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ORIGINAL RESEARCH

Effects of Treadmill Incline and Speed on Ankle Muscle Activity in Subjects After a Stroke

Roghayeh Mohammadi, PhD,[a] Saeed Talebian, PhD,[a] Chetan P. Phadke, PhD,[b,c,d] Mir Saeed Yekaninejad, PhD,[e] Mohammad-Reza Hadian, PhD[a,f]

From the [a]Physical Therapy Department, Rehabilitation Faculty, Tehran University of Medical Sciences, Tehran, Iran; [b]Spasticity Research Program, West Park Healthcare Centre, York, Ontario, Canada; [c]Department of Physical Therapy, University of Toronto, Toronto, Ontario, Canada; [d]Faculty of Health, York University, Toronto, Ontario, Canada; [e]Department of Epidemiology and Biostatistics, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran; and [f]Faculty of Rehabilitation, Brain and Spinal Injury Research Center, Imam Hospital, Tehran University of Medical Sciences, International Campus, Tehran, Iran.

Abstract

Objectives: To examine the effects of walking on a treadmill at varying gradients and speeds on ankle muscle activation in stroke survivors, and to compare the effect of increasing speed on plantarflexor muscle activity in participants grouped according to spasticity severity.

Design: Within-subject and cross-sectional design. Participants walked on a standard treadmill at 3 different inclines (0°, 3°, 6°) and speeds (self-selected, self-selected+20%, self selected+40%).

Setting: University laboratory.

Participants: A convenience sample of stroke survivors (N=19; 13 men, 6 women) available in university clinics.

Interventions: Not applicable.

Main Outcome Measures: Electromyographic activity of medial gastrocnemius (MG) and tibialis anterior (TA) muscles at push-off phase of the gait.

Results: Paretic MG muscle activity increased (but TA did not change) at faster speeds irrespective of the incline (P<.05). In contrast, MG muscle activity increased at a higher incline in the nonparetic side (P<.05), but not in the paretic side (P>.05). In the high-spasticity subgroup (Tardieu Scale ≥2), paretic MG activity increased as walking speed increased (P=.004).

Conclusions: Stroke survivors appear to use distinct muscle activation strategies on the paretic and nonparetic sides in response to different walking speeds and inclines. Our data indicates that individuals with stroke can be safely trained on a treadmill to walk 20% to 40% above the self-selected pace to improve MG output without adversely affecting TA output. The speed-dependent characteristic of spasticity may help generate greater MG activity during push-off.

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The most prevalent impairment after stroke is contralateral paresis.[1,2] Decreased activation of the lower limb muscles, particularly the plantarflexor muscles, is linked to impaired motor control and decreased weight-bearing and limb use.[3] A decrease in activation of the plantarflexor muscles, a major contributor to the propulsive force in the terminal stance of gait,[4] leads to inadequate propulsion after stroke. In addition to propulsion, plantarflexor muscle activity in the stance phase also ensures a smooth swing phase.[5] Hip flexors act in a compensatory manner to propel the limb through the swing phase when plantarflexor muscle activities are decreased.[6-8] The resulting decrease in activity of the plantarflexors can limit gait speed in hemiparetic participants.

Walking on an inclined surface has been recommended to enhance the plantarflexor output.[9-20] Quadriceps[17] and plantarflexor[21] muscle activity increases in the stance phase during uphill walking[17,21] and fast walking conditions[17] in healthy control subjects. Extending these findings to stroke participants, Phadke[22] reported that plantarflexor muscle activity increased in response to higher inclines only on the nonparetic side. Most of the work to

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date has focused on the effects of walking on surfaces of varying gradient at a self-selected walking speed, though very few studies have investigated the effects of walking at faster speeds.[22-25]

An increase in walking speed over the course of stroke rehabilitation is associated with an improvement in the amplitude of,[26] but not with temporal changes in, muscle activation patterns.[27,28] Although both increased walking speed and higher inclines individually have the potential to increase muscle activity, it is not clear whether the combination of these 2 variables results in even greater muscular activity than each variable alone. Therefore, the main objective of this study was to explore the effects of varying the incline and walking speed on ankle muscle activity in participants with stroke. We hypothesized that participants walking at higher inclines and faster speeds would show greater muscle activity than participants walking at slower speeds and lower inclines.

Differences have been found in muscle cocontraction (MCo) patterns between participants with central nervous system disorders[29-31] and healthy participants during walking.[27,32] MCo increases in both groups while learning a new skill[33] or in the presence of instability.[34] However, the adverse effects of increased MCo, such as the increase in compressive joint loading and decreased movement flexibility, can result in decreased movement adaptability.[31] For example, in the chronic stage poststroke the longer MCo between the tibialis anterior (TA) and the medial gastrocnemius (MG) during the gait cycle[35] hinders walking ability. Thus, it is important to address the impact of varying the walking speed and incline on MCo. Additionally, spasticity is known to be speed dependent,[36] but it is not clear whether ankle plantarflexor spasticity affects MCo as a result of changes in the walking speed and incline. A secondary purpose of this study was to compare the effect of a faster walking speed on MCo between plantarflexor and dorsiflexor muscles in participants grouped according to spasticity severity. We hypothesized that MCo would increase with a faster walking speed in the participants with high spasticity.

Methods

Participants

Forty stroke survivors were identified from university clinics in Tehran and approached; 24 of them agreed to participate in the study. Nineteen participants (6 women, 13 men; mean age ± SD, 55.37±7.54y; mean body mass index ± SD, 29.10±4.52kg/m^2) completed the study. Five participants failed to complete the study either because their fear of walking on a treadmill prevented them from completing all the tasks, or because there were equipment-related technical issues. All the participants were more than 6 months poststroke and could walk at least 10m independently. Exclusion criteria included comprehensive aphasia, incontinence, unstable medical condition, history of falling, sensory disturbance of the lower limbs, and medical conditions (apart from stroke) that prevented them from walking. One participant who usually walked with an ankle-foot orthosis did not wear it during the trials. In this study, with 19 participants and 171 measurements, the statistical power for conducting a multiple linear regression model with 4 predictors at a significance level of 5% was 94%.[37] The research ethics committee of Tehran University of Medical Sciences approved the study, and each participant provided written informed consent.

List of abbreviations:

LMM	**linear mixed model**
MCo	**muscle cocontraction**
MG	**medial gastrocnemius**
MVC	**maximum voluntary contraction**
RMS	**root mean square**
ROM	**range of motion**
sEMG	**surface electromyography**
SSS	**self-selected speed**
TA	**tibialis anterior**

Protocol

The level of motor impairment in the lower extremities was measured using the Fugl-Meyer lower extremity assessment, a test used to examine the level of motor recovery poststroke, with scores ranging from 0 to 34 (table 1). All participants were tested by the same examiner using the Fugl-Meyer lower extremity assessment protocol.[38]

For the modified Tardieu scale and Tardieu angle, participants lay in a relaxed supine position. Plantarflexor muscle tone was assessed at 2 speeds: the speed while moving the limb as slow as possible (velocity 1), and the speed while moving the limb as fast as possible (velocity 2). In velocity 1, the angle of full passive range of motion (ROM 1) was measured with the goniometer; the talocrural joint was moved from a position of maximum plantarflexion to a position of maximum available dorsiflexion slowly. ROM 2 recorded for velocity 2 represented the point in the joint range where a speed-dependent "catch" was felt during a quick stretch of the plantarflexor muscles. After measuring ROM 2, we subtracted ROM 2 from ROM 1, and the difference was termed the Tardieu angle. The quality of muscle reaction to passive fast movement was scored using the Tardieu Scale (appendix 1, see table 1).[39] To determine self-selected walking speed, the average overground walking speed was calculated across 3 trials over a distance of 10m. After recording the self-selected speed (SSS) overground, the participants walked on the treadmill and their SSS (on the treadmill) was recorded; most found that walking slower on the treadmill was more comfortable. The +20% and +40% SSSs were determined for the treadmill walking trials. During treadmill walking, participants wore a safety harness connected to an overhead support. The harness did not offload any body weight and only provided support in case of a loss of balance. Additionally, participants could hold the handrail for support. Participants warmed up at a constant speed on the treadmill for 2 minutes and then completed 9 trials lasting 2 minutes each in random combinations of gradients (0°, 3°, 6°) and speeds (self-selected, self-selected+20%, and self-selected+40%). A 2-minute rest break (sitting) was provided between the various walking conditions to minimize fatigue. Electromyographic data were recorded during the final 15 seconds of each trial, and the middle 3 steps were selected for further analysis. Although stroke survivors can voluntarily double their overground walking speed,[40] we decided to impose a modest increase in treadmill walking speed of up to 40%SSS and up to a 6° incline (an optimal combination) to minimize stumbling and maximize opportunities to improve paretic plantarflexor electromyographic output.[19,22]

Electromyography recording

The skin overlying MG and TA muscles was shaved and cleaned with alcohol. Surface electromyography (sEMG) was recorded