# Effect of Footstep Vibrations and Proprioceptive Vibrations Used with an Innovative Navigation Method


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## Abstract

This study proposes to investigate the effect of adding vibration feedback to a navigation task in virtual environment. Previous study used footstep vibrations and proprioceptive vibrations in order to decrease the cyber-sickness and increase the sense of presence. In this study, we experiment the same vibration modalities but with a new navigation method.

The results show that proprioceptive vibrations do not impact the sense of presence neither the cyber-sickness while footstep vibrations increase sense of presence and decrease in a certain way cyber-sickness.



**Keywords**: Virtual Reality, Navigation Method, Vibrations, Cyber-sickness, Presence

**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


## 1. Introduction

The purpose of Virtual reality is to explore a virtual environment and to interact with it. This virtual environment can be infinite and can afford numerous possibilities. Therefore, navigation interfaces and metaphors are necessary to explore the virtual environment. Thus many navigation methods have been developed. The navigation task in the virtual environment differ from the real world. The action of moving is different and feedbacks are different. Thus, users can get sick because of this lack of feedback. They experience the cyber-sickness, similar to the motion sickness that car passenger suffer.

## 2. Related Work

Some previous researches showed that adding modalities to the simulation like audio, visual and tactile feedback improve the sensation of walking in virtual world. The Alive Floor can simulate uneven grounds. [1]. It is composed of actuated tiles. Vibrotactile information can also be provided through shoe-based devices [2]. Using contact sensors and vibrators, the shoes can simulate different ground types by producing adapted vibrotactile feedback at each step. It is also possible to improve the walking feedback using vibrotactile device like Terzimann's King-Kong effect. The user feels the virtual floor contact through a tactile vibration applied to the feet. Lécuyer and al. [3] use haptic feedback to improve the perception of self-motion in virtual environment. They show that haptic feedback improves the performance and the presence. Farkhatdinov [4] inputs vibrotactile information to the feet to modulate the vection feeling. With the vibrotactile feedback, users can feel their self-motion better. Other studies use continuous vibration to give a vection effect. The vibrations are applied under a seat, in the shoes or on the ground. They increase the movement feeling sensation.

Kitazaki and al. [5,6] showed that using rhythmic foot vibrations with a real-scene optic flow enhance the footstep sensation during virtual walking. Feng and al. [7] show that adding footstep vibrations increase slightly task performance and increase significantly user experience.

## 3. Methods

Our study takes place after a study about foot vibrations and proprioceptive vibrations applied to users during a navigation task in a virtual environment using a speed control navigation method was used.

The purpose here is to expose and compare the effect on cyber-sickness, sense of presence and navigation performance of the foot vibrations and proprioceptive vibrations with another type of navigation method where the user needs to indirectly act on his avatar to move in the virtual environment. Therefore, we developed a new navigation method based on the virtual companion from Cirio and al. [8]. We call our navigation method "Butterfly Navigation".

The companion is a butterfly. We use a Hydra gamepad from Razor as navigation device. The user controls directly the butterfly witch acts on the avatar to move it in the virtual world. The butterfly is controlled by acceleration for the translations. A position of the right joystick corresponds to an acceleration. With the effect of friction, the butterfly reaches a speed limit depending on the given acceleration. The left joystick allows the butterfly's rotation on the vertical axis. Then the avatar is pulled by companion through a mass spring relation.

Footstep vibrations or proprioceptive vibrations are applied respectively on ankles and on gluteus maximus. The purpose is to increase the user's experience in virtual reality by adding a new dimension to the simulation. Footstep vibrations aim to make the user feels when his virtual feet hit the ground. Proprioceptive vibrations purpose is to simulate an imbalance forward when user walks in the virtual environment.

Footstep vibration are applied with vibrating bracelets Vibrotac on the ankles. Vibrations are synchronized with the virtual space. The vibrations are activated for 200ms when the corresponding virtual foot touch the ground in the virtual environment. To synchronize the vibrations with the pace, with adapted the results from Hirasaki's [9] work about body movements during walking task. The pace depends on the speed. The vibrations amplitude is proportional to the speed.

Meanwhile, for proprioceptive vibrations we use two Uni Vibe 45mm Vibration Motor - 28mm Type. They are powered by 2.4 Volt to provide a vibration of 80Hz and an amplitude of 0.8 mm. They are put in an ergonomic box fixed against the lower gluteus maximus muscles to provide an illusion of slight imbalance


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forward. To walk, we create an imbalance forward and our legs offset this imbalance. Thus, the simulated imbalance corresponds to the walking initialization movement. The motors are activated while the avatar moves.

## 4. Scientific Question and Hypotheses

The research issue that we intend to address is as follows:

*What is the impact of footstep vibrations or proprioceptive vibrations on user's experience?*

Based on Plouzeau's work we consider six hypotheses:

H1- Footstep vibrations increase significantly the sense of presence compared to a simulation without vibrations.

H2- Footstep vibrations decrease the cyber-sickness felt by the user compared to a simulation without vibrations.

H3- Footstep vibrations do not affect the navigation performance compared to a simulation without vibrations.

H4- Proprioceptive vibrations do not affect the sense of presence compared to a simulation without vibrations.

H5- Proprioceptive vibrations do not affect the cyber-sickness compared to a simulation without vibrations.

H6- Proprioceptive vibrations do not affect the navigation performance compared to a simulation without vibrations.

## 5. Experimentation and Results

To validate or not these hypotheses, we set up an experimentation were participants had to navigate in a virtual environment either without vibrations, or with footstep vibrations, or with proprioceptive vibrations. For the experiment, we evaluate the sense of presence with a questionnaire (PQ). We also evaluate the cyber-sickness through a questionnaire (SSQ) and objective measurements as postural stability (Stabilotest Platform) and Electrodermal Activity (E4 bracelet).

The scenario is composed by two environments. The first is a park with a path going through trees and houses. The second environment takes place inside a building. A slalom is indicated with cones 2 m laterally spaced and 3 m longitudinally spaced.

The experiment has three parts. Each part includes one of the following modality: without vibration, proprioceptive vibrations and footstep vibrations. As immersion induces the cyber- sickness and we want the measure to compare for each modality, participants must complete each part spaced at least for one day. This allows independent results for cyber-sickness. The modalities order is randomized.

Results support that the experienced vibration modalities do not affect the simulation in the same way.

Footstep vibrations increase the sense of presence but the increase is global. Each factor is slightly increased. Concerning the cyber-sickness, results show some interesting aspects. Indeed, the questionnaire indicates a significant decrease in perceived cyber-sickness. The two factors, nausea and oculo-motor, show significant decreases. However, objective measures, postural stability and Electrodermal Activity, indicate no impact of these vibrations on the cyber-sickness. Thus footstep vibrations help to reduce the felt cyber-sickness but it remains present. Regarding the navigation performance, footstep vibrations have no impact neither on the travel time nor on the displacement accuracy. Finally, the results of the feedback questionnaire show that footstep vibrations disturb only a little the user and gives him a good indication on the achieved movement in the virtual environment.

On the other hand, proprioceptive vibrations have no effect on the sense of presence. Similarly, the subjective and objective measures of the cyber-sickness allow to conclude that these proprioceptive vibrations do not affect cyber-sickness. Navigation performance is not affected by proprioceptive vibrations either. In contrast, the feedback questionnaire indicates that the proprioceptive vibrations do not disturb at all the user and allow a good feeling when moving in the virtual environment.

## 6. Conclusion and Discussion

This allows us to validate 5 of our hypotheses H1, H3, H4, H5, H6.

The second hypothesis is partly validated. Footstep vibrations do not decrease the cyber-sickness but the user feels less sick with these vibrations.

Comparing these results with Plouzeau's work allows to show that depending on the navigation method, effects of vibrations feedbacks differ.

We showed that when the user indirectly acts on his avatar to move, proprioceptive vibrations do not reduce cyber-sickness neither increase the sense of presence. This may result from the proprioceptive vibration mechanism. The proprioceptive illusion may operate only when user acts on himself.

We have to keep in mind that the studies were made with few participants. A future study could validate the results by integrating the different vibration modalities to existing simulations where cyber-sickness and sense of presence need to be improved.

Future studies could merge both vibration modalities in order to get benefits from both of them.

After showing the proprioceptive vibrations impact on cyber-sickness and presence, future works could develop this aspect more and try to simulate other movements and actions.


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## References


[1] Y. Visell, B. Giordano, G. Millet and J. Cooperstock, "Vibration Influences Haptic Perception of Surface Compliance During Walking", *PLoS ONE*, vol. 6, no. 3, p. e17697, 2011.

[2] S. Papetti, F. Fontana, M. Civolani, A. Berrezag and V. Hayward, "Audio-tactile Display of Ground Properties Using Interactive Shoes", *Haptic and Audio Interaction Design*, pp. 117-128, 2010.

[3] A. Lecuyer, M. Vidal, O. Joly, C. Megard and A. Berthoz, "Can haptic feedback improve the perception of self-motion in virtual reality?", *12th International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2004. HAPTICS '04. Proceedings*, 2004.

[4] I. Farkhatdinov, N. Ouarti and V. Hayward, "Vibrotactile inputs to the feet can modulate vection", *2013 World Haptics Conference (WHC)*, 2013.

[5] M. Kitazaki, K. Hirota and Y. Ikei, "Minimal Virtual Reality System for Virtual Walking in a Real Scene", *Human Interface and the Management of Information: Information, Design and Interaction*, pp. 501-510, 2016.

[6] T. Hayashizaki, A. Fujita, J. Nozawa, S. Ueda, K. Hirota, Y. Ikei and M. Kitazaki, "Walking experience by real-scene optic flow with synchronized vibrations on feet", *Proceedings of the 6th Augmented Human International Conference on - AH '15*, 2015.

[7] M. Feng, A. Dey and R. Lindeman, "An initial exploration of a multi-sensory design space: Tactile support for walking in immersive virtual environments", *2016 IEEE Symposium on 3D User Interfaces (3DUI)*, 2016.

[8] G. Cirio, P. Vangorp, E. Chapoulie, M. Marchal, A. Lecuyer and G. Drettakis, "Walking in a Cube: Novel Metaphors for Safely Navigating Large Virtual Environments in Restricted Real Workspaces", *IEEE Transactions on Visualization and Computer Graphics*, vol. 18, no. 4, pp. 546-554, 2012.

[9] E. Hirasaki, S. Moore, T. Raphan and B. Cohen, "Effects of walking velocity on vertical head and body movements during locomotion", *Experimental Brain Research*, vol. 127, no. 2, pp. 117-130, 1999.