The Effect of Multi-Sensory Cues on Performance and Experience During Walking in Immersive Virtual Environments

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Abstract

To examine the effects of multi-sensory cues during non-fatiguing walking in immersive virtual environments, we selected sensory cues including movement wind, directional wind, footstep vibration, and footstep sounds, and investigated their influence and interaction with each other. We developed a virtual reality system with non-fatiguing walking interaction and low-latency, multi-sensory feedback, and used it to conduct two successive experiments measuring user experience and performance through a triangle-completion task. We noticed some positive effects due to the addition of footstep vibration on task performance, and saw significant improvement in reported user experience due to the added wind and vibration cues.

Keywords: Immersive Virtual Environments, Multi-sensory Cues.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—artificial, augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces—haptic I/O, evaluation/methodology

1 Introduction

Travel is a fundamental task in Virtual Environments (VEs) [2], and walking is one of the most commonly used types of travel. While physical walking is intuitive and can make people remain oriented with little cognitive effort, using it in VEs incurs technical and perceptual challenges [5]. Furthermore, it induces fatigue. An alternative method is to move in the VE using simulated walking, such as non-fatiguing walking, that requires little accumulated physical exertion. The cost includes the loss of spatial orientation, self-motion perception, and overall presence, compared to physical walking. The main key factors that can help maintain the above, on a perceptual level, include field of view (FoV), motion cues (e.g., peripheral vision and vestibular cues), and multi-sensory cues (e.g., auditory and tactile cues). While the first two have been fairly thoroughly studied, the use of multi-sensory cues still remains open [2, 5].

Multi-sensory feedback has been proven to increase immersion in VEs, and successful systems provide similar cues to what humans perceive in the real world (e.g., visual, auditory, and haptic cues). In our study, we chose certain types of cues and investigated their effects in our VR setup, a non-fatiguing walking system, with a wide FoV, and vestibular, visual, and auditory cues. We wanted to see whether a user's navigational performance and experience could be further enhanced when multi-sensory cues are introduced. We chose four cues, movement wind (MW) and footstep vibration (FV), directional wind (DW) and footstep sounds (FS), to study their effect and interaction during non-fatiguing walking in immersive VEs.

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2 Experimental Setup

We developed an immersive VR system [3] with multi-sensory cues including visual, auditory, wind and floor vibration feedback, using a modified version of the ChairIO travel technique [1]. We created a cage-like setup for the hardware components (Figure 1). The user is positioned at the center, sitting on a Swopper Chair[1], which is transformed into a motion-control input device using an accelerometer. The user wears an Oculus Rift DK2 head-mounted display and a noise-cancelling headset. This setup enables the user to *walk around* in the virtual scene by leaning to control the pitch and roll of the chair using her body, and to look/hear around by swivelling her chair and head. The user is surrounded by eight pan-tilt fan units mounted on the octagonal frame of the cage for wind cues, and four low-frequency vibration actuators[2] mounted under a raised floor for vibration cues.

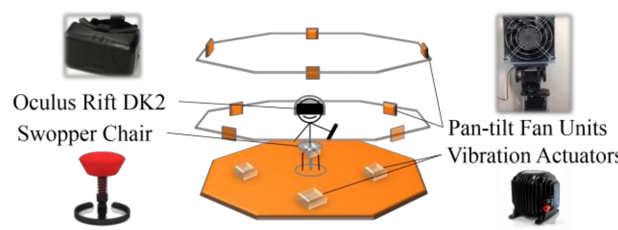

Figure 1: The primary components of our VR system

The wind subsystem is a group of pan-tilt fan units controlled by two Arduinos connected to a Wind Server through USB. Each fan unit (Figure 1) has a 120mm DC fan mounted on a pan-tilt platform controlled by two servomotors. The wind speed of each fan is controlled over a range from 0 to 255. By using the pan-tilt fan unit instead of a fixed fan, we are able to reduce the latency of wind feedback, mainly caused by fan motor speed changes [4]. The fans on our pan-tilt platforms always spin at a minimum level of 100, but are turned away from the user when the wind should be still, and can quickly be turned towards the user and spun up when needed. We did a frame analysis using 30 fps video capture, to measure and compare fixed and pan-tilt fan systems. It takes a fixed fan 3.53s to start generating wind from zero, but only takes 0.33s for the pan-tilt fan unit, which is already spinning at a lower level, to turn to the user. With such a design, near-instant movement-wind feedback can be applied or removed.

3 Experiment 1: Movement Wind and Footstep Vibration

An experiment was designed to evaluate the effects of selected cues (MW, FV, and FS) on user performance on a spatial orientation task, as well as on overall user experience. We used a well-defined triangle-completion task to measure the user's spatial orientation in VEs [5] (Figure 2). We designed a within-subjects experiment. All trials included visual and ambient audio feedback. There were eight combinations of the three independent variables, with/without MW, with/without FV, and with/without FS.

[1] Swooper – Air URL: http://www.swopper.com/swopper-air-5/
[2] Buttkicker LFE URL: http://www.thebuttkicker.com/lfe

Table 1: Subjective measures.

No	Question (range: 1-6)
1	To what extent did you experience the sensation of movement?
2	To what extent did you experience the sensation of walking?
3	How close did the computer-generated world get to be like the real world?
4	To what extent were there times during the experience when the computer-generated world became the "reality" for you, and you almost forgot about the "real world" outside?
5	To what extent did you experience the sense of "being there" while you were travelling in the VE, as opposed to being a spectator?
6	Please rate your sense of direction while you were travelling in the VE.
7	Please rate the extent to which you think the feedback in this condition helped your performance of the task.
8	How much dizziness did you experience while performing the task in this condition?

We also varied the triangle layout and direction with the purpose of varying and counterbalancing. Twenty-four participants (21 male) took part in the experiment. Every participant experienced 8x4=32 triangle-completion trials. After each condition section, she filled out a subjective questionnaire (Table 1), used as subjective measures. The objective measures of spatial-orientation performance included signed and absolute distance error (DE and |DE|), signed and absolute angle error (AE and |AE|), Closeness, etc. (Figure 2).

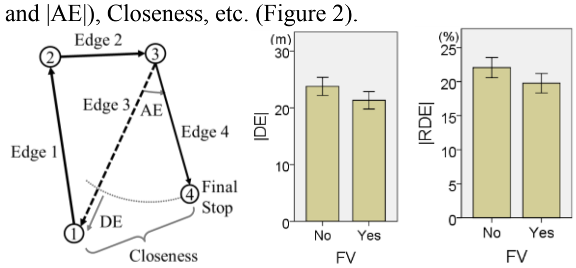

Figure 2: Objective measures (left). Main effect of FV on |DE| and |RDE| (right).

We hypothesized that the selected cues (MW and FV) would enhance task performance and user experience. By running 2x2x2 factorial repeated measures ANOVAs, examining the main effects and interactions of the three independent variables (MW, FV and FS), we noticed a significant main effect of FV on |DE|: $F(1, 23) = 7.27$, $p = 0.013$, $\eta_p^2 = 0.24$, and on |RDE|: $F(1, 23) = 7.3$, $p = 0.013$, $\eta_p^2 = 0.24$ (Figure 2). The result showed that the error was 2.5 meters (or 2.3%) less in the trials with FV. From the results of a one-way repeated measures ANOVA, comparing homogeneous means of the eight conditions for each question, we noticed a strong preference for the ALL condition and a strong disfavour for the NONE condition (Figure 3).

4 Experiment 2: Directional Wind

In Experiment 1, 10 of the 24 participants mentioned that they would have preferred DW (wind blowing from a fixed direction). We conducted another experiment to investigate whether this would affect user performance and experience. Sixteen participants (nine male) took part, but contrary to our expectations, we did not find any significant differences on objective measures.

5 Conclusion

In this poster, we investigated the effect of certain multi-sensory cues, movement wind, directional wind, footstep vibration and footstep sounds, using an immersive VR system with simulated walking. We found that footstep vibration had a significant influence on triangle-completion task performance, and the all of the selected cues were preferred in terms of user experience.

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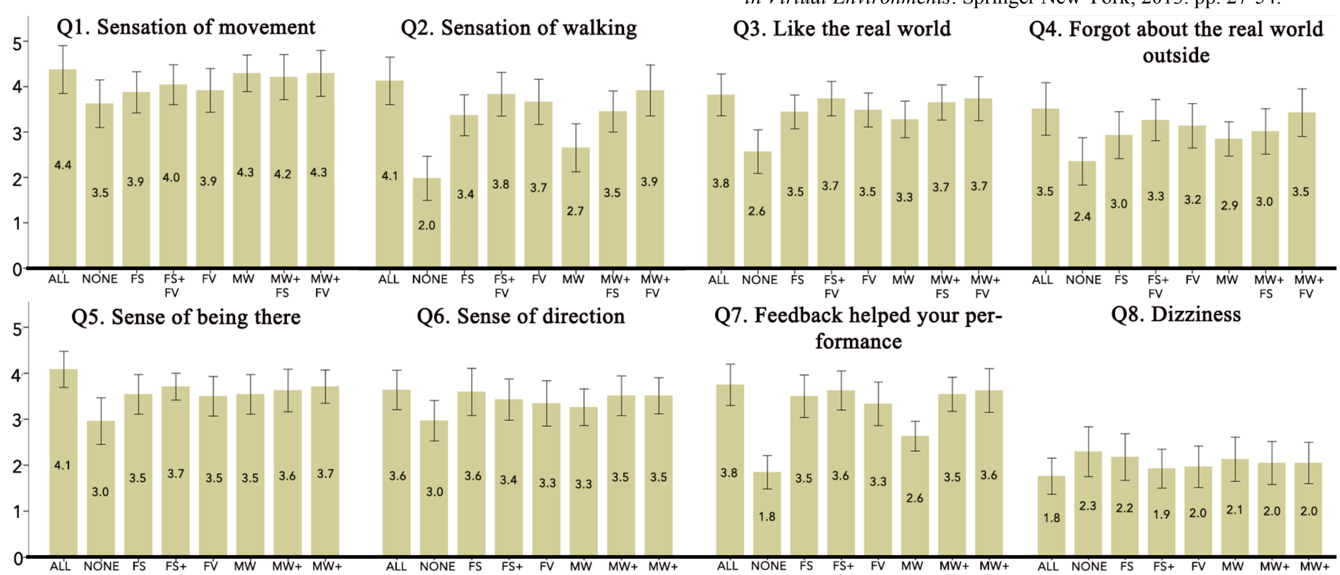

Figure 3 Subjective ratings for each of the eight questions in Experiment 1. Whiskers represent ±95% confidence intervals.