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Role of proprioceptive information to control balance during gait in healthy and hemiparetic individuals

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ABSTRACT

Proprioceptive information is important for balance control yet little is known about how it is used during gait or how a stroke affects its use. The aim of this study was to evaluate the role of proprioception in controlling balance during gait in healthy participants and after stroke. Twelve healthy and 9 hemiparetic participants walked on an instrumented treadmill in a fully lit room, while whole-body, three-dimensional kinematics were quantified. Vibration was applied continuously or during the stance phase only, on the posterior neck muscles and triceps surae tendon on the non-dominant/paretic side. Difficulty in maintaining dynamic and postural balance was evaluated using stabilizing and destabilizing forces, respectively. Continuous and stance phase vibration of the triceps surae reduced the difficulty in maintaining both dynamic and postural balance in healthy participants ($p < .05$), with a greater distance between the center of pressure and the limit of the potential base of support, a more backward body position, and no change in spatio-temporal gait parameters. No effect of neck muscle vibration was observed on balance ($p = .63$ and above). None of the vibration conditions affected balance or gait parameters among stroke participants. The results confirmed that proprioceptive information was not used to control balance during gait in stroke participants. The importance of proprioceptive information may depend on other factors such as walking and visual conditions. Changes in sensory integration ability likely explain the results after stroke. Further study is needed to understand the integration of proprioceptive and visual information to control balance during gait after stroke.

1. Introduction

Control of body posture and dynamics, i.e., segment alignment and velocity of the center of mass (CoM), depends on the integration and weighting of somatosensory, vestibular and visual sensory information [1,2]. Among them, muscle proprioception continuously informs the central nervous system (CNS) on the position of each segment of the body [3]. Muscle vibration is commonly used to study the role of proprioceptive information in motor control as it generates a strong proprioceptive stimulation when applied at a frequency of 80–100 Hz and with amplitude between 0.5 and 1 mm [4–6]. It also induces a contraction of the vibrated muscle or its antagonist depending on the conditions of application [7].

When applied during quiet standing, muscle vibration induces oriented postural reactions [8,9]: vibration of the triceps surae resulted in a backward postural response [8] while vibration to the back neck muscle resulted in a forward postural reaction [8,10]. During gait, the role of proprioception in controlling balance has scarcely been studied. Vibration has been shown to affect kinematics, speed, and muscle activity during gait [9,11,12]. The results most closely related to balance control during gait showed changes in CoM displacements and accelerations during gait when vibration was applied at the ankle [11].

Contrary to quiet standing, sensory activity during gait is cyclical (due to repetitive movements of the limbs) and random in the case of gait perturbations. As such, sensory activity plays different roles in the motor control of gait. For example, the transition between stance and swing phase, and the organization of alternated flexor and extensor activity in the lower limbs is mediated by phasic sensory activity [13]. Moreover, sensory

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background affects responses to new sensory information: during standing, the position of the joints alters gains in cutaneous reflexes [14], and instability of the support surface inhibits postural reactions to vibration of ankle muscles [15]. Thus, sensory afferents may have different effects on balance control during gait depending on the gait phase examined.

The use of proprioceptive information to control balance is also affected by neurological lesions such as stroke. Persons with hemiparesis generally have impaired proprioception [16], associated with increased postural sway [17]. Alterations in the center of pressure (CoP) excursion due to sensory manipulation during quiet standing [17] or gait [18] also indicate that stroke-related sensorimotor impairments affect the neuromuscular activity necessary to control balance. However, gait speed has been increased via proprioceptive stimulation applied at the ankle during gait in participants with hemiparesis [19]. Ankle vibration only affected temporal (vs. spatial) gait parameters in stroke patients, regardless of any ankle joint position sense impairment [20], suggesting that the use of proprioception information to control gait might be reduced at the sensorimotor integration level rather than the sensory perception level after stroke [20–22]. To our knowledge, no study has evaluated how proprioceptive information is used to control balance during gait after stroke.

The first objective of the study was to evaluate how continuous and phasic proprioceptive information from the neck and ankle alters postural and dynamic balance during gait in healthy participants. A secondary objective was to determine how hemiparesis due to stroke affects the use of proprioceptive information in postural and dynamic balance control during gait.

2. Methods

2.1. Participants

A convenience sample of 21 volunteers (12 healthy, 9 with hemiparesis due to stroke) was recruited for this study. The inclusion criteria were to be able to walk on a treadmill without any assistance, have no orthopedic or neurological problems affecting gait, or cognitive deficits prior to the experiment (for healthy participants) or prior to stroke (for hemiparetic participants) and be able to sustain 90 min of activity with rest periods as required. The main characteristics of the participants are presented in Table 1.

All participants gave written consent to participate in the study after having been informed of the details of the experiment according to local ethics board recommendations.

2.2. Data collection and proprioceptive stimulation

Three-dimensional whole-body kinematics were recorded at 60 Hz with an Optotrak Certus system (NDI, Waterloo, Canada), using three to six non-collinear infrared markers placed on each main segment of the body (15 segments for a total of 75 markers). A digitizing probe was used to locate the contour of the shoe soles, with respect to the infrared markers on the respective foot segments, and anatomical landmarks to complete the definition of the rigid bodies representing each body segment along with anthropometric measurements and to define a 3-D link-segment model for each participant [23].

Ground reaction forces and moments were measured under each foot using an instrumented split-belt treadmill (Bertec Fit®). Kinetic data were collected at a frequency of 600 Hz, filtered with a fourth-order Butterworth zero-lag filter with a cut-off frequency of 10 Hz and re-sampled at 60 Hz to match the kinematic data. Belt speed was set to the participants' comfortable gait speed using progressive speed increases and decreases.

Proprioceptive stimulation was applied using an electromechanical vibrator (VB115, Technoconcept, France) at 80 Hz (amplitude between 0.5 and 1 mm) on the tendon of the non-dominant or paretic triceps surae and on the bilateral posterior neck muscles during gait. Continuous (with the vibrator on throughout the entire trial) and phasic (with the vibrator turned on only when the heel was in contact with the ground as detected by a foot switch placed on the heel of the shoe) modes of vibration were used. Preliminary tests showed delays between vibrator activations and stance phase of about less than 80 ms.

2.3. Experimental protocol

The following conditions were tested among all participants: control condition without vibration, posterior neck muscle vibration in the continuous and phasic mode, and triceps surae tendon vibration in the continuous and phasic mode. The control

Table 1
Clinical characteristics of stroke participants.

	Age (years)	BMI (kg/m^2)	OG velocity (m/s)	Treadmill velocity (m/s)	CMMSA		Sensory perception		
					Leg score	Foot score	Cut. (/4)	Mov. (/10)	Pall. (s)
S1	60	31.2	0.85	0.35	5	4	3/3	10/10	13.2/13.2
S2	32	21.6	0.82	0.75	6	4	4/4	10/10	14.7/15.4
S3	64	27.5	0.80	0.60	5	3	3/3	10/10	9.6/10.0
S4	53	22.8	0.72	0.70	4	2	3/3	10/10	10.7/11.6
S5	55	27.7	0.73	0.70	4	4	3/3	10/10	17.1/14.0
S6	54	25.7	0.55	0.55	6	4	2/2	10/10	13.1/12.4
S7	39	25.7	1.08	0.65	5	4	4/3	10/10	8.0/9.2
S8	37	37.4	1.31	0.95	6	5	2/2	10/10	14.1/14.8
S9	36	20.6	1.22	0.60	5	3	4/4	10/10	15.5/16.2
Mean	**47.8**	**26.7**	**0.90**	**0.65**	**5**	**4**	**3/3**	**10/10**	**12.9/13.0**
SD or range	**11.8**	**5.2**	**0.25**	**0.16**	**[4:6]**	**[2:4]**	**[2:4/2:4]**	**[10/10]**	**2.9/2.4**
Mean	*47.6*	*26.4*	*1.55*	*1.02*					
SD	*14.5*	*6.0*	*0.15*	*0.17*					

BMI, body mass index; OG, overground; CMMSA, Chedoke-McMaster Stroke Assessment; SD, standard deviation. Pallesthesia: duration perception with a 128 Hz tuning fork on the malleolus lateralis. Mov.: Number of passive movements at the big toe perceived correctly out of 10. Cut.: cutaneous perception of 2 out of 3 Semmes–Weinstein filament contacts on the malleolus lateralis; 1: anesthesia (6.65 filament perceived); 2: severe deficit (5.18 filament perceived); 3: hypoesthesia (4.31 filament perceived); 4: normal sensitivity (4.17 filament perceived). Paretic/Non-paretic are indicated for these three tests. The last two lines in italics are the mean results for the group of healthy participants.