Walking in Virtual Reality - How the Attendance of an Avatar and the Feeling of Embodiment Influence Human Gait

Gregor Schwinn[1], Maximilian Stasica[1], André Seyfarth[1]
[1]Lauflabor Locomotion Laboratory, Institute of Sport Science and Centre for Cognitive Science, TU Darmstadt, Germany
gregorschwinn@googlemail.com
stasica@sport.tu-darmstadt.de
seyfarth@sport.tu-darmstadt.de

1 Motivation

Virtual Reality (VR) has emerged as a powerful research tool over the past decades in various application fields, for example to examine movements. It enables the creation of scenarios and setups that would otherwise be difficult, unfeasible, or even impossible. This naturally provides promising opportunities for human gait analysis, such as walking in fear-inducing circumstances (e.g., high bridges). However, research has shown that walking in VR differs from walking in the real world [1–3]. In general, humans tend to behave more naturalistic in virtual environments with a high level of immersion and *presence* [4]. One way to increase the sense of *presence*, is to create and enhance a strong feeling of embodiment [5]. Embodiment refers to the feeling that the properties of an artificial or virtual body are perceived and processed as if they were those of one's own biological body. [6, 7]. To achieve a high sense of embodiment, a virtual avatar, animated in real time using motion capture, can be used. Furthermore, research has shown that virtual self-representations can influence user behavior through their appearance — a phenomenon known as the *Proteus Effect* [8]. For instance, users with avatars in sporty clothes showed better results in exercising compared to business clothes [8]. This effect is closely related towards a sub-component of embodiment, called *Change*, which covers the aspect of a perceived alteration in one's own body schema. This study therefore aims to investigate whether the *presence* of an avatar influences gait in VR and whether it promotes a more naturalistic walking pattern. For a better understanding, the participant's sense of embodiment was queried to see potential correlations with the naturalism of the gait. The influence of the appearance of an avatar was investigated by manipulating its size.

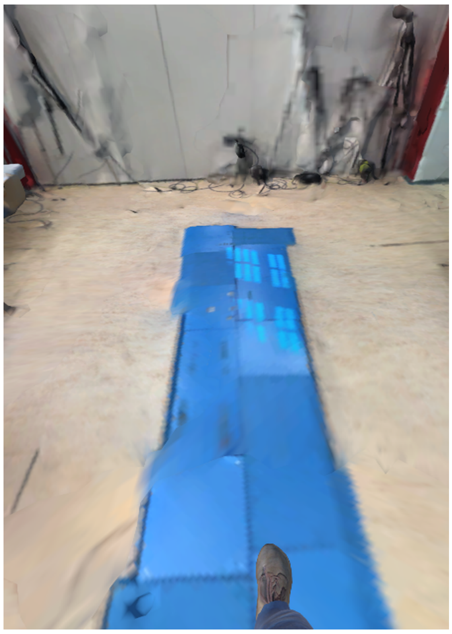

Figure 1: First person perspective during a trial with a virtual (normal sized) avatar. The virtual representation of the participant was animated with real-time motion data.

2 Methods

The experiment consisted of four main conditions (no avatar, normal sized, enlarged and downsized avatar) occurring in an random order, and a baseline measurement conducted beforehand, where the participants walked a 5-meter-long track consisting of 4 ground reaction force plates and several dummy plates. This setup ensured, that the participants were able to hit the force plates to measure the gait initiation forces without disturbing their normal gait. The four main conditions took place in a custom-built virtual environment (VE), which was a virtual replication of the laboratory including the walking track (Fig. 1). The avatar was animated by capturing the movements of the whole body with a motion capture system. Additionally, after each condition the participants completed a questionnaire on the avatar's embodiment using the *Virtual Embodiment Questionnaire* (VEQ) [6]. The experiment was conducted with 10 participants (all male, 24.6 ± 4.4 years, average height: 182.3 ± 5.5 cm, average weight: 76.3 ± 12.8 kg), who were able to walk unrestricted and were non-prone for motion sickness. The statistical analysis was done in Matlab and Python, all motion data were pre-processed with filtering and normalization. Since most of the parameters were not normally distributed non-parametric tests with a statistical significance level of 95 % were conducted.

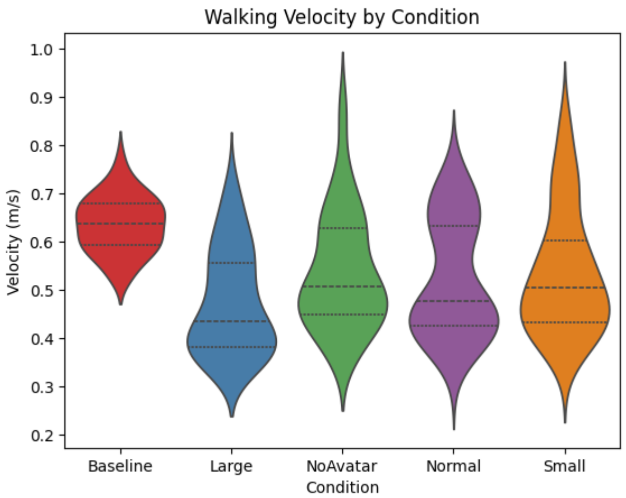

Figure 2: Violin-plots of the walking velocity by each condition. Significant differences of the walking velocity between all conditions are visible.

3 Results

Nearly all investigated biomechanical gait parameters such as the walking velocity (Fig. 2), differed significantly between the baseline measurement and the test conditions. The participants tended towards a more stability-oriented gait, which is for example visible in a higher vertical ground reaction force or a shorter stride length. The results of the VEQ indicate no significant differences between the VR conditions for its subdimensions *Body Ownership* and *Agency*, which goes along with the findings that there are no significant differences between the conditions without an avatar and with the regular sized avatar. However, there were significant differences between the different sized avatars. On the one hand, participants experienced changes of their body, visible by the *Change* sub dimension of the VEQ. Also, there are significant differences for most of the gait parameters: For example, the walking velocity decreased when the avatar was enlarged and increased when the avatar was downsized (Fig.: 2). Both the stride length and the distance covered were significantly higher for the downsized avatar in comparison to the regular sized one, but also in comparison to the baseline measurement. Similar, the enlarged avatar decreased those parameters.

4 Discussion

The findings of previous research that humans tend towards a more stability-oriented gait style in VR could be confirmed. However, the missing variance in the embodiment score, especially for body ownership, combined with the absence of differences in gait parameters between the normal-avatar condition and the no-avatar condition, indicates a lack of perception of the avatar. This goes along with the comments of some of the participants that they did not recognize their avatar that much while walking. Therefore, the actual influence of an avatar should be researched in a way, which enhances the perception of the virtual body like adding a mirror in the virtual world and use eye-tracking. Also, the findings regarding the influence of the avatar's size need to be further explored. While those differences and the results of the *Change* sub-component of the VEQ indicate that there are opportunities to manipulate the human gait using an avatar, the origin of the behavior could also be linked to the different height perspective. This is because the point of view aligned with the new height of the avatar, which may impacted the participants behavior. To gain a better understanding of those behavioral changes and allow more comprehensive statements and statical models, more diverse data is needed. In particular the data of female participants needs be collected in future research.

5 Conclusions

The results suggest that future human gait research in VR must account for differences compared to real-world walking. Furthermore is has been demonstrated, that the appearance of an avatar can significantly impact the human gait, for instance the adaption fo the stride length to the avatars size. The influence of such avatars on gait needs more research, in particular with enhanced perception of the their virtual body properties, to unlock the potential power of virtual self representations.

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