

Does proprioceptive system stimulation improve sit-to-walk performance in healthy young adults?

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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 spatiotemporal 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

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INTRODUCTION

Muscle vibration elicits an activation of muscle spindles Ia sensory endings¹⁻³⁾. 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 reflex^{1, 2)}. Local vibration has been used like this to manipulate the proprioceptive system^{4, 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 noticed⁶⁾. For instance, when the tibialis anterior, rectus femoris and upper trapezius are stimulated, the CoP shifts forward⁶⁾. 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 momentum^{11, 12)}. Thereafter, when sufficient forward momentum is generated, the center of mass (CoM) shifts forward, eliciting the first step¹¹⁾. 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 populations¹²⁾. 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 ceased^{1, 2)}. This observation suggests that in order to elicit any effects, a vibration stimulus should be applied during movement.

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On the other hand, previous studies also demonstrated that vibration-induced effects continues to be observed after the end of stimulation during gait¹⁵. In addition, another study showed that during transitional movements, such as gait initiation, greater postural effects are elicited when vibration is applied before movement execution¹⁶. 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 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 RCVibro 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 $4.5 \text{ cm} \times 2 \text{ cm} \times 2 \text{ cm}$; containing constant-velocity DC motors (Faulhaber[®]) 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 displacement⁶. The used vibration frequency and amplitude were the same for all devices: 120 Hz and 0.8 mm.

Prior to movement initiation, participants were seated on an armless 45 cm-high stool with their arms crossed over their chest and looking ahead. They positioned their feet as they wanted and kept the position consistent during all trials. After the examiner finished explaining the instructions, the participants were instructed to stand up from the stool and initiate gait at their own speed in a fluid and smooth way. They were instructed to not split the movement into two phases: they should initiate gait before reaching the full standing position. Participants performed three trials under three different experimental conditions: a baseline condition, without vibration (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 condyles, 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 ($50 \times 50 \text{ cm}$ – 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 (DVIDEOW) software¹⁷. 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 segments¹⁸. 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^{19, 20}: (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.

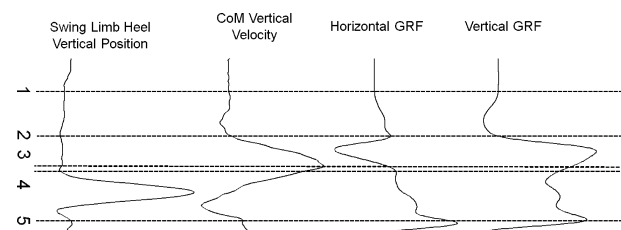


Fig. 1. Kinematic and kinetic data traces used to define each task phase

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

ure 1 shows the kinematic and kinetic traces of a single trial of one participant under the NonVib condition. Data were processed using specific MatLab (MathWorks®) algorithms.

The following kinematic dependent variables were determined: first step time, length, width, velocity, and total duration (time between movement onset and swing limb heel strike). In addition, the CoM horizontal, latero-lateral and vertical displacements and velocities were determined for each movement phase.

The Statistica 7.0 software was used for all statistical procedures. Seeking to determine whether experimental conditions (NonVib vs. Du vs. Be) could influence dependent variables, a series of one-way ANOVAs with repeated measures was used. Whenever necessary, for univariate comparisons, Tukey post hoc tests were used. P values were considered as statistically significant when <0.05 .

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

Table 1. Mean duration (\pm standard deviation) of sit-to-walk phases

	Be	Du	NonVib
Phases duration (s)			
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 (\pm standard deviation) of the center-of-mass in the vertical, horizontal and latero-lateral directions for all sit-to-walk phases and events

	Vertical			Horizontal			Latero-lateral		
	Be	Du	NonVib	Be	Du	NonVib	Be	Du	NonVib
Displacement (cm)									
Flexion	-0.95 (1.96)	-1.97 (0.88)	-1.08 (2.91)	18.45 (5.47)	19.89 (4.22)	18.19 (4.07)	-2.38 (2.01)	-2.06 (2.42)	-2.36 (2.60)
Extension	16.24 (3.74)	15.87 (1.96)	14.68 (3.48)	16.24 (4.85)	15.45 (2.28)	18.11 (3.55)	-1.84 (1.49)	-1.88 (1.15)	-1.89 (1.55)
Transition	-6.94 (2.38)	-7.11 (3.20)	-7.29 (5.94)	-3.30 (1.32)	-3.10 (1.47)	-2.88 (2.24)	0.78 (0.83)	0.90 (0.86)	0.93 (0.64)
Execution	6.52 (3.34)	7.21 (2.99)	7.99 (4.90)	32.53 (3.52)	33.11 (5.24)	32.99 (5.89)	32.53 (3.52)	33.11 (5.24)	32.99 (5.89)
Velocity (cm/s)									
Seat-off	7.51 (14.71)	3.88 (8.37)	1.89 (17.65)	65.31 (13.70)	67.62 (10.20)	70.22 (9.48)	0.39 (1.36)	0.31 (0.77)	0.16 (0.60)
Standing	78.41 (10.46)	77.36 (8.44)	79.50 (1.76)	32.74 (7.88)	33.44 (9.96)	33.98 (9.61)	-5.86 (4.39)	-5.89 (4.64)	-5.28 (3.17)
Heel off	66.47 (12.06)	66.35 (14.12)	68.62 (17.38)	33.50 (8.06)	32.85 (9.90)	32.95 (10.18)	9.61 (7.30)	11.01 (6.61)	10.54 (6.19)
Heel strike	0.56 (6.03)	2.89 (9.68)	1.64 (6.72)	95.05 (12.17)	92.87 (18.84)	93.13 (13.76)	-2.30 (3.34)	-2.70 (2.64)	-2.05 (4.10)

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

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 interrupted^{1, 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 preprogrammed motor patterns could have masked the vibration effects⁶. This hypothesis, is based on the notion

that healthy young adults do not rely on proprioception information to scale transitional movements^{8, 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 energy⁷). 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 absent⁸).

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 patients²⁷), vibration improves walking performance^{7, 28}). 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.

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