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Research Article

Effects of Tactile Stimulation Near the Auricle on Body Sway

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ABSTRACT

This paper describes the relationship between tactile stimulation and human body sway. We previously proposed a tactile stimulation-based body sway stabilization system and revealed that simultaneous stimulation behind both auricles significantly improved human balance function, and unilateral stimulation may induce the deviation of the center of pressure (COP). In this paper, some stimulation patterns were applied to participants and COP distribution before/after stimulation was extracted. The results showed that COP values after stimulation could be inclined to the same of the stimulation site. It indicates that tactile stimuli can control human balance function.

1. Introduction

Falls account for about 80 percent of accidents in Japan[1], and prevention of falls is an urgent issue. It is said that the decline of motor function with aging increases the risk of falls by about five times[2], making fall prevention an essential issue in Japan where the population is rapidly aging[3].

Various fall prevention and balance function improvement systems have been developed[4-10]. Studies focusing on improving balance function can be divided into two categories: those that use light touch contact (LTC)[4] and those that use stimulation to the human body to improve vestibular and somatosensory fuctions[5-9]. In LTC, it has been shown that the balance function can be improved by touching a fixed point. It has also been shown that it is possible to decrease and control body sway by applying acoustic[5,6], electrical[7,8] and vibratory[9] stimuli. For example, it has been shown that white noise acoustic stimulation[5] and galvanic vestibular stimulation stabilizes body sway[7,8]. In addition, it has been also shown that vibration to the head is effective in improving balance function in Parkinson's disease (PD) patients[9]. However, because these approaches may exert a physical burden on the use, it is difficult to use in daily life.

To overcome these problems, our research group has been proposed the body sway mitigation system based on tactile stimulation and showed that body sway can be reduced via the application of vibratory stimuli around the pinna[10]. Here, acoustic stimulation can induce body sway to the opposite direction of the stimulus[6], however, previous studies have not fully clarified the relationship between tactile stimulation and body sway. In order to clarify these relationships, we have previously tried to quantify the change in COP by applying unilateral stimulation[11]. As a result, it can be concluded that there is a tendency for COP distribution to be biased in the direction contrary to the stimulated side. The results showed that the COP distribution tended to be biased in

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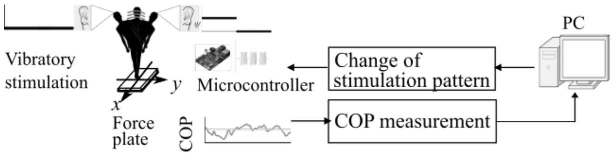


Fig. 1. Overview of the proposed balance function analysis system.

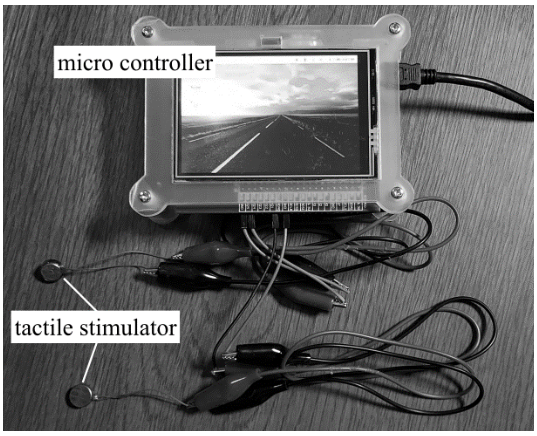


Fig. 2. Overview of the tactile stimulation system.

the opposite direction to the stimulus side, however, there was only one participant, and the bias of COP was not sufficiently examined.

In this paper, we attempt to quantify the influence of vibration stimulation on body sway by clarifying the relationship between vibratory stimulation near the auricle and body sway deflection.

2. Method

Figure 1 shows the proposed vibratory stimulation-balance function analysis method based on the body sway mitigation system using tactile stimulation[8]. The system consists of a stabilometer, tactile stimulators, a microcontroller for controlling vibratory stimulation pattern (See Fig. 2), and a PC. Stimulation patterns can be changed from the PC before experiments via TCP/IP communication. Figure 3 shows an example of stimulation pattern. The system can change the on-off interval T_s [s], stimulation interval T_{on} [s], and non-stimulation interval T_{off} [s] of each tactile stimulator. In addition, the magnitude of the stimulus can be changed by adjusting the duty ratio D using PWM control. The

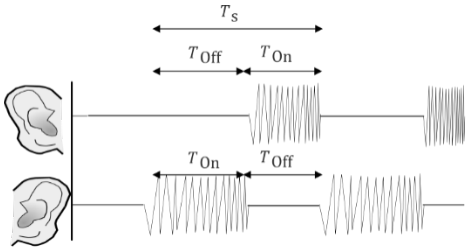


Fig. 3. Vibration stimulation pattern used in the experiments.

subjects were asked to maintain an eye-closed tandem limb stance for T [s]. Tactile stimulators were applied near the left and right auricles to provide vibration stimulation to the subjects.

3. Posture stabilization experiment by vibration stimulation

Our research group has reported that steady stimulation near the auricles stabilizes posture[10]. In this paper, we first clarify that body sway can be reduced by applying constant vibration stimulation to the left and right sides near the auricle to reveal the mechanism of body sway reduction by vibration stimulation.

3.1. *Experimental conditions*

In the experiment, COP sway was measured in three participants (Sub. A--C, 22.3 ± 0.471 [years]) when constant vibration stimuli were applied alternately to the left and right mastoid processes. Two motor oscillators (KD18B1) were connected to a Raspberry Pi 3B, and voltage was applied using PWM with a duty cycle of 0.01 [s]. The stimulus was applied to the right side during T_{on} [s], then switched to the left side, and switched to the left side again after T_{on} [s]. Therefore, the stimulus was not applied to the mastoid region on the side (D = 0.0) different from the stimulus side at the same time.

The subjects were asked to maintain the tandem limb position with the left foot back on the force plate with eyes closed for $T = 60$ [s], including 5 [s] before and after the measurement (See Fig. 4). The COP was measured using the Wii Balance Board (Nintendo Co., Ltd.) at a sampling frequency of 100 [Hz]. The stimulus pattern given to the subject is $T_s = 10$ [s], the left side stimulus duration is $T_{\mathrm{on}}^{\mathrm{left}} = 5$ [s], $T_{\mathrm{off}}^{\mathrm{left}} = 5$ [s] and the right side stimulus duration is $T_{\mathrm{on}}^{\mathrm{right}} = 5$ [s], $T_{\mathrm{off}}^{\mathrm{right}} =$

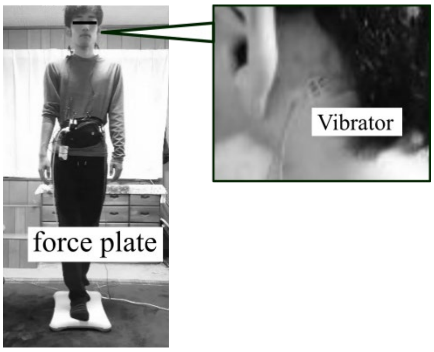


Fig. 4 Experimental scene.

5 [s] ($T_{\mathrm{on}}^{\mathrm{left}} + T_{\mathrm{off}}^{\mathrm{left}} = T_{\mathrm{on}}^{\mathrm{right}} + T_{\mathrm{off}}^{\mathrm{right}} = T_s$). The voltage was applied to the motor at a duty ratio of D = 0.8, and a steady-state stimulus was applied to the subject. To compare and evaluate the effect of this stimulation pattern on the postural sway, the comparison experiment was also performed under the condition without stimulation. The number of trials was 10 with and without stimulation.

3.2. *Results and discussion*

Figure 5 shows measured COPs (a) with and (b) without stimulation. The time-series waveform $\mathrm{COP}_{\{x,y\}}(t)$ of each axis of the measured center of pressure (COP) was smoothed by a second-order Butterworth digital low-pass filter (cut-off frequency: $f_c = 10$ [Hz]). It could be found that the COP sway decreased with stimulation compared to that without stimulation.

Here, we calculated several evaluation indices to assess the stability of COP sway between stimulated and unstimulated conditions based on the method of Watanabe *et al.*[10]. The stability of COP oscillation is quantitatively evaluated by calculating the posture holding time, variation of COP, and index of movement from the smoothed COP signal.

Figure 6 shows the experimental results. Note that Fig. 6 shows the mean values of all subjects normalized so that the mean value of each index value in the no-stimulus condition is 1. The results of an unpaired *t*-test are also shown simultaneously in the figure. As shown in Fig. 6, each index tended to decrease significantly (p<0.05, posture maintaining time did not change because no fall occurred in all trials). This indicates that COP sway can be stabilized by alternating stimulation of the left and right sides. Here, previous studies have

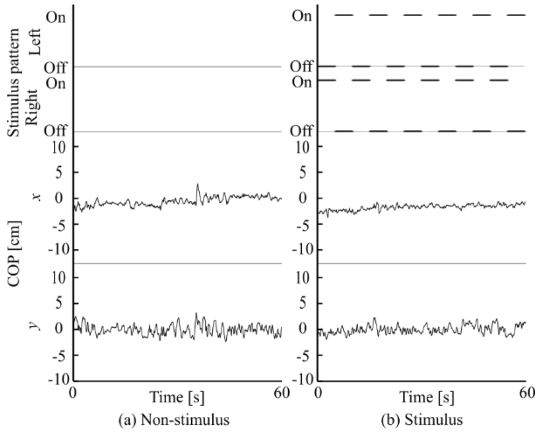


Fig. 5 Examples of measured COPs.

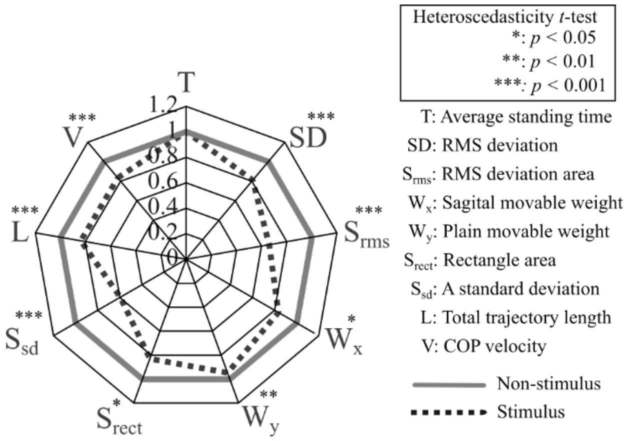


Fig. 6 Evaluation indices of human body sway.

shown that a fixed-sound source provides a reference for body orientation[12] (same as the light touch contact[4]) and increasing attention to acoustic stimuli effect on body sway[5]. It is possible that the same phenomenon occurred in this experiment.

4. Body sway evaluation experiment by unilateral vibration stimulation

The experimental results showed that the COP sway stabilized even when the stimuli were not applied bilaterally. To clarify how the stimulation near the auricle affects the body sway, we evaluated the body sway during unilateral stimulation.

4.1. *Experimental conditions*

In the experiments performed, COP sway during the application of vibratory stimulation was measured with three healthy males (22.7±0.471 [years]). Two motor oscillators (KD18B1) were connected to a Raspberry Pi 3B and a voltage was applied by pulse width control with a duty cycle of 0.01 [s]. The stimulus was applied to only one of the left and right sides.

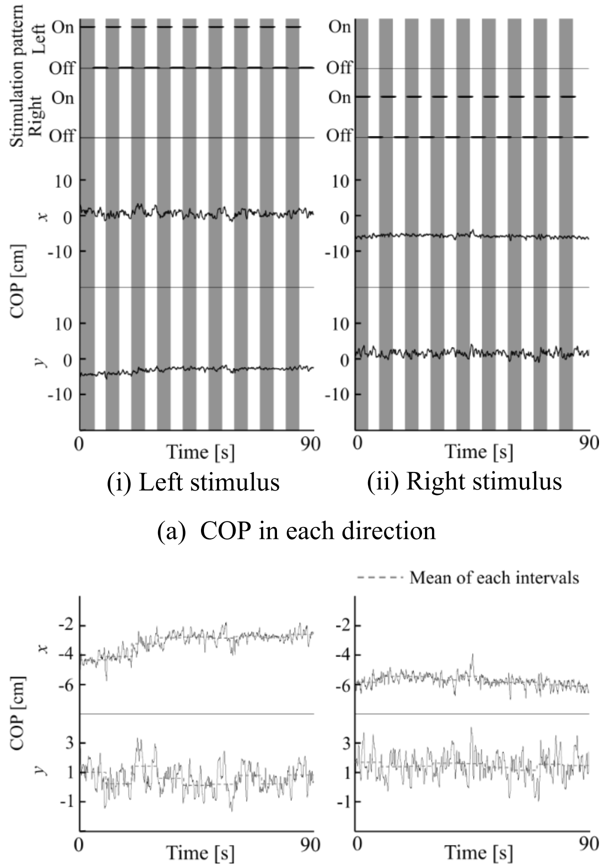
The subject was asked to maintain tandem limb stance with eye-closed and the left leg back for $T = 90$[s] after a preparation time for 10 [s]. The COP was measured at a sampling frequency of 100 [Hz] using a Wii Balance Board (Nintendo Co., Ltd.). The stimulus pattern applied to the subject was steady-state stimulus with $T_s = 10$ [s], duty ratio $D_{\max} = 1.0$ during $T_{\text{on}} = 5$ [s], and $D_{\min} = 0.32$ determined in advance, which was less than or equal to the minimum stimulus amplitude perceived by the subject, during $T_{\text{off}} = 5$ [s]. This stimulus pattern was applied to the left or right side.

4.2. *Results and discussion*

The filtered COP value $\overline{\text{COP}_{\{x,y\}}}(t)$ was divided into M every T_s [s], and the error between mean values ave_m in each interval $(m = 1, 2, \dots, M)$ and median values med_m^{on} for stimulation interval and $\text{med}_m^{\text{off}}$ for non-stimulation interval were evaluated. This clarifies the bias of body sway with and without vibratory stimulation.

Figure 7 (a) shows examples of signals measured during the experiments: (i) for the left-side stimulus and (ii) for the right-side stimulus, respectively. Figure 7 (a) shows the results from the first trial, indicating stimulation patterns and COPs. The shaded areas represent times during non-stimulations. Figure 7 (b) is an enlargement of COPs from Fig. 7 (a), and it cannot be confirmed that the stimulus affected to the balance function.

Figure 8 (a) and (b) show histograms of COP of *y* axis (frontal plane) with median and mean values for the left-side and right-side stimulus conditions, respectively. Figure 8 (a) of the results for the left-side stimulus



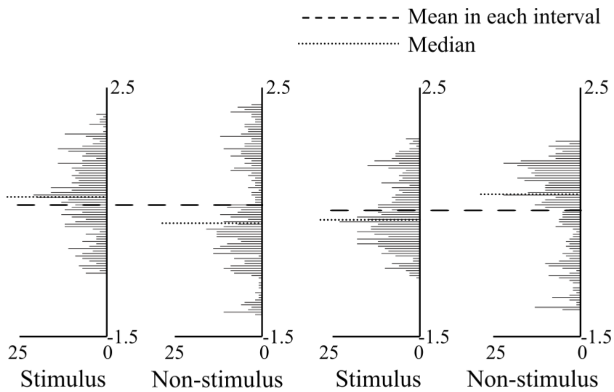
(i) Left stimulus (ii) Right stimulus

(a) COP in each direction

(i) Left stimulus (ii) Right stimulus

(b) An enlargement of COPs

Fig. 7 Examples of experimental results.



(a) Left stimulus (b) Right stimulus

Fig. 8 Examples of experimental results.

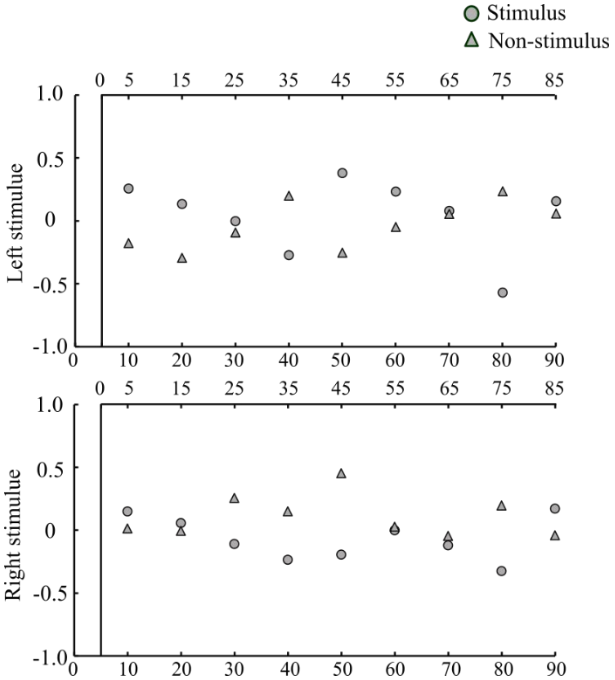


Fig. 9 Examples of experimental results.

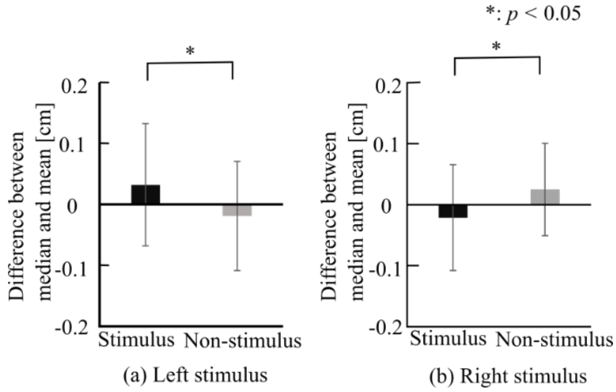


Fig. 10 Examples of experimental results.

condition shows that the mean is smaller than the median value in the stimulus interval, and conversely, the mean is larger than the mean value in the non-stimulus interval. In Fig. 8, the positive value shows deviation to the left side, therefore, the subject may tilt the same side of the stimulation.

Figure 9 shows the difference between mean values during stimulation and non-stimulation and the median in the interval of 10 [s] for left-side stimulation condition and right-side stimulation condition, respectively. The positive component represents the bias to the left side of COP distribution, and the negative component represents the bias to the right side of COP distribution. Note that in Fig. 9, the phase of the unstimulated values is shifted by 5 [s]. In Fig. 9, we can see that the COP of the left stimulus was positive (biased toward the left side) in the stimulus presence interval and negative (biased toward the right side) in the stimulus off interval. In the right stimulus, these relationships were reversed compared to the left stimulus, and there was a tendency for many intervals to be negative when the stimulus was On and negative when the stimulus was Off.

The results of the heteroskedasticity *t*-test confirmed a significant difference at the level of 5 [%] (see Fig. 10 (a)). On the other hand, when right stimulation was applied, there was a bias to the right side during stimulation ($p < 0.05$), and a bias to the left side during non-stimulation ($p < 0.05$) (see Fig. 10 (b)). These results suggest that COP bias in the left-right direction may be induced to the same side of the stimulated side. It is possible that COP bias is induced to the same side of the stimulus, resulting in a larger bias toward the stimulus to maintain body balance equilibrium.

These results indicate that regular unilateral steady stimulation to the auricle induces COP sway on the same side of the stimulus, and that the sway may be deflected to the stimulus side to resist it. In the future, we will increase the number of subjects and investigate whether this tendency appears or not, and also whether it is possible to induce body sway arbitrarily by changing the vibration pattern or not.

5. Conclusion

In this paper, we examined the effects of regular unilateral steady-state stimulation patterns on COP bias when they were applied to the near pinna. In the first experiment, the participant was asked to maintain tandem limb positions with closed eyes, and quantitatively evaluated whether alternating left and right stimulation induces stability of COP sway. The results of the experiment showed that the values of all indices related to COP sway decreased significantly before and after the stimulation, indicating that the COP sway tended to be stabilized even when bilateral short-term oscillatory stimuli were applied alternately. In another experiment, the subject was asked to maintain tandem limb positions with closed eyes, and the change of COP deviation with and without stimulation in each stimulation pattern was compared. It is confirmed that the stimulation may induce the deviation of COP oscillation in the frontal plane to the same side of the stimulated side. This suggests that the amount of deflection to the stimulus opposite side may increase to maintain the equilibrium against the induced COP oscillation.

In future research, we will increase the number of subjects and deepen the verification of the experiment conducted in this study. In addition, we plan to change the pattern of the vibratory stimulation and investigate the relationship with the body sway.

Acknowledgments

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Authors Introduction

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