TYPE Original Research
PUBLISHED 26 April 2024
DOI 10.3389/frvir.2024.1363043

OPEN ACCESS

EDITED BY
Daniel Thalmann,
Swiss Federal Institute of Technology Lausanne, Switzerland

REVIEWED BY
Michel Guerraz,
Université Savoie Mont Blanc, France
Omar Janeh,
University of Technology, Iraq

*CORRESPONDENCE
Yusuke Koseki,
koseki-yusuke551@g.ecc.u-tokyo.ac.jp
Tomohiro Amemiya,
amemiya@vr.u-tokyo.ac.jp

RECEIVED 29 December 2023
ACCEPTED 10 April 2024
PUBLISHED 26 April 2024

CITATION
Koseki Y and Amemiya T (2024), Being an older person: modulation of walking speed with geriatric walking motion avatars.
Front. Virtual Real. 5:1363043.
doi: 10.3389/frvir.2024.1363043

Being an older person: modulation of walking speed with geriatric walking motion avatars

Yusuke Koseki[1]* and Tomohiro Amemiya[2,3]*

[1]Graduate School of Information Science and Technology, University of Tokyo, Tokyo, Japan, [2]Information Technology Center, University of Tokyo, Tokyo, Japan, [3]Virtual Reality Educational Research Center, University of Tokyo, Tokyo, Japan

The phenomenon of one's walking speed being affected by that of other pedestrians on the street is often observed in real-world scenarios. However, the effects of the motion and familiarity of avatars on a user in virtual reality have not been thoroughly investigated. Therefore, this study explored how alterations in human avatars affect the walking speed and sensation of users. Furthermore, walking speed has been shown to be influenced not only by visual perception but also by cognition. However, few studies have investigated the relationships between visual perception, cognition, and behavior. Therefore, we examined the relationships between stereotypical words for older people, a representative example of cognition-induced changes in walking speed, and visual perception stimuli of avatars. The results revealed a significant interaction between the stereotype and avatar walking motion. In particular, in the absence of the stereotype, participants were strongly affected by the older walking motion of the avatar, and their walking speed decreased. We also found that the walking motion of avatars significantly affects participants walking speed and sensation. These findings provide pioneering insights into the psychological factors that regulate human walking speed and propose a new method for manipulating the user's walking speed and sensation in VR space.

KEYWORDS

walking, virtual reality, locomotion, social behavior, avatar

1 Introduction

1.1 Walking research in virtual worlds

Walking as a means of movement in virtual reality (VR) spaces has become increasingly important for rehabilitation and training applications [Janeh and Steinicke (2021); Nilsson et al. (2018); Janeh et al. (2017a); Janeh et al. (2017b)]. Real-walking, which allows users to synchronize the speed, direction, and distance of walking in real space with walking in VR space, has stood out as an essential technique for offering high-quality walking sensation and immersion (Slater et al., 1995; Usoh et al., 1999). This approach has the challenge of requiring a large real space. Therefore, various methods have been proposed for walking in VR environments.

The walking-in-place method has been proposed as a method that does not require movement in real space (Slater et al., 1995; Templeman et al., 1999; Nilsson et al., 2016). This technique enables users' to move virtual space by performing stepping-like movements on the spot. This technique has been realised using specific equipment such as omni-directional treadmills (Darken, 1997; Iwata, 1999; Wehden, 2021). Also, seated VR, a virtual walking system by mapping the cycling biomechanics of seated users' legs to virtual walking (Amemiya et al., 2019; Amemiya et al., 2020; Freiwald et al., 2020; Matsuda et al., 2021; Moullec et al., 2023), has been proposed for walking VR space.

On the other hand, utilizing psychological approaches that take advantage of human illusions to generate a walking sensation has attracted much attention. The redirected walking approach was realized to compress a large virtual environment into a physical space that could be significantly smaller while maintaining the feeling of real walking (Razzaque et al., 2002; Razzaque, 2005; Steinicke et al., 2009; Suma et al., 2011; Matsumoto et al., 2016). This approach enables users to walk in a large virtual space in a narrow real space by presenting users with virtual images with manipulations for the amount of movement and walking direction. Unfortunately, this method has the problem that when the user's walking speed or walking path deviates from the assumption, the visual and tactile information becomes inconsistent and the effect of redirected walking does not occur.

Although extensive research has been carried out on walking in VR, methods for controlling the walking speed of users in VR spaces have not been sufficiently studied. Also, it has not been investigated how the VR experience with multiusers simultaneously, which has been increasing with the development of the social VR Platform in recent years, affects the walking speed and sensation. In order to apply the previously studied walking methods in VR space to multi-user VR, further investigation of the influence of other avatars on walking speed and walking sensation is needed.

1.2 Virtual reality and avatars

The representation that takes the place of the real body in VR space is called an avatar. As well as research findings in real space (Rio et al., 2014), research has shown that human walking speed, deviation, and trajectory length are influenced by walking in a virtual environment surrounded by a moving virtual avatar population (Koilias et al., 2020). In addition to virtual crowds, silhouettes and moving point-light dots on walls affect walking speed when perceived as the walking motion of humans (Tanizaki et al., 2021). However, previous research on avatars and walking has not investigated the effects of the avatar's walking motion and relationship with the user on walking sensation.

Also, as an effect specific to avatar, studies of older people (Beaudoin et al., 2020; Reinhard et al., 2020; Tammy Lin and Wu, 2021; Vahle and Tomasik, 2022) have uncovered the *Proteus* effect (Yee and Bailenson, 2007; Kilteni et al., 2013; Banakou et al., 2018), in which individuals' behavior is affected by the stereotypes of their embodied avatars. Reinhard et al. (2020) showed that participants who had previously embodied older avatars took significantly longer to walk a set distance than either young avatar or control group participants. However, the effect of the other avatar instead of one's own avatar on walking speed has not been investigated.

1.3 The stereotypical words for older people

Behavioral economics has delved into people's subconscious and irrational behavior, leading to the development of "nudging" techniques that can shape subsequent behavior and decision-making (Thaler, 2018). This approach has been integrated into various policy applications (Ferraro and Price, 2013). Various theories have been proposed in behavioral economics, one of which is the priming effect. The priming effect generally refers to the processing of a preceding stimulus facilitating the processing of a subsequent stimulus.

Priming effects can be classified into two types: direct and indirect. A direct priming effect is a phenomenon in which processing is facilitated by prior information identical to the target information with a relatively long interval between the two stimuli. A specific example of this phenomenon is that in the fragment-completion task, previously seen words from a list are primed (facilitated) more than words not on the list, resulting in better performance on the fragment-completion task (Tulving et al., 1982). This indicates that people may retain the information provided by the preceding stimulus and facilitate information processing when they encounter the same stimulus. In contrast, an indirect priming effect is a phenomenon in which the processing of target information is facilitated by semantically related preceding stimuli, and the time interval between the two stimuli ranges from tens of msec to a few seconds. For instance, one study showed that the word "bread" was recognized more quickly and accurately when a word associated with "bread," such as "butter," was presented as a preceding stimulus (Meyer and Schvaneveldt, 1971).

Furthermore, a priming effect is not only a word or concept association but also an unconscious triggering of behavior based on trait concepts and stereotypes (Bargh et al., 1996; Blair and Banaji, 1996; Levy, 1996; Chen and Bargh, 1997; Dijksterhuis et al., 2000; Dijksterhuis and Bargh, 2001; Wheeler and Petty, 2001; Spears et al., 2004). One study found that people primed with words associated with older people subsequently walked slower (Bargh et al., 1996). Some argue that the effects of older adult priming may be influenced merely by the experimenter's expectations (Doyen et al., 2012). In addition, the effect of priming older people has not yet been demonstrated for walking in VR space.

1.4 Objective and research question

Despite previous findings, the impact of familiarity and movements of virtual avatars surrounding a user on walking speed and sensation has not been extensively investigated. The aim of this study is to investigate how avatars walking beside an user affects the user's walking speed and walking sensation. Especially, we investigate the modulation of walking speed and sensation using various familiarity and motions of an avatar walking alongside individuals (Figure 1). In addition, considering the critical role of stereotypes, we investigated whether the combination of an avatar and the stereotypical words for older people influenced the walker's speed. Therefore, we posed the following research questions:

- RQ1. How does walking speed change when a textured humanoid avatar runs alongside the user?
- RQ2. How does walking sensations and speed change depending on the walking motion and familiarity of the humanoid avatar?

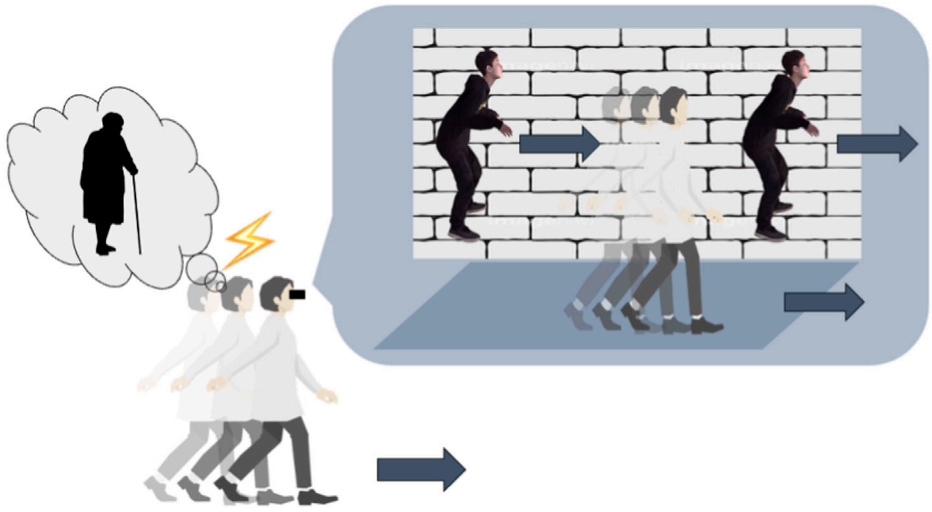

FIGURE 1
Walking speed modulation by a virtual avatar moving alongside in the presence (absence) of the stereotypical words for older people.

- RQ3. How does a stereotyped word task that reminds the user of older people change the above effects?

We establish the following hypotheses: For RQ1, as Tanizaki et al. (2021) (in Japanese) showed that walking with silhouettes or moving point-light dots on walls made participants walk faster, we thought that walking speed might be similarly faster when a realistic avatar walked with them.

For RQ2, we considered that the walking motion of the avatar would be slower than that of young people when the walking motion of the avatar was that of an older person. The young and older avatar motions used in this experiment had the same walking speed, but different walking motions, particularly walking tones and postures. Therefore, we formulated a hypothesis based on findings from two previous studies: gradual alignment of two people walking together (Zivotofsky and Hausdorff, 2007; Zivotofsky et al., 2012) and the chameleon effect (Chartrand and Bargh, 1999). In the latter, the participants unconsciously imitate the behavior and posture of others and are influenced by the motion of older people, consequently slowing down their walking speed. Moreover, we believe that the difference in familiarity affects the immersiveness of the VR space and the reality of the avatar. A higher reality avatar should exhibit a greater effect of walking speed modulation.

Finally, for RQ3, we predicted that the participants' walking speed would slow in response to the stereotypical words for older people. A previous study reported that participants who received an older priming stimulus had slower walking speeds (Bargh et al., 1996). In addition, we expected the walking speed of the participants to be slower when the avatar had a familiar texture and older person motion after getting exposure to stereotypical words for older people. However, the older priming effect may be experimental. In addition, whether the effects of older priming stimuli can be reproduced by walking in a VR environment is unknown.

2 Materials and methods

2.1 Participants

Twenty participants (nine women and 11 men, aged 23.2 ± 8.04) participated in the study and they have known the authors for more than a year and have met them in person. The number of participants was determined by referring to previous studies Tanizaki et al. (2021); Koseki and Amemiya (2023); Yoshida et al. (2018), since 3-way ART-ANOVA analysis was not supported by G*Power (Kang, 2021). All participants were undergraduates, graduate students, or university staff. The participant recruitment and experimental procedures were approved by the local ethical committee at the University of Tokyo. The participants did not notice the purpose of the experiment. All participants had normal or corrected-to-normal vision and no visual or vestibular sensory deficits were reported.

2.2 Apparatus

A computer (Intel Core i7 10700 CPU, NVIDIA GeForce RTX 2070 Super Graphics, DDR4 32 GB Memory) controlled the visualization using Unity (2019.4.18f1). Visual stimuli were presented on a head-mounted display (HMD, Meta Quest2, resolution W1,832 × H1,920 pixels for each eye, and refresh rate 90 Hz). The experiment was conducted indoors (lasting approximately 5 m × 10 m), inside the Engineering Building #1, University of Tokyo. The participants wore an HMD, held the Oculus Touch controller in their right hand, and walked in the experimental space (Figure 2). Head movements in the real space corresponded to head movements in the VR space, and the image was updated in conjunction with the movement in the real space to simulate the sensation of walking in VR space.

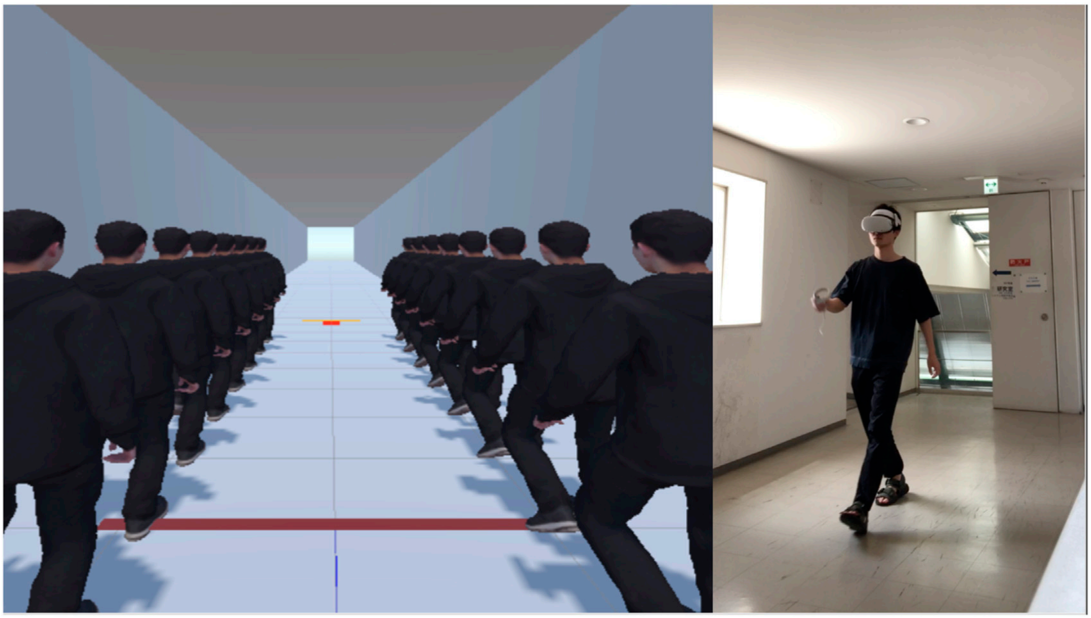

FIGURE 2
Virtual space and avatars used in the experiment (left) and real space (right).

2.3 Avatars walking alongside

In the experiment, the avatars walked side by side with the participants, as displayed in Figure 2. The type of avatar (3D model) displayed involved a combination of familiarity differences ("neutral," "unfamiliar to the participants," and "familiar to the participants") (Figure 3) and motion differences ("young man walking" and "older man walking") (Figure 4). For the texture of "familiar with the participants," we used a photo-realistic texture of the authors. The word "familiar" was defined as "a friend or colleague who has been acquainted with the participants for more than 1 year and has met them in person." The motions were selected from an animation library of full-body characters, Adobe mixamo[1], and the motion data were attached to the 3D model of each avatar. For the young person walking motion, we chose an animation named *walking*; for the older person walking motion, we chose an animation named *old man walk*. The size of the 3D models, number of pieces placed in the space, and walking cycle were identical across all conditions. The gender of the avatar was matched to that of each participant.

2.4 The scrambled sentence test

In the current experiment, the stereotypical words for older people was provided using a scrambled sentence test (SST), in which participants were asked to freely create sentences using multiple

1 https://www.mixamo.com/

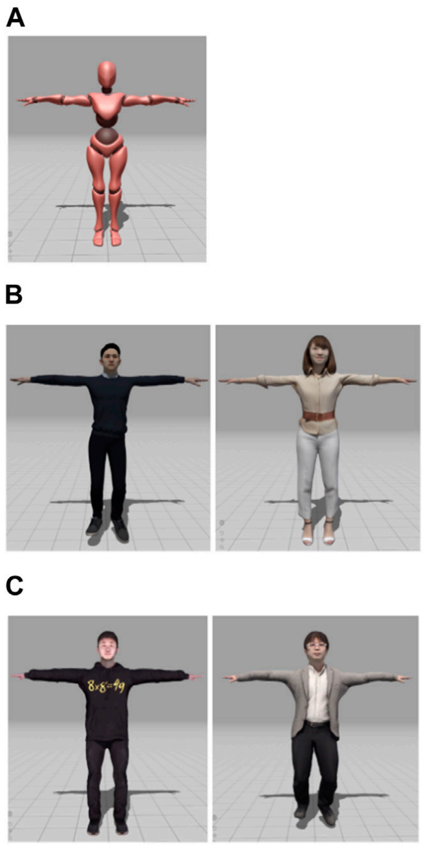

FIGURE 3
Appearance of the 3D models used in the experiment. **(A)** Neutral texture **(B)** Unfamiliar with the participants **(C)** Familiar with the participants.

FIGURE 4
Motion of the 3D models used in the experiment. **(A)** Motion of a young man walking. **(B)** Motion of an older man walking.

TABLE 1 Example of words for the scrambled sentence test (SST).

#	Word set				
1	Work	I	Helpless	Always	Depend
2	Go	Strong	Charming	Ancient	She
3	Someday	Personal	You	Still	Work
4	Together	They	There	Conservative	Decisive
5	Obedient	Quick	He	Deceive	Understand
6	Food-stalls	Anytime	Ramen	I	Sunny
7	Student	Knit	Not so much	Strict	Him
8	Up	Wrinkle	He	Often	Sea
9	Territorial	Alone	Already	I	Withdrawal
10	Traditional	Night	She	Bitter	Mountain
11	Cutting	Mass	Little	Desk	Paper
12	View	Eat	I	Sometimes	Like
13	Room	Clean	Early	Girlfriend	Sleep
14	Rare	Snowy	Crowd	Very	Exciting
15	Cool	They	River	Thirsty	Insects

words given randomly. Following a previous study, we created 30 sets of SSTs, in which five words were arranged in a row. Furthermore, we prepared two word sets, one containing the stereotypical words for older people words, and the other containing only neutral words, based on studies by Bargh et al. (1996). Of these 30 sets, 15 contained words that included the stereotypical words for older people. In accordance with previous research, the stereotypical words for older people were *strict, bitter, obedient, conservative, knit, ancient, helpless, dependent, alone, withdrawn, traditional, retired, forgetful, bingo, polite, stubborn, wise, lonely, gray, sentimental, old, worried, cautious, selfish*, and *gullible*. For the neutral words, we selected words that have not been applied to the stereotypical words for older people in previous studies (Perdue and Gurtman, 1990).

Table 1 details an example of the SST used in the experiment, where each line had five words and the participants were asked to repeat the process of freely creating sentences using four of the five words 30 times per set. Data on all words used in the experiment are available in the Supplemental Material.

2.5 Questionnaire

In this study, five questions were used, and the participants were asked to answer each time the combination of walking alongside avatars was changed (Table 2). For Q1: *How strongly were you aware of the avatar's presence while walking?*, Q3: *How immersive was the avatar?*, and Q5: *Did you feel the presence of people on either side?*, we considered that the difference in motion and familiarity might have caused a change in the participants' sensations. For Q2: *Did the avatar's movements make walking easier or more difficult?* and Q4: *Did you feel lighter or heavier*

TABLE 2 Questionnaire items.

	Statement item	Level
Q1	How strongly were you aware of the avatar's presence while walking?	7: Strongly aware of avatar, 4: Neutral, 1: Not at all aware
Q2	Did the avatar's movements make it easier/more difficult to walk?	7: Easier, 4: Neutral, 1: More difficult
Q3	How immersive was the avatar?	7: Very immersive, 4: Neutral, 1: Not immersive
Q4	Did you feel lighter/heavier when walking with the avatar?	7: Heavier, 4: Neutral, 1: Lighter
Q5	Did you feel the presence of people on either side?	7: Felt it significantly, 4: Neutral, 1: Not at all

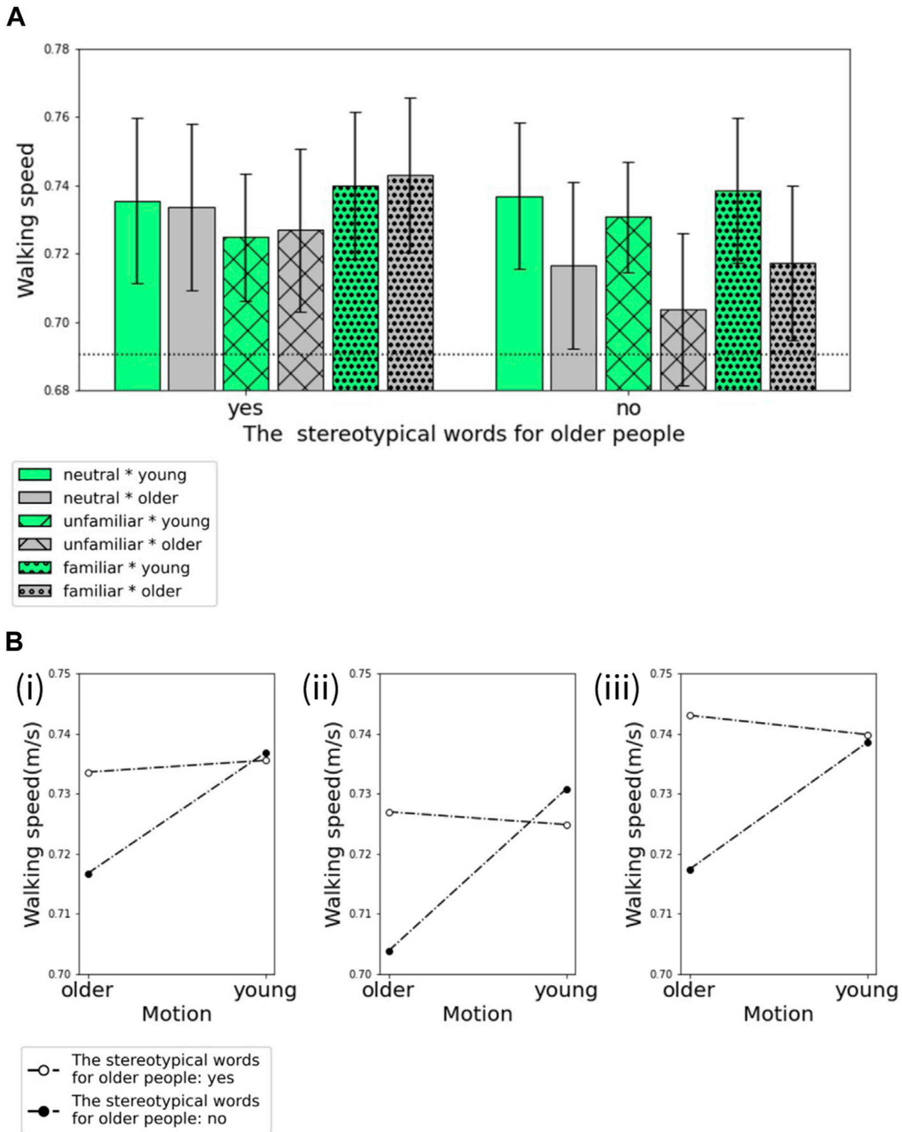

FIGURE 5
The results on walking speed modulation in this walking experiment. **(A)** Walking speed with the parallel walking avatars (m/s). The dotted line indicates that under the baseline condition. **(B)** Interaction between motion and the stereotypical words for older people [(i) neutral texture/(ii) center: unfamiliar texture/(iii) familiar texture].

when walking with the avatar, we thought that the differences in motion and the stereotypical words for older people might have caused changes in the subjective impression of the walking action. To investigate the relationship between these sensory changes and changes in walking speed, we obtained questionnaire data.

2.6 Procedures

In the experiment, the participants performed a series of procedures. First, the participants executed the SST task (See Section 2.4). Next, the participants wore an HMD and walked two round trips with no avatar displayed for practice. Subsequently, the participants walked one round trip (i.e., there were two trials) under each specific condition where the avatar was displayed and responded to the questionnaire answers after every trip. To measure the baseline, no avatars were displayed under any of these conditions. When the participants completed the walking task, they repeated the SST task. The stereotypical words for older people was included in the SST task either for the first or second time. The order in which the avatar was displayed was randomly assigned to each participant. The experimental design was based on a preliminary experiment (Koseki and Amemiya, 2023).

2.7 Data

The walking speed and cycle were calculated from the elapsed time and position coordinates obtained by the inside-out tracking system built into the HMD. Subjective scores for the sense of walking were collected using a Google Form questionnaire, which was answered for each round of walking. Data were analyzed using Python and R. Differences were considered significant at $p < 0.05$.

3 Results

Figure 5 shows the difference in walking speed due to the parallel walking avatars. The walking speed of the participants increased from baseline in all conditions. The assumption of multiple comparisons was verified. We collected data from 12 groups. Normality was not observed in more than one group in terms of walking speed, and most groups were non-normal in terms of questionnaire responses. Homogeneity of variance was not observed between the two groups with and without the stereotype condition for walking speed. A three-way repeated-measures ART-ANOVA was conducted on the aligned ranks for walking speed considering the within-subject factors of motion type (young or older), stereotype (yes or no), and familiarity (neutral, unfamiliar, familiar). Aligned Rank Transform ANOVA (ART-ANOVA) is a nonparametric approach to factorial ANOVA models that enables us to analyze the interaction as well as the main effects (Wobbrock et al., 2011).

The one-way interaction between the *motion type* and *stereotype* was significant [F (1,11) = 11.10, $p = 0.0035$, $\eta_p^2 = 0.368$] (Figure 5), but not for other possible interactions (ps > 0.656). Thereafter, we performed Wilcoxon signed-rank tests to examine the simple main effects of stereotype and motion. In the older motion condition, the results for the stereotypical words for older people showed a significant simple main effect ($p = 0.0018$), whereas no significant simple main effect was observed in the young motion condition ($p = 0.8945$). In addition, in the absence of the stereotype, the results of avatar walking motion showed a significant simple main effect ($p = 0.0017$), whereas no significant simple main effect was observed with stereotype ($p = 0.8424$).

In addition, the results showed a significant main effect of familiarity [F (1, 11) = 4.31, $p = 0.0205$, ${\eta_p}^2 = 0.184$] (Figure 6). Data on participants' walking speed and sensations are available in the Supplemental Material.

In terms of the questionnaire response, significant differences were observed for *stereotype*familiarity* [F (1,11) = 4.15, $p = 0.0233$, $\eta_p^2 = 0.179$]; and *stereotype*motion type*familiarity* [F (1,11) = 3.94, $p = 0.027$, $\eta_p^2 = 0.171$]; for questionnaire item 1. In addition, significant differences were found for the *motion type* [F (1,11) = 14.62, $p < 0.001$, $\eta_p^2 = 0.434$] in questionnaire item 2 (Figure 7). Furthermore, significant differences were confirmed for *motion type* [F (1,11) = 4.14, $p = 0.017$, $\eta_p^2 = 0.262$] and *stereotype*familiarity* [F (1,11) = 4.14, $p = 0.0236$, $\eta_p^2 = 0.178$] in questionnaire item 4 (Figure 7).

In the post-experiment interviews, none of the participants noticed that there were many words on the list of SST task that reminded them of older people. Also, none of the participants realized that the experiment was intended to induce walking speed through a priming effect.

4 Discussion

4.1 Overall result

The participants' walking speed increased from baseline acroszs all conditions. For RQ1, we found that the participants' walking speed tended to increase when the humanoid avatar walked with them, as hypothesized. This result was consistent with that of a previous study by Tanizaki et al. (2021) (in Japanese). Speeding up the user's walking speed in this way could be used for rehabilitation to improve walking ability to prevent ageing. In addition, by projecting an avatar walking in parallel on a wall, it could be applied to walking guidance during disaster evacuation, for example.

A significant difference was observed in the interaction between *motion type* and *stereotype* (Figure 5). Interestingly, as shown in Figure 5, in the presence of stereotype, the speed did not change with the motion type; however, in the absence of the stereotype, the average walking speed of the participants slowed down with the older motion avatars. For RQ3, we found that in the presence of the stereotype, the participants' walking speed did not differ from that of young walking motion, even in the older walking motion type. Therefore, the hypothesis was rejected. We discuss this point in more detail in the next Section 4.2.

Furthermore, the results of the questionnaire surveying walking sensations showed that the participants felt significantly more difficulty in walking and felt heavier while walking with the older walking motion avatar than with the young walking motion avatar. Regarding RQ2, this study found that the participants' walking speeds tended to change depending on the motion type. As hypothesized, the participants' walking speed decreased in the case of older walking motion, which was related to the results of the questionnaire. Based on this results, an elderly person may improve her/his gait ability of sensation and posture by avatars walking with a young walking motion next to her/him.

Regarding familiarity, although the ART-ANOVA test revealed significant differences overall, no significant differences were found among familiarity in the *post hoc* test. As shown in the graph, the

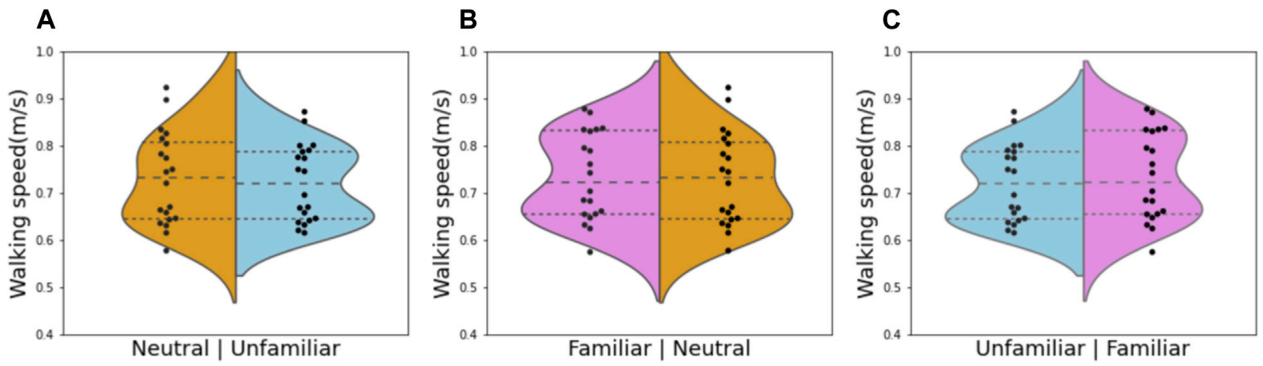

FIGURE 6
Change in the walking speed of the virtual avatar due to differences in avatar texture of familiarity. Horizontal dashed lines indicate medians, and dotted lines indicate quartiles. **(A)** Comparison between Neutral and Unfamiliar categories. **(B)** Comparison between Unfamiliar and Familiar categories. **(C)** Comparison between Familiar and Neutral categories.

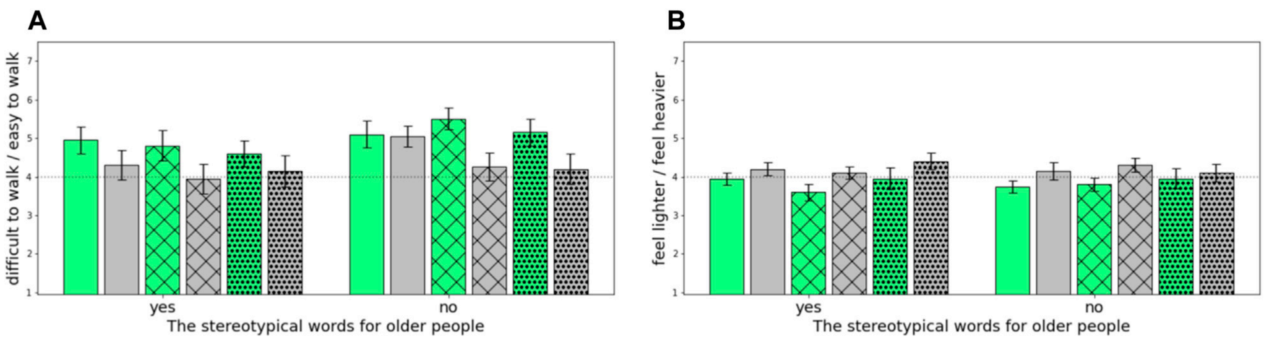

FIGURE 7
Change in the walking sensation of the virtual avatar. Horizontal dotted lines indicate the four-point shape. **(A)** Did the avatar's movements make it easier/more difficult to walk? **(B)** Did you feel lighter/heavier when walking with the avatar?

differences in unfamiliar textures tended to slow the walking speed slightly. The participants' walking speed tended to be faster when the avatar texture was familiar than when it was unfamiliar; however, no interaction was found between *familiarity* and *motion type*. Therefore, the hypothesis was rejected. The results of the walking sensation questionnaire also showed no evidence of increased immersion in familiar avatars. We hypothesized that in the case of a familiar texture, participants' attention would be directed more toward the avatars, and their posture and gait would imitate that of the avatars. We assumed that this would affect their walking speed because of the chameleon effect (Bailenson and Yee, 2005; Hasler et al., 2014; Hale and Hamilton, 2016). However, in this experiment, the duration of exposure to the surrounding avatars in each condition was short, and we did not perform any tasks other than walking together; therefore, the effect was limited, and we could not observe a strong effect of the "familiar" texture.

In summary, we found that walking speed and walking sensation can be manipulated by the avatars walking in parallel and by the walking motion of the avatars, and this technology may be used for rehabilitation to improve walking ability and for walking guidance during evacuation and other situations.

4.2 Interaction between the stereotype and walking motion

Our results showed that the participants who performed the SST task using older stereotyped words before walking with avatars did not change their walking speed, regardless of whether the avatar's motion was young or older. However, for non-biased participants who did not perform the task using older stereotyped words, walking speed was reduced compared with biased participants. This result contradicted that of Bargh et al. (1996), who found that activating a trait using geriatric words as if the participants were old was sufficient to elicit a reduction in walking speed (see also Doyen et al., 2012). Assuming that the effect of older stereotype words exists, this inconsistency may be due to a conflict in the priming effect.

Both the avatar's motion and stereotype words can be interpreted as priming stimuli based on age, although differences existed in the specificity and timing of the priming stimuli. We believe that these two types of priming stimuli cause a different effect from that of a single priming stimulus, which explains the present results. Previous studies supporting the idea that priming stimuli cancel each other out include those on priming assimilation and contrast. In addition to the "assimilation effect," in which priming responses are mainly in the direction of activation, a "contrast effect" may exist, in which a reactionary response that counteracts the effect is observed when the primer is well aware of the effect (Herr et al., 1983; Biernat, 2005). The contrast effect indicates that when one is aware of an extreme antecedent stimulus and consciously tries to modify one's attitude or behavior, one overmodifies rather than undermines it, thereby promoting the opposite effect. Therefore, the stereotipical words for older people may have played a role in evoking an image of older people, and thus, the avatar of older walking motion was processed more quickly and accurately as an older person, promoting the contrast effect. The fact that the older stereotype task caused participants to recognize the avatar as an old man more quickly may be due to a semantic priming bias. This is similar to a study in which the word bread was recognized more quickly and accurately when participants were presented with words related to bread, such as butter, than when they were presented with words related to a nurse (Meyer and Schvaneveldt, 1971). In addition, according to the interpersonal interaction model proposed by Cesario et al. (2006), priming stimuli by social category, such as old-age priming stimuli, increase the readiness to interact appropriately with the social category (in this case, the older population). This may have led the participants to quickly process the avatar's motion as that of an older person and may have promoted the contrast effect.

Assuming that the effect of older stereotype words did not exist, exposure to stereotypical words for older people did not influence walking speed, and only the avatar motion of older walking contributed to the reduction in walking speeds of the participants.

These results could be due to the participants' age. The majority of participants in this experiment were under 30 years of age. When participants got exposure to stereotypipical words for older people, participants were more likely to recognize the surrounding avatars rather than themselves as older, as they were unconsciously imprinted with the older stereotype and were younger than the avatars. We believe that the stereotypical word may have induced cognitive processing that the avatars around them were old men. This could have caused the difference for young people, and the participants were not guided by the walking movements of the avatar, which had little effect on the change in speed.

As the results of the questionnaire also showed differences in terms of walking difficulty and body weight depending on the avatar's motion, regardless of the change in walking speed, we assumed that the participants were consciously affected in both cases. Therefore, the results of this study can be attributed to unconscious cognitive processing.

This result can also be interpreted from the viewpoint that the cognitive/perceptual system is generally independent of the sensorimotor system (Goodale et al., 1991; Flanagan and Beltzner, 2000). In this case, the perceived avatars themselves were the same-motion avatars; however, the participants' walking speeds (motion) may have been different.

In summary, this study shows the possibility that walking speed and sensation can be manipulated by differences in avatar walking motion, without the need for unconscious induction such as the priming effect.

4.3 Limitations and future work

One of limitation is the inadequate diversity of the participants. For instance, many participants experienced a VR world for the first time. Moreover, the age range of the participants, who were mainly university students, was narrow. Future studies should examine the effects on older participants. In addition, as described in Section 4.1, the expected effect of familiarity may not have been achieved because of the limited interaction time with the surrounding avatars.

This study used a virtual avatar and stereotypical words for older people for cognitive stimulation to investigate the link between cognition and behavior. However, we failed to replicate recent studies, which primed undergraduate students with words related to old age, with subsequently slowed walking rates (Bargh et al., 1996). Similar findings in the social priming literature have prompted a heated debate and led to widespread efforts to replicate a wide range of priming results. Therefore, we hope to provide a new perspective on the existing research results through a new study that combines the replication of previous studies with new technology.

Additionally, in this experiment, we did not take into account any particular differences in the effects of gender, and while we used avatars of each gender for the unfamiliar avatar because they were available, we used only male avatars for the familiar avatar because all the experimenter in this experiment were male. The difference in the effect of the familiar condition between males and females was examined after the experiment, but no effect on walking speed or walking sensation was found.

Moreover, in this experiment, the participants did not use a self-avatar, and only saw the avatars around them. Studies have already been conducted on walking speed when one's own avatar is changed (Reinhard et al., 2020); however, whether the change in walking speed depends on the stereotype of the relationship between the user's avatar and surrounding avatars remains unknown. For example, if the participants were to use an old man's avatar and the surrounding avatars were also old men, it is still unclear whether a change in walking speed would occur. Future studies should examine the psychological effect of using avatars, as well as the change in walking speed.

5 Conclusion

This study examined the effects of various familiarity and walking motions of humanoid avatars on walking speed and sensation, as well as stereotypical words for older people. We found a significant effect of stereotypical words and motion interactions, particularly older walking motion, which made participants walk slowly in the absence of the stereotypical words. Moreover, the walking motion type also produced conscious changes in terms of feeling lighter or heavier and experiencing ease or difficulty of walking. This study makes several major contributions. First, we revealed that avatars walking together can change the walking speed and sensations of pedestrians. Second, we demonstrated unconscious behavioral changes by providing a cognitive bias associated with a specific behavior before one's behavior. This result extends our knowledge of the field of research on unconscious behavior. Third, we showed that the walking motion of the avatars around the user has a significant effect on the user's walking sensation. Our results show the possibility of manipulating the user's walking speed and walking sensation in the VR space by motion and familiarity of the avatars around the user. Combining the results of this research with the conventional knowledge of walking methods in VR space may enable the pursuit of a more realistic walking experience and using for rehabilitation.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

Ethics statement

The studies involving humans were approved by the Ethics Committee of the University of Tokyo. 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. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

YK: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing–original draft, Writing–review and editing. TA: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing–review and editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This research was supported in part by JSPS KAKENHI (grant number 21H04883) provided to TA.

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

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2024.1363043/full#supplementary-material

References

Amemiya, T., Ikei, Y., and Kitazaki, M. (2019). Remapping peripersonal space by using foot-sole vibrations without any body movement. *Psychol. Sci.* 30, 1522–1532. doi:10.1177/0956797619869337

Amemiya, T., Kitazaki, M., and Ikei, Y. (2020). Pseudo-sensation of walking generated by passive whole-body motions in heave and yaw directions. *IEEE Trans. Haptics* 13, 80–86. doi:10.1109/TOH.2020.2965937

Bailenson, J. N., and Yee, N. (2005). Digital chameleons: automatic assimilation of nonverbal gestures in immersive virtual environments. *Psychol. Sci.* 16, 814–819. doi:10.1111/j.1467-9280.2005.01619.x

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

Biernat, M. (2005). *Standards and expectancies: contrast and assimilation in judgments of self and others.* New York: Psychology Press.

Blair, I. V., and Banaji, M. R. (1996). Automatic and controlled processes in stereotype priming. *J. personality Soc. Psychol.* 70, 1142–1163. doi:10.1037//0022-3514.70.6.1142

Cesario, J., Plaks, J. E., and Higgins, E. T. (2006). Automatic social behavior as motivated preparation to interact. *J. personality Soc. Psychol.* 90, 893–910. doi:10.1037/0022-3514.90.6.893

Chartrand, T. L., and Bargh, J. A. (1999). The chameleon effect: the perception–behavior link and social interaction. *J. personality Soc. Psychol.* 76, 893–910. doi:10.1037/0022-3514.76.6.893

Chen, M., and Bargh, J. A. (1997). Nonconscious behavioral confirmation processes: the self-fulfilling consequences of automatic stereotype activation. *J. Exp. Soc. Psychol.* 33, 541–560. doi:10.1006/jesp.1997.1329

Darken, C. (1997). "The omni-directional treadmill: a locomotion device for virtual worlds," in *In Proceedings of the 10th annual ACM symposium on User interface software and technology*, 213–221.

Dijksterhuis, A., Aarts, H., Bargh, J. A., and Van Knippenberg, A. (2000). On the relation between associative strength and automatic behavior. *J. Exp. Soc. Psychol.* 36, 531–544. doi:10.1006/jesp.2000.1427

Dijksterhuis, A., and Bargh, J. A. (2001). "The perception-behavior expressway: automatic effects of social perception on social behavior," in *Advances in experimental social psychology (Elsevier)*, 33, 1–40. doi:10.1016/s0065-2601(01)80003-4

Doyen, S., Klein, O., Pichon, C.-L., and Cleeremans, A. (2012). Behavioral priming: it's all in the mind, but whose mind? *PLOS ONE* 7, e29081–e29087. doi:10.1371/journal.pone.0029081

Ferraro, P. J., and Price, M. K. (2013). Using nonpecuniary strategies to influence behavior: evidence from a large-scale field experiment. *Rev. Econ. Statistics* 95, 64–73. doi:10.1162/rest_a_00344

Flanagan, J. R., and Beltzner, M. A. (2000). Independence of perceptual and sensorimotor predictions in the size–weight illusion. *Nat. Neurosci.* 3, 737–741. doi:10.1038/76701

Freiwald, J. P., Ariza, O., Janeh, O., and Steinicke, F. (2020). "Walking by cycling: a novel in-place locomotion user interface for seated virtual reality experiences," in *CHI*, 1–12.

Goodale, M. A., Milner, A. D., Jakobson, L., and Carey, D. (1991). A neurological dissociation between perceiving objects and grasping them. *Nature* 349, 154–156. doi:10.1038/349154a0

Hale, J., and Hamilton, A. F. D. C. (2016). Testing the relationship between mimicry, trust and rapport in virtual reality conversations. *Sci. Rep.* 6, 35295. doi:10.1038/srep35295

Hasler, B. S., Hirschberger, G., Shani-Sherman, T., and Friedman, D. A. (2014). Virtual peacemakers: mimicry increases empathy in simulated contact with virtual outgroup members. *Cyberpsychology, Behav. Soc. Netw.* 17, 766–771. doi:10.1089/cyber.2014.0213

Herr, P. M., Sherman, S. J., and Fazio, R. H. (1983). On the consequences of priming: assimilation and contrast effects. *J. Exp. Soc. Psychol.* 19, 323–340. doi:10.1016/0022-1031(83)90026-4

Iwata, H. (1999). "Walking about virtual environments on an infinite floor," in *Proceedings IEEE virtual reality (cat. No. 99CB36316)* (IEEE), 286–293.

Janeh, O., Bruder, G., Steinicke, F., Gulberti, A., and Poetter-Nerger, M. (2017a). Analyses of gait parameters of younger and older adults during (non-) isometric virtual walking. *IEEE Trans. Vis. Comput. Graph.* 24, 2663–2674. doi:10.1109/tvcg.2017.2771520

Janeh, O., Langbehn, E., Steinicke, F., Bruder, G., Gulberti, A., and Poetter-Nerger, M. (2017b). Walking in virtual reality: effects of manipulated visual self-motion on walking biomechanics. *ACM Trans. Appl. Percept. (TAP)* 14, 1–15. doi:10.1145/3022731

Janeh, O., and Steinicke, F. (2021). A review of the potential of virtual walking techniques for gait rehabilitation. *Front. Hum. Neurosci.* 15, 717291. doi:10.3389/fnhum.2021.717291

Kang, H. (2021). Sample size determination and power analysis using the g* power software. *J. Educ. Eval. health Prof.* 18, 17. doi:10.3352/jeehp.2021.18.17

Kilteni, K., Bergstrom, I., and Slater, M. (2013). Drumming in immersive virtual reality: the body shapes the way we play. *IEEE Trans. Vis. Comput. Graph.* 19, 597–605. doi:10.1109/tvcg.2013.29

Koilias, A., Nelson, M. G., Anagnostopoulos, C.-N., and Mousas, C. (2020). Immersive walking in a virtual crowd: the effects of the density, speed, and direction of a virtual crowd on human movement behavior. *Comput. Animat. Virtual Worlds* 31, e1928. doi:10.1002/cav.1928

Koseki, Y., and Amemiya, T. (2023). "Modulation of the walking speed by moving avatars with age stereotype stimuli," in *Proceedings of the HCI international 2023 late breaking papers*, 101–110. doi:10.1007/978-3-031-48050-8_7

Levy, B. (1996). Improving memory in old age through implicit self-stereotyping. *J. personality Soc. Psychol.* 71, 1092–1107. doi:10.1037/0022-3514.71.6.1092

Matsuda, Y., Nakamura, J., Amemiya, T., Ikei, Y., and Kitazaki, M. (2021). Enhancing virtual walking sensation using self-avatar in first-person perspective and foot vibrations. *Front. Virtual Real.* 2, 654088. doi:10.3389/frvir.2021.654088

Matsumoto, K., Ban, Y., Narumi, T., Yanase, Y., Tanikawa, T., and Hirose, M. (2016). "Unlimited corridor: redirected walking techniques using visuo haptic interaction," in *ACM SIGGRAPH 2016 emerging technologies*, 1–2.

Meyer, D. E., and Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: evidence of a dependence between retrieval operations. *J. Exp. Psychol.* 90, 227–234. doi:10.1037/h0031564

Moullec, Y., Cogné, M., Saint-Aubert, J., and Lécuyer, A. (2023). Assisted walking-in-place: introducing assisted motion to walking-by-cycling in embodied virtual reality. *IEEE Trans. Vis. Comput. Graph.* 29, 2796–2805. doi:10.1109/TVCG.2023.3247070

Nilsson, N. C., Serafin, S., and Nordahl, R. (2016). "Walking in place through virtual worlds," in *Human-computer interaction. Interaction platforms and techniques: 18th international conference, HCI international 2016, Toronto, ON, Canada, july 17-22, 2016. Proceedings, Part II 18* (Springer), 37–48.

Nilsson, N. C., Serafin, S., Steinicke, F., and Nordahl, R. (2018). Natural walking in virtual reality: a review. *Comput. Entertain. (CIE)* 16, 1–22. doi:10.1145/3180658

Perdue, C. W., and Gurtman, M. B. (1990). Evidence for the automaticity of ageism. *J. Exp. Soc. Psychol.* 26, 199–216. doi:10.1016/0022-1031(90)90035-K

Razzaque, S. (2005). *Redirected walking*. The University of North Carolina at Chapel Hill.

Razzaque, S., Swapp, D., Slater, M., Whitton, M. C., and Steed, A. (2002). Redirected walking in place. *Egve* 2, 123–130. doi:10.2312/EGVE/EGVE02/123-130

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

Rio, K. W., Rhea, C. K., and Warren, W. H. (2014). Follow the leader: visual control of speed in pedestrian following. *J. Vis.* 14, 4. doi:10.1167/14.2.4

Slater, M., Usoh, M., and Steed, A. (1995). Taking steps: the influence of a walking technique on presence in virtual reality. *ACM Trans. Comput.-Hum. Interact.* 2, 201–219. doi:10.1145/210079.210084

Spears, R., Gordijn, E., Dijksterhuis, A., and Stapel, D. A. (2004). Reaction in action: intergroup contrast in automatic behavior. *Personality Soc. Psychol. Bull.* 30, 605–616. PMID: 15107160. doi:10.1177/0146167203262087

Steinicke, F., Bruder, G., Jerald, J., Frenz, H., and Lappe, M. (2009). Estimation of detection thresholds for redirected walking techniques. *IEEE Trans. Vis. Comput. Graph.* 16, 17–27. doi:10.1109/tvcg.2009.62

Suma, E. A., Clark, S., Krum, D., Finkelstein, S., Bolas, M., and Warte, Z. (2011). "Leveraging change blindness for redirection in virtual environments," in *2011 IEEE virtual reality conference* (IEEE), 159–166.

Tammy Lin, J.-H., and Wu, D.-Y. (2021). Exercising with embodied young avatars: how young vs. older avatars in virtual reality affect perceived exertion and physical activity among male and female elderly individuals. *Front. Psychol.* 12, 693545. doi:10.3389/fpsyg.2021.693545

Tanizaki, M., Matsumoto, K., Narumi, T., Kuzuoka, H., and Amemiya, T. (2021). Modulation of walking speed by the change in motion and shape of the virtual avatar moving alongside. *Trans. VRSJ* 26, 208–218. doi:10.18974/tvrsj.26.3_208

Templeman, J. N., Denbrook, P. S., and Sibert, L. E. (1999). Virtual locomotion: walking in place through virtual environments. *Presence* 8, 598–617. doi:10.1162/105474699566512

Thaler, R. H. (2018). Nudge, not sludge. *Science* 361, 431. doi:10.1126/science.aau9241

Tulving, E., Schacter, D. L., and Stark, H. A. (1982). Priming effects in word-fragment completion are independent of recognition memory. *J. Exp. Psychol. Learn. Mem. cognition* 8, 336–342. doi:10.1037/0278-7393.8.4.336

Usoh, M., Arthur, K., Whitton, M. C., Bastos, R., Steed, A., Slater, M., et al. (1999). "Walking > walking-in-place > flying, in virtual environments," in *Proceedings of the 26th annual conference on Computer graphics and interactive techniques*, 359–364.

Vahle, N. M., and Tomasik, M. J. (2022). Younger and older adults' cognitive and physical functioning in a virtual reality age manipulation. *Front. Aging* 3, 851687. doi:10.3389/fragi.2022.851687

Wehden, R., Reer, F., Janzik, R., Tang, W. Y., and Quandt, T. (2021). The slippery path to total presence: how omnidirectional virtual reality treadmills influence the gaming experience. *Media Commun.* 9, 5–16. doi:10.17645/mac.v9i1.3170

Wheeler, S. C., and Petty, R. E. (2001). The effects of stereotype activation on behavior: a review of possible mechanisms. *Psychol. Bull.* 127, 797–826. doi:10.1037/0033-2909.127.6.797

Wobbrock, J. O., Findlater, L., Gergle, D., and Higgins, J. J. (2011). "The aligned rank transform for nonparametric factorial analyses using only anova procedures," in *Proceedings of the SIGCHI conference on human factors in computing systems*, 143–146.

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

Yoshida, N., Hanasaki, S., and Yonezawa, T. (2018). "Attracting attention and changing behavior toward wall advertisements with a walking virtual agent," in *Proceedings of the 6th international conference on human-agent interaction*, 61–66.

Zivotofsky, A. Z., Gruendlinger, L., and Hausdorff, J. M. (2012). Modality-specific communication enabling gait synchronization during over-ground side-by-side walking. *Hum. Mov. Sci.* 31, 1268–1285. doi:10.1016/j.humov.2012.01.003

Zivotofsky, A. Z., and Hausdorff, J. M. (2007). The sensory feedback mechanisms enabling couples to walk synchronously: an initial investigation. *J. neuroengineering rehabilitation* 4, 28–35. doi:10.1186/1743-0003-4-28