Effects of Tactile Stimulation Near the Auricle on Body Sway During Foot Stamping

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Abstract

This paper describes the effects of tactile stimulation near the auricles on body sway in during foot stamping. The system measures center of pressure, acceleration of upper body, and whole-body movements by skeleton tracking with a depth camera while the participant performs foot stamping on the stabilometer, and extracts evaluation indices based on four perspectives: the amplitude, variation of body sway, rhythm of body sway, and correlation between of each limb. In the prototype experiment conducted with one healthy male, the body sway during foot stamping for ten trials in non-stimulus condition is compared with that for two trials in stimulus condition that the constant tactile stimulus is applied. As a result, the variation of the movement of lower limb and upper body sway were significantly reduced. This result implies that applying the constant tactile stimulation near both of auricles may be effective in stabilizing posture during foot stamping.

Keywords: dynamic balance function, body sway, tactile stimulation, center of pressure, foot-stamping

1. Introduction

According to the 2021 Annual Report on the Aging Society,[1] the number of elderly people requiring care is increasing every year, which is one of the most important issues considering the recent super-aging population and the number of elderly people in Japan (approximately 28.4% of the total population[2]). It is important for elderly people to extend their healthy life expectancy, maintain their quality of life (QOL), and support their independent lives. Falls and fractures are a major cause of the major causes of decreased QOL and account for 18.1 % of the factors causing the need for care.[1] Even if the elderly do not require nursing care, the fear of falling can affect their cognitive ability and gait abilities[3], causing a decline in the QOL and affecting the activities of daily living (ADL). In addition, it is said that decline in cognitive function increases the risk of falls[4], and therefore, preventing falls is an urgent and essential issue.

(a). Initial stance (b). Left stamp (c). Right stamp

Fig. 1. Protocol of the experiment.

There are two types of equilibrium functions in humans: static balance and dynamic balance, and measures to prevent falls are required for both.

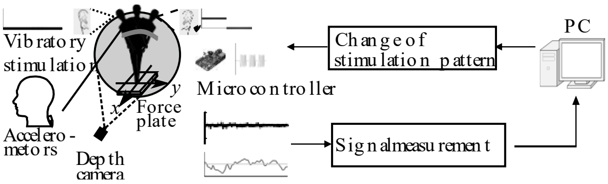


Fig. 2. The overview of the dynamic balance function analysis system based on tactile stimuli.

In the study of static balance function, body sway has been mainly analyzed by upright testing on a stabilometer, and light touch contact (LTC)[5], a phenomenon in which body sway is reduced by touching the fixed point with a fingertip at a force of less than approximately 1 [N], auditory stimulation[6], tactile stimulation[7], and galvanic vestibular stimulation (GVS) have been reported to reduce body sway[8]. In the study of dynamic balance function, rhythmic auditory stimulation (RAS) has been reported to improve gait function in gait analysis[9]. However, because of the possibility of being distracted by external stimulation owing to attention to rhythmic sounds, they are difficult to use in daily life. Our research group has shown that body sway can be reduced by applying vibratory stimulation around both sides of the pinna during tandem limb stance[10]. However, the effects of tactile stimulation on dynamic balance function have not been discussed.

This paper describes the evaluation of the effect of tactile vibratory stimulation on dynamic balance function by measuring the body sway during foot stamping on a stabilometer.

2. Method

The participant in the experiment was one healthy male who provided informed consent. The oscillator motors (KD18B1) were attached near both sides of the mastoid region of the participant and were connected to a Raspberry Pi 3 B and controlled via pulse width modulation (PWM) control with a duty cycle of 0.1 [s]. First, the participant was asked to face the front with both feet shoulder-width apart on the stabilometer (see Fig.1 (a)). Then, the participant was required to perform foot stomping from the left foot with natural arms swing and height of thigh in synchronization with a 1.0 [Hz] beep sound from the PC during 40 [s] with his eyes closed. The evaluation time was $T = 30$ [s], excluding

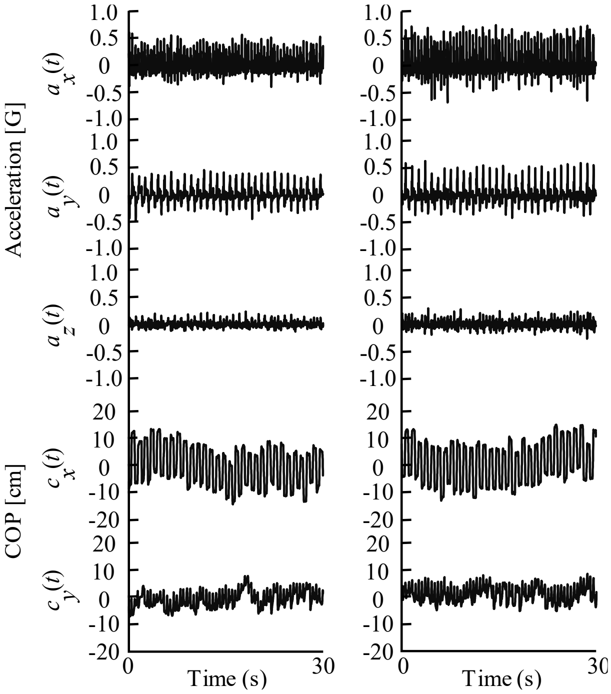


Fig. 3. An example of experimental results.

the 5 [s] before and after the start of the measurement. A steady-state stimulus was applied to the participant with a constant duty ratio ($D = 1.0$) on both sides of near the auricles. The number of trials was 10 for both the stimulus and non-stimulus conditions, and the trials were conducted at intervals.

Figure 2 shows an overview of the dynamic balance function analysis system based on tactile stimuli. Two-dimensional time series data of center of pressure (COP) $c_{\{x,y\}}(t)$ were obtained from a Wii balance board (Nintendo, Co., Ltd.) at a sampling frequency of 100 [Hz] and smoothed using a second-order digital Butterworth low-pass filter (cut-off frequency: $f_c^L = 10$ [Hz]). To measure the participant's upper body sway, acceleration signals $a_{\{x,y,z\}}(t)$ were also measured using acceleration sensor (IMU-Z2, ZMP Inc.) attached to the back neck. The DC component in the signal was removed using a second-order digital Butterworth high-pass filter (cut-off frequency: $f_c^H = 0.5$ [Hz]). In addition, an RGB-D camera (Intel RealSense D435, Intel Corp.) was used to measure the body movements (sampling frequency: 30 [Hz]), and skeleton tracking was performed in real time with the skeleton detection middleware Nuitrack (3DiVi Inc.).

The filtered COP $c_{\{x,y\}}(t)$ and acceleration signal $a_{\{x,y,z\}}(t)$ were used to evaluate body sway from three perspectives: (i) amount and (ii) variation of movement and (iii) rhythm. Each index value was categorized as follows:

(i) Amount of movement

The evaluation indices based on COP:

- I_1: Movement width for $c_{\{x,y\}}(t)$ [cm]
- I_2: Total trajectory length [cm]

and that based on acceleration:

- I_3: Root mean square (RMS) that can be expressed by the combination of axes of $a_{\{x,y,z\}}(t)$ [cm]

(ii) Variation of movement

Mainly to evaluate the density of the body sway.

- I_4: RMS deviation area [cm^2]
- I_5: Rectangle area [cm^2]
- I_6: A standard deviation area [cm^2]

(iii) Rhythm

Mainly to evaluate the periodicity of the body sway.

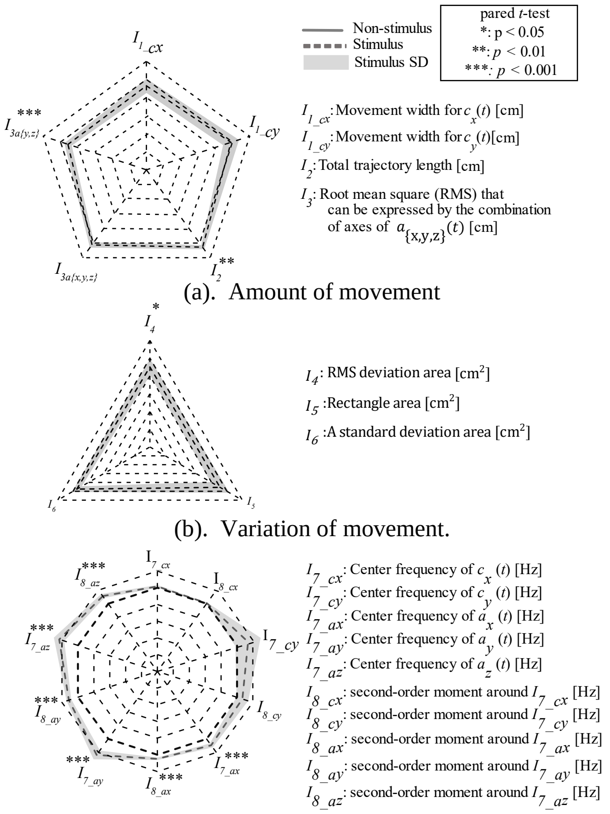
- I_7: Center frequency of $c_{x,y}(t)$ and $a_{\{x,y,z\}}(t)$ [Hz]
- I_8:Second-order moment of I_7 [Hz]

3. Results and discussion

Figure 3 shows the COP and acceleration signals measured in the experiment. The results shows that waveforms on the right fluctuated slightly.

Figure 4 shows the radar charts of each evaluation index for each category. Note that Fig. 4 shows the mean values of normalized the no-stimulus condition is 1. The results of a pared *t*-test are simultaneously shown in the figure. As shown in Fig. 4(a), the amount of movement, trajectory length I_2 significantly increase and horizontal plane composite acceleration I_3 decreased ($p < 0.01$). In addition, variation of COP (I_4) decreased ($p < 0.05$, see Fig. 4(b)). Although the trajectory length in the present measurement was considered to be affected by the change in foot width during foot-stamping and the force of stepping on the stabilometer, the velocity of COP movement was faster in stimulus condition that may have resulted in denser lower limb sway. Focusing on the index of rhythm, the center frequency and second-order moment of $a_{\{x,y,z\}}(t)$ increased significantly ($p < 0.001$).

Taguchi *et al*. reported that the amount of head sway in the horizontal plane increased in participants who were prone to body sway, such as abnormal peripheral vestibular function, as a result of attaching an accelerometer to the head and measuring the amount of sway[11]. In this study, these results implied that body sway was stabilized because of applying tactile stimulation to both auricles of the participant.



(a). Amount of movement

(b). Variation of movement.

(c). Rhythm.

Fig. 4. The experimental results.

4. Conclusion

This study investigated the effects of tactile stimuli applied to around the both sides mastoid region on dynamic equilibrium function by measuring body sway during foot stamping. In the experiment, the participant was asked to perform foot stomping in sync with a beep sound played every 1 [s] from the PC, and the changes in body sway with and without stable stimulation were compared. The results showed that the COP variation ($p < 0.05$) and the sum of horizontal RMS of acceleration ($p < 0.001$) decreased and the COP trajectory length ($p < 0.01$), and acceleration in all directions center frequency, and second-order moment increased ($p < 0.001$).

In future research, we plan to increase the number of participants and deepen the knowledge in this study and applying various stimulus patterns, and we will investigate the relationship between dynamic balance function and tactile stimulation.

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