

# The Relationship between Physical Function and Postural Sway during Local Vibratory Stimulation of Middle-aged People in the Standing Position

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**Abstract.** [Purpose] The purpose of this study was to examine the relationship between physical function and postural sway during local vibratory stimulation of middle-aged subjects in an upright position. [Subjects] The subjects were 25 healthy community-dwelling middle-aged people. [Methods] We measured postural sway using a Wii board while vibratory stimulations of 30, 60, or 240 Hz were applied to the subjects' lumbar multifidus or gastrocnemius muscles. Physical function was evaluated by 5-m usual gait speed and grip strength. [Results] Gait speed was strongly correlated to the anteroposterior body sway in the upright position during 30 Hz gastrocnemius muscles vibration (GMV). [Conclusion] Postural sway during 30 Hz GMV was strongly associated with gait speed and showed a posterior displacement. These findings show that the lower leg's response to balance control under 30 Hz proprioceptive stimulation might be a good indicator of declining gait function.

**Key words:** Postural sway, Physical function, Middle age

(This article was submitted Mar. 4, 2014, and was accepted Apr. 26, 2014)

## INTRODUCTION

In daily life, humans are constantly faced with new postural control tasks to which they have to adapt and adjust. To detect motion and adjust voluntary and reflexive muscle responses, the balance system uses sensory information from visual, vestibular and somatosensory receptors<sup>1)</sup>. Nevertheless, decline in the function of proprioceptive sensation is part of the aging process. Proprioception in the leg and trunk muscles plays an important role in maintaining postural stability<sup>2)</sup>. Past studies have reported that proprioception and vibration sensation in the lower limbs decrease during normal aging<sup>3, 4)</sup>, and reported postural instability has been observed in elderly people<sup>5)</sup>. Also, both muscle strength and lower postural stability decline with aging<sup>6, 7)</sup>. Therefore, a vibratory stimulus that matches the response frequency of the receptors present in skeletal muscle may influence body sway. The representative receptor and response frequencies are 30 Hz in the Meissner corpuscle, 60 Hz in the muscle spindle, and 240 Hz in the corpuscle of Vater-Pacini.

The acquisition of a motor skill is generally a gradual process requiring many repetitions over a period of time<sup>8)</sup>. In addition, several reports have shown that body movements induced during repeated exposure to postural disturbances gradually decrease<sup>9)</sup>. Furthermore, it is probable that sensory deficits result from either location or physical performance reduction, and might be a causative factors of postural instability.

Past cross-sectional and longitudinal studies have reported that the course of decline for measures of muscle strength, gait and balance accelerates with advancing age<sup>10, 11)</sup>. For instance, there are reports that grip strength may begin to decline from the age of 30<sup>12)</sup>. Likewise, measures of balance function, gait and motor function have been reported to deteriorate after the age of 40<sup>11)</sup>. Therefore, it is important to measure muscle strength, balance, gait speed and response to proprioceptive input during middle age for a comprehensive assessment of age-related changes in physical performance, health and balance ability.

The aim of this study was to investigate whether a vibratory stimulation applied to the proprioceptive inputs of the lumbar multifidus and the gastrocnemius muscles affects postural stability and physical performance of middle-aged subjects.

## SUBJECTS AND METHODS

The subjects were 25 (13 males, 12 females) middle-aged people (age = 46.0 ± 3.0). They were recruited from

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Aichi and Gifu Prefectures, Japan. Inclusion criteria were: middle-aged at the time of the examination in 2013, living at their home in Aichi or Gifu, and had not participating in another study. We measured subjects' height (to the nearest 0.1 cm) and weight (to the nearest 0.1 kg). Additional inclusion criteria were: absence of low back pain, ability to perform the task, and absence of neuromuscular or orthopedic diseases, artificial pacemakers, digestive diseases, or symptoms of dehydration.

The assessment measures were performed by a well-trained physiotherapist. The assessment included some physical tests. The center of pressure (CoP) was recorded using a Wii Balance Board (Nintendo Co., Ltd., Kyoto, Japan). Recently, the Wii Balance Board has been much used in the field of medical research, and it has been reported that results from the Wii Balance Board correlate closely with those of commercially available force plates<sup>13-16</sup>. By fixing two of the vibrators from the vibration device on the participants' lumbar multifidus and gastrocnemius muscles, vibratory stimulus was delivered alternately to the two muscles. The subjects stood barefoot on the Wii Balance Board with their feet together and their eyes closed. They were instructed to remain still and relax in a standing posture with their arms hanging loosely at their sides. The amplitude of the vibration was 1.6 mm, and the frequencies were 30, 60 and 240 Hz. Each subject's CoP was measured under six conditions, the two different muscles and the three different frequencies of vibratory stimulation: (1) 30 Hz on the lumbar multifidus; (2) 30 Hz on the gastrocnemius muscles; (3) 60 Hz on the lumbar multifidus; (4) 60 Hz on the gastrocnemius muscles; (5) 240 Hz on the lumbar multifidus; and (6) 240 Hz on the gastrocnemius muscles. The measurement time was 30 seconds, which was divided into two intervals of 15 seconds. Vibratory stimulation was applied to participants during the last 15 sec. We labeled the first 15 sec as "Pre" and the last 15 sec as "During". The participants rested on a chair for 60 sec between each measurement. Muscle function was assessed by grip strength. Grip strength of the subjects' dominant hands was measured in kilograms using a digital handheld dynamometer (MCZ-5041, Macros Ltd, Tokyo, Japan). Gait function was assessed by gait time tests conducted on a defined path. Subjects' usual gait speed was measured in seconds with a stopwatch. Participants were asked to walk on the flat, straight surface at their usual gait speed. Two markers were used to indicate the start and end of the path, and a 5 m and over approach was allowed before reaching the start marker so that participants could attain their usual gait pace before reaching the timed path. They were instructed to continue their gait past the end of the path for a further 5 m and over to ensure that the gait pace was consistent throughout the task.

Informed consent was obtained from all the subjects prior to their inclusion in the study, and the Ethics Committee of the National Center for Geriatrics and Gerontology at the Nagoya Institute of Technology approved the study protocol.

Pearson correlation coefficients were calculated to determine the relationships between gait speed, grip strength and postural sway during vibratory stimulations of 30, 60, or

240 Hz applied to the lumbar multifidus or gastrocnemius muscles. Postural sway was assessed using CoP displacement the anterior-posterior direction. We defined the change in anteroposterior displacement of CoP as:  $\Delta Y = Y(\text{During}) - Y(\text{Pre})$ . Where Y is the displacement of the Y-coordinate of the CoP recorded by the Wii Balance Board, and Y(Pre) and Y(During) are the mean values of the time series data of Y for the first 15 sec and the last 15 sec, respectively. These calculations were using performed a program we wrote using Matlab (The MathWorks, Inc.).

Multiple linear regression analysis was used to examine whether postural sway during vibratory stimulations was associated with physical performance. Physical performance was set as the dependent variable. Postural sway during each vibratory stimulation was also investigated using the stepwise method of multiple linear regression analysis.

All analyses were performed using IBM SPSS statistics software (Version 20; SPSS Inc., Chicago, IL, USA). Statistical significance was accepted for values of  $p < 0.05$ .

## RESULTS

The characteristics of the subjects are shown in Table 1. During upright stance with vibratory stimulations, participants showed increased body sway in the anteroposterior direction (Table 1). Subjects showed a negative correlation between CoP displacement of the 30 Hz gastrocnemius muscles vibration (GMV) and their gait speed ( $r = -0.50$ ,  $p < 0.05$ ) (Table 2), and the regression coefficient was significant ( $R^2$  25%,  $\beta = -0.50$ ,  $p < 0.01$ ).

There was no significant correlation between body sway or grip strength at this level of proprioceptive stimulation (GMV of 30 Hz), even though there was a significant correlation between postural sway and gait speed.

## DISCUSSION

A 30 Hz proprioceptive stimulation elicited as a change in the average displacement of CoP away from the center of support, in the posterior direction (negative value). The faster the subjects' habitual gait, the larger the change in CoP displacement of 30 Hz GMV became. In the stepwise multiple regression analysis, only the change in CoP displacement of 30 Hz GMV was identified as a significant independent variable related to gait speed.

Previous studies have reported that vibration perception and proprioception decline with increasing age<sup>3, 4</sup>. Sensory information from receptors in the muscles and joints provide feedback regarding joint position sense, movement and touch. Sensory information from the lower extremity is arguably the most important contributor to standing balance, because the proprioceptive threshold is lower than the threshold for the perception of the speed of center of foot pressure sway<sup>17</sup>. Functional decline in the somatosensory system occurs with aging and these changes are associated with postural instability. During gait, joint and muscle mechanoreceptors provide information to help adjustment with each step and achieve the ideal foot placement. Previous studies have reported that elderly people have decreased responses to vibration compared with younger people<sup>5, 18</sup>.

**Table 1.** Physical characteristics of the study participants

Variables	Participants (n = 25)
Age (years)	46.0 ± 3.0
Height (cm)	165.6 ± 8.3
Weight (kg)	61.1 ± 11.2
Grip strength (kg)	33.1 ± 7.6
Usual gait speed (m/s)	1.4 ± 0.2
Center of pressure: GMV 30 Hz, during-pre (cm)	-0.23 ± 0.30
Center of pressure: LMV 30 Hz, during-pre (cm)	-0.08 ± 0.43
Center of pressure: GMV 60 Hz, during-pre (cm)	-0.44 ± 0.50
Center of pressure: LMV 60 Hz, during-pre (cm)	0.79 ± 0.58
Center of pressure: GMV 240 Hz, during-pre (cm)	-0.29 ± 0.53
Center of pressure: LMV 240 Hz, during-pre (cm)	-0.23 ± 0.51

Values are mean±SD.

GMV, gastrocnemius muscles vibration; LMV, lumbar multifidus vibration.

Center of pressure displacement (averages ± deviation) of the participants during vibration of the gastrocnemius muscles, lumbar multifidus. Positive values signify anterior body sway, negative values indicate posterior body sway.

**Table 2.** Correlation coefficients of center of pressure sway changes induced by GMV (30, 60, 240 Hz), and LMV (30, 60, 240 Hz) and grip strength and gait speed

Variables	Grip strength	Usual gait speed
Center of pressure: GMV 30 Hz, during-pre	0.20	-0.50*
Center of pressure: LMV 30 Hz, during-pre	0.34	-0.18
Center of pressure: GMV 60 Hz, during-pre	0.01	0.02
Center of pressure: LMV 60 Hz, during-pre	-0.06	0.39
Center of pressure: GMV 240 Hz, during-pre	-0.01	0.12
Center of pressure: LMV 240 Hz, during-pre	0.04	0.01

The asterisk denotes a significant differences, \* $p < 0.05$ .

The negative correlation indicates that subjects gait speed increased with increasing posterior shift of center of pressure sway.

A previous study demonstrated that measures of balance and gait function deteriorate from the ages of 40 and 60, respectively<sup>11</sup>.

Kilner et al. reported the presence of coherent oscillatory activity in the human hand and forearm muscles, and showed that the 15–30 Hz component has task-dependent modulation<sup>19</sup>. Other studies of vibration frequencies that are usually applied for exercise purposes have reported effects on the vastus lateralis, and showed that EMG amplitudes are larger at stimulation of 30 Hz<sup>20</sup>. Additionally, the frequency for eliciting appearances and disappearances of postural effects has been reported to be in the range of 25–30 Hz for the leg and trunk muscles<sup>21</sup>.

The cutaneous and subcutaneous mechanoreceptors that innervate glabrous or hairless skin are the rapidly adapting Meissner corpuscles.

It has been suggested that the stimulation of the gastrocnemius muscles influences gait speed and body sway. Because tactile information from the sole affects postural control<sup>22</sup>, the number of Meissner corpuscles has been shown to reduce with age<sup>23</sup>, with a corresponding decrease in gastrocnemius muscle vibration perception and gait speed.

Daly et al.<sup>24</sup> reported the importance of promoting ex-

ercise interventions to improve muscle strength from the age of 50 years and onward, with the need to develop more targeted programs designed to enhance both balance and gait speed in the elderly. Gait and balance exercise might be a key factor in postural stability, as previously shown in several studies, and such exercise could be important for preventing falls<sup>10, 11</sup>. Han et al.<sup>25</sup> reported that vibration may have a positive effect on the maintenance of static balance by activating proprioceptors. The results of the present study suggest that 30 Hz GMV is an important proprioceptive stimulus and that exercise with 30 Hz vibratory stimulation, particularly for middle-aged people, would help to improve their gait speed and balance function by stimulating the Meissner corpuscles of the gastrocnemius muscle. Taken together, these data support the possibility that reduced gait function in middle-age results from a reduction in the number of Meissner's corpuscles in the gastrocnemius muscle. Thus, a decrease in CoP sway induced by 30 Hz GMV may indicate a reduction in gait speed due to increasing postural instability. This suggests that variables derived from CoP sway measured during 30 Hz GMV can be used as an index for predictive factors of gait function in middle age.

A limitation of this study was that only healthy middle-age people were surveyed. Additional study is needed to determine whether the age difference in the age-related postural control decline of proprioceptive sensitivity is caused by declines in physical performance or other characteristics.

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