# EFFECT OF SOMATOSENTORY INPUT FROM PLANTAR SOLE AND LOWER LIMB MUSCLE IN HUMAN ERECT STANDING

**Yohei Okumura, Shin-Ichiro Yamamoto**

**Graduate School of Engineering and Science, Shibaura Institute of Technology**

**mf13023@shibaura-it.ac.jp**

**ABSTRACT**

In human, somatosensory input from whole body are integrated and used to maintain the erect standing. It is well known that the one of the ways to evaluate the somatosensory effect for postural stable is the vibratory stimulation. The several previous report using vibratory stimulus have cleared frequencies of vibration, while did not identify the vibratory intensity [N]. Further, it has been hardly reported the postural effect applying vibration simultaneously both lower limb muscle and plantar sole.

Therefore, we monitored the vibration intensity [N] using force plate and LabVIEW. Using the monitored system, four vibratory frequencies (40, 60, 80 and 100[Hz]) that we applied in this experiment were adjusted to 8[N]. Then, ten healthy young adults were examined postural changes applying adjusted vibration in single and simulataneous vibration.

In single vibration, Heel and Tibialis anterior (TA) vibration evoked forward leaning. On the other hand, Toe and SOL vibration induced backward leaning. The increase of the postural change during lower limb vibration was bigger than the change during plantar sole vibration. In simultaneous vibration, Toe×SOL vibration increased backward leaning than single vibration in either Toe or SOL. Further, 100Hz vibration increased postural leaning more than lower frequencies (60Hz) in both single and double vibration.

The results suggest that lower limb muscle contribute to input afferent information to maintain standing more than plantar sole. In simultaneous vibration however, it is also mentioned that sensory integration between lower limb sensory information and plantar was not a simple addition of single response.

## 1. INTRODUCTION

In human, visual, vestibular and somatosensory input from whole body are integrated and used to maintain the erect standing. Previous reports have suggested that somatosensory information has more important role than other sensory information [1, 2].

It is well known that the one of the way to evaluate the somatosensory effect for postural stable is the vibratory stimulation. The several previous report about human posture have suggested that the stimulation using the vibration to the either plantar sole or lower limb muscle evoked the postural displacement during standing. For instance, Kavounoudias [3] suggested that vibration to the plantar sole in human evoked the change of afferent sensory information and it induced postural leaning. Also, the amplitude of postural leaning were different depending on the vibratory frequencies. As well as plantar sole, vibration to lower limb muscle or tendon have elicited afferent discharge in muscle spindle [4]. In those reports, it was indicated that the vibratory stimulation of higher frequencies (40-100[Hz]) induced the prominent postural displacement because of generating larger afferent discharge. Most of those reports cleared frequencies of vibration, while it was not identified the intensity [N] of vibration. Then, the interaction between vibration intensity and postural change has not been cleared yet.

Therefore, the first aim of our study was to evaluate the effect of postural change with adjusted vibrations which were quantified the intensity of vibration as well as vibration frequencies. To apply the unified vibratory stimulus, we monitored and adjusted vibration intensity using LabVIEW and force plate. Further, the relationship of afferent input between plantar sole and lower limb muscle is not distinct. Therefore, the second aim of our study was to examine the proprioceptive contributions of the afferent input between the plantar cutaneous and the lower limb muscle. To assess the proprioceptive contributions, the vibratory stimulation (40, 60, 80, 100[Hz]) were applied to both plantar sole (Heel or Toe) and lower limb muscle (Soleus: SOL or Tibialis Anterior: TA) simultaneously.

## 2. METHODS

### 2.1 Subjects

Ten healthy young adults (age: 22.8±1.0 [year], height: 169.4±4.0, weight: 22.8±11.2) participated in the study. All subjects had no visual, vestibular, musculoskeletal or neurological disease. Subjects stood on the styrofoam box with bare feet. The Styrofoam box which were installed vibrations was put on the force platform (KISTER, 9286AA). Four vibrations were fixed following lower limb muscles: muscle calf of TA and SOL in both legs. During the trials, subjects were asked to close both eyes and not to resist the postural leaning. Also, subjects got an instruction to fold up their arm. To assess the postural effect using a simple inverted model, subjects were attached knee joint fixing orthosis at both knees. Sujects had been applied counteseous vibtation for 10sec in a trial(20sec). The experimental system was set up as shown in Fig. 1.

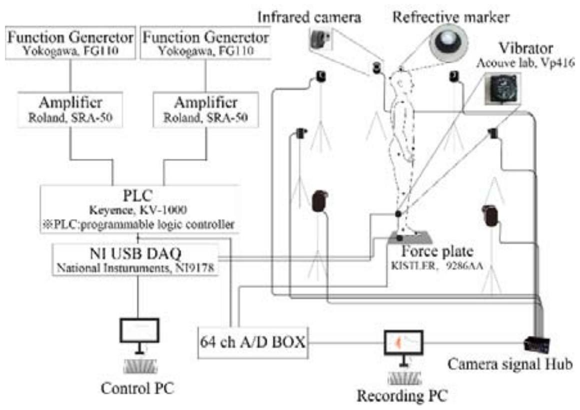



Fig. 1 Experimental set-up

### 2.2 Vibratory stimulus

Eight vibro-transducer (Acouve Laboratory, Vp416) were used to apply vibratory stimulus with 40, 60, 80 and 100Hz. Vibration force was monitored using another forceplate with LabVIEW (Version 15.0, National Instruments). In all trials, vibrations were adjusted to 8[N] (peak-to- peak) and recorded before starting trials.

### 2.3 Data analysis

To calculate the Center of Mass (COM), fourteen reflective markers were attached on following landmarks: acromion, anterior superior iliac spine, greater trochanter, lateral condyle, external condyle and third metatarsal in both sides, top and back of head. The coordinates of reflective markers were recorded by the seven motion capture cameras (Motion Analysis, USA, Hawk-200PT). The sampling frequency of force plate and motion capture was 200Hz. The sampled data were smoothed with Butterworth at 6Hz cut-off. To reconfirm the COM displacement, Center of Pressure (COP) was measured. To compare measured parameters with quantified data, integrated value was calculated during vibtation onset.

### 2.4 Statistical analysis

To test statistically the difference beween vibratory frequencies and theoretical values, two-way repeated ANOVA was used. T-test was used for past hoc analysis. $P<0.05$ was defined as a level of significance. Significant differences were indicated with " * " sign in Fig. 5 and Fig. 6.

## 3. RESULTS

Fig. 2 shows an example of stick picture from a typical subject at 100Hz both single vibration and simultaneous vibration. The movement of sticpicture are captured from vibration onset (0sec) to the end of vibration (10sec).

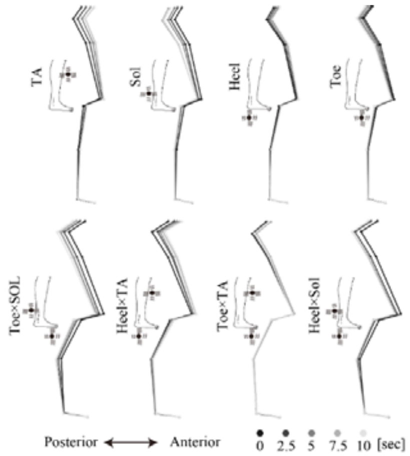



Fig. 2 Typical example of stick picture during 100[Hz] vibration

### 3.1 Single vibration

Fig. 3 shows an example from a typical subject of ensemble average of COM during Heel, Toe, TA, or SOL. In either Heel or TA vibration, COM sway are increased toward anterior. On the other hand, in either Toe or SOL vibration are changed COM to posterior. During 60-100[Hz], COM movement increased with the frequency went up. However, it seemed that 40Hz and 60Hz vibration are unchanged the COM movement by the vibratory frequencies.

Further, comparing the stimulation parts between lower limb and plantar sole, vibration to lower limb might produce change of COM bigger than vibration to plantar sole.

Fig. 5 shows the integration value of COM in single vibration. In TA vibration, COM are increased toward anterior significantly with frequency went up. Likewise, there are significant effect toward posterior during vibratory stimulus to Toe and SOL vibration. However, there is no significant effect among frequencies at Heel vibration.

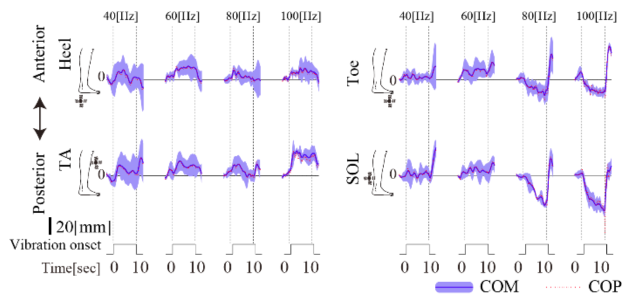



Fig. 3 Typical example of COM change in single vibration

### 3.2 Simultaneous vibration

Fig. 4 shows an example from a typical subject of ensemble average of COM during Heel× SOL, Toe× SOL, Heel× TA and Toe× TA. In either Heel× SOL or Toe× SOL, COM are moved toward posterior. In either Heel× TA or Toe× TA, COM are increased toward anterior. As with single vibration, it is seemed that 100Hz vibration induced obviously. Fig. 6 and shows the comparison between integration value of COM in simultaneous vibration and theoretical value. Theoretical value was calculated using result from single vibration.

In Heel× SOL vibration, COM are moved toward posterior significantly with frequency went up. Similarly, Toe× SOL vibration are moved the COM toward posterior. On the other hands, both Heel× TA and Toe× TA evoke the increase of COM toward anterior significantly.

Comparing with theoretical values, in 100Hz vibration of Toe× SOL, Heel× TA and Toe× TA, significant differences are observed. However, there is no significant difference in 100Hz of Heel× SOL.

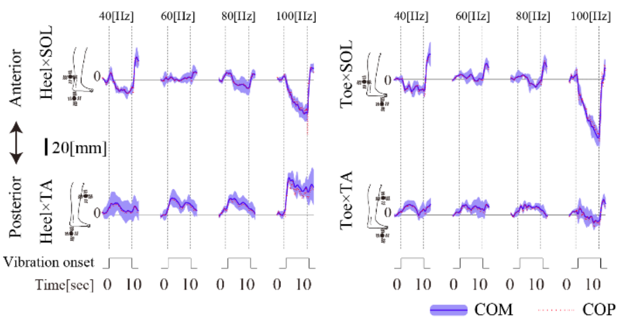



Fig. 4 Typical example of COM change in simultaneous vibration

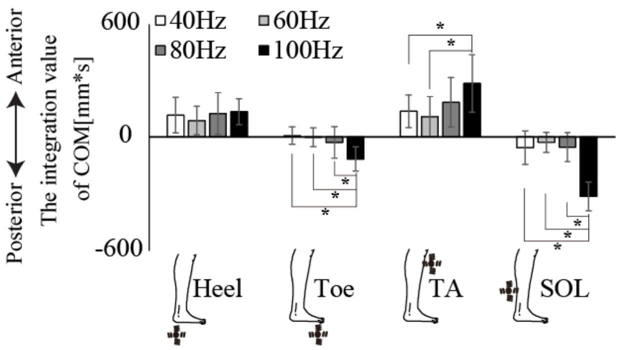



Fig. 5 The integrated value of COM in single vibration

## 4. DISCUSSION

Our experiment was designed to assess the postural effect using vibratory stimulus in standing subject. There are significant differences by the change of vibratory frequencies. Further, the leaning directions were different with vibratory locations. It corresponded with the previous study that vibratory stimulus was used [3, 4]. Further, it is suggested that the rate of afferent discharge which induced by vibration may depend on the vibratory frequency. Therefore, the amount of actual postural movement were different by stimulatory parts. For instance, in the comparison plantar sole, Heel were seemed that it was response to vibratory stimulus constantly in all frequencies. On the other hand, the responses to Toe vibration were obviously different with vibration frequencies. Weinstein et al reported the evaluation of sensation using two point discrimination [5]. They indicated that in plantar sole, the sensation of Heel was higher than Toe. Considering of this case, our result are able to suggest that Toe plays a more important role than Heel in normal standing. However, several previous report also suggested that the postural response to vibration may be affected by the experiment environment and the level of task [6]. Therefore, we need to examine the postural effect during locomotion as well as static task.

Our one hypothesis was that the amount of postural change in simultaneous vibration might correspond with the theoretical values which are sum of amount of the single vibration. However, there are significant differences between theoretical values and the result of simultaneous vibration. Also, the vibration to lower limb muscle might cause affect larger than plantar sole vibration. It is able to suggest that the gain of sensory information may be changed at Central Nervous System (CNS). The somatosensory sensation is different with each location therefore, we have to assess the postural effect considering both the level of sensation and the gain of sensory information.

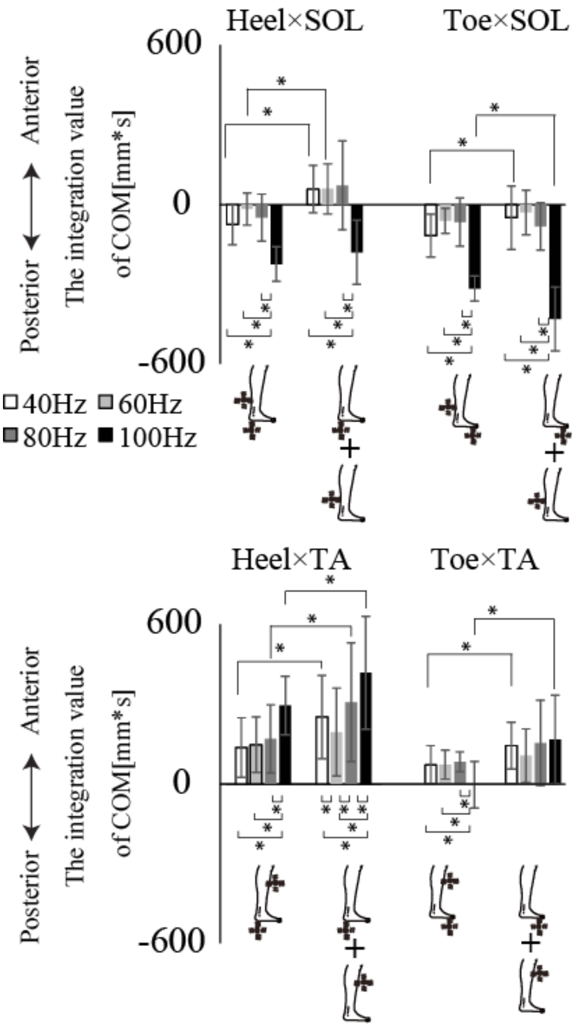
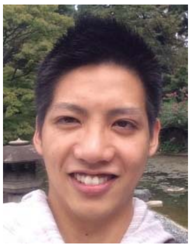



Fig. 6 The integration value of COM in simultaneous vibration

**REFERENCES**
[1] Peterka R.J, Sensorimotor integration in human postural control, J Neurophysiol, Vol 88, 1097-1118, 2002
[2] Adaptation of multi-segmented body movements during vibratory proprioceptive and galvanic vestibular stimulation, Journal of Vestibular Research, 17, 47–62, 2007
[3] Kavounoudias A, Foot sole and ankle muscle inputs contribute jointly to human erect posture regulation, Journal of Physiology, 532(3), 869-878, 2001
[4] Hlavacka F, Human postural responses to different frequency vibrations of lower leg muscles, Physiol Res 50, 405-410, 2001
[5] Weinstein S, "Intensiveand extensive aspects of tactile sensitive ityasafunctionofbodypart, sex and laterality, The Skin Senses (Kenshalo D.R ed), CharlesC.Thomas III (USA), 223–261.
[6] Sorensen K.L, The effect of human ankle muscle vibration on posture and balance during adaptive locomotion, Exp Brain Res 143, 24-34, 2002



**Yohei Okumura** received the B.E. (2013), degrees in engineering from department of Bioscience and Engineering, Shibaura Institute of Technology. He is a master course's student at SIT.

**Shin-ichiroh Yamamoto** received the PhD degree from the Depatment of Life Science, The University of Tokyo, in 2000. He is a Professor,department of Bio-science and Engineering, Shibaura Institute of Technology, Japan. His major research interests focus on neuro-rehabilitation engineering and neural mechanism for human motor control.