Gait-like vibration training improves gait abilities: a case report of a 62 year old person with a chronic incomplete spinal cord injury

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Abstract

The purpose of this single-subject case study was to quantify the effect of gait-like vibration training on gait abilities after an incomplete spinal cord injury. A 62 year old male with a chronic AIS D spinal cord injury at T11 completed nine sessions of gait-like vibration training in a standing position. Self-selected gait speed and distance covered within 6 minutes were determined before and after training to evaluate the impact of training on gait performance. Associated changes in gait kinematics were assessed with a 3D motion analysis system. Results showed an improvement of gait speed (0.26 m/s vs 0.35 m/s) and distance (23 m vs 37m) after nine gait-like vibration training sessions (+34.6%; +60.9%). In addition, more bilateral hip extension and larger left hip range of motion improved hip-knee cyclograms. Gait-like vibration training improved gait abilities in a person with chronic incomplete spinal cord injury.

Keywords

Spinal cord injury, locomotion, vibration, proprioception, training, human

Introduction

After a non-degenerative neurological deficit such as a spinal cord injury, improvements in gait depend largely on sensory afferents generated by repeated lower limb gait movements during gait training [1, 2]. These afferents are essential for motor learning and adaptive plasticity during locomotor training [3]. The need to provide task-specific sensory afferents explains in part the development of task-oriented approaches such as treadmill training with or without body-weight support, robotic exoskeletons [4].

Another alternative to generate muscle afferents in the absence of movements relies on localized muscle vibration. Muscle vibration is a powerful sensory stimulation that mainly activates *Ia* muscle afferents [5, 6]. This stimulation is associated with the perception of joint movement without actual movement [7], muscle activity of the vibrated muscle or its antagonist [8, 9], and brain activity similar to the one producing voluntary contraction of the vibrated muscle [10, 11]. Application of muscle vibration may improve motor performance after spinal cord injury, and particularly during gait. After motor incomplete spinal cord injury (American Spinal Injury Association (ASIA) Impairment Scale (AIS) C & D), activity of the thigh muscles increased and had better timing during robotic-assisted walking when 80 Hz vibration was applied on the quadriceps muscle during specific phases of the gait cycle [12]. This indicates that muscle activity intensity and timing can be altered with bouts of muscle vibration after incomplete spinal cord injury. Continuous 60 Hz vibration of one lower limb muscle can also elicit involuntary, step-like lower limb movements, in participants with spinal cord injury (AIS A to D), lying sideways, with their lower limbs supported and free to move in the horizontal plane without friction [13]. Finally, reduction of spasticity has been observed after continuous vibration (frequency of 50 to 100 Hz) of different lower limb muscles in individuals with AIS A to D spinal cord lesions [14].

When properly patterned, multiple localized vibrations can induce a perception of complex movements, such as writing, in healthy individuals [15]. Multiple vibrations can also be patterned on the sequence of lower limb muscle lengthening to mimic sensory activity of normal gait [16]. Applied in individuals with spinal cord injury [16] or hemiparesis due to stroke (personal communication) in quiet standing, these gait-patterned vibrations induced small amplitude stepping-in-place movements of the lower limbs. Gait-like vibrations may therefore be an appropriate sensory stimulation for gait training after spinal cord injury. The objective of this case-study was thus to test whether gait-like vibration training can improve gait abilities in an individual with incomplete spinal cord injury.

Methods

Participant

A 62 year old male with a chronic AIS D spinal cord injury at the T11 level, due to a cycling accident 10 years before, participated to the study. He was able to ambulate 10 meters with a walker, no braces, and close supervision of one person as he relies on a manual wheelchair as his primary mode of locomotion.

On the AIS, his lower extremity motor score (LEMS) was 30/50, light touch score was 92/112, and pin/prick score was 77/112. Mild spasticity was measured (modified Ashworth scale) at the right hip adductors (1) and plantarflexors (1), left knee extensors (1) and bilateral knee flexors (1).

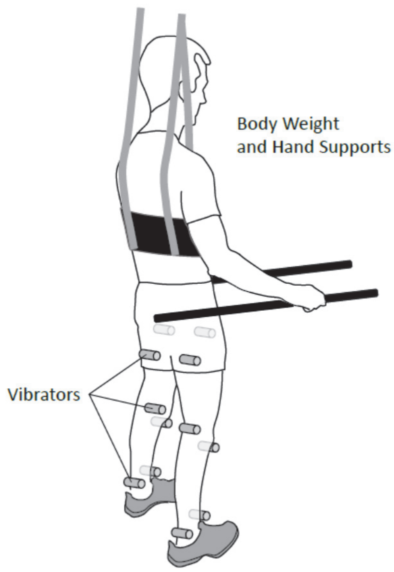
Vibration training program

Prior to the vibration training program, the participant completed a home-based 12-week standing program to prepare for the vibration training program. The standing time was progressed to reach one hour of continuous standing within a standing frame daily before initiating the vibration training program.

Thereafter, he attended nine vibration training sessions within 2 weeks (5 sessions during week 1 and 4 sessions during week 2). It included only gait-like patterned muscle vibrations in various combinations of one, two or five minute vibration bouts for a total vibration duration of 20-25 minutes for the first six sessions and progressed to 35-40 minutes for the last three sessions. The vibrations were applied when the participant was in a quiet standing position, supported and helped for balance by a body-weight support system. His weight was relieved by about 40% of his body weight, as measured by the support system. He was also holding himself upright using minimal upper-limb support. As previously described, gait movements of small joints amplitudes were induced during the vibration sessions. For the 1st and 2nd sessions, the participant received the vibration without performing any voluntary activity. At the 3rd session, he was encouraged to add voluntary movements to increase the amplitude of the stepping-in-place movements triggered by the patterned vibrations. Amplitudes of this stepping-in-place movements were not quantified. The first bout of vibration was applied with the eyes closed for the participant to focus on the stimulation. Then for some bouts of vibration, the subjects was asked to open his eyes and look straight ahead. Rest periods were allowed upon participant's request.

Vibration stimulation

Twelve electromechanical vibrators (VB115, Technoconcept, France) were fixed bilaterally and transversally on the flexor and extensor muscle groups at the hips (i.e. on the proximal tendon of rectus femoris below the anterior inferior iliac spine and on the proximal tendon of the hamstring below the ischial tuberosity), knees (i.e. on the patellar tendon below the patella and on the medial hamstrings above the medial femoral condyle) and ankles (i.e. on the distal tendon of dorsiflexors and of the triceps surae tendon both in regard of the malleoli) using elastic bands (Figure I). The vibrators were activated and deactivated cyclically according to a pattern mimicking the timing of muscle lengthening during a typical gait pattern. The duration of each cycle lasted 1 or 2 seconds to vary gait speed, and cycles were repeated consecutively for one, two or five minutes periods. The targeted frequency during the activation of the vibrators is 80 Hz, as this frequency strongly activates muscle sensory afferents [17, 18]. The feasibility of producing this stimulation has been documented previously [16].



<u>Figure I</u>. Vibration stimulation device and installation for vibration training

Twelve vibrators (grey cylinders) were placed bilaterally on the flexor and extensor muscle groups at the hips, knees and ankles. They were held in place using elastic bands. The participant was in a quiet standing position, supported and helped for balance by hand supports and a body-weight support system that relieved about 40% of his body weight.

Clinical evaluations

Self-selected gait speed was evaluated using the 10-meter walk test and the walking distance was measured using the 6-minute walk test [19, 20] . During these evaluations, the participant used a rolling walker and no other physical assistance was provided. The tests were performed twice before the beginning of the training session to establish initial locomotor capacity and measure natural variability of these measures, and once the day after the last training session. A familiarization test session was also completed before the first evaluation session. The pre-training locomotor capacity (i.e., speed and distance) represents the mean of the values obtained during the two pre-training assessment sessions.

Gait assessment

Lower limb kinematics was recorded using an NDI Certus® motion capture system, with at least three non-collinear markers on each major lower-limb segments (feet, shanks and thighs) and on the pelvis. The participant walked continuously (30 consecutive steps) on a Bertec® dual-belt instrumented treadmill, using handrails to support part of his body weight. A security harness was used only to prevent fall and provided no body weight support. To test the effects of training on kinematics, the same self-selected speed was used in both pre- and post-training assessment (i.e. 0.185 m/s). No vibration was applied during gait evaluation. Flexion peak, extension peak and range of motion at the ankle, knee and hip were calculated on both sides from 10 gait cycles for each gait trial.

Data analysis

Descriptive statistics were used for pre- and post-training clinical evaluations (gait speed and walking distance over 6 min). The effect of the vibration training program on kinematic data was assessed by comparing each variable pre- and post-training. Kinematics was also analysed using hip-knee cyclograms. Their shape was compared to normative data [21] before and after vibration training.

Results

Clinical evaluations

Gait speed increased from 0.26 m/s (0.26 m/s at each pre-training trial) to 0.35 m/s in post-training (increase of 34.6 %). Walking distance over 6 minutes increased from 23 m (25 and 20 m for each pre-training trial) to 37 m in post-training (increase of 60.9%).

Kinematic data

Joint amplitudes were overall smaller than expected based on normative data. Pre-training cyclograms (Fig. II) were mainly affected due to alterations of both hip and knee joint motions. During stance phase, hip and knee flexions were exaggerated, leading to an "upward-rightward" cyclogram after heel contact. This showed the difficulty to maintain the lower-limb position during weight acceptance, particularly on the right lower-limb. Hip and knee joints were also more in flexion throughout the cycle, leading to a shift of the whole cyclograms towards flexion values. At the end of stance phase, hip flexion was initiated but stopped and reversed towards extension, to a larger extent at the right hip, before knee flexion and a limited flexion only on the right hip generated swing. The swing phase was largely produced by knee extension and limited hip flexion, particularly small at the left hip.

After training, there were little changes in ROM at the knees (Table 1). At the left hip, the range of motion increased (ROM pre = 9.8°, ROM post = 14.1°), due to an increase of the maximal hip extension angle. At the right hip, ROM did not change. However, for both hips, the whole ROM shifted towards extension by more than 20°, resulting in hip motions reaching below-zero values, i.e. in the actual extension range (Table 1). In addition, the relative motion of the hip and knee improved at the right lower limb during swing phase, leading to a cyclogram more similar to the one of the left lower limb particularly before swing phase (Fig. II).

Table 1. Mean bilateral amplitudes at the ankle, knee and hip joints during gait evaluation on the treadmill (mean of 10 gait cycles)

	Right ankle			Left ankle		
	Dorsi-flexion (°)	Plantar flexion (°)	ROM (°)	Dorsi-flexion (°)	Plantar flexion (°)	ROM (°)
Pre	7.7	-17.1	24.8	8.6	-13.2	21.8
Post	4.6	-17.5	22.1	8.8	-13.9	22.6
	Right knee			Left knee		
	Flexion (°)	Extension (°)	ROM (°)	Flexion (°)	Extension (°)	ROM (°)
Pre	42.9	14.2	28.8	40.0	8.8	31.2
Post	39.6	13.9	25.6	38.1	9.5	28.6
	Right hip			Left hip		
	Flexion (°)	Extension (°)	ROM (°)	Flexion (°)	Extension (°)	ROM (°)
Pre	30.4	10.4	20.0	21.6	11.7	9.8
Post	11.7	-7.0	18.7	9.6	-4.5	14.1

ROM: range of motion

Variability of the lower limb movements also increased between cycles post-training with less superimposition between cycles on the cyclograms compared to pre-training (Fig. II).

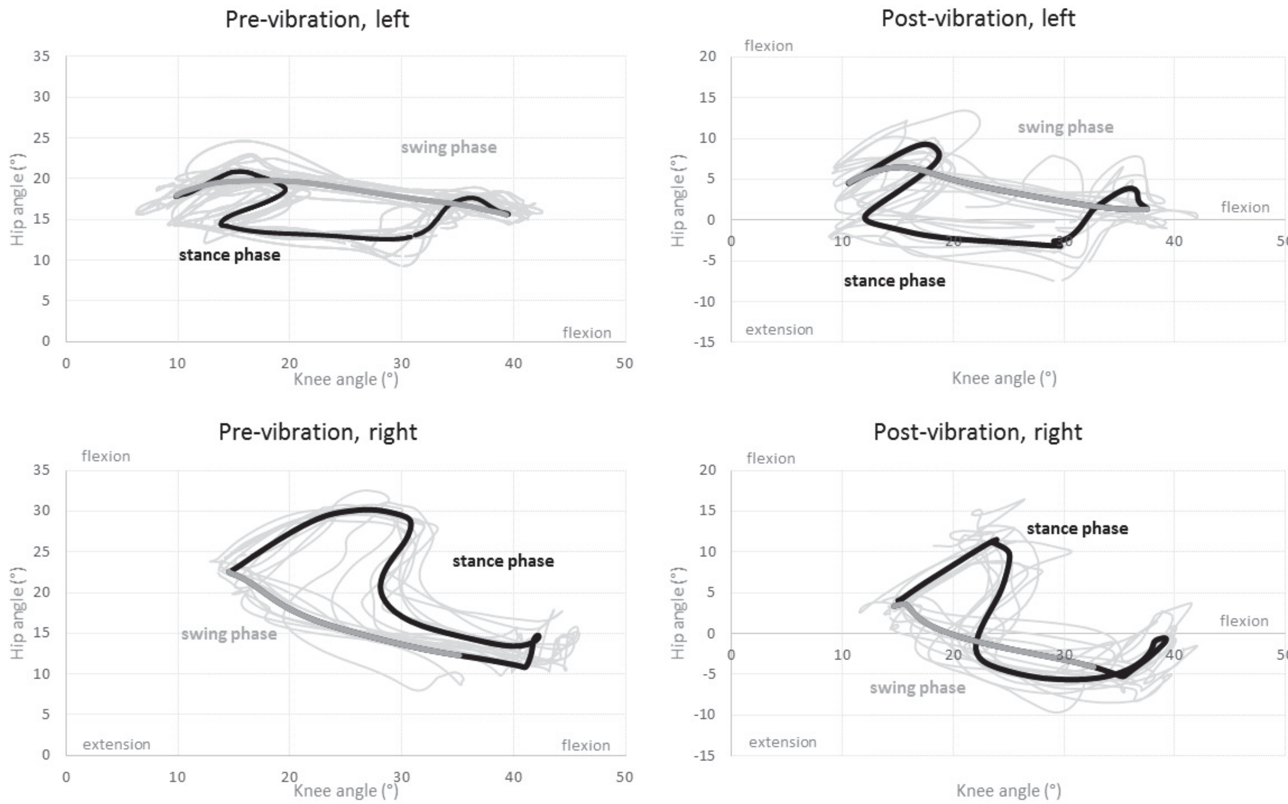


Figure II. Joint angle analysis, hip-knee cyclograms
Top of the panel: left lower limb, bottom of the panel: right lower limb, left part of the panel: cyclograms before vibration training, right part of the panel: cyclograms after vibration training, bold black (stance phase) and dark grey (swing phase) lines are for average gait trial and thin light grey lines represent each gait trial. Note that the vertical scale was adapted due to the shift of the cyclograms towards hip extension in post-training.

Discussion

The results showed that patterned gait-like vibrations, used repeatedly and exclusively in a gait training program, can improve self-selected gait speed and total distance traveled over 6 minutes in a male with a chronic incomplete SCI. These improvements in performance are similar to those obtained in training programs requiring actual gait practice [1, 4]. Interestingly, these training programs lasted often more than 20 sessions and up to 144 session in some cases [1, 4]. Further study will have to test whether longer vibration training would be more efficient, and to what extent it relates to the initial level of performance or time since injury.

The vibration training also altered the participant's lower limb kinematics toward an improved gait pattern that likely contributed to improve gait performances. Among the positive kinematic changes, a shift towards extension was obtained at both hips post-training. The more extended hip position is not likely due only to the sessions in standing position, as the participant prepared for this training by standing daily during the month before the vibration training. It is more likely that the motor facilitation induced by the vibration improved the voluntary control of lower limb muscle activity [12] at the hips and particularly at the right lower limb that also showed improved coordination. This might also explain the larger variability of the cyclograms observed post-training. The increased variability suggests that the participant has more ability to alter his gait pattern than before training and represents a favourable outcome [22].

Overall, this study strengthens existing evidence that sensory activity patterned according to the task can improve this task as already proposed before [1, 3]. However, the importance of the pattern of the sensory stimulation remains to be thoroughly evaluated since whole-body vibration has also been found to improve gait speed to a similar extent (0.06 m/s) among 17 persons with a chronic SCI participants with similar clinical characteristics [23]. One can suspect that the mechanisms of action differ slightly, between a global, non-specific stimulation during whole-body vibration compared to a task-oriented specific stimulation during patterned vibration.

This case-study report aimed to test whether gait-like vibration training could improve gait abilities in one person with chronic AIS D SCI. The results of this study provides preliminary evidence of a positive effect of patterned vibration training associated with voluntary movements on gait abilities after spinal cord injury. Vibration training uses low-tech and low-cost technology that can easily be integrated into clinical practice in rehabilitation facilities or at home. Further studies are now warranted to further test the generalisability of the results, the perceived satisfaction of the users, and the efficiency of this novel rehabilitation intervention.

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