109. doi:10.1371/journal.pone.0190109

Gliem, J. A., and Gliem, R. R. (2003). *Calculating, interpreting, and reporting cronbach's alpha reliability coefficient for likert-type scales Midwest Research-to-Practice Conference in Adult, Continuing, and Community*.

Gorisse, G., Christmann, O., Amato, E. A., and Richir, S. (2017). First-and third-person perspectives in immersive virtual environments: presence and performance analysis of embodied users. *Front. Robotics AI* 4, 33. doi:10.3389/frobt.2017.00033

Greenwald, A. G., McGhee, D. E., and Schwartz, J. L. (1998). Measuring individual differences in implicit cognition: the implicit association test. *J. personality Soc. Psychol.* 74, 1464–1480. doi:10.1037/0022-3514.74.6.1464

Greenwald, A. G., Nosek, B. A., and Banaji, M. R. (2003). Understanding and using the implicit association test: I. an improved scoring algorithm. *J. personality Soc. Psychol.* 85, 197–216. doi:10.1037/0022-3514.85.2.197

Groom, V., Bailenson, J. N., and Nass, C. (2009). The influence of racial embodiment on racial bias in immersive virtual environments. *Soc. Influ.* 4, 231–248. doi:10.1080/15534510802643750

Hamilton-Giachritsis, C., Banakou, D., Garcia Quiroga, M., Giachritsis, C., and Slater, M. (2018). Reducing risk and improving maternal perspective-taking and empathy using virtual embodiment. *Sci. Rep.* 8 (1), 2975. doi:10.1038/s41598-018-21036-2

Hasler, B. S., Spanlang, B., and Slater, M. (2017). Virtual race transformation reverses racial in-group bias. *PloS one* 12, e0174965. doi:10.1371/journal.pone.0174965

Hefner, D., Klimmt, C., and Vorderer, P. (2007). "Identification with the player character as determinant of video game enjoyment," in *International conference on entertainment computing* (Springer), 39–48.

Hoffman, K. M., Trawalter, S., Axt, J. R., and Oliver, M. N. (2016). Racial bias in pain assessment and treatment recommendations, and false beliefs about biological differences between blacks and whites. *Proc. Natl. Acad. Sci.* 113, 4296–4301. doi:10.1073/pnas.1516047113

Hoffner, C. (1996). Children's wishful identification and parasocial interaction with favorite television characters. *J. Broadcast. Electron. Media* 40, 389–402. doi:10.1080/08838159609364360

Hoffner, C., and Buchanan, M. (2005). Young adults' wishful identification with television characters: the role of perceived similarity and character attributes. *Media Psychol.* 7, 325–351. doi:10.1207/s1532785xmep0704_2

Holz, T., Dragone, M., and O'Hare, G. M. (2009). Where robots and virtual agents meet. *Int. J. Soc. Robotics* 1, 83–93. doi:10.1007/s12369-008-0002-2

Jarrell, M., Ghaiumy Anaraky, R., Knijnenburg, B., and Ash, E. (2021). "Using intersectional representation and embodied identification in standard video game play to reduce societal biases," in *Proceedings of the 2021 CHI conference on human factors in computing systems*, 1–18.

Karpinski, A. (2004). Measuring self-esteem using the implicit association test: the role of the other. *Personality Soc. Psychol. Bull.* 30, 22–34. doi:10.1177/0146167203258835

Kaufman, G., Flanagan, M., and Seidman, M. (2016). Creating stealth game interventions for attitude and behavior change: an "embedded design" model. *Trans. Digital Games Res. Assoc.* 2. doi:10.26503/todigra.v2i3.57

Kawakami, K., Young, H., and Dovidio, J. F. (2002). Automatic stereotyping: category, trait, and behavioral activations. *Personality Soc. Psychol. Bull.* 28, 3–15. doi:10.1177/0146167202281001

Kilteni, K., Groten, R., and Slater, M. (2012). The sense of embodiment in virtual reality. *Presence Teleoperators Virtual Environ.* 21, 373–387. doi:10.1162/pres_a_00124

Kim, S. Y. S., Prestopnik, N., and Biocca, F. A. (2014). Body in the interactive game: how interface embodiment affects physical activity and health behavior change. *Comput. Hum. Behav.* 36, 376–384. doi:10.1016/j.chb.2014.03.067

Kokkinara, E., Slater, M., and López-Moliner, J. (2015). The effects of visuomotor calibration to the perceived space and body, through embodiment in immersive virtual reality. *ACM Trans. Appl. Percept. (TAP)* 13, 1–22. doi:10.1145/2818998

Kolasinski, E. M. (1995). *Simulator sickness in virtual environments*. US Army Research Institute for the Behavioral and Social Sciences.

Lai, C. K., Marini, M., Lehr, S. A., Cerruti, C., Shin, J., Joy-Gaba, J., et al. (2014). Reducing implicit racial preferences: I. A comparative investigation of 17 interventions. *J. Exp. Psychol. General* 143, 1765–1785. doi:10.1037/a0036260

Lee, K. M. (2004). Presence, explicated. *Commun. theory* 14, 27–50. doi:10.1093/ct/14.1.27

Lenggenhager, B., Mouthon, M., and Blanke, O. (2009). Spatial aspects of bodily self-consciousness. *Conscious. cognition* 18, 110–117. doi:10.1016/j.concog.2008.11.003

Lopez, S., Yang, Y., Beltran, K., Kim, S. J., Cruz Hernandez, J., Simran, C., et al. (2019). "Investigating implicit gender bias and embodiment of white males in virtual reality with full body visuomotor synchrony," in *Proceedings of the 2019 CHI conference on human factors in computing systems*, 1–12.

Lougiakis, C., Katifori, A., Roussou, M., and Ioannidis, I.-P. (2020). "Effects of virtual hand representation on interaction and embodiment in hmd-based virtual environments using controllers," in *2020 IEEE conference on virtual reality and 3D user interfaces (VR)* (IEEE), 510–518.

Lugrin, J.-L., Ertl, M., Krop, P., Klüpfel, R., Stierstorfer, S., Weisz, B., et al. (2018). "Any "body" there? avatar visibility effects in a virtual reality game," in *2018 IEEE conference on virtual reality and 3D user interfaces (VR)* (IEEE), 17–24.

Mathur, V. A., Richeson, J. A., Paice, J. A., Muzyka, M., and Chiao, J. Y. (2014). Racial bias in pain perception and response: experimental examination of automatic and deliberate processes. *J. pain* 15, 476–484. doi:10.1016/j.jpain.2014.01.488

McConahay, J. B. (1986). *Modern racism, ambivalence, and the modern racism scale*.

Monteiro, D., Liang, H.-N., Xu, W., Brucker, M., Nanjappan, V., and Yue, Y. (2018). Evaluating enjoyment, presence, and emulator sickness in vr games based on first-and third-person viewing perspectives. *Comput. Animat. Virtual Worlds* 29, e1830. doi:10.1002/cav.1830

Mott, M., Cutrell, E., Franco, M. G., Holz, C., Ofek, E., Stoakley, R., et al. (2019). "Accessible by design: an opportunity for virtual reality," in *2019 IEEE international symposium on mixed and augmented reality adjunct (ISMAR-Adjunct)* (IEEE), 451–454.

Niedenthal, P. M., Barsalou, L. W., Winkielman, P., Krauth-Gruber, S., and Ric, F. (2005). Embodiment in attitudes, social perception, and emotion. *Personality Soc. Psychol. Rev.* 9, 184–211. doi:10.1207/s15327957pspr0903_1

Nylund, A., and Landfors, O. (2015). *Frustration and its effect on immersion in games: a developer viewpoint on the good and bad aspects of frustration*.

Olson, D. M., and Harrell, D. F. (2020). "i don't see color": characterizing players' racial attitudes and experiences via an anti-bias simulation videogame. *Int. Conf. Found. Digital Games* 52, 1–4. doi:10.1097/JNN.0000000000000484

Parger, M., Mueller, J. H., Schmalstieg, D., and Steinberger, M. (2018). "Human upper-body inverse kinematics for increased embodiment in consumer-grade virtual reality," in *Proceedings of the 24th ACM symposium on virtual reality software and technology*, 1–10.

Peck, T. C., Doan, M., Bourne, K. A., and Good, J. J. (2018). The effect of gender body-swap illusions on working memory and stereotype threat. *IEEE Trans. Vis. Comput. Graph.* 24, 1604–1612. doi:10.1109/tvcg.2018.2793598

Peck, T. C., and Gonzalez-Franco, M. (2021). Avatar embodiment. a standardized questionnaire. *Front. Virtual Real.* 1, 44. doi:10.3389/frvir.2020.575943

Peck, T. C., Good, J. J., and Bourne, K. A. (2020). "Inducing and mitigating stereotype threat through gendered virtual body-swap illusions," in *Proceedings of the 2020 CHI conference on human factors in computing systems*, 1–13.

Peck, T. C., Good, J. J., and Seitz, K. (2021a). Evidence of racial bias using immersive virtual reality: analysis of head and hand motions during shooting decisions. *IEEE Trans. Vis. Comput. Graph.* 27, 2502–2512. doi:10.1109/tvcg.2021.3067767

Peck, T. C., McMullen, K. A., and Quarles, J. (2021b). Divrsify: break the cycle and develop vr for everyone. *IEEE Comput. Graph. Appl.* 41, 133–142. doi:10.1109/mcg.2021.3113455

Peck, T. C., Seinfeld, S., Aglioti, S. M., and Slater, M. (2013). Putting yourself in the skin of a black avatar reduces implicit racial bias. *Conscious. cognition* 22, 779–787. doi:10.1016/j.concog.2013.04.016

Peck, T. C., and Tutar, A. (2020). The impact of a self-avatar, hand collocation, and hand proximity on embodiment and stroop interference. *IEEE Trans. Vis. Comput. Graph.* 26, 1964–1971. doi:10.1109/tvcg.2020.2973061

Penner, L. A., Dovidio, J. F., Gonzalez, R., Albrecht, T. L., Chapman, R., Foster, T., et al. (2016). The effects of oncologist implicit racial bias in racially discordant oncology interactions. *J. Clin. Oncol.* 34, 2874–2880. doi:10.1200/jco.2015.66.3658

Ratan, R. (2013). "Self-presence, explicated: body, emotion, and identity extension into the virtual self," in *Handbook of research on technoself: identity in a technological society* (IGI Global), 322–336. doi:10.4018/978-1-4666-2211-1.ch018

Ratan, R. (2019a). Cars and contemporary communication— when automobiles are avacars: a self-other-utility approach to cars and avatars. *Int. J. Commun.* 13, 19.

Ratan, R. (2019b). When automobiles are avacars: a self-other-utility approach to cars and avatars. *Int. J. Commun.* 13, 1–19.

Reinhard, R., Shah, K. G., Faust-Christmann, C. A., and Lachmann, T. (2020). Acting your avatar's age: effects of virtual reality avatar embodiment on real life walking speed. *Media Psychol.* 23, 293–315. doi:10.1080/15213269.2019.1598435

Rosa, N., van Bommel, J.-P., Hürst, W., Nijboer, T., Veltkamp, R. C., and Werkhoven, P. (2019). "Embodying an extra virtual body in augmented reality," in *2019 IEEE conference on virtual reality and 3D user interfaces (VR)* (IEEE), 1138–1139.

Shu, Y., Huang, Y.-Z., Chang, S.-H., and Chen, M.-Y. (2019). Do virtual reality head-mounted displays make a difference? a comparison of presence and self-efficacy between head-mounted displays and desktop computer-facilitated virtual environments. *Virtual Real.* 23, 437–446. doi:10.1007/s10055-018-0376-x

Silvervarg, A., Raukola, K., Haake, M., and Gulz, A. (2012). "The effect of visual gender on abuse in conversation with ecas," in *International conference on intelligent virtual agents* (Springer), 153–160.

Slater, M., and Usoh, M. (1993). Representations systems, perceptual position, and presence in immersive virtual environments. *Presence Teleoperators Virtual Environ.* 2, 221–233. doi:10.1162/pres.1993.2.3.221

Smith, S. L. (2006). *Perps, pimps, and provocative clothing: examining negative content patterns in video games*.

Spanlang, B., Normand, J.-M., Borland, D., Kilteni, K., Giannopoulos, E., Pomés, A., et al. (2014). How to build an embodiment lab: achieving body representation illusions in virtual reality. *Front. Robotics AI* 1, 9. doi:10.3389/frobt.2014.00009

Staton, L. J., Panda, M., Chen, I., Genao, I., Kurz, J., Pasanen, M., et al. (2007). When race matters: disagreement in pain perception between patients and their physicians in primary care. *J. Natl. Med. Assoc.* 99, 532–538.

Stewart, E. A., Baumer, E. P., Brunson, R. K., and Simons, R. L. (2009). Neighborhood racial context and perceptions of police-based racial discrimination among black youth. *Criminology* 47, 847–887. doi:10.1111/j.1745-9125.2009.00159.x

Swartout, W. R., Gratch, J., Hill, R. W., Jr, Hovy, E., Marsella, S., Rickel, J., et al. (2006). Toward virtual humans. *AI Mag.* 27, 96. doi:10.1609/aimag.v27i2.1883

Tajadura-Jiménez, A., Banakou, D., Bianchi-Berthouze, N., and Slater, M. (2017). Embodiment in a child-like talking virtual body influences object size perception, self-identification, and subsequent real speaking. *Sci. Rep.* 7 (1), 9637. doi:10.1038/s41598-017-09497-3

Taylor, T. (1999). *Life in virtual worlds: plural existence, multimodalities, and other*.

Taylor, T. L. (2002). "Living digitally: embodiment in virtual worlds," in *The social life of avatars* (Springer), 40–62.

Tham, J., Duin, A. H., Gee, L., Ernst, N., Abdelqader, B., and McGrath, M. (2018). Understanding virtual reality: presence, embodiment, and professional practice. *IEEE Trans. Prof. Commun.* 61, 178–195. doi:10.1109/tpc.2018.2804238

Tsakiris, M., Schütz-Bosbach, S., and Gallagher, S. (2007). On agency and body-ownership: phenomenological and neurocognitive reflections. *Conscious. cognition* 16, 645–660. doi:10.1016/j.concog.2007.05.012

Whitford, D. K., and Emerson, A. M. (2019). Empathy intervention to reduce implicit bias in pre-service teachers. *Psychol. Rep.* 122, 670–688. doi:10.1177/0033294118767435

Wobbrock, J. O., Gajos, K. Z., Kane, S. K., and Vanderheiden, G. C. (2018). Ability-based design. *Commun. ACM* 61, 62–71. doi:10.1145/3148051

Yee, N. (2006). The demographics, motivations, and derived experiences of users of massively multi-user online graphical environments. *Presence Teleoperators virtual Environ.* 15, 309–329. doi:10.1162/pres.15.3.309

Yee, N., and Bailenson, J. (2007). The proteus effect: the effect of transformed self-representation on behavior. *Hum. Commun. Res.* 33, 271–290. doi:10.1111/j.1468-2958.2007.00299.x

Yee, N., Bailenson, J. N., and Ducheneaut, N. (2009). The Proteus effect: implications of transformed digital self-representation on online and offline behavior. *Commun. Res.* 36, 285–312. doi:10.1177/0093650208330254

Yuan, Y., and Steed, A. (2010). "Is the rubber hand illusion induced by immersive virtual reality?," in *2010 IEEE virtual reality conference (VR)* (IEEE), 95–102.

Zichermann, G., and Cunningham, C. (2011). *Gamification by design: implementing game mechanics in web and mobile apps*. O'Reilly Media, Inc.

Ziegert, J. C., and Hanges, P. J. (2005). Employment discrimination: the role of implicit attitudes, motivation, and a climate for racial bias. *J. Appl. Psychol.* 90, 553–562. doi:10.1037/0021-9010.90.3.553