Title: Immediate effect of treadmill walking practice versus overground walking practice on overground walking pattern in ambulatory stroke patients: an experimental study

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Abstract

Objective: To determine if ten-minutes of treadmill walking had a different effect on overground walking pattern compared with ten-minutes of overground walking in newly-ambulatory stroke patients. Are any changes influenced by walking ability?

Design: A within-participant, repeated measures experimental study was conducted. Each participant carried out ten minutes of overground walking practice followed by ten minutes of treadmill walking practice at matched heart rate on separate days.

Setting: An inpatient rehabilitation facility

Subjects: Twenty-one participants receiving inpatient rehabilitation following stroke.

Measures: Overground walking pattern was measured as linear and angular kinematics using GAITRite and a 2D webcam application respectively.

Results: Following treadmill walking practice, there was 6 deg (95% CI 2 to 10) more knee extension at heelstrike during overground walking than following overground walking practice. Poorer walkers increased non-paretic limb step length following treadmill walking practice more than those with better walking ability (mean difference 2.2 cm, 95% CI 0 to 5).

Conclusions: 10 minutes of treadmill walking practice resulted in a similar overground walking pattern compared with overground walking practice in newly-ambulatory stroke patients undergoing rehabilitation, regardless of walking ability.

INTRODUCTION

A recent systematic review found that treadmill training following stroke was associated with faster walking speeds¹. However, clinicians seem reluctant to implement treadmill training for stroke patients due to a fear that an abnormal walking pattern will be practiced² resulting in an abnormal overground walking pattern³. Current motor learning principles suggest that optimal motor recovery is driven by task-specific repetitive practice⁴. Treadmill walking is well placed to provide task-specific repetitive practice as it permits the continuous practice of complete gait cycles. However treadmill walking may not be comparable to overground walking⁵.

When people with stroke walk on a treadmill the walking pattern changes slightly. Some changes are beneficial and some undesirable. During treadmill walking the belt moves the stance leg backward^{3, 6} resulting in beneficial changes such as increased hip extension⁶ and inter-limb symmetry⁷ as well as increased paretic and non-paretic limb step length⁸. In contrast, the unchanging environment during treadmill walking provides conflicting proprioceptive, visual and vestibular information⁹ while the greater balance and attentional demands^{9, 10} result in undesirable changes such as the need to hold the handrail¹¹, slower walking speeds, smaller stride length and faster cadence¹⁰. Changes to the angular kinematics of the walking pattern while walking on a treadmill following stroke has received little investigation with only one study reporting greater hip flexion during swing phase at faster treadmill speeds⁸.

Following stroke the energetic cost of walking is increased^{12, 13}. The effect of these beneficial and undesirable changes in walking pattern on the energetic cost of treadmill walking for people with stroke is unclear. In healthy adults, a lower energetic cost was found in young

adults¹⁴ but elders¹⁵ had higher heart rates (mean difference 6 bpm, 95% CI 1 to 10) and an increased energetic cost (mean difference 0.46 ml.kg⁻¹.min⁻¹) during treadmill walking. Slower walking speeds are associated with higher energetic costs^{12, 13}. People with stroke walk slower on the treadmill compared to overground walking^{7, 10} suggesting that treadmill walking is harder. It is possible that those with a stroke who walk at slower speeds, with greater asymmetry^{16, 17} and a higher energetic cost^{12, 13} may respond differently to treadmill walking compared to those who walk faster.

The carry-over of these beneficial and undesirable changes to the treadmill walking pattern onto overground walking has not been investigated. It is important to investigate these effects as the goal of rehabilitation following stroke is to regain good walking performance³ in order to be able to ambulate in the community¹⁸. This study is an initial attempt to investigate the effect of treadmill walking practice on overground walking by examining the overground walking pattern immediately following treadmill walking practice.

Therefore, the research questions for this study were:

1. Does ten minutes of treadmill walking practice immediately result in a different pattern of overground walking compared to ten minutes of overground walking practice, when performed at the same workload?
 2. Are any differences influenced by walking ability?
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METHOD

Design

This was a within-participant repeated measures experimental study involving two modes of walking practice at matched workload. Participants participated in ten-minutes of overground and treadmill walking practice on separate days. Overground walking practice was conducted first, recording heart rate which was then matched during treadmill walking practice. Heart rate (HR) was measured continuously during both modes of walking practice via a portable heart rate monitor (Polar S610i). Average and maximum heart rates were recorded and converted to a percentage of heart rate reserve (%HRR) using Karvonen's formula¹⁹ to calculate workload. For participants taking beta-blocker medication, the calculation of HR age predicted maximal was adjusted (85% [220-age]) to accommodate the heart rate - lowering effect of this type of medication^{20, 21}. Overground walking was measured before and after each walking practice mode. Institutional ethics committees approved this study and informed consent was obtained from all participants. All participants had medical clearance for participation in the study.

Participants

Patients admitted consecutively to a tertiary rehabilitation unit of a large metropolitan hospital in Brisbane, Australia were recruited for this study. Patients were eligible for admission if they had a primary diagnosis of stroke, were admitted following their first stroke, were referred for physiotherapy, were medically stable, had a Motor Assessment Scale (MAS)²² Item 5, walking score of at least 3 and were able to consent to participate in this study. Therefore the study included people with stroke able to walk at least three metres with or without a walking aid without standby help. Participants were not receiving treadmill practice as part of their routine care. Potential participants were excluded if they had other

neurological or musculoskeletal conditions affecting their gait, any cardiovascular problems that limited their participation in physiotherapy or if gait velocity was considered normal, more than 1.23 m/sec for women and 1.33 m/sec for men²³. Demographic and clinical information obtained from the medical record included date of birth, gender, time since stroke, side of stroke, medications which may affect heart rate such as beta-blockers, Functional Independence Measure (FIM)²⁴ and Mini-Mental State Exam (MMSE)²⁵ score. Participants were grouped into poorer and better walking ability groups based on scores on Item 5 of the Motor Assessment Scale²².

Experimental interventions

All participants were familiarised to treadmill walking prior to study participation. This involved walking on the treadmill until they reported feeling comfortable. This took on average 15 minutes (range 5 - 40) across 2.4 sessions (range 1 - 5).

Overground walking practice, conducted first, consisted of walking forwards, backwards sideways on flat or uneven surfaces appropriate to participant walking ability for ten minutes. Rest periods were provided as required. Treadmill walking practice, conducted on a separate day, consisted of ten minutes walking on the treadmill (with no incline) at a matched average and maximum heart rate to that recorded during overground walking. Participants were encouraged to hold onto treadmill hand rails and treadmill speed was manipulated to ensure matched heart rate. Rest periods were provided as required. A treadmill safety stop cord was attached to the participant and an assistant was available at all times for safety. If at any time participants wished to cease walking on the treadmill they were able to do so. Treadmill speed and distance walked was recorded. Both walking practice modes were conducted by first author.

Measures

Overground walking pattern was measured as linear and angular kinematics. Linear kinematics were measured on an 8m GAITRite mat (CIR Systems, Clifton, NJ, USA), which has demonstrated validity and reliability in young and older healthy adults²⁶⁻²⁹, neurological patients^{30, 31} and has been used with stroke patients^{6, 32, 33}. Participants performed 2 passes of a 10m path, immediately before and after each mode of walking practice, including a moving start and finish to reduce any acceleration or deceleration effect, using their usual gait aids with a seated rest at each end between passes. An assistant walked beside the participant at all times. Linear kinematics recorded by GAITRite (CIR Systems, Clifton, NJ, USA) in the central 8m of the path included velocity, cadence, step length (paretic and non-paretic limb), step time (paretic and non-paretic limb) and stance as a percentage of the gait cycle (paretic and non-paretic limb).

Angular kinematics were measured at heel strike, mid stance, heel off, toe off and mid-swing phases of gait using a 2-dimensional webcam (Logitech) application developed for telerehabilitation and shown to be accurate and reliable for analysing joint angles³⁴⁻³⁶. Adhesive white dot markers were placed on bony prominences of acromion, greater trochanter, lateral malleolus, head of fifth metatarsal, left and right posterior superior iliac crests, third thoracic vertebrae, first lumbar vertebrae as well as the mid lateral knee joint line, and mid posterior thigh and lower leg approximately three fingers width below the gluteal fold and knee joint crease line respectively. Cameras were placed so that a posterior and lateral view of the walking pass over the GAITRite was captured, at a height ensuring that all markers were visible. The cameras captured data at twenty-five Hz and were placed to ensure capture of maximum number of steps. Sagittal plane hip, knee and ankle joint angles were calculated

between segments while frontal plane pelvic, hip abduction and trunk lateral flexion were calculated to a plumbline vertical reference. They were recorded from the frames that best represented each gait phase. When it was impossible to select an appropriate frame, no data was recorded for that gait phase.

Data Analysis

Preliminary analyses to determine final participant numbers revealed that to achieve 80% equivalence, with no difference for gait parameters between overground or treadmill modes, at a significance of 0.05 a total of 21 participants were required.

To ensure that workload of the two walking modes was comparable, recorded average and maximal heart rates were converted to percentage heart rate reserve and compared between the two modes using paired t-tests. Paired t-tests were used to compare gait parameters before overground and treadmill walking.

Repeated measures (RM) analysis of variance (ANOVAs) with a polynomial contrast was used to test whether there was a different pattern of overground walking following overground walking practice compared to treadmill walking practice (interaction of walking mode [overground or treadmill] x time [pre and post walking practice]). Participants were divided into two groups according to walking ability based on their Motor Assessment Scale Item 5 scores. Those participants who scored 3-4 were categorised as low walking ability and those who scored 5-6 were categorised as high walking ability. Independent t-tests were used to describe differences between the two groups. Then, RM-ANOVA was used to test whether walking ability influenced any difference in overground walking pattern following overground walking practice and treadmill walking practice (interaction of walking mode

[overground or treadmill] x walking ability [low and high MAS scores]). Group and within-group data are presented as means (SD) while between-group data are presented as means (95% CI).

Analyses were performed using SPSS, version 14.0.1 for Windows, and statistical significance was set at 0.05.

RESULTS

Characteristics of participants

Twenty-one people with a first stroke participated in this study. Average age of participants was 64 years (SD 13) with 11 (52%) being male and 11 (52%) having suffered a left sided stroke. Participants were on average 72 (SD 48) days post stroke. They walked at 0.65 m/s (range 0.3 - 1.04) indicating mild to moderate disability. Grouping participants based on their score on Item 5 of the MAS resulted in 11 participants with poor walking ability and 10 participants with better walking ability. Participant characteristics are presented in Table 1.

Compliance with intervention

The workload during walking practice was low. Average heart rates during overground and treadmill walking practice were 86 bpm (SD 15) and 89 (SD 18) respectively - representing 24% and 28% heart rate reserve respectively. Maximum heart rates reached 38% (average 96, SD 19 bpm) and 39% heart rate reserve (average 97, SD 18bpm) for overground and treadmill walking practice respectively. Paired t-tests demonstrated no difference between recorded heart rates (mean difference 2 bpm; 95% CI -1 to 5) or percentage heart rate reserve (mean difference 1 bpm; 95% CI -3 to 5) for the two modes of walking ($p > 0.21$). There was on average 1.6 days (range 1-5) between the overground and treadmill walking practice. Two

participants completed the two trials more than 3 days apart. This was due to weekends, commitments of investigator and other rehabilitation demands of the participants.

Two participants were unable to complete ten minutes of overground walking as described. These participants completed ten minutes of gait related activities including stepping practice, block work, and walking forwards. During treadmill practice participants walked an average distance of 256 m (SD 89, range 133 – 416) at a speed of 0.42 m/s (SD 0.14, range 0.25 - 0.83). All but two participants completed ten minutes of treadmill walking practice. No adverse incidents occurred during the treadmill or overground walking practice but one participant stumbled and was lowered to the ground during a pass over the GAITRite following overground walking session. No injury was sustained and participant continued to participate in the study. Paired t-tests revealed no significant difference in the pre-walking gait parameters between the treadmill and overground session ($p > 0.15$).

Effect of mode of walking practice

The effect of mode of walking practice on walking pattern is presented in Table 2. The only significant effect of mode of walking practice on walking pattern was in knee extension on heel strike ($p = 0.01$). Following treadmill walking practice, there was 6 deg (95% CI 2 to 10) more knee extension at heel strike during overground walking than following overground walking practice. There was no difference between modes of walking practice for all other measures ($p = 0.09$ to 0.72).

Effect of walking ability on mode of walking practice

Poorer walkers increased non-paretic limb step length after treadmill walking practice more than those with better walking ability (mean difference 2.2 cm, 95% CI 0 to 5cm) ($F = 4.7$, $p = 0.04$). No influence of walking ability was found for any other measure.

DISCUSSION

This study, the first to investigate if treadmill walking practice affects overground walking pattern, found that overground walking pattern was similar following overground or treadmill walking practice when matched for workload in stroke patients able to walk who were undergoing rehabilitation.

We found several beneficial changes to the overground walking pattern following treadmill walking practice compared with overground walking practice. Seven of the thirteen (8 linear and 5 angular) kinematic measures trended towards a more normal walking pattern with one being clinically and statistically significant. There was 6 degrees greater knee extension at heel strike following treadmill walking practice. At heel strike the knee should reach approximately 2 degrees of flexion³⁷. Participants in this study still demonstrated excessive knee flexion at heel strike compared to normal walking^{17, 37} but showed greater improvement following treadmill walking practice than overground practice. Three of the overground kinematic measures in this study; cadence and paretic and non-paretic limb step time, were no different after overground or treadmill walking practice. Three overground measures – speed, paretic step length and hip abduction – trended towards an undesirable change after treadmill practice compared with overground. In addition, walking ability may have a small effect on the overground walking pattern. Poorer walkers in this study demonstrated an average

increase in non-paretic limb step length after treadmill walking practice of two centimetres more than after overground practice compared to those with better walking ability.

The concerns held by some clinicians that treadmill walking practice might result in an abnormal overground walking pattern were not supported by this study since the walking pattern was similar following ten minutes of overground to treadmill walking practice. Previous studies have compared walking kinematics during treadmill⁸ and overground walking^{6, 7, 10}. With the validity of kinematic measures taken while walking on the treadmill recently questioned¹¹ it is of more clinical significance to investigate any effect of the treadmill practice on overground walking pattern. The trend towards beneficial changes after treadmill walking practice found in the majority of outcomes in this study gives us confidence that these findings are not due to chance and suggests that even if the practice during treadmill walking is not exactly the same as overground walking, the subsequent overground walking pattern is, if anything, becoming more normal following treadmill walking practice.

Clinical trials have demonstrated increases in overground walking speed^{38, 39}, cadence and stride length³⁹ following four to six weeks of treadmill training in stroke patients who could walk undergoing rehabilitation. We also found improvements in many of these linear kinematics with just one ten minute session of treadmill walking practice. Angular kinematics have not been measured during clinical trials. It seems reasonable to predict that treadmill training over 4-6 weeks will result in similar improvements in overground angular kinematics but this remains to be tested.

There are several limitations in this study. The main limitation is the fixed order of walking practice modes. This was necessary to match the workload according to heart rate. Workload

could also have been matched by the number of steps taken during the walking practice.

Available pedometers were unable to record an accurate measure of the number of steps taken during overground walking practice due to the slowness of the participants walking.

In summary, in this group of newly-ambulating stroke patients undergoing rehabilitation, overground walking pattern was similar following ten minutes of overground or treadmill walking practice. This study can assist physiotherapists to feel confident that using the treadmill to retrain walking following stroke should not result in an abnormal walking pattern.

CLINICAL MESSAGES

- Walking on a treadmill for ten minutes results in a similar overground walking pattern (although with more knee extension at heel strike) to overground practice in newly-ambulating stroke patients undergoing rehabilitation
 - Walking on a treadmill for ten minutes results in a similar overground walking pattern to overground practice in better and poorer walkers (although with larger step length by poorer walkers)
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Table 1. Mean (SD) or N (%) characteristics of participants with poorer and better walking ability.

	Poorer walkers	Better walkers
Age (years)	60 (15)	67 (10)
Males	7 (64)	4 (40)
Left side hemiplegia	7 (64)	4 (40)
Walking speed (m/s)	0.54 (0.19)	0.87 (0.22)
Cadence	75 (20)	102 (10)
P Limb step length (m)	0.41 (0.07)	0.51 (0.13)
NP limb step length (m)	0.44 (0.07)	0.51 (0.12)
P, paretic; NP, nonparetic		

Table 2. Mean (SD) walking pattern before and after overground (OG) and treadmill (TM) walking practice, mean (SD) difference within walking modes and mean (95% CI) difference between walking modes.

Walking pattern	Walking modes				Difference within walking modes		Difference between walking modes
	Before		After		After minus Before		After minus Before
	TM	OG	TM	OG	TM	OG	TM minus OG
Linear kinematics							
Velocity (m/s)	0.75 (0.27)	0.71 (0.26)	0.76 (0.26)	0.73 (0.24)	0.01 (0.09)	0.02 (0.10)	-0.01 (-0.09 to 0.07)
Cadence (steps/min)	90 (20)	89 (20)	90 (20)	89 (19)	0 (6)	0 (8)	0 (-5 to 5)
P step time (s)	0.8 (0.3)	0.8 (0.2)	0.8 (0.2)	0.8 (0.2)	0 (0.1)	0 (0.07)	0.0 (-0.1 to 0.1)
NP step time (s)	0.7 (0.2)	0.7 (0.2)	0.7 (0.2)	0.7 (0.2)	0.0 (0.1)	0.0 (0.1)	0.0 (-0.1 to 0.1)
P step length (m)	0.48 (0.1)	0.46 (0.12)	0.49 (0.10)	0.48 (0.10)	0.01 (0.04)	0.02 (0.04)	-0.01 (-0.04 to 0.01)
NP step length (m)	0.48 (0.12)	0.48 (0.10)	0.5 (0.11)	0.48 (0.10)	0.02 (0.05)	0.00 (0.04)	0.02 (-0.01 to 0.05)
P stance phase (% gait cycle)	63 (4)	64 (4)	64 (5)	63 (4)	1 (4)	-1 (2)	2 (-1 to 3)
NP stance phase (% gait cycle)	69 (7)	69 (5)	68 (5)	69 (6)	-1 (4)	0 (3)	-1 (-3 to 2)
Angular kinematics (°) (where anatomical position = zero)							
Knee extension at heel strike	-21 (8)	-15 (7)	-16 (8)	-16 (7)	5 (8)	-1 (8)	6 (2 to 10)
Knee extension at mid stance	-15 (7)	-13 (8)	-13 (9)	-13 (10)	2 (5)	0 (9)	2 (-5 to 8)

Ankle plantar flexion at toe-off	31 (8)	32 (9)	37 (10)	31 (9)	6 (10)	-1 (11)	7 (-2 to 15)
Hip extension at push off	7 (11)	6 (10)	7 (10)	4 (9)	0 (6)	-2 (7)	2 (-2 to 7)
Hip abduction during mid swing	5 (5)	5 (4)	4 (4)	5 (4)	-1 (4)	0 (4)	-1 (-5 to 2)

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