Abstract. [Purpose] Sit-to-walk performance is linked to proper proprioceptive information processing. Therefore, it is believed that an increase of proprioceptive inflow (using muscle vibration) might improve sit-to-walk performance. However, before testing muscle vibration effects on a frail population, assessment of its effects on healthy young people is necessary. Thus, the aim of this study was to investigate the effects of muscle vibration on sit-to-walk performance in healthy young adults. [Subjects and Methods] Fifteen young adults performed the sit-to-walk task under three conditions: without vibration, with vibration applied before movement onset, and with vibration applied during the movement. Vibration was applied bilaterally for 30 s to the tibialis anterior, rectus femoris, and upper trapezius muscles bellies. The vibration parameters were as follows: 120 Hz and 1.2 mm. Kinematics and kinetic data were assessed using a 3D motion capture system and two force plates. The coordinates of reflective markers were used to define the center-of-mass velocities and displacements. In addition, the first step spatio-temporal variables were assessed. [Results] No vibration effect was observed on any dependent variables. [Conclusion] The results show that stimulation of the proprioceptive system with local muscle vibration does not improve sit-to-walk performance in healthy young adults.

Key words: Sit-to-walk, Proprioception, Muscle vibration

INTRODUCTION

Muscle vibration elicits an activation of muscle spindles Ia sensory endings1, 2). This sensory firing results in an illusory stretching sensation of the receptor-bearing muscle2). As a result, an involuntary muscle contraction of the receptor-bearing muscle is observed via the monosynaptic spinal reflex4, 5). Local vibration has been used like this to manipulate the proprioceptive system4, 5) in two different ways: to facilitate movement execution or to disturb the proprioceptive system6–8). During upright standing, lower limb muscle vibration elicits a center-of-pressure (CoP) displacement towards the receptor-bearing muscle9). On the other hand, when trunk muscles are stimulated, CoP displacement towards the opposite side is noticed10). For instance, when the tibialis anterior, rectus femoris and upper trapezius are stimulated, the CoP shifts forward11). Therefore, stimulation of the proprioceptive system through muscle vibration applied to these muscles could improve motor patterns that require forward movement, such as gait initiation and the sit-to-walk movement.

The sit-to-walk movement is a sequential task in which a person performs a continuous transition from sitting to walking10). The success of this task relies on the generation of forward momentum11, 12). Thereafter, when sufficient forward momentum is generated, the center of mass (CoM) shifts forward, eliciting the first step13). Previous research observed a poorer sit-to-walk performance in fragile populations, as in older people or in people with Parkinson’s disease12–14). This poorer performance was related to an impaired proprioceptive system14). As a consequence of an impaired proprioceptive system, a more cautious strategy is adopted by these fragile populations15). Therefore, it is suggested that increasing the proprioceptive information inflow to the central nervous system could improve the sit-to-walk performance of these people. In the same way, the forward movement elicited by vibration applied to the tibialis anterior, rectus femoris, and upper trapezius could enhance the forward momentum generated to perform the sit-to-walk movement.

However, to the best of our knowledge, the effects of proprioceptive system manipulation on the sit-to-walk performance has never been tested. Thus, before we could suggest that it be used on frail individuals, we needed to establish its effects on healthy young adults. One issue that needs to be resolved is the best moment to apply this specific sensory manipulation to enhance sit-to-walk performance: before or during the movement execution. Previous physiological studies showed that the effects of vibration on sensory endings are interrupted as soon as the stimulus is ceased1, 2). This observation suggests that in order to elicit any effects, a vibration stimulus should be applied during movement.
On the other hand, previous studies also demonstrated that vibration-induced effects continue to be observed after the end of stimulation during gait. In addition, another study showed that during transitional movements, such as gait initiation, greater postural effects are elicited when vibration is applied before movement execution. Therefore, it is clear there is no consensus about this topic.

Therefore, the aims of this study were: (i) to evaluate the effects of proprioceptive manipulation through muscle vibration on the performance of the sit-to-walk task and (ii) to determine whether applying vibration during or before the sit-to-walk task could elicit different performance effects. As hypotheses, we believe (i) that muscle vibration will improve sit-to-walk performance and (ii) that the effects induced by vibration will be greater when the vibration it is applied during movement execution.

SUBJECTS AND METHODS

Fifteen (7 males) healthy young adults (age, 21.40±4.26 years; height, 164.61±10.08 cm; body-mass, 66.17±10.04 kg) participated in this study. The institution’s Human Ethics Committee approved all procedures. All participants reported that they were right-footed and signed an informed consent form before participation in the study. Exclusion criteria included any neurological, orthopedic, vestibular or uncorrected visual disturbances that could interfere with the procedures. Participants were personally invited to participate, and none refused or were excluded. The participants were asked to not perform any physical activity 24 hours before the assessment.

A custom-made system was used (named the RC Vibro System). This system was composed of up to eight vibrating devices and a movable electronic board capable of receiving information from regular personal computers via radio waves emitted by a USB interface device. Three pairs of cylindrical vibratory devices (measuring 4.5 cm × 2 cm × 2 cm; containing constant-velocity DC motors (Fauchabert) bearing eccentric masses) were positioned bilaterally on the bellies of the upper trapezius, tibialis anterior, and rectus femoris. For fixation, elastic bands were used. These muscles were chosen because stimulation of them elicits a forward CoP movement. For all participants, the first condition tested was the baseline condition (NonVib); with vibration applied during (Du) movement; and with vibration applied before (Be) movement. For all participants, the first condition tested was always NonVib, and it was always followed by the other two (randomly distributed). Rest periods of 30 seconds between trials and 3 minutes between conditions were given.

For all conditions, the vibration stimulus was continuously applied for 30 seconds. For the Du trials, participants started the movement after a verbal command given at the 28th second of vibration. For the Be trials the participants were asked to perform the movement immediately after the devices were switched-off, that is, at the 30th second of vibration. This procedure ensured that all participants performed the movement after the same amount of time: 30 seconds. During the NonVib trials, the vibratory units were kept in place, but not switched on.

Four camcorders (sampling rate of 60 Hz) were used to capture the positions of 22 passive markers attached to the following anatomic landmarks: bilaterally on the 3rd metatarsal bones, heels, lateral malleolus, femoral condylyes, great trochanters, anterior superior iliac spine, hip joint projection, superior face of the acromion, lateral condyle of the humerus and temporal regions. Additionally, one marker was attached to the top of the head, and another was attached to sacral region (between second and third sacral vertebrae). To assess kinetic data, two force plates (50 × 50 cm – AMTI®) were positioned side by side, allowing the subjects to step with one foot on each force plate. Kinetic data were obtained with a sampling rate of 200 Hz using the NetForce (AMTI®) software.

In order to assess kinematic variables, the passive markers position were digitized automatically by the Digital Video for Windows (DVDEOW) software. The trajectories of all markers were filtered offline (4th order Butterworth filter with cut-off frequency of 8 Hz). To determine the center-of-mass (CoM) behavior, thirteen rigid segments were determined using classical anthropometric tables. The CoM position was assessed through the sum of these thirteen rigid segments. After offline filtering (4th order Butterworth filter with cut-off frequency of 9 Hz), kinetic data were used to determine specific task events.

The sit-to-walk task was subdivided in four phases (Fig. 1), according to previous published papers. (i) flexion phase: from the movement initiation (first detectable event in the total vertical ground reaction force) until seat-off (identified as the first peak in the total horizontal ground reaction force); (ii) extension phase: from the end of the previous phase until the CoM peak vertical velocity; (iii) transition phase: from the end of the extension phase until the swing limb heel off; and (iv) execution phase: determined from the swing limb heel off until heel strike for the same limb. Fig.

Fig. 1. Kinematic and kinetic data traces used to define each task phase
1: movement onset; 2: seat-off; 3: standing position; 4: swing heel-off; 5: swing heel-strike. GRF: ground reaction force; CoM: center of mass.
Confirming this result, Table 2 shows that vibration was effective in modifying the duration of any of the task phases. The only phase that presented a tendency for statistical significance (p>0.57) was the flexion phase. All other variables showed no statistical significance. Hence, according to Table 1, local vibration was ineffective in modifying the duration of any of the task phases. Confirming this result, Table 2 shows that vibration was not able to modify CoM displacement (p=0.44) or velocity (p=0.66) in any direction during any of the task phases and main events. These results show no movement-pattern modification with the use of local vibration as applied in this study.

In agreement with the above results, the spatiotemporal parameters of the first step were not modified by vibration. This was the case for step duration (Be, 0.56±0.07 s; Du, 0.59±0.07 s; NonVib, 0.59±0.08 s; p=0.56), step length (Be, 67.10±6.24 cm; Du, 66.21±6.24 cm; NonVib, 64.00±5.20 cm; p=0.24), step width (Be, 20.12±5.34 cm; Du, 19.85±7.12 cm; NonVib, 21.32±8.02 cm; p=0.32) and step velocity (Be, 121.77±15.06 cm/s; Du, 114.42±13.33 cm/s; NonVib, 111.04±11.18 cm/s; p=0.25).

### RESULTS

Table 1 shows a complete absence of vibration effects on the durations of the sit-to-walk phases. The only phase that presented a tendency for statistical significance was the flexion phase. All other variables showed no statistical significance (p>0.57).

Hence, according to Table 1, local vibration was ineffective in modifying the duration of any of the task phases. Confirming this result, Table 2 shows that vibration was not able to modify CoM displacement (p=0.44) or velocity (p=0.66) in any direction during any of the task phases and main events. These results show no movement-pattern modification with the use of local vibration as applied in this study.

In agreement with the above results, the spatiotemporal parameters of the first step were not modified by vibration. This was the case for step duration (Be, 0.56±0.07 s; Du, 0.59±0.07 s; NonVib, 0.59±0.08 s; p=0.56), step length (Be, 67.10±6.24 cm; Du, 66.21±6.24 cm; NonVib, 64.00±5.20 cm; p=0.24), step width (Be, 20.12±5.34 cm; Du, 19.85±7.12 cm; NonVib, 21.32±8.02 cm; p=0.32) and step velocity (Be, 121.77±15.06 cm/s; Du, 114.42±13.33 cm/s; NonVib, 111.04±11.18 cm/s; p=0.25).

### DISCUSSION

The aim of this study was to investigate if muscle vibration could influence sit-to-walk performance in healthy young adults. In addition, we aimed to investigate whether the timing of vibration application (before or during movement) could influence the sit-to-walk motor behavior and performance. The results clearly show that, at least in healthy young adults, local vibration does not change the motor behavior and performance of the sit-to-walk task. Thus, we suggest that the proprioceptive system does not play an important role in the CoM scaling movement during the sit-to-walk movement.

The lack of vibration effects under the Be condition was not surprising, since previous studies have shown that muscle vibration effects are lost as soon as the vibration is interrupted1, 9, 21). In line with this hypothesis, a previous study did not find significant effects on the gait performance when participants walked after neck muscles vibration22). Therefore, since vibration effects are lost as soon as the vibration is interrupted1, the lack of significant effects under the Be condition was not completely unexpected.

On the other hand, the lack of positive results under the Du condition is opposite to our initial hypothesis. The presence of preprogramed motor patterns could have masked the vibration effects6). This hypothesis, is based on the notion

### Table 1. Mean duration (± standard deviation) of sit-to-walk phases

| Phases duration (s) | Be     | Du     | NonVib |
|---------------------|--------|--------|--------|
| Flexion             | 0.56 (0.09) | 0.64 (0.07) | 0.62 (0.06) |
| Extension           | 0.37 (0.11) | 0.34 (0.07) | 0.36 (0.09) |
| Transition          | 0.10 (0.05) | 0.11 (0.07) | 0.12 (0.14) |
| Execution           | 0.56 (0.07) | 0.59 (0.07) | 0.59 (0.08) |
| Total duration (s)  | 2.42 (0.25) | 2.51 (0.24) | 2.50 (0.25) |

Be: vibration applied before the movement; Du: vibration applied during the movement; NonVib: no vibration.

### Table 2. Mean displacement and velocity (±standard deviation) of the center-of-mass in the vertical, horizontal and latero-lateral directions for all sit-to-walk phases and events

| Displacement (cm) | Vertical | Horizontal | Latero-lateral |
|-------------------|----------|------------|----------------|
| Flexion           | −0.95 (1.96) | −1.97 (0.88) | −1.08 (2.91) |
| Extension         | 16.24 (3.74) | 15.87 (1.96) | 14.68 (3.48) |
| Transition        | −6.94 (2.38) | −7.11 (3.20) | −7.29 (5.94) |
| Execution         | 6.52 (3.34) | 7.21 (2.99) | 7.99 (4.90) |

Be: vibration applied before the movement; Du: vibration applied during the movement. NonVib: no vibration. Positive values refers to upward, forward and towards the swing-limb.
that healthy young adults do not rely on proprioception information to scale transitional movements\(^8\),\(^{16, 23}\).

The sit-to-walk movement is a transitional task in which potential energy transfer to kinetic energy is needed in order to allow the first step\(^14\),\(^{19}\). Previous research suggested that lower limbs vibration could disturb transfer between gravitational potential energy and kinetic energy\(^7\). However, our participants were not disturbed by vibration, suggesting that the proprioceptive information inflow provided by vibration was ignored. This result suggests that during transitional tasks, such as the sit-to-walk movement, proprioception does not have a great importance in scaling the movement execution. This hypothesis is in line with the findings of previous studies\(^{16, 23}\) that demonstrated a lack of proprioception information usage during gait initiation. In agreement with this, Ruget et al. showed that proprioceptive information is only used to scale gait initiation in healthy young adults when all other sensory information was absent\(^5\).

Taken together, all these results suggest that, at least in healthy young adults, preprogrammed motor patterns are not modified by proprioceptive system manipulation. In agreement with this idea, previous results have shown few if any vibration effects in healthy young people when walking on normal ground\(^{24–26}\). Otherwise, when vibration is applied to the lower limbs of patients with impairments in the execution of preprogrammed motor patterns, such as Parkinson’s disease patients\(^7\), vibration improves walking performance\(^2\),\(^{18}\). Thus, our results reinforce the hypothesis that proprioception information is neglected during the execution of preprogrammed motor patterns\(^8\),\(^{16, 23}\). To confirm this hypothesis, we suggest that future studies should assess the effects of local vibration on people showing impairments in the pre-programmed motor patterns execution, such as Parkinson’s disease patients.

We cannot explain by our results the true reason why vibration did not elicit any response in the sit-to-walk performance in healthy young adults. However, our results, reinforce the hypothesis that in healthy young adults, sensory information other than proprioception is more important in scaling transitional movements\(^8\),\(^{16, 23}\). The present study has some limitations, such as the small number of participants assessed. However, the kinematic data are clear in showing a complete absence of vibration effects in the sit-to-walk execution performance in healthy young adults.

The results of this study show that healthy young adults do not benefit from muscle vibration when performing the sit-to-walk task. This lack of motor adaptation to vibration occurs regardless of when vibration is applied: before or during the movement. The reasons for this lack of significant effects is not clear, but the lack of significant effects suggests that healthy young adults neglect proprioceptive information when executing preprogrammed motor patterns.

**REFERENCES**

1) Burke D, Hagbarth KE, Lofstedt L, et al.: The responses of human muscle spindle endings to vibration of non-contracting muscles. J Physiol, 1976; 261: 673–693. [Medline] [CrossRef]

2) Martin BJ, Park HS: Analysis of the tonic vibration reflex: influence of vibration variables on motor unit synchronization and fatigue. Eur J Appl Physiol Occup Physiol, 1997; 75: 504–511. [Medline] [CrossRef]

3) Hagbarth K, Burke D, Wallin G, et al.: Single unit spindle responses to muscle vibration in man. Prog Brain Res, 1976; 44: 281–289. [Medline] [CrossRef]

4) Rabin E, Muratori L, Svoros K, et al.: Tactile/proprioceptive integration during arm localization is intact in individuals with Parkinson’s disease. Neurosci Lett, 2010; 470: 38–42. [Medline] [CrossRef]

5) Tan T, Almeida QJ, Rahimi F: Proprioceptive deficits in Parkinson’s disease patients with freezing of gait. Neuroscience, 2011, 192: 746–752. [Medline] [CrossRef]

6) Courtine G, De Nunzio AM, Schmid M, et al.: Stance- and locomotion-dependent processing of vibration-induced proprioceptive inflow from multiple muscles in humans. J Neurophysiol, 2007, 97: 772–779. [Medline] [CrossRef]

7) De Nunzio AM, Grasso M, Nardone A, et al.: Alternate rhythmic vibratory stimulation of trunk muscles affects walking cadence and velocity in Parkinson’s disease. Clin Neurophysiol, 2010, 121: 240–247. [Medline] [CrossRef]

8) Ruget H, Blouin J, Coyle T, et al.: Modulation of proprioceptive inflow when initiating a step influences postural adjustments. Exp Brain Res, 2010, 201: 297–305. [Medline] [CrossRef]

9) Capiçicò N, Rocchi L, Hlavacova F, et al.: Human postural response to lower leg muscle vibration of different duration. Physiol Res, 2006, 55: S129–S134. [Medline]

10) Kouta M, Shinkoda K, Kanemura N: Sit-to-walk versus sit-to-stand or gait initiation: biomechanical analysis of young men. J Phys Ther Sci, 2006, 18: 201–206. [CrossRef]

11) Chen T, Chou L.S: Altered center of mass control during sit-to-walk in elderly adults with and without history of falling. Gait Posture, 2013, 38: 696–701. [Medline] [CrossRef]

12) Kouta M, Shinkoda K: Differences in biomechanical characteristics of sit-to-walk motion between younger and elderly males dwelling in the community. J Phys Ther Sci, 2008, 20: 185–189. [CrossRef]

13) Kouta M, Shinkoda K, Shimizu ME: Biomechanical analysis of the sit-to-walk series of motion frequently observed in daily living: effects of motion speed on elderly persons. J Phys Ther Sci, 2007, 19: 267–271. [CrossRef]

14) Buckley TA, Pitsikoulis C, Hass CJ: Dynamic postural stability during sit-to-walk transitions in Parkinson disease patients. Mov Disord, 2008, 23: 1274–1280. [Medline] [CrossRef]

15) Courtine G, Pozzo T, Schiappati M: Vibration after effect during human walking. J Soc Biol, 2001, 195: 443–446. [Medline]

16) Ruget H, Blouin J, Teasdale N, et al.: Can prepared anticipatory postural adjustments be updated by proprioception? Neuroscience, 2008, 155: 640–648. [Medline] [CrossRef]

17) Figueroa PJ, Leite NJ, Barros RM: A flexible software for tracking of markers used in human motion analysis. Comput Methods Programs Biomed, 2003, 72: 155–165. [Medline] [CrossRef]

18) Hahn ME, Chou LS: Age-related reduction in sagittal plane center of mass motion during obstacle crossing. J Biomech, 2004, 37: 837–844. [Medline] [CrossRef]

19) Buckley T, Pitsikoulis C, Barthelemy E, et al.: Age impairments sit-to-walk motor performance. J Biomech, 2009, 42: 2318–2322. [Medline] [CrossRef]

20) Kerr A, Rafferty D, Kerr KM, et al.: Timing phases of the sit-to-walk movement: validity of a clinical test. Gait Posture, 2007, 26: 11–16. [Medline] [CrossRef]

21) Wierzbicka MM, Gilhodes JC, Roll JP: Vibration-induced postural posteffects. J Neurophysiol, 1998, 79: 143–150. [Medline]

22) Bove M, Diverio M, Pozzo T, et al.: Neck muscle vibration disrupts steering of locomotion. J Appl Physiol 1985, 1981, 91: 581–588. [Medline]

23) Mochunlini L, Blouin J: When standing on a moving support, cutaneous inputs provide sufficient information to plan the anticipatory postural adjustments for gait initiation. PLoS ONE, 2013, 8: e55081. [Medline] [CrossRef]

24) Courtine G, Pozzo T, Lucas B, et al.: Continuous, bilateral Achilles’ tendon vibration is not detrimental to human walk. Brain Res Bull, 2001, 55: 107–115. [Medline] [CrossRef]

25) De Nunzio AM, Nardone A, Picco D, et al.: Alternated trains of postural muscle vibration promote cyclic body displacement in standing parkinsonian patients. Mov Disord, 2008, 23: 2186–2193. [Medline] [CrossRef]

26) Ivanenko YP, Grasso R, Lacquintini F: Influence of leg muscle vibration on human walking. J Neurophysiol, 2000, 84: 1737–1747. [Medline]

27) Hausdorff JM: Gait dynamics in Parkinson’s disease: common and distinct behavior among stride length, gait variability, and fractal-like scaling. Chaos, 2009, 19: 026113. [Medline] [CrossRef]

28) Ghoseiri K, Forough H, Sanjari MA, et al.: The effect of a vibratory lumbar orthosis on walking velocity in patients with Parkinson’s disease. Prosthet Orthot Int, 2009, 33: 82–88. [Medline] [CrossRef]