International Conference on Artificial Reality and Telexistence
Eurographics Symposium on Virtual Environments (2019)
Y. Kakehi and A. Hiyama (Editor)



# Footstep Sound for Suppression of VR Sickness and Promotion of Sense of Agency

Reon Nashiki[1], Vibol Yem[1], Tomohiro Amemiya[2] and Yasushi Ikei[1]

[1]Tokyo Metropolitan University, Hino, Tokyo 1910065, Japan
[2] The University of Tokyo, Bunkyo, Tokyo 1138654, Japan

**Abstract**

*Providing realistic bodily sensation in a virtual reality (VR) space is crucial for natural integration of multisensory information that we receive in a real space. In the present paper, we consider to use auditory stimulus to enhance bodily sensation as an indirect representation of a body in the VR space. Three levels of visually presented virtual locomotion conditions using a head mounted display (HMD) and four levels of footstep sound stimulus were evaluated regarding VR sickness and the sense of agency. The result showed that the footstep sound decreased both of VR sickness and the discomfort level of the visual presentation of moving down a virtual corridor when the footstep sound was synchronized with the visual stimulus. The sense of agency was also increased by synchronized footstep sound presentation.*

**CCS Concepts**

• ***Human-centered computing*** → Human computer interaction (HCI) → Interaction paradigms → Virtual reality;

## 1. Introduction

Along with the development of recent technology, by using an HMD and the omnidirectional camera, it becomes readily possible to experience the three-dimensional video of the remote location in real time [MCE*17] [CBF07] [TFI*17]. The visual information provided by these system is compelling and they may induce VR sickness specifically in the case the cameras move in the remote place. The VR sickness is considered to occur from inconsistency of sensory information. Usually, visual information and bodily sensation contradict each other especially when the camera motion is not created by the body. Since it is not easy and considerably expensive that whole body sensation is generated along with the visual input somewhat heteronomous.

In the present study, we propose to use the sound of footsteps as auditory stimulus generated to invoke bodily sensation indirectly. We easily or unconsciously imagine walking body state by hearing the sound of footsteps. It is known that to hear the footstep sound enhances the sensation of walking [OIA*15]. It is expected that the bodily sensation indirectly induced by the sound of footsteps may reduce the VR sickness.

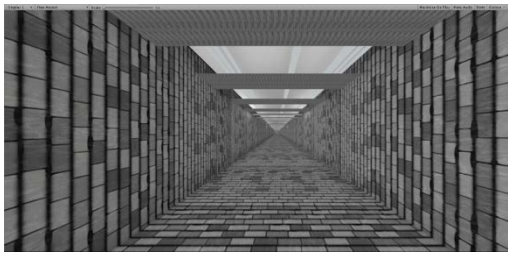

**Figure 1:** *Virtual straight corridor as visual stimulus*

## 2. Evaluation of footstep sound effects

The effects of footstep sound on VR sickness and the sense of agency (sense of active motion) were investigated presenting a 3D scene on a HMD that moves down the virtual corridor. The participants of this experiment were 15 university students of average age 22.5 years.

### 2.1 Procedure

The VR corridor (4 m wide, 5 m high) was created by Unity game engine as shown in Figure 1. Two virtual cameras were placed at 170 cm height from the floor textured to easily induce vection as well as the walls. The camera moved on a straight trajectory to the end of the corridor with three patterns of velocity: a constant speed (6 m/s), a slow triangular wave speed (.3-5.7 m/s), and a fast triangular wave speed (.6-11.4 m/s). The speed was exaggerated to make the result difference clear.

The sound of footsteps was presented in four profiles. The first one had a constant tempo that is most synchronized with the constant visual motion. The second was with a tempo synchronized to slow/fast sinewaves. The third one is with a



DOI: 10.2312/egve.20191293

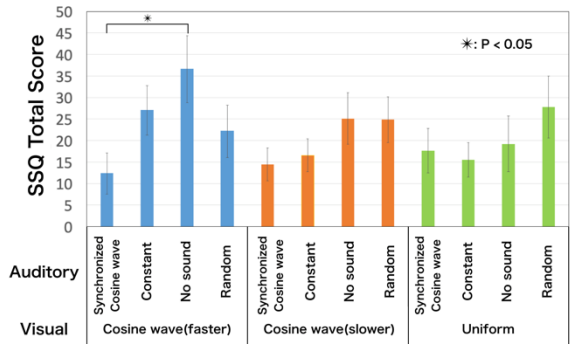


**Figure 2:** *SSQ Total Score (n=15)*

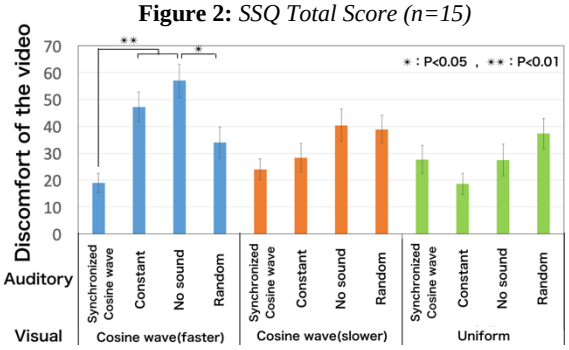


**Figure 3:** *Discomfort level of visual stimulus (n=15)*

randomly changed tempo. The rest was without the footstep sound. This makes 12 stimuli in total.

The participant was allowed to look around with an HMD, and the duration of the video was 15 second a stimulus. After each trial, the participant answered to nine items: the SSQ [KLB*93], discomfort of the video, vection, presence of the environment, sense of body ownership, sense of agency, sense of activeness, sense of passiveness, walking sensation.

### 2.2 Results

Figure 2 shows the SSQ total score, and Figure 3 shows the discomfort level. The SSQ involves the oculomotor, disorientation, and nausea symptoms, while the discomfort level was reported on a single visual analogue scale. The SSQ score had larger distribution than the discomfort level that was easy to answer. It was demonstrated that by presenting synchronized footstep sound, both of the SSQ score and the discomfort level were significantly reduced in the case of the fast triangular wave speed (Tukey's multiple comparison). In contrast, in the case of constant speed motion, adding irregular footstep sound stimulus (random) showed a tendency of increasing the SSQ.

Figure 4 shows the sense of agency. Presenting the synchronized footstep sound markedly increased the sense of agency.

### 2.3 Discussion

It was shown from these results that the footstep sound was effective for reducing the SSQ (VR sickness) score and discomfort level of the video in cases that the sound is synchronized to the visually presented eye point (virtual body) motion. The result was more definite when the visual motion was largely changed. In contrast, when the footstep sound was presented irrespective to the visual motion, there was no

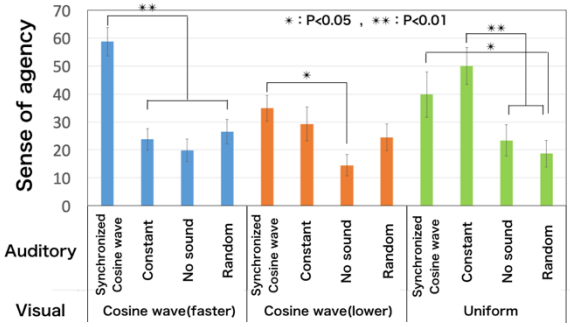


**Figure 4:** *Sense of agency (n=15)*

reduction effect, rather the VR sickness was sometimes increased. This may be attributed to the increase of the sensory conflict between the visual and auditory feedback by presenting asynchronous auditory stimulus that did not induce the body motion of the participant.

### 2.4 Conclusion

The result of the experiment suggested that the presentation of the footstep sound stimulus was effective for the eye point motion in a VR space, in which the visual flow and the footstep sound are integrated to the perception of virtual body.

The future work will be to investigate the effects of footstep sound stimulus when it is applied to the real scene such as a telexience system that provides a remote vision.

### Acknowledgment

This work was partially supported by the MIC/SCOPE #141203019,191603003, JSPS KAKENHI Grant Number JP26240029, JP18H04118, JP18964558, JKA, SCAT and NICT #143U101 past projects.

### References

[MCE*17] Matzen K., Cohen M., Evans B., Kopf J., and Szeliski R., Facebook Inc.: Low-Cost 360 Stereo Photography and Video Capture. ACM Transactions on Graphics, (2017)

[CBF07] Cohen M., Bolhassan N., Fernando O.: A Multiuser Multiperspective Stereographic QTVR Browser Complemented by Java3D Visualizer and Emulator. Teleoperators and Virtual Environments Volume 16 Issue 4, (2007), 414-438.

[TFI*17] Tashiro K., Fujie T., Ikei Y., Amemiya T., Hirota K., Kitazaki M.: TwinCam: Omni-directional Stereoscopic Live Viewing Camera for Reducing Motion Blur during Head Rotation. ACM SIGGRAPH 2017 Emerging Technologies (2017).

[OIA*15] Okuya Y., Ikei Y., Amemiya T., Hirota K., Third person's footsteps enhanced moving sensation of seated person. IEEE Virtual Reality Conference 2015 (2015), 251-252.

[KLB*93] Kennedy R. S., Lane N. E., Berbaum K. S., Lilienthal M. G.: Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. The International Journal of Aviation Psychology. 3, (1993), 203-220

[NO98] Nakagawa C., Ohsuga M..: The present situation of the studies in VE-Sickness and its close field. The Virtual Reality Society of Japan, 3, 2, (1998), 31-39