International Conference on Artificial Reality and Telexistence
Eurographics Symposium on Virtual Environments (2024)
T. Tanabe and V. Yem (Editors)

Demo

Enhancing VR Walking Experience Through Dual-Point vibratory stimuli on the Legs

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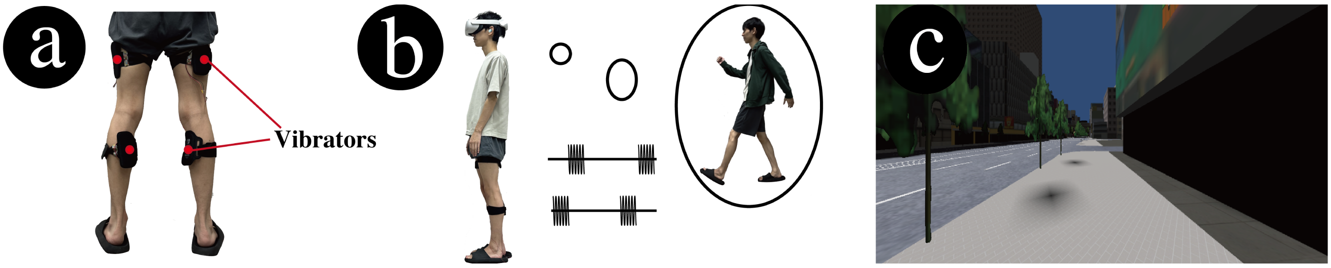

Figure 1: *(a) Attachment of vibrators to the biceps femoris long head (BFL) and medial gastrocnemius (mGAST) muscles, (b) Enhancement of walking sensation through vibration, (c) Screenshot of the VR application.*

Abstract

This paper proposes a method of enhancing the virtual walking experience by inducing proprioceptive sensations through vibratory stimuli applied to the legs while standing. Vibrators were attached to the biceps femoris long head (BFL) and medial gastrocnemius (mGAST) muscles of the participants, providing vibratory stimuli synchronized with the walking cycle. This approach aimed to reduce the discrepancy between visual and proprioceptive feedback by inducing muscle movement sensations without actual physical motion. Experimental results showed that participants experienced an enhanced sense of walking and presence under the vibratory stimuli condition, as well as a reduction in VR sickness.

CCS Concepts

• ***Human-centered computing*** → *Virtual Reality;*

1. Introduction

In virtual environments, walking is often used as a primary mode of movement. However, in VR spaces, walking is typically controlled by finger movements on a controller, eliminating the need to move the upper or lower limbs, resulting in a loss of proprioception. This mismatch between visual and proprioceptive feedback can lead to a reduced sense of walking, decreased immersion, and the onset of VR sickness. While it is possible to reflect real-world walking in virtual environments, this requires large physical spaces. Solutions such as treadmills are often used to address this issue, but they are expensive and large in size. Therefore, a compact solution that does not require lower limb movement is highly desirable.

This paper proposes a method to enhance the virtual walking experience by inducing proprioceptive illusions through vibratory stimuli applied to the legs. This approach aims to improve the sense of walking without requiring actual physical movement. The induction of proprioception through vibratory stimuli has been well-documented [GMM72]. Vibratory illusion is a phenomenon in which vibratory stimuli, applied at frequencies between 7 and 80 Hz, are delivered to muscle spindles—receptors that detect muscle stretch—causing a sensation of muscle stretch and movement. Several studies have exploited this phenomenon, including a method that enhances the illusion of arm movement by applying vibratory stimuli to multiple tendons and muscles simultaneously [UTTK19], or an approach that reproduces the sensation of ground motion by alternately applying vibratory stimuli to the tendons of the ankle [NUMK24].

We applied this vibration illusion to the muscles involved in walking by delivering vibratory stimuli to two points on the legs while the user was in a standing position. This induces propriocep-

DOI: 10.2312/egve.20241405

tion in the lower limbs while the user is standing still, enhancing the sensation of walking in virtual environments without requiring actual leg movement.

2. Experiment

2.1. Experimental Setup

This section describes the vibratory stimuli points and the timing of the vibratory stimuli. Vibrators (Acouve Lab VP2-210), attached to leg supporters, were placed on the participants' biceps femoris long head (BFL) and medial gastrocnemius (mGAST) muscles, as shown in Figure 1(a). These two sites were selected based on findings that demonstrated a clear perception of amplitude changes in BFL and mGAST [ARC23]. The timing and intensity of the vibratory stimuli were set empirically. Figure 2 shows a time chart of the sound and the vibratory stimuli for each site. Vibratory stimuli alternated between the left and right legs during the interval between the first and second sounds. At the beginning of the cycle, a footstep sound was played, representing the moment when the heel makes contact with the ground. Participants listened to this sound through earphones. A sinusoidal wave at 80 Hz, known to be effective in inducing proprioceptive illusions, was generated using a Python module. This waveform signal was sent to a selected device using Python's audio device driver interface and amplified through two amplifiers (AK-270), with independent control over the left and right channels. This setup enabled the output of signals to four channels corresponding to the four vibratory stimuli points, with each signal controlled independently according to the time chart.

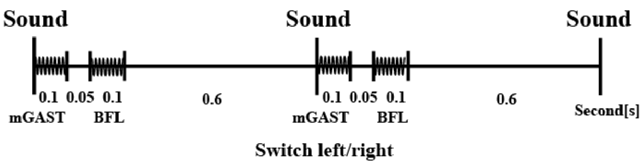

Figure 2: *Time chart.*

2.2. Experimental Procedure

Participants conducted the experiment under two 30-second conditions: (1) visual and auditory stimuli only, and (2) the same stimuli with additional vibratory stimuli. The condition order was counterbalanced among participants to mitigate order effects. Visual stimuli included head bobbing synchronized with footsteps, and participants experienced a first-person VR application of walking through a city, which was created using Unity (Figure 1(c)). After each experiment, they rated their experience on 7-point Likert scales for sense of presence and walking sensation (1: "none" to 7: "strong"), and VR sickness (1: "feel very sick" to 7: "do not feel sick at all"). Higher scores indicate stronger presence and walking sensation, and less VR sickness. Additional open-ended questions were included.

3. Results

Eight participants (including two females) aged between 22 and 29 participated in the experiment. The results comparing the conditions with and without vibratory stimuli are presented below. Firstly, for the sense of presence, the average score was 3.3 points without vibration and 5.6 points with vibration, indicating an increase of 2.3 points. For the walking sensation, the average score was 3 points without vibration and 5.8 points with vibration, showing an improvement of 2.8 points. Regarding VR sickness, the average score increased from 2.3 points without vibration to 6.1 points with vibration, indicating a significant reduction in VR sickness (since higher scores represent less sickness). A paired t-test confirmed that the differences in presence, walking sensation, and VR sickness were all significant ($p < 0.05$). These results demonstrate that the condition with vibratory stimuli improved all evaluation metrics compared to the condition without vibration.

4. Discussion

The experiment confirmed that using vibratory stimuli enhanced the walking experience and sense of presence in VR, while significantly reducing VR sickness. These results suggest that vibratory stimuli applied to the legs induced proprioception, which likely contributed to the improved experience by reducing the mismatch between visual and proprioceptive feedback. However, the timing of the vibratory stimuli set by the authors did not match the muscle activity time chart referenced in the literature, indicating the need for further investigation. In addition, in the post experiment discussions, two participants questioned whether the timing of the vibrations was optimal, although they acknowledged that the vibrations enhanced the sense of walking. Moreover, some participants suggested that performing light tasks while receiving tactile feedback might yield better results, as simply walking caused them to focus too much on the tactile sensations. Based on these observations, we suggest that adding a light task to divert attention away from the leg vibrations could potentially provide a better overall experience.

5. Future Work

Future challenges include analyzing the timing of the vibrations and designing stimuli based on the activity patterns of individual muscles. We aim to apply this method not only as a passive stimulus but also as feedback for active operations, such as controller inputs or arm movements during walking.

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