Vestibular Display for Walking Sensation in a Virtual Space

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Abstract. This paper describes characteristics of walking sensation created by a vestibular display (a motion seat). An active input was introduced to a passive presentation of a walking stimulus. The participant triggered one step motion repeatedly by a game-controller button to introduce agency of motion. First, the magnitude of the seat motion was optimized to increase the walking sensation. Then, passive and partially active seat motion was evaluated. As a result, it was shown that added activity increased the walking sensation .

Keywords: Vestibular stimulation · Motion seat · Active input
Walking sensation

1 Introduction

Locomotion is one of the important functions of experience in a virtual space [1]. The display for the bodily sensation of locomotion in a virtual space has been studied mostly in the form that the user moves his/her body in the real space. The display cancels the user's physical movement in the real space typically by treadmill [2]. Otherwise, the real walk motion was modified to keep the user within a limited area as walk-in-place [1] and redirect walking [3]. The present study proposes a different approach in that the user does not walk in the real space, but sits on a seat and receives the sensation of walking from a multisensory display. It creates the sensation of virtual body motion as well as the environmental reality. It is designed to have the user relive the other person's walking [4] and feel the sensation that was received by the person. Reliving here means to project someone's bodily experience to oneself. This is useful for skill transfer or bodily learning as well as entertainment such as a sightseeing tour.

Although a steady walk is almost automatically repeated motion without conscious control, adjustment of motion is performed consciously following to the environment as well as motion error [5, 6]. The real walk is an active motion in that sense, however it is not a completely conscious-controlled motion as being observed passive. Therefore, it is considered that walking in a virtual space should be both active and passive as the real walk.

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In this paper, we discuss the effect of introduction of an active control within a passive reception of a walking stimulus. The vestibular display (Fig. 1) was developed originally to stimulate the user's body passively (as watching a movie) to have he/she feel like walking. We added a game-controller button that input a trigger one step motion at a time to give the sensation of agency on the walking motion. The participant evaluated nine factors of walking sensation as well as the sensation of agency (activity) and the sensation of walking evoked by passive and partially active motion of the vestibular display.

Fig. 1. A vestibular display (motion seat) of three degrees of freedom (lift, roll, pitch motion)

2 Optimization of Motion Stimulus

2.1 Objective

The optimum amount of motion of the seat to produce the sensation of walk was measured when the participant controlled the start timing of the seat motion.

2.2 Participants and Optimization Procedure

The participants of the measurement were ten undergraduate and graduate students at the average age of 23.1 years.

They walked a flat floor for more than 20 m at a 1.4 s walk period (0.7 s each step), and remembered the sensations of the body motion of lifting, pitch and roll rotations during the walk. Then they sat on the motion seat and adjusted the amplitude of the 3-dof motion (lift, pitch, roll rotation) and velocity to produce the optimal sensation of walk using game-controller buttons, with closed eyes and noise emitting earphones.

The motion of the seat at around 1.4 s period was activated by the participant who pushed the buttons periodically. The period depended on the participant's memory. The seat motion was either ipsilateral or contralateral. The ipsilateral motion means that the same side (e.g. right side) of the seat as the pushed button (right) lifted to make a roll motion. The contralateral motion means that the opposite side was lifted.

2.3 Result of Motion Optimization

The optimal motion for the ipsilateral input was 1.28 mm lift, 0.15° roll rotation, and 0.183° pitch rotation with a lift speed of 6.5 mm/s rise and 6.29 mm/s fall. Those for the contralateral input was 1.32 mm lift, 0.155° roll rotation, 0.146° pitch rotation with a lift speed of 6.63 mm/s rise and 6.88 mm/s fall.

As a result of Friedman's test, these values were not significantly different from the optimum value obtained when passive stimulation without input of the participant was rated where the number of participants was nine with the average age of 23.5 years.

3 Evaluation of Walking Sensation in Nine Factors

3.1 Objective

Walking sensation produced by the optimum stimulus adjusted in the previous section was rated as compared to the sensation of a real walk. Rating was performed in terms of nine factors related to the walking sensation.

3.2 Participants and Procedure

Participants in the evaluation were ten undergraduate and graduate students with the average age of 23 years. They evaluated the optimum stimulus in the nine factors shown in Table 1.

Table 1. Factors of walking sensation.

Factors of walking sensation	Definition of factors (awareness)
Power (acceleration)	Sensation of applied force to make the body forward. Sensation of lifting the body at stairs
Walk velocity	Sensation of walking speed
Periodicity (repetitive motion)	Sensation of repetitiveness of the motion
Lateral alternation (lateral sway)	Sensation of the alternated contact motion of legs on the ground
Muscle tension (perceived)	Sensation of muscular effort of lower extremity to support the weight of the body
Continuous body motion	Sensation of total amount of continuous motion of the body
Regularity of continuous body motion	Sensation of regular continuous motion of the body
Balance control (posture maintenance)	Sensation of maintaining/controlling posture to continue a balanced walking
Sole taction (tactile sensation) at the foot	Sensation of sole skin when the foot contacted to the ground

First, the participant realized nine factors of walking sensation after they walked a flat floor for more than 20 m at a 1.4 s walk period (0.7 s each step). Second, they sat on the vestibular display and played the stimulation optimized beforehand with closed eyes and noise emitting earphones. Finally, they evaluated the walking sensation using VAS (Visual Analog Scale) ranging from no sensation (0) to very definite (100). Both the ipsilateral and the contralateral inputs were evaluated.

3.3 Result

The results are shown in Fig. 2. Ratings of the real walk and the passive stimulus are from the previous studies. The Kruskal-Wallis test was applied in terms of four stimulations since the data lacked the normality and the equal variance based on Shapiro-Wilk and Bartlett's tests. The four factors indicated significant difference: Walk velocity ($p = 0.0312$), Muscle tension ($p = 0.003$), Continuous body motion ($p = 0.006$), and Sole taction ($p < 10^{-06}$).

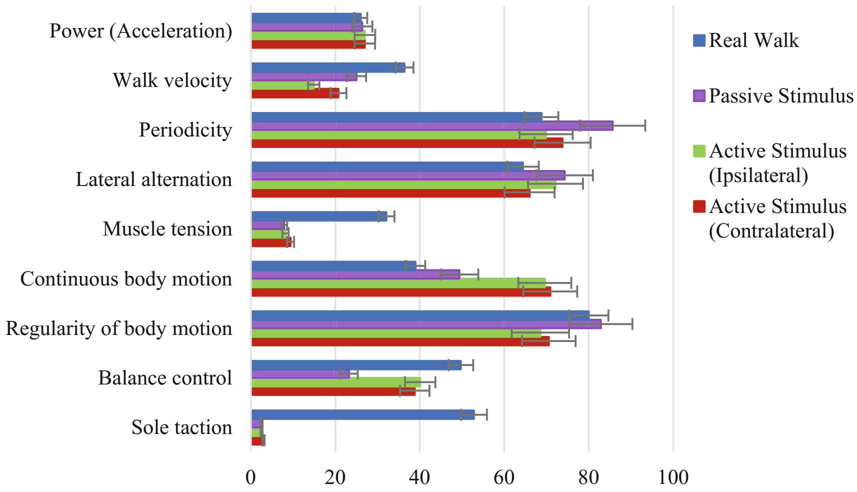

Fig. 2. Result of sensation (awareness) ratings of a real walking on level floor and VR walking by the seat motion presentation (SE error bar)

The sensation of walk velocity was weaker in the three stimulus conditions than the real walk. The reason might be the visual vection that was involved only in the real walk. The large difference in the muscle tension and the sole taction is due to lack of the active muscle motion and foot sole stimulus that occurred in a real walk. The continuous body motion in the active stimuli exceeded the real walk. This may be caused by increased attention to the body (seat) swing motion that was induced by input of the participant. Other factors indicated that stimulation by the motion seat could impart almost equivalent sensation to the real walking.

4 Evaluation of Sensations of Activity and Walking

4.1 Objective

The contribution of active and passive seat motions to the sensation of activity (voluntariness) and the sensation of walking was investigated, since the walking experience involves both active and passive aspects of motion sensation.

4.2 Participants and Optimization Procedure

Eleven university students (average age 22.9) participated in the evaluation to compare three stimuli. The passive seat motion, the active seat motion in ipsilateral input, and the active seat motion in contralateral input were evaluated in terms of the sensation of activity and the sensation of walking. They walked as the previous experiment to memorize the sensation, and rehearsed periodic active input before the rating session with more than 30 steps of the seat motion. The stimulation was added only by seat motion.

4.3 Result of the Sensation of Activity

Figure 3 shows the result of activity rating. A significant difference was observed ($p < 0.05$, Friedman's test). The activity rating was higher in the active stimuli than passive stimulus ($p = 0.012$, Holm's multiple comparison). The difference between the ipsilateral stimulus and the contralateral stimulus was not significant. The sensation of activity was increased markedly by introducing voluntary trigger input by the finger. However, the finger input did not sufficiently substitute for the leg motion in walking.

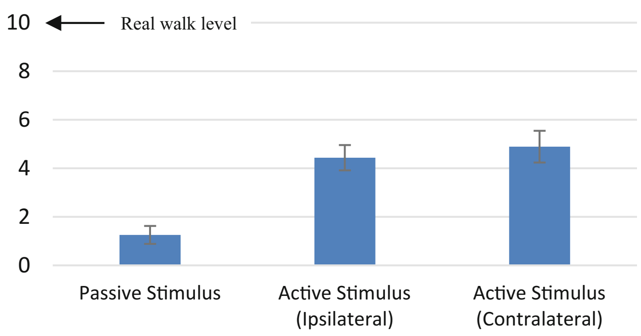

Fig. 3. Sensation of activity by vestibular stimulation (single modality)

4.4 Result of the Walking Sensation

Figure 4 shows the result of walking sensation. A significant difference ($p < 0.05$) was observed (Friedman's test). The rating of the active stimuli was higher than the passive stimulation ($p = 0.026$). There was no significant difference between the ipsilateral and the contralateral stimuli (Holm's multiple comparison). The sensation of walking was effectively raised by the active trigger input that might have cognitively imitated active aspect of walking motion.

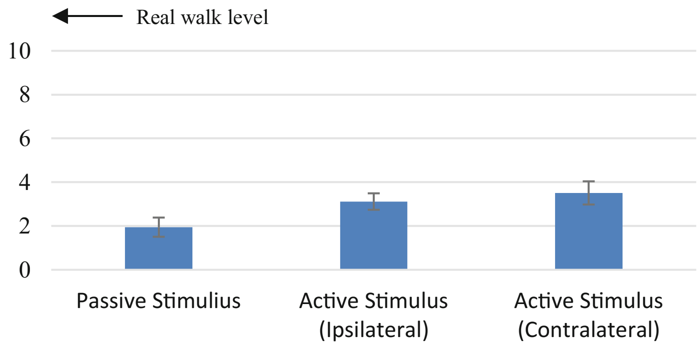

Fig. 4. Walking sensation by vestibular stimulation (single modality)

5 Conclusion

The periodic active input to trigger each of the single step motion of the vestibular display could increase the sensations of both walking and activity (agency). The active aspect of a real walk may have been provided by this input performed along with passive awareness of seat motion as body acceleration during walking.

Further studies are needed to clarify the relationship between passive and active sensations of a real walk, and their substitutes by a seat motion.

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