Investigation of Simulator Sickness in Walking with Multiple Locomotion Technologies in Virtual Reality

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ABSTRACT

With the increasing development of Virtual Reality, locomotion has become an essential component of interaction in VR. Currently, various locomotion technologies have been developed to provide users with a natural walking experience in virtual environments. However, the multiple walking techniques impact users' walking experience in different ways. Simulator sickness is a common issue in VR experiences. Since different walking methods may influence simulator sickness differently, we conducted a user study to evaluate simulator sickness in walking with three relevant walking methods: real walking, arm-swing, and omnidirectional treadmill, and the results indicated that these three walking methods caused different levels of simulator sickness, and people perceived stronger sickness when they walked on the omnidirectional treadmill.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; **Virtual reality**.

KEYWORDS

Virtual Reality, Locomotion Technologies, Natural Walking Techniques, Simulator Sickness

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1 INTRODUCTION

Virtual Reality (VR) technology is able to immerse users in simulated spatial environments with multiple senses and interactions. Locomotion is one of the crucial components of interaction between users and the Virtual Environment (VE) in VR. Locomotion is the technology for traveling in virtual environments, which is controlled by the self-propulsion of the user [1, 9]. Based on most of the existing research, locomotion is expected to affect many critical aspects of user experience such as effort, enjoyment, frustration, motion sickness, and presence [2]. Walking is one of the fundamental human activities in the physical world. Meanwhile, it is also indispensable interactivity of the user and the VE [7], and natural walking provides highly immersive sensations in VR [3].

Except for the research of wide-area trackers that enabled the "real walking" method [11], the development of simulating walking with body-active surrogates is an essential research topic [10]. Nilsson et al. [4] have systematically categorized the existing natural walking techniques into proxy gestures, repositioning systems, and redirection techniques. Locomotion based on proxy gestures performs gestures of lower body or upper body serving as a proxy for actual steps [4]; repositioning systems offer constant travel in VE by maintaining the relative fixed position of the user by counteracting the forward movements [4]; redirection walking techniques refers to the approaches that control the user's traveling path through the physical environment by manipulating the stimuli used to represent the VE [8].

The multiple locomotion technologies could affect users' perception of natural walking in different ways. The conflicting sensory of the visual system and vestibular will induce simulator sickness [6], and it is also one of the key problems of VR exposure [12]. In this study, we aim to investigate simulator sickness of walking in VR with different walking methods. Therefore, we conducted three walking methods: real walking, which relies on the accurate position-tracking function of the HMD; an arm-swing virtual walking interface, which refers to an upper-body proxy gestures method; and walking on the omnidirectional treadmill, one of the repositioning walking systems.

2 USER STUDY

We conducted a user study with a within-subject to assess and compare the simulator sickness when people walk with different technologies in VR. We recruited 15 participants (11 male and 4

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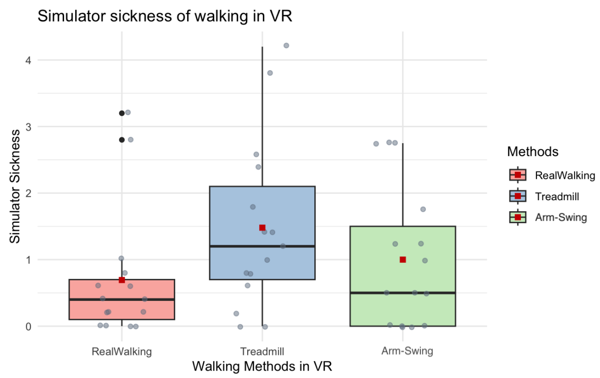

Figure 1: Measured simulator sickness in natural walking with three walking methods: real walking, walking on the omnidirectional treadmill, and walking with an arm-swing interface in VR.

female) to participate in the study. All participants voluntarily consented to join the experiment. Over half of the participants had less or zero experience with VR technology before.

2.1 Experiment Design

During the experiment, participants walked in a virtual room featuring an open central area and planned path with three technologies: real walking, arm-swing gesture proxy, and walking on an omnidirectional treadmill separately. The virtual scenario and the methods of the walking simulation were developed in the game engine Unity and implemented with the HMD Meta Quest 2. The real walking method based on the tracking system integrated into the HMD, participants were able to freely walk in a limited physical space; with the arm-swing virtual walking interface, participants stood in a fixed place and swayed their arms with the controller holding in hands, the swing of the controller drove the movement in the VE; and for the omnidirectional treadmill method, we implemented the virtual walking with the KAT Walk C 2 Core. We used SSQ [5] to measure the levels of simulator sickness, thereby assessing how different walking methods in virtual reality would affect the incidence of such sickness symptoms.

2.2 Results

We used Repeated Measures ANOVAs and Bonferroni-corrected post-hoc tests to analyze the subjective results of self-reported measures SSQ. The data analysis results indicate that different walking methods affect simulator sickness of walking in VR significantly ($F = 7.235$, $p = .003$, $\eta^2 = .341$). Compared to the method of Real Walking, walking on the omnidirectional treadmill increases the simulator sickness significantly ($Md = .787, p = .002$). See the Figure1.

3 CONCLUSION AND FUTURE WORK

Locomotion is an essential part of interaction in VR, and the various locomotion technologies have also become a popular topic in current research. However, simulator sickness is a common issue in VR studies and the popularization of VR technology. In this work, we implemented three different locomotion technologies (real walking, arms-swing gesture proxy, and omnidirectional treadmill) to achieve natural walking in VR. Meanwhile, we measured and evaluated users' simulator sickness when they walked with different methods in the same VE. The results revealed that these three walking methods caused different degrees of simulator sickness in walking in VR. Compared to the other two walking methods, participants got stronger simulator sickness when they walked on the omnidirectional treadmill.

The omnidirectional treadmill is proposed as a promising locomotion approach in large-scale virtual environments to enable users with full freedom of movement in VR. Therefore, it's worth continuing further research on the phenomenon and the feasible evolution of the omnidirectional treadmill to improve its usability and acceptance. Locomotion technologies contribute significant interaction between users and VE; the evaluation and further development of various techniques to improve the walking experience in VR would be important for future research.

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