Acting your avatar’s age: effects of virtual reality avatar embodiment on real life walking speed

René Reinhard a, Khyati Girish Shah b, Corinna A. Faust-Christmann c, and Thomas Lachmann b,d

a Fraunhofer Institute for Industrial Mathematics ITWM, Kaiserslautern, Germany; b Center for Cognitive Science, University of Kaiserslautern, Kaiserslautern, Germany; c Junior Research Group wearHEALTH, Department of Computer Science, University of Kaiserslautern, Kaiserslautern, Germany; d Facultad de Lenguas y Educación, Universidad Nebrija, Madrid, Spain

ABSTRACT

When immersive virtual reality users employ digital self-representations, i.e., avatars, they may be subject to the Proteus effect. This effect describes changes in attitudes and behaviors in accordance with identity cues derived from the employed avatar’s appearance, which can persist after leaving virtual reality. Individual reactions to the experience can affect the strength of observed Proteus effects. Especially the experienced illusions of body ownership of avatars and of being in the virtual environment (spatial presence) have been discussed in this context. This study investigated a Proteus effect of avatar age on post-embodiment walking speed, with special focus on how body ownership and spatial presence moderated this effect. Participants who had previously embodied older avatars took significantly longer to walk a set distance than either young avatar or control group participants. This was only apparent during the first half of the walking phase, which may indicate fast decay rates of the effect after embodiment ended. The reported body ownership could not be shown to impact the strength of the Proteus effect. Participants reporting more pronounced spatial presence were subject to stronger Proteus effects, with only the two-thirds of the sample with higher spatial presence showing evidence of the effect.

Introduction

Using immersive virtual reality (IVR) technologies offers its users novel experiences by inducing feelings of being in the presented virtual environment (spatial presence; Schubert, Friedmann, & Regenbrecht, 2001) and of inhabiting a virtual body that may differ markedly from the IVR user’s own (body ownership illusion; Slater & Sanchez-Vives, 2014). These experiences do, however, open up new questions about the short- and long-term consequences of IVR usage (Madary...
In this context, the consequences of the illusion of embodiment have been discussed as one of the central concerns in examinations of the ethical challenges of IVR (Madary & Metzinger, 2016). This includes the Proteus effect, wherein embodying an avatar in IVR can influence behaviors and attitudes even after the embodiment experience has ended, which holds the potential for both risks (Fox, Bailenson, & Tricase, 2013) and benefits (Peck, Seinfeld, Aglioti, & Slater, 2013) for IVR users. There is, however, evidence that IVR embodiment of a relevant avatar is not, in itself, sufficient to induce a Proteus effect, but that the subjective experience of the IVR user might partially determine whether such an effect occurs (Ash, 2016). The current study examined a Proteus effect through the use of avatars of different age groups on later real-life walking speed. Here, the study also investigated the effect’s preconditions, specifically, how individual reactions to the IVR experiences can moderate this effect.

**Proteus Effect**

Recent IVR research has investigated whether IVR users’ actions and cognitions can be impacted through their avatars, the users’ embodied digital self-representations. This included the Proteus effect (Yee & Bailenson, 2007), wherein users derive identity cues from the appearance of their avatars, which systematically impacts their behaviors or attitudes. The effect can occur while the user embodies the avatar (Yee & Bailenson, 2007), but may also persist for at least a short time thereafter, outside IVR (Yee, Bailenson, & Ducheneaut, 2009).

Several examples of avatar-age-related Proteus effects have been reported. For instance, embodying elderly, compared with embodying younger, avatars led to more positive word associations with age (Yee & Bailenson, 2006). Similarly, people who embodied their digitally aged, compared to their current, selves allocated more resources toward retirement (Hershfield et al., 2011) and were less likely to exhibit cheating behavior (Van Gelder, Hershfield, & Nordgren, 2013). Moreover, embodying children, compared to scaled-down adults, resulted in overestimations of object sizes and self-attribute of more childlike attributes (Banakou, Groten, & Slater, 2013).

Other Proteus effects include the impact of avatar height on negotiation behavior (Yee & Bailenson, 2007; Yee et al., 2009); avatar attractiveness on interpersonal distance (Yee & Bailenson, 2007, 2009), self-disclosure (Yee & Bailenson, 2007), and dating site usage (Yee & Bailenson, 2009); avatar attire on body-related thoughts and rape myth acceptance (Fox et al., 2013); avatar clothing and skin color on drumming behavior (Kilteni, Bergstrom, & Slater, 2013); avatar skin color has shown the potential to both increase (Groom, Bailenson, & Nass, 2009) and decrease (Peck et al., 2013) implicit racial bias. Even embodying animals, compared with watching videos of others embodying them, led to greater inclusion of nature in the self (Ahn et al., 2016). Besides
conceptual replications, avatar-related effects have an appreciable history of
direct replications (Ahn et al., 2016; Hershfield et al., 2011; Peña, Khan, &
Alexopoulos, 2016; Peña & Kim, 2014; Yee & Bailenson, 2007, 2009; Yee et al.,
2009).

The Proteus effect is often explained via self-perception theory (Yee &
Bailenson, 2007), wherein a person partially infers internal states, e.g., atti-
tudes, by scrutinizing themselves and their behavior as an outside observer
would (Bem, 1972). However, Peña (2011) argued for an interpretation in
line with priming research, where perceptual features of, e.g., a person, are
associated with chronically available structures of social knowledge, e.g.,
stereotypes, thereby leading to nonconscious changes in perceptions, cogni-
tions, or behavior (Bargh, Chen, & Burrows, 1996). Peña (2011) argued that
spreading inhibition mechanisms found in their research (Peña, Hancock, &
Merola, 2009) would be best explained by supraliminal priming mechanisms,
with less emphasis placed on embodiment or self-perception. Priming and
self-perception have been described as conceptually distinct and may lead to
conflicting predictions (Yee & Bailenson, 2009). Although the aforemen-
tioned inhibition effects were suggested to be unique to priming (Peña
et al., 2009), effects of self-perception have been claimed to contribute to
behavioral effects beyond any effects of priming (Yee & Bailenson, 2009).

The current literature indicates evidence for the existence of such embodi-
ment-specific components. Proteus effects have repeatedly been shown to exceed effects of passive viewing (Ahn et al., 2016; Banakou et al., 2013; Yee
& Bailenson, 2009), with asynchronous avatar movements extinguishing the
effect (Banakou et al., 2013; compare Tamborini et al., 2018). Additionally,
when taking the subjective IVR experience into account, subjective feelings of
body ownership of the avatar were shown to mediate Proteus effects (Ahn
et al., 2016; Yoon & Vargas, 2014). It has also been suggested that a threshold
of subjective body ownership may have to be exceeded for avatar effects to
occur (Ash, 2016). This would fall in line with the explanation suggested by
self-perception theory, indicating that observations of the avatar have to be
connected to the IVR user’s self in order for embodiment-specific compo-
nents of the Proteus effect to occur. Thus, it is likely that both priming
through mere exposure and embodiment-specific components contribute to
the observed effects (Peña et al., 2016).

**Reach of Proteus Effects**

The Proteus effect’s importance for commercial-grade IVR is tied to its, as of
yet, unclear persistence after the user has left IVR (Peña, 2011; Yee et al.,
2009). Although attitudinal changes have been demonstrated a week after
embodiment (Ahn et al., 2016), behavioral changes may not be sustained for
long. In a study by Yee et al. (2009), participants who had previously
embodied taller avatars later assigned themselves larger proportions of $100 in face-to-face negotiations outside IVR. This held true in the first real-life split, but not in later instances, which the authors discussed as possible indication of fast decay rates.

The Proteus effect also relates to avatar effects found outside IVR, especially in console- or desktop computer-based applications (Ash, 2016; Peña et al., 2009; Yang, Gibson, Lueke, Huesmann, & Bushman, 2014; Yee et al., 2009; Yoon & Vargas, 2014). Under desktop conditions, embodiment has been found to act as a moderator in avatar effects (Ash, 2016); postulated mediator effects could so far not be established (Yoon & Vargas, 2014). The effects of embodying an avatar in monitor-based games on later behavior were also shown to exceed effects of passive viewing conditions (Yoon & Vargas, 2014).

Proteus effects may also relate to phenomena outside of computer-generated worlds. Transformations of one’s physical appearance have an established influence on self-evaluations, attitudes, and behavior (Johnson, Lennon, & Rudd, 2014). For example, participants wearing white coats exhibited better selective attention when the coats were described as doctor’s, rather than painter’s, coats, but only if the coats were worn (Adam & Galinsky, 2012). Manipulations of avatar attire have repeatedly reproduced the results of clothing effect studies (Peña et al., 2009). Additionally, inducing the illusion that dark-skinned rubber hands belong to light-skinned participants reduced implicit racial bias (Maister, Sebanz, Knoblich, & Tsakiris, 2013), comparable to reductions achieved via Proteus effect (Peck et al., 2013). IVR can complement this research, because many bodily transformations elude experimental manipulation for ethical or pragmatic reasons, such as plastic surgeries or affordable age transformations.

It is, however, important to note that in inducing the Proteus effect, the individual user’s reaction to the IVR technology and to the avatar can be a distinct influence on the effect (Ahn et al., 2016). This may not only relate to the previously mentioned feeling of body ownership of (Ahn et al., 2016), or identification with, the avatar (Yoon & Vargas, 2014), but also the subjective feeling of being present in the virtual environment (spatial presence; Ahn et al., 2016). This includes the possibility that IVR users need to experience a certain minimal degree of body ownership and/or presence to exhibit a Proteus effect (Ash, 2016). The extent of the user reactions’ influence on the Proteus effect has not yet been definitively established.

Especially Proteus effects on post-embodiment, real-life behavior have been ascribed importance, and have even been named among the central ethical challenges of wider IVR usage (Madary & Metzinger, 2016). There are first indications that individual reactions to the technologically mediated presentation can impact these effects (Yoon & Vargas, 2014). Exploring the role of these individual reactions can help establish grounded expectations of
when IVR usage could affect real life behaviors. The presented experiment investigated this through the study of a Proteus effect of avatar age on post-embodiment walking behavior.

**The Impact of Age Related Stereotypes on Walking Speed**

Studies in the context of exergames, video games centered around acts of physical exercise, indicate that the employed avatar can impact its user’s physical activity (Li & Lwin, 2016). This has been shown, both for exergames using IVR (Fox & Bailenson, 2009) and for games utilizing classical screen-based technologies (Peña & Kim, 2014). There is also reason to belief that walking behavior in particular could be affected by characteristics of the embodied avatar.

For nonimmersive applications, Yoo, Peña, and Drumwright (2015) found that participants using elderly avatars took longer to traverse a predetermined distance in the virtual world than those using young avatars. This relates to priming studies by Bargh, Chen, and Burrows (1996; see also Cesario, Plaks, & Higgins, 2006), wherein participants, for whom elderly had been primed, subsequently took longer to walk down a hallway, interpreted as activated stereotypes about slow elders unconsciously influencing the choice of walking speed. The respective priming effect has recently become the topic of controversial discussion due to its history of inconsistent direct replications (Bargh et al., 1996; Doyen, Klein, Pichon, & Cleeremans, 2012; Pashler, Harris, & Coburn, 2008).

Expanding on these studies, this experiment examined whether embodying elderly, compared to young, avatars impacts the time participants take to walk a set distance after they have left IVR. In line with results from previous research (e.g., Yoo et al., 2015), we predict that participants who had previously embodied an older avatar should require more time to traverse the same set distance than participants who had previously embodied younger avatars (H1: walking time \( t_{old} > t_{young} \)). This could result from older avatars leading to slower walking speeds and consequently to longer walking times compared to a control group who did not enter IVR (H2a: \( t_{old} > t_{control} \)), or it could result from younger avatars leading to faster walking speeds, i.e., shorter walking times compared to a non-IVR control group (H2b: \( t_{control} > t_{young} \)). Additionally, a first exploration of the temporal stability of avatar effects on walking speed over the time of the walk was conducted. Here, the existence of an interaction effect between avatar group and elapsed time since embodiment was postulated (H3: avatar \( \times \) time-interaction). Finally, moderating influences of body ownership (H4) and spatial presence (H5) were examined. In accordance with previous research (e.g., Ahn et al., 2016), it was expected that participants with higher reported feelings of body ownership
and spatial presence should exhibit an increased avatar effect on post-embodiment walking speed.

**Methods**

The study was approved by the local ethics committee and adhered to the Declaration of Helsinki and its latest amendments. All measures, manipulations, and exclusions are reported in this article.

**Sample**

A total of 74 young adults took part in the experiment, and received compensation of either course credit or 10€. This targeted sample size was based on power calculations for an expected Cohen’s $f$ effect size index of 0.40 based on the experiment in the literature that was closest in its methodological approach to the current study (compare Yoo et al., 2015), with an expected attrition rate of 15% (compare Classen, Bewernitz, & Shechtman, 2011). Further discussions of the power analysis, including a more detailed rational for the choice of the expected effect size, can be found in the supplementary materials (see S1 in the online supplementary materials available at https://www.tandfonline.com/hmep20). Additional details on participation requirements and screening procedures are also described in the supplementary materials (S2).

Anticipated reasons for exclusion from data analyses were technical difficulties, e.g. with the full-body tracking equipment (actual exclusion: 3 participants), breaking of the experimenter’s blindness by asking a question about the avatar’s appearance (1 participant), leaving the intended walkway or stopping during the walk (1 participant), seeing one of the cameras (2 participants), guessing the experiment’s intent (0 participants), choosing to abort the experiment or refusing to give informed consent including for the usage of video recordings (0 participants), and, last, experiencing high levels of visually induced motion sickness (VIMS; 0 participants), assessed between any two tests, using the Fast Motion Sickness Scale (FMS; Keshavarz & Hecht, 2011; cut-off criterion 15 as suggested by the original authors). Additionally, one participant was excluded from analyses related to the reported body ownership illusion due to incomplete questionnaire data.

The data of 67 participants were considered in the main analysis ($M_{age} = 24.79$; range: 18–34 years; 69% male). Among these, 45 participants took part in the IVR condition, with 22 participants randomly assigned to the young avatar and 23 participants to the old avatar condition. A control group consisting of 22 further young adults did not enter IVR.
**Apparatus and Materials**

**IVR technology**
In the IVR group, the virtual environment was displayed using the Oculus Rift Development Kit 2, a head-mounted display with a resolution of 960 × 1080 pixels per eye and a 100° nominal field of view, running at a refresh rate of 75 Hz. The participants’ head movements were tracked using the head-mounted display’s internal tracking, which was used to update the avatar’s head rotation. Skeletal tracking was achieved through optical tracking using the Microsoft Kinect for Windows utilizing a depth sensor at a 30 Hz refresh rate (see Figure 2). This was used to update the body of the avatar.

**IVR environment**
The virtual environment consisted of an octagonal room with participants placed in a central position. On the wall in front of them, they could see a screen whereupon instructions and test materials were displayed. Control elements used to work on the tasks were displayed as semitransparent elements in the space reachable from the central position. On either side of this screen were virtual mirrors angled in such a way that the avatar could be seen in the periphery when the participant attended to the screen and came more prominently into view when they interacted with the control elements.

**Avatars**
For each gender, one body model was constructed based on data from the SizeGERMANY project, a representative serial measurement campaign of the Forschungsinstitut Hohenstein Prof. Dr. Jürgen Mecheels GmbH & Co.KG and the Human Solutions GmbH. Independent of avatar age, all models’ body measurements were based on the data of average 18- to 25-year-old Germans assessed between 2007 and 2008. Besides the avatar shown in virtual mirrors, participants also saw a congruent headless mesh when looking down or moving their arms and hands into their line of sight. The avatar faces were created based on photos chosen from the CAL/PAL Face Database (Minear & Park, 2004) based on a study by Ebner (2008). Four photosets from the neutral expression group (one per gender and age group) were chosen, that showed minimal multivariate distance on the dimensions attractiveness, likeability, energy, and mood, while providing a clearly different perceived age (young group majority rating between 20 and 30 years; old age group between 60 and 70 years). The resulting avatars (Figure 2) had been shown to differ in their perceived age and, between age groups, in the explicit age-related stereotypes they elicited with regards to speed, yet they were evaluated as similar with regards to their attractiveness, likeability, energy, or mood (Christmann, Reinhard, & Lachmann, 2016; Faust-Christmann,
Reinhard, Hoffmann, Lachmann, & Bleser, in press). Walking-speed-related stereotypes were also observed for these avatars in a questionnaire-based prestudy and for the participants at hand (see S3). Participants were not familiar with the avatars used in the study and the avatars did not relate to any designed narrative.

**Video recordings**

The experiment utilized two GoPro Hero 3 cameras recording at 60 fps. OpenCV based image processing software was used in conjunction with markers in the scene to automatically yield walking times to the next frame. The video feed was further searched for anything that may have threatened the interpretation of the resulting walking times, such as obstructions, i.e., other people entering the walking path, or stopping behavior.

**Procedure**

The 45-min experiment was conducted by two trained experimenters stationed in separate rooms: the briefing room (BR) and the test room (TR). The rooms were connected by a 29.2 m (95.8 feet) walkway, which was outfitted with two synchronized hidden cameras on either side of the walkway (see Figure 1). To analyze walking speed, a stretch of 24 m (78.7 feet) of straight walkway was chosen, where in pretests raters judged that participants walked straight ahead, and were not, e.g., entering a room. The start and end points of this distance, as well as the middle point between them, were marked using unobtrusive optical markers identifiable in the camera’s video feed. Green footstools were placed at either end of the walkway, so

![Figure 1. Layout of locale utilized in the experiment.](image-url)
that participants did not have to search for the relevant doors. They were visible from every point of the chosen stretch of the walkway.

All sessions were conducted in the evenings to minimize the risk of uninvolved personal obstructing the walking phases between the two rooms. Each session started in the briefing room where participants gave informed consent to take part in the experiment. To ensure an unobstructed walk, they were asked to leave any additional burdens, such as jackets or bags in the briefing room. The first experimenter then instructed them to proceed to the test room using a standardized formulation. The participant’s walk was recorded by the two cameras, yielding the time taken from the briefing room to the test room ($t_{BRtoTR}$), divisible into a first and second half of the walk, as well as video feed that was later analyzed for stopping behavior.

In the test room, participants in the IVR groups were then instructed on the usage of the head-mounted display by the second experimenter, using semistandardized guidelines. This included the instruction that questions concerning the tasks could be directed to the second experimenter; all other questions should be posed afterward to the first experimenter. This was included to minimize the risk of participants in the IVR condition asking about the appearance of the avatar, thereby breaking the experimenter’s blindness. All unprompted instructions after this point were delivered in written form, either inside the IVR or on paper for the control group.

The following embodiment phase lasted, on average, 20.38 min (Range: 13.12–32.67 min). Participants in the IVR groups embodied an avatar of their own gender, which was randomly either depicted as young or old (Figure 2). The virtual room was not mirrored on any other display, leaving the experimenters blind toward the avatar condition. After a tracking test with a full-body mirror, participants performed a set of vision tests (Landolt ring test of visual acuity, Ishihara Color Vision test, Titmus Wirt ring test), and an attention test (based on the Frankfurter Aufmerksamkeits-Inventar-2 by Moosbrugger & Oehlenschlägel, 2011) in random order. The avatar moved synchronously with the participants’ movements, with body movements providing user inputs, e.g., to indicate the empty space in Landolt rings, the IVR users moved their arm in that direction. These tests were primarily meant to disguise the reason behind the experiment, but also provided participants with an engaging task that showcased the synchronicity between body and avatar movements. The control group worked on the same tests outside of IVR using printed stimuli.

Afterward, the second experimenter followed trained procedures to conclude this part of the experiment, which included the use of a standardized formulation to send participants back to the briefing room. Again, their walk on the corridor was recorded, resulting in
a measure of the time taken from the test room to the briefing room \( t_{TRioBR} \), as well as analyzable video feed.

In the briefing room, participants completed a battery of questionnaires, were debriefed by the first experimenter and gave informed consent related to the analysis of pertaining video recordings.

**Questionnaires**

**Igroup presence questionnaire**
The subjective feeling of presence in the virtual environment was measured using the Igroup Presence Questionnaire (IPQ; Schubert et al., 2001). In the questionnaire, 14 items were answered using a seven-point response format with differing descriptive anchors. It provides insights into the participant’s *spatial presence* \( \alpha_{SP} = .80 \), characterized by a feeling of being present in the virtual environment in contrast to feeling like an outside observer, *involvement* \( \alpha_{INV} = .76 \), referring to a feeling of being engaged with the virtual world, and *realism* \( \alpha_{REAL} = .68 \), a feeling that the virtual environment seemed consistent with its real-world equivalent.

![Figure 2. Avatar faces of female (upper row) and male (middle row) for avatars in the old (left column) and young (right column) age conditions and an illustration of avatar usage (lower row).](image-url)
Due to its low internal consistency, no further results pertaining to the realism scale will be reported.

**Body ownership questionnaire**
A questionnaire measuring the feeling of embodiment with regard to the utilized avatar was adapted from a measure reported by Ash (2016). In this questionnaire, four items were rated on a five-value numerical scale translating to labels ranging from 1 (*strongly disagree*) to 5 (*strongly agree*) and a sum scale was calculated. However, the resulting scale showed relatively low reliability ($\alpha_{BO\text{ orig}} = .68$). To increase the scales internal consistency, one item was deleted, resulting in an acceptable reliability ($\alpha_{BO\text{ mod}} = .79$). The analyzed items and related statistics are reported in the supplementary materials (Table S2).

**Simulator sickness questionnaire**
To assess individual symptom levels, the Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1993) was used. Participants rated their current status with regards to 16 symptoms associated with simulator sickness on a four-point response format ranging from *none* to *severe*, which were scored from 0 to 3. Weighted sum scales were calculated for the total level of symptoms ($r_{\text{split-half corrected}} = .89$ according to Kennedy et al., 2001) and three component scales related to nausea, oculomotor problems, and disorientation.

**Karolinska sleepiness scale**
A separate measure of subjective sleepiness, the Karolinska Sleepiness Scale (KSS; Akerstedt & Gillberg, 1990), was used to evaluate post-embodiment tiredness. In this single item measure participants rated their status using a nine-point response format ranging from 1 (*extremely alert*) to 9 (*very sleepy, great effort to keep awake, fighting sleep*).

**Miscellaneous questionnaire items**
Further administered items related to age, gender, handedness, previous computer and IVR experience, and exercise habits. Also included was an explicit check whether a camera had been seen.

**Participant’s inferences concerning research question**
Participants wrote a paragraph answering whether they had any beliefs concerning the research question behind the experiment. These texts were evaluated by two raters unaffiliated with the experiment, using a category system, including categories for mentions of the avatar or the corridor (for details see Table S2). The statements of any one participant could be placed in multiple categories.
Data Analysis

All statistical analysis was performed in IBM SPSS Statistics 24. Across tests unequal variance was assumed in case of a significant Levene’s test result at $\alpha = .1$ where applicable.

The following tests were performed to evaluate possible confounds: In the case of data from the IPQ presence questionnaire and the body ownership measure, only the two IVR groups were compared using two-tailed independent $t$-tests, because the questionnaire was developed for mediated experiences. For SSQ scores and pre-embodiment walking times, univariate ANOVAs were performed on the data of all groups. The three groups were further compared with regard to their post-embodiment tiredness using a Kruskal-Wallis H test, due to the ordinal nature of the single item measure. To increase the statistical power of tests, which guard against possible confounds, no correction for multiple testing was applied.

Hypotheses 1, 2a, 2b, and 3 were examined by exploring post-embodiment walking times ($t_{TRoBR}$), using a mixed-design ANCOVA with the two halves of the walk as a two-level within-subject factor, the three groups as the between subject factor, the pre-embodiment walking times ($t_{BRoTR}$) as a covariate, and gender as a fixed factor. Gender was chosen because there are indications that it can impact comfortable and maximal walking speed (Bohannon, Andrews, & Thomas, 1996), as well as individual reactions to IVR (Felnhofer, Kothenbauer, Beutl, Hlavacs, & Kryspin-Exner, 2012). In case of significant interactions with walking halves, any main effects were further explored using simple main effects. Subsequent post-hoc tests were Holm-Bonferroni corrected for multiple tests.

Last, the PROCESS macro 2.15 for SPSS (Hayes, 2013) was utilized to investigate the possibility that spatial presence or body ownership acted as moderators on the effect of avatar age on total walking time (Hypothesis 4). As the presence and body ownership questionnaires were developed and validated for mediated experiences, the non-IVR control group was excluded from these considerations. IVR group avatar age condition was effect coded with older avatars at the higher value. In case of significant moderation, Johnson-Neyman techniques were used for significance region specification.

Results

Demand Characteristics

Neither rater found any instances of a participant either referring to the avatar, its characteristics, or the walk down the corridor in the paragraphs they wrote about their ideas concerning the research questions behind the experiment (see Table S2 for the most common answers of each group).
Possible Confounds

An overview of the comparisons of the experimental groups, including central tendency measures, can be found in Table 1. In comparing the two IVR groups, independent t-tests could not establish differences between the avatar groups in spatial presence, \( t(36.258) = -0.311, p = .758, d = 0.093 \); involvement, \( t(43) = -0.081, p = .936, d = 0.024 \); or body ownership, \( t(42) = -0.223, p = .824, d = 0.071 \).

Univariate ANOVAs did not reveal significant differences between the three experimental groups with regard to baseline walking times, neither in the total time taken to walk from the briefing room to the test room, \( F(2,64) = 0.048, p = .953, \eta^2_p = .002 \), nor for the walking times during the first, \( F(2,64) = 0.054, p = .947, \eta^2_p = .000 \), or second halves of the walking time to the test room, \( F(2,64) = 0.187, p = .830, \eta^2_p = .006 \).

One-way ANOVAs did not yield significant differences between the experimental groups in the SSQ’s total level of symptoms, \( F(2,64) = 1.590, p = .212, \eta^2_p = .047 \); nor for oculomotor-related symptoms, \( F(2,64) = 0.215, p = .807, \eta^2_p = .007 \); or disorientation, \( F(2,64) = 0.884, p = .418, \eta^2_p = .027 \). However, a one-way ANOVA analyzing nausea-related symptoms revealed differences between the three groups, \( F(2,64) = 4.701, p = .012, \eta^2_p = .128 \), with post-hoc tests indicating higher symptoms in the control group compared to both the old

| Variable | Young Avatar | Old Avatar | Control Group |
|----------|--------------|------------|---------------|
| Baseline walking time (ttBRtoTR) | | | |
| – First half of walk [s] | 9.69 | 2.07 | 9.59 | 2.16 | 9.63 | 1.63 |
| – Second half of walk [s] | 9.89 | 2.33 | 10.17 | 1.64 | 9.88 | 1.21 |
| Post-embodiment walking time (ttTRtoBR) | | | |
| – First half of walk [s] | 10.37 | 1.61 | 10.33 | 1.45 | 9.77 | 1.11 |
| – Second half of walk [s] | 9.16°O | 1.35 | 10.51YC | 1.46 | 9.48°O | 1.46 |
| Igroup Presence Questionnaire (IPQ) | | | |
| – Spatial presence | 4.54 | 0.80 | 4.61 | 0.53 | - | - |
| – Involvement | 4.58 | 1.18 | 4.61 | 1.23 | - | - |
| Body ownership | 3.46 | 0.80 | 3.52 | 0.99 | - | - |
| Simulator Sickness Questionnaire (SSQ) | | | |
| – Total | 24.99 | 16.62 | 20.05 | 20.02 | 31.87 | 23.03 |
| – Nausea | 15.61°C | 8.89 | 9.92C | 10.95 | 25.30Y0 | 23.47 |
| – Oculomotor | 22.05 | 15.32 | 20.01 | 22.16 | 25.05 | 19.15 |
| – Disorientation | 29.74 | 35.71 | 23.39 | 26.62 | 35.70 | 28.68 |
| Karolinska Sleepiness Scale (KSS) | | | |
| Mdn | IQR | Mdn | IQR | Mdn | IQR |
| 2 | 1 | 1 | 1 | 1 | 1 |

C = differs significantly from control group at \( \alpha = 0.05 \),
O = differs significantly from old avatar group at \( \alpha = 0.05 \),
Y = differs significantly from young avatar group at \( \alpha = 0.05 \)
\( \Delta C-O = 15.381 \), \( p = .004 \), and young avatar groups \( \Delta C-Y = 9.694 \), \( p = .049 \), though not between the two IVR groups \( \Delta Y-O = 5.698 \), \( p = .331 \).

With regard to tiredness experienced after the experiment, a Kruskal-Wallis H test did not uncover any significant differences between the three groups, \( \chi^2(2, N = 67) = 2.227 \), \( p = .328 \), \( \varepsilon^2 = .026 \).

**Effect of Avatar Age Condition on Post-embodiment Walking Time**

The mean post-embodiment walking times are reported in Table 1 and are further illustrated in Figure 3. In a mixed-design ANCOVA of the time taken to walk from the IVR room to the briefing room after embodiment, divided into two halves, controlling for baseline walking times, the between subject effects revealed a significant effect of group, \( F(2,59) = 3.785 \), \( p = .028 \), \( \eta^2_p = .114 \); as well as a marginal significant between subject effect of gender, \( F(1,59) = 2.985 \), \( p = .089 \), \( \eta^2_p = .048 \); but no interaction between gender and group, \( F(2,59) = 1.116 \), \( p = .334 \), \( \eta^2_p = .036 \). To further elucidate the effects of experimental group on walking speed, within-subject effects divided the walking time into the time taken from the IVR room to the halfway point and the second half ending at the briefing room. The analysis did not reveal a main effect of the comparison of these two halves on walking time, \( F(1,59) = 1.339 \), \( p = .252 \), \( \eta^2_p = .022 \); but it did yield a significant interaction between walkway half and the experimental group, \( F(2,59) = 3.790 \), \( p = .028 \), \( \eta^2_p = .114 \) (H3). Simple main effect analysis showed significant differences between experimental groups

![Figure 3](image-url)

**Figure 3.** Means of the post-embodiment walking times (from the test room to the briefing room) for the groups who previously embodied either young or old avatars in immersive virtual reality, and for the control group who did not use immersive virtual reality technologies. Error bars display standard errors of the mean.

---

1. A repeated measurement ANOVA without the inclusion of gender produced the same pattern of results as the analysis with gender, i.e., a between-subject effect of group, \( F(2,62) = 4.289 \), \( p = .018 \); no within-subject effect of walkway-half, \( F(1,62) = 1.364 \), \( p = .247 \); but a significant interaction between walkway-half and group, \( F(2,62) = 3.392 \), \( p = .040 \).
during the first half of the walk, \( p = .026 \), but not during the second half of the walk, \( p = .125 \). During the first half of the post-embodiment walk, participants of the IVR group that just embodied an older avatar, took significantly longer to reach the halfway point than those who had just embodied the younger avatar \( (\Delta_{Y-O} = -1.34s) \), \( p = .033 \) (H1, H3) and the non-IVR control group \( (\Delta_{C-O} = -1.03s) \), \( p = .100 \) (H2a). The young avatar and control groups did not differ in the time taken to reach the halfway point \( (\Delta_{C-Y} = 0.31s) \), \( p = .380 \) (H2b).

During the second half of the walk, neither the IVR groups \( (\Delta_{Y-O} = 0.04s) \), \( p = .821 \) (H1, H3), nor the control group and old avatar \( (\Delta_{C-O} = 0.56s) \), \( p = .225 \) (H2a), or young avatar groups \( (\Delta_{Y-C} = 0.59s) \), \( p = .155 \) (H2b), differed in their walking times. A pairwise comparison with regards to gender revealed that men \( (M_{male} = 19.88s) \) tended to take marginally less time to walk from the IVR room back to the briefing room than women \( (M_{female} = 20.62s) \), \( p = .089 \). Further interactions of the walkway halving factor did not reach significance, neither with gender, \( F(1,59) = 0.514, p = .476, \eta^2_p = .009 \); nor in a higher order interaction with group and gender, \( F(2,59) = 1.064, p = .352, \eta^2_p = .035 \).

**Moderator Effects of Spatial Presence and Body Ownership**

An analysis of possible moderator effects of spatial presence on the relationship between age of avatar embodied in IVR and total walking time after embodiment showed that spatial presence itself did not significantly impact post-embodiment walking time, \( b_{\text{Presence}} = -0.327, t(41) = -0.591, p = .558, d = 0.185 \), but an interaction of spatial presence with avatar age group did reach marginal significance, \( b_{\text{PresenceXGroup}} = 1.870, t(41) = -1.957, p = .057, d = 0.611 \) (H5; Figure 4a), with a change in \( R^2 \) due to the interaction of 6.4%. The Johnson-Neyman technique indicated a significance region above a spatial presence value of 4.555 (Figure 4b), with 37.8% of the observed spatial presence values falling below this threshold and 62.2% above it. Thus a conditional effect of avatar age on post-embodiment walking time for a low spatial presence of 3.909 (one standard deviation below mean) does not result in a significant effect, \( b_{\text{Group|Presence=Mean-1SD}} = -0.020, t(41) = -0.023, p = .982, d = 0.007 \); it reaches significance at the sample’s mean spatial presence, \( b_{\text{Group|Presence=Mean}} = 1.231, t(41) = -2.098, p = .042, d = 0.655 \), and further increases at higher reported values of spatial presence of 5.247 (one standard deviation above mean), \( b_{\text{Group|Presence=Mean+1SD}} = 2.482, t(41) = -2.885, p = .006, d = 0.901 \).

Regression with body ownership as a moderating third variable with regards to the effect of embodied avatar age on post-embodiment walking time neither yielded a significant effect of body ownership itself, \( b_{\text{BodyOwnership}} = -0.007, t(40) = -0.117, p = .991, d = 0.037 \), nor of an interaction between avatar group and body ownership, \( b_{\text{BodyOwnershipXGroup}} = 0.426, t(40) = 0.553, p = .583, d = 0.184 \) (H4).
Discussion

The study at hand investigated the effects of embodying avatars of different ages on post-embodiment walking behavior within a short timespan after an IVR experience. Possible moderator effects of the subjective IVR experience on this avatar effect were a special focus of the study.

In comparing the young avatar, old avatar, and non-IVR control groups, no differences were found in their baseline walking speed, their spatial presence, or in their tiredness after the experiment. However, the control group reported higher levels of specifically nausea-related symptoms than either IVR group. These symptoms are usually thought to result from artifacts of IVR usage (Keshavarz, Hecht, & Lawson, 2015), but implied demand could have played a role. Participants who experienced IVR might have tried to downplay their symptoms to suggest more positive IVR experiences, whereas non-IVR group participants might have thought that the experimenter wanted to induce symptoms. This was, however, not evident in the collected statements concerning the supposed purpose of the experiment. Given that higher symptom levels would be expected to result

Figure 4. Conditional effects of avatar age on post-embodiment walking speed dependent on levels of the Igroup presence questionnaire’s spatial presence dimension: (a) illustration of predicted group differences; (b) predicted group differences with 95%-confidence intervals (negative values indicate faster old avatar group).
in slower walking speeds (Sundelin et al., 2015), this is unlikely to impact the conclusions below.

Proteus Effect of Avatar Age on Post-embodiment Walking Time

In this study, participants who had previously embodied older avatars took longer to traverse the same distance than participants who had embodied younger avatars (H1). Hereby, the study offers additional evidence (compare Van Gelder et al., 2013; Yee & Bailenson, 2007, 2009; Yee et al., 2009) that the avatar that IVR users embody can affect their behavior after they have left IVR. This fact is at the heart of ethical discussions of avatar effects as a consequence of IVR usage (Madary & Metzinger, 2016). The established effect on walking speed is also comparable to reports by Yoo et al. (2015), though by choosing their own walking speed, participants were more directly involved in the study, compared to the usage of input mechanisms to affect an avatar’s walking speed in the study by Yoo and colleagues. Although this may indicate plausibility for the results obtained by Bargh et al. (1996), it is likely that mechanisms beyond mere exposure priming are engaged in the Proteus effect (Peña et al., 2016; Yee et al., 2009). To address concerns raised in relation to earlier priming studies (Doyen et al., 2012), this study made efforts to protect blindness and used automated mechanisms to calculate walking times.

Comparisons with the control group indicate that the older avatar group slowed down (H2a); the younger avatar group did not speed up (H2b). Given the sample of young adults, this suggests that Proteus effects require identity cues generated by the avatar that differ between users and their avatars. In this vein, Fox et al. (2013) have stated that Proteus effects occur when the avatar’s differences from the physical self are meaningful, which, according to them, is often expressed through dissimilarities. Alternatively, the activated stereotype may relate more consistently to older people walking slowly than to young people walking fast. Further research that differentiates between these possible explanations could help establish when embodiment-specific avatar effects should be expected to occur.

Temporal Stability of Behavioral Changes

The persistence of the Proteus effect after IVR usage is an important consideration in gauging the effect’s practical implications. In this context, a Proteus effect affecting walking speed could be of special interest because walking is a relatively innocuous task, which can be extended over longer periods of time and can be repeatedly performed by participants, even without threatening their blindness to the experiments purpose. As such, a walking-speed-based task could be used to further study the temporal extends of the Proteus effect. Our experiment offers a first exploration of this phenomenon and shows that behavioral changes
were only evident during the first half of the post-embodiment walk (H3), which could indicate fast post-embodiment decay rates for behavioral changes. This matches previous experimental results (Yee et al., 2009), where embodiment-specific effects of avatar appearance on real-life behavior could not be demonstrated to be sustained past early post-exposure instances tests.

Additional research should expand on these results and could, e.g., by using Proteus effects on walking speed, study the temporal stability of behavioral effects past the first few minutes after the embodiment experience. In this context, attitudinal changes have been shown to persist even a week after embodiment (Ahn et al., 2016) and to partly mediate behavioral changes (Yang et al., 2014). Future studies could incorporate concurrent attitudinal effects as a possible sustaining mechanism for behavioral changes beyond the early minutes after embodiment.

**Moderator Effects of Subjective IVR Experience**

Previous studies have identified influences of perceived body ownership on avatar effects (Ahn et al., 2016; Ash, 2016). This study did not find an analogous effect on post-embodiment walking speed differences (H4). It should be noted that one item was deleted from the body ownership scale in the current study due to the scale’s low initial reliability. Although the scale’s low reliability in this study could have impacted the results, the study also focused on two conditions that are thought to produce high degrees of experienced body ownership. By contrast, previous studies used a non-IVR boxing game without motion controls (Ash, 2016), a monitor-based third-person shooting game (Yoon & Vargas, 2014), or they compared embodiment to passive viewing (Ahn et al., 2016). Subjective body ownership may affect Proteus effects most clearly in the form of a threshold at midlevel intensities that has to be exceeded for avatar effects to occur (Ash, 2016).

Spatial presence functioned as a moderator for this behavioral Proteus effect (H5), with avatar age only impacting post-embodiment walking speed for the two-thirds of the sample who reported more pronounced feelings of being in the virtual world. This matches inconsistent reports identifying presence as a mediator between embodiment of animals and later attitudinal changes (Ahn et al., 2016). The data indicates that those individuals who develop a stronger feeling of being in the virtual environment will also be more strongly impacted by a Proteus effect.

Because IVR technologies tend to produce more pronounced feelings of spatial presence than classical screen-based setups (Cummings & Bailenson, 2015), the connection between the strength of behavioral Proteus effects and the experienced spatial presence suggest that effects of avatar embodiment constitute a special ethical challenge (compare Madary & Metzinger, 2016), but also a novel opportunity (compare Hershfield et al., 2011; Peck et al.,
A clear understanding of the preconditions and moderators of these avatar effects can help us evaluate the connected potential risks, e.g., with regard to aggressive cognitions and behaviors after leaving IVR (Ash, 2016). This study indicates that the role of subjective IVR experiences, specifically spatial presence, should be considered in this context and that highly immersive experiences are more likely to induce Proteus effects that impact behavior even after the embodiment experience has ended.

**Limitations**

The sample tested in this study consisted of young adults between the ages of 18 and 34 and showed a clear gender imbalance with 69% of the participants being men. Although no interaction between avatar group and gender has been found in this study, further studies with a more balanced sample are needed to evaluate the impact of gender on behavioral Proteus effects.

The study also only tested for an effect of avatar embodiment after a single, short embodiment experience. Future research could address how repeated and prolonged exposure affects Proteus effects—whether it consolidates the effects or if further familiarization with an avatar decreases novelty and saliency of existing differences, and thereby, possibly, avatar effects. This study only targeted a head-mounted display-based presentation of the virtual environment with motion-based input mechanisms. Although previous studies showed similar avatar effects using a desktop display (Yoo et al., 2015) or without motion controls (Ash, 2016), more research is needed to evaluate how and when display and input mechanisms impact Proteus effects.

**Conclusion**

Immersive virtual reality and Proteus effects are promising tools for psychological research, though subjective reactions to IVR need to be acknowledged. Commercial-grade IVR technologies offer the possibility to embody different avatars to a wider audience, with the Proteus effect literature indicating a potential impact on post-embodiment behavior. However, these effects may not affect all IVR users. This study indicates that those who experience a stronger feeling of spatial presence in the presented virtual environment also exhibit a stronger effect of the embodied avatar on their behavior after leaving IVR.

**Acknowledgments**

We thank Natalie C. Ebner, and the SizeGERMANY project of the Forschungsinstitut Hohenstein Prof. Dr. Jürgen Mecheels GmbH & Co.KG and the Human Solutions GmbH for their support during the avatar creation phase.
Disclosure statement
No potential conflict of interest was reported by the authors.

ORCID
René Reinhard http://orcid.org/0000-0001-9660-7963
Corinna A. Faust-Christmann http://orcid.org/0000-0002-6445-797X

References
Adam, H., & Galinsky, A. D. (2012). Enclothed cognition. Journal of Experimental Social Psychology, 48(4), 918–925. doi:10.1016/j.jesp.2012.02.008
Ahn, S. J., Bostick, J., Ogle, E., Nowak, K. L., McGillicuddy, K. T., & Bailenson, J. N. (2016). Experiencing nature: Embodying animals in immersive virtual environments increases inclusion of nature in self and involvement with nature. Journal of Computer-Mediated Communication, 21(6), 399–419. doi:10.1111/jcc4.12173
Akerstedt, T., & Gillberg, M. (1990). Subjective and objective sleepiness in the active individual. The International Journal of Neuroscience, 52(1–2), 29–37. doi:10.3109/00207459008994241
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 and Culture, 11(4), 422–440. doi:10.1177/1555412014568870
Banakou, D., Groten, R., & Slater, M. (2013). Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. Proceedings of the National Academy of Sciences, 110(31), 12846–12851. doi:10.1073/pnas.1306779110
Bargh, J. A., Chen, M., & Burrows, L. (1996). Automaticity of social behavior: Direct effects of trait construct and stereotype activation on action. Journal of Personality and Social Psychology, 71(2), 230–244. doi:10.1037/0022-3514.71.2.230
Bem, D. J. (1972). Self-perception theory. In L. Berkowitz (Ed.), Advances in experimental social psychology: Advances in experimental social psychology (Vol. 6, pp. 1–62). New York, NY: Academic Press.
Bohannon, R. W., Andrews, A. W., & Thomas, M. W. (1996). Walking speed: Reference values and correlates for older adults. Journal of Orthopaedic & Sports Physical Therapy, 24(2), 86–90. doi:10.2519/jospt.1996.24.2.86
Cesario, J., Plaks, J. E., & Higgins, E. T. (2006). Automatic social behavior as motivated preparation to interact. Journal of Personality and Social Psychology, 90(6), 893–910. doi:10.1037/0022-3514.90.6.893
Christmann, C., Reinhard, R., & Lachmann, T. (2016). Explizite und implizite Stereotype bezüglich Alter und Geschlecht bei der Einschätzung des Fahrverhaltens anderer Personen. Talk presented at the 50. Congress of the German Society for Psychology (DGPs), Leipzig, Germany.
Classen, S., Bewernitz, M., & Shechtman, O. (2011). Driving simulator sickness: An evidence-based review of the literature. American Journal of Occupational Therapy, 65, 179–188.
Cummings, J. J., & Bailenson, J. N. (2015). How immersive is enough? A meta-analysis of the effect of immersive technology on user presence. Media Psychology, 19, 272–309. doi:10.1080/15213269.2015.1015740
Doyen, S., Klein, O., Pichon, C.-L., & Cleeremans, A. (2012). Behavioral priming: It's all in the mind, but whose mind? *PLoS One*, 7(1), e29081. doi:10.1371/journal.pone.0029081

Ebner, N. C. (2008). Age of face matters: Age-group differences in ratings of young and old faces. *Behavior Research Methods*, 40(1), 130–136.

Faust-Christmann, C. A., Reinhard, R., Hoffmann, A., Lachmann, T., & Bleser, G. (in press). A face validation study for the investigation of proteus effects targeting driving behavior. In *HCI International 2019*. Cham, Switzerland: Springer.

Felnhofer, A., Kothgassner, O. D., Beutl, L., Hlavacs, H., & Kryspin-Exner, I. (2012). Is virtual reality made for men only? Exploring gender differences in the sense of presence. In *ISPR, 2012: Annual proceedings of the international society on presence research* (pp. 103–112). Philadelphia, PA: ISPR Press.

Fox, J., & Bailenson, J. N. (2009). Virtual self-modeling: The effects of vicarious reinforcement and identification on exercise behaviors. *Media Psychology*, 12, 1–25. doi:10.1080/15213260802669474

Fox, J., Bailenson, J. N., & Tricase, L. (2013). The embodiment of sexualized virtual selves: The proteus effect and experiences of self-objectification via avatars. *Computers in Human Behavior*, 29(3), 930–938. doi:10.1016/j.chb.2012.12.027

Groom, V., Bailenson, J. N., & Nass, C. (2009). The influence of racial embodiment on racial bias in immersive virtual environments. *Social Influence*, 4(3), 231–248. doi:10.1080/15534510802643750

Hershfield, H. E., Goldstein, D. G., Sharpe, W. F., Fox, J., Yeykelis, L., Carstensen, L. L., & Bailenson, J. N. (2011). Increasing saving behavior through age-progressed renderings of the future self. *JMR, Journal of Marketing Research*, 48(SPL), S23–S37. doi:10.1509/jmkr.48.SPL.S23

Johnson, K., Lennon, S. J., & Rudd, N. (2014). Dress, body and self: Research in the social psychology of dress. *Fashion and Textiles*, 1(1), 20:1–20:24. doi:10.1186/s40691-014-0020-7

Kennedy, R. S., Drexler, J. M., Compton, D. E., Stanney, K. M., Lanham, S., & Harm, D. L. (2001). Configural scoring of simulator sickness, cybersickness and space adaptation syndrome: Similarities and differences? In L. J. Hettinger & M. W. Haas (Eds.), *Virtual and adaptive environments: Applications, implications, and human performance* (pp. 247–278). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, 3(3), 203–220. doi:10.1207/s15327108ijap0303_3

Keshavarz, B., & Hecht, H. (2011). Validating an efficient method to quantify motion sickness. *Human factors: The journal of the human factors and ergonomics society*, 53(4), 415–426.

Keshavarz, B., Hecht, H., & Lawson, B. D. (2015). Visually-induced motion sickness: Causes, characteristics, and countermeasures. In K. S. Hale & K. M. Stanney (Eds.), *Human factors and ergonomics series: Handbook of virtual environments. Design, implementation, and applications* (2nd ed., pp. 647–698). Boca Raton, FL: CRC Press Taylor and Francis.

Kilteni, K., Bergstrom, I., & Slater, M. (2013). Drumming in immersive virtual reality: The body shapes the way we play. *IEEE Transactions on Visualization and Computer Graphics, 19*(4), 597–605. doi:10.1109/TVCG.2013.29

Li, B. J., & Lwin, M. O. (2016). Player see, player do: Testing an exergame motivation model based on the influence of the self avatar. *Computers in Human Behavior*, 59, 350–357. doi:10.1016/j.chb.2016.02.034
Madary, M., & Metzinger, T. K. (2016). Real virtuality: A code of ethical conduct - Recommendations for good scientific practice and the consumers of VR-technology. *Frontiers in Robotics and AI, 3*(3). doi:10.3389/frobt.2016.00003

Maister, L., Sebanz, N., Knoblich, G., & Tsakiris, M. (2013). Experiencing ownership over a dark-skinned body reduces implicit racial bias. *Cognition, 128*(2), 170–178. doi:10.1016/j.cognition.2013.04.002

Minear, M., & Park, D. C. (2004). A lifespan database of adult facial stimuli. *Behavior Research Methods, Instruments, & Computers, 36*(4), 630–633. doi:10.3758/BF03206543

Moosbrugger, H., & Oehlschlägel, J. (2011). *Frankfurter Aufmerksamkeits-Inventar 2 (FAIR-2).* Bern, Switzerland: Huber.

Peck, T. C., Seinfeld, S., Aglioti, S. M., & Slater, M. (2013). Putting yourself in the skin of a black avatar reduces implicit racial bias. *Consciousness and Cognition, 22*(3), 779–787. doi:10.1016/j.concog.2013.04.016

Peña, J., Khan, S., & Alexopoulos, C. (2016). I am what I see: How avatar and opponent agent body size affects physical activity among men playing exergames. *Journal of Computer-Mediated Communication, 21*(3), 195–209. doi:10.1111/jcc4.2016.21.issue-3

Peña, J., & Kim, E. (2014). Increasing exergame physical activity through self and opponent avatar appearance. *Computers in Human Behavior, 41*, 262–267. doi:10.1016/j.chb.2014.09.038

Peña, J. F. (2011). Integrating the influence of perceiving and operating avatars under the automaticity model of priming effects. *Communication Theory, 21*(2), 150–168. doi:10.1111/j.1468-2885.2011.01380.x

Peña, J. F., Hancock, J., & Merola, N. A. (2009). The priming effects of avatars in virtual settings. *Communication Research, 36*(6), 838–856. doi:10.1177/0093650209346802

Schubert, T., Friedmann, F., & Regenbrecht, H. (2001). The experience of presence: Factor analytic insights. *Presence: Teleoperators and Virtual Environments, 10*(3), 266–281. doi:10.1162/105474601300343603

Slater, M., & Sanchez-Vives, M. V. (2014). Transcending the self in immersive virtual reality. *Computer, 47*(7), 24–30. doi:10.1109/MC.2014.198

Sundelin, T., Karshikoff, B., Axelsson, E., Hoglund, C. O., Lekander, M., & Axelsson, J. (2015). Sick man walking: Perception of health status from body motion. *Brain, Behavior, and Immunity, 48*, 53–56. doi:10.1016/j.bbi.2015.03.007

Tamborini, R., Novotny, E., Prabhu, S., Hofer, M., Grall, C., Klebig, B., … Bente, G. (2018). The effect of behavioral synchrony with black or white virtual agents on outgroup trust. *Computers in Human Behavior, 83*, 176–183. doi:10.1016/j.chb.2018.01.037

Van Gelder, J.-L., Hershfield, H. E., & Nordgren, L. F. (2013). Vividness of the future self predicts delinquency. *Psychological Science, 24*(6), 974–980. doi:10.1177/0956797612465197

Yang, G. S., Gibson, B., Luke, A. R., Huesmann, L. R., & Bushman, B. J. (2014). Effects of avatar race in violent video games on racial attitudes and aggression. *Social Psychological and Personality Science, 5*(6), 698–704. doi:10.1177/1948550614528008

Yee, N., & Bailenson, J. (2006). Walk a mile in digital shoes: The impact of embodied perspective-taking on the reduction of negative stereotyping in immersive virtual environments. In C. C. Bracken & M. Lombard (Eds.), *Presence 2006. Proceedings of the 9th international workshop on presence* (pp. 147–156). Cleveland, OH: International Society for Presence Research.

Yee, N., & Bailenson, J. (2007). The proteus effect: The effect of transformed self-representation on behavior. *Human Communication Research, 33*(3), 271–290. doi:10.1111/hcre.2007.33.issue-3
Yee, N., & Bailenson, J. N. (2009). The difference between being and seeing: The relative contribution of self-perception and priming to behavioral changes via digital self-representation. *Media Psychology, 12*(2), 195–209. doi:10.1080/15213260902849943

Yee, N., Bailenson, J. N., & Ducheneaut, N. (2009). The proteus effect: Implications of transformed digital self-representation on online and offline behavior. *Communication Research, 36*(2), 285–312. doi:10.1177/0093650208330254

Yoo, S.-C., Peña, J. F., & Drumwright, M. E. (2015). Virtual shopping and unconscious persuasion: The priming effects of avatar age and consumers’ age discrimination on purchasing and prosocial behaviors. *Computers in Human Behavior, 48*, 62–71. doi:10.1016/j.chb.2015.01.042

Yoon, G., & Vargas, P. T. (2014). Know thy avatar: The unintended effect of virtual-self representation on behavior. *Psychological Science, 25*(4), 1043–1045. doi:10.1177/0956797613518350