Treadmill interface for virtual reality vs. overground walking: a comparison of gait in individuals with and without pain

Wendy Powell PhD Candidate [a,1], Brett Stevens PhD [a] , Maureen Simmonds PhD, PT [b],
[a] *School of Creative Technologies, University of Portsmouth, UK*
[b] *School of Physical & Occupational Therapy, McGill University, CANADA*

Abstract. A treadmill (TR) interfaced with a virtual reality (VR) system can provide an engaging environment that could improve activity adherence and walking function for individuals with pain. Furthermore, inclusion of discrete visual and auditory cues into the VR environment (e.g. manipulation of optic flow speed or audio beat frequency) could improve walking. This study compared gait characteristics (speed and cadence) of a baseline over ground walk (OVR) with a TR walk as part of a project to develop gait referenced visual and auditory frequency cues. Thirty six participants aged between 22 and 80 years, with pain (n=19) and without pain (n=17) took part. A 2x2 MANOVA conducted on the speed and cadence for all participants showed a significant difference between pain and control groups for speed ($F_{1,34} = 9.56$, $p<0.01$) and cadence ($F_{1,34} = 5.75$, $p<0.05$), as well as a significant decrease from overground to treadmill conditions for both speed ($F_{1,34} = 81.39$, $p<0.01$) and cadence ($F_{1,34} = 25.46$, $p<0.01$). Differences between OVR and TR walking indicate that visual or auditory cues for VR walk training should be referenced according to TR baseline measures.

Introduction

Virtual Reality (VR) displays, as a tool of rehabilitation, can help engage patients [1], improve movement [2, 3] and potentially enhance adherence to activity based rehabilitation interventions. Preliminary studies have also shown that VR can decrease pain [4], and improve motor function [e.g. 5]. However the ability of VR to simultaneously reduce pain and increase active movement has not been established.

This could be important for musculoskeletal problems such as osteoarthritis, which are major health problems, characterized by significant morbidity, mortality and economic burden [6]. The numbers of those impacted and the associated medical and human costs will only increase as the projected rise in life expectancy develops and the proportion of elderly people increases [7]; currently over half of the older population has arthritis [6]. Historically, rest and avoidance of physical activity were the mainstays of treatment. However, it is now apparent that inactivity causes many of the same problems that were originally attributed to arthritis (e.g., muscle weakness, decreased flexibility) and obesity [8] . More recently, exercise and activity have played a changing role in the management of arthritis.

[1] Corresponding Author.

The beneficial effects of exercise on local joint structures, on physical function, and on psychological mood are all well established, and clinical guidelines now recommend that the management of arthritis should be based on a combination of exercise/activity and education. Unfortunately, adherence to the recommended exercise and physical activity remains problematic, and there is a growing interest in the potential of Virtual Reality to address this issue, both to improve understanding of the factors which influence movement, and to manipulate these to improve rehabilitation outcomes.

Previous studies have indicated that decreasing the rate of optic (visual) flow relative to normal walking speed is correlated with an increase in walk speed in healthy individuals [3], although this has not yet been investigated in individuals with musculoskeletal pain. In addition, the use of audio frequency cues ('beat') has been demonstrated to modulate movement speed in healthy individuals [9, 10]. There is also some evidence that audio cues can improve walk speed in patients with Parkinson's disease [11] but there has been little investigation into the effects of audio cues on the rehabilitation outcomes in other clinical populations.

These findings suggest that the use of altered audio and visual cue frequencies in treadmill-mediated virtual rehabilitation may improve movement. However, such cues need to be referenced to the participant's baseline gait; specifically optic flow referenced to walk speed and audio beat referenced to cadence. Walk tests such as the 6-minute walk test are commonly used to assess walking ability [12], and are carried out overground, whilst interventions are commonly carried out on a treadmill [13]. However, it cannot be assumed that treadmill gait characteristics are the same as those during overground walking and thus, the baseline speed and cadence measures taken from such tests may be unsuitable for use as cue- references in treadmill-mediated VR interaction.

To further complicate the matter, there are three main categories of treadmill, each requiring a different approach to locomotion. The simplest are non-motorized treadmills ("self-driven") which require the belt to be driven by the walking effort of the subject. These typically have fairly narrow and short walking surfaces and often are slightly inclined to facilitate belt movement. More commonly used are motor-driven treadmills, which can have a much wider and longer walking surface. Most of these motorized treadmills operate at "pre-set" speeds, which use non-natural (i.e. manually controlled) interfaces to alter the speed incrementally. This will not support any natural variation in walking speed. The third category of treadmill (self-paced), whilst also motorized, is coupled to the walk speed of the user (measured continuously whilst on the treadmill) updating the motor speed in real-time to accommodate natural fluctuations in gait [14]. These treadmills are thus well suited to traversal through virtual environments.

A number of studies have compared gait characteristics of overground and treadmill walking, for pre-set treadmills that have been set to the overground walking speed [e.g. 15, 16]. However, if the development of treadmill interaction with VR for rehabilitation is to continue successfully, any potential differences between the walking modalities needs to be understood, and there are, to date, no studies which have compared overground walking with self-paced treadmill walking.

The purpose of this study was thus to compare gait characteristics during baseline assessment of an over ground (OVR) vs. a self-paced treadmill (TR) walk test in participants with and without pain during walking, in order to establish whether there are significant differences in speed and cadence .

1. Methods

Thirty six participants, (21 females, 15 males aged 22-80 yrs, mean age 51 yrs) were assigned to one of two groups based on the presence (n=19) or absence (n=17) of musculoskeletal pain that compromised walking.

A static, high-contrast image of a linear walkway lined with pillars was back projected onto a 2.5m x 2m screen. The motorized self-paced treadmill was placed in front of the screen.

All participants completed a standard OVG walk test (6-min walk), with the average cadence being recorded across 10m sections of walkway. After a rest of approximately 30mins, the participants practiced on the treadmill system. When they were confident walking on the treadmill, a 2 minute trial was initiated, during which the speed was recorded to a computer. The total number of steps were counted in 30 second blocks (a random sample were cross checked against results from a motion capture system). The cadence (steps per second) was calculated from this.

2. Results

		Pain (n = 19)		Control (n = 17)		
		Mean	**StDev**	**Mean**	**StDev**	
OVR	**Speed**	1.16	0.26	1.45	0.18	**OVR vs Treadmill** Speed ($F_{1,34}$ = 81.39, p<0.001) Cadence ($F_{1,34}$ = 25.46, p<0.001)
	Cadence	1.79	0.23	1.94	0.14	
TR	**Speed**	0.84	0.33	1.07	0.28	
	Cadence	1.57	0.32	1.76	0.23	

Pain vs Control

Speed ($F_{1,34}$ = 9.56, p<0.01)
Cadence ($F_{1,34}$ = 5.75, p<0.05)

Table 1:Mean speed (m/s) and cadence (steps/s) for group (pain or control) and condition (overground or treadmill)

A 2x2 MANOVA conducted on the speed and cadence for all participants (Table 1) showed a significant difference between pain and control groups for speed ($F_{1,34}$ = 9.56,

$p<0.01$) and cadence ($F_{1,34} = 5.75$, $p<0.05$) , as well as a significant decrease from overground to treadmill conditions for both speed ($F_{1,34} = 81.39$, $p<0.01$) and cadence ($F_{1,34} = 25.46$, $p<0.01$).

However, there was no significant interaction effect ($F_{1,34} = 0.74$, $p = 0.4$) between pain and walk condition for speed and no significant interaction ($F_{1,34} = 0.23$, $p = 0.63$) between pain and walk condition for cadence .

3. Discussion

Although a number of studies have compared overground and treadmill walking, they have generally pre-set the treadmill speed to match the preferred overground speed and then compared gait biomechanics between the two conditions [e.g. 15, 16]. Whilst useful in establishing that treadmill walking is biomechanically comparable to overground walking for therapeutic purposes, these studies fail to fully investigate changes in temporal characteristics between the two walking modes, which can only become apparent if the participants are allowed to select their own pace on the treadmill in the same way as on the overground component. It has been suggested that fixed-speed treadmill walking can give rise to a “sense of urgency” to place the foot of the swing limb down because the supporting leg is moving backwards on the treadmill [15]. This is supported by the observation that stance time is decreased and cadence increased in these studies [15, 16]. In contrast, during self-paced treadmill walking an increase in stance time would not result in significant backward movement of the supporting leg.

Furthermore, it has also previously been noted that a given walking speed is perceived as faster on a treadmill when compared to overground walking [15]. This effect was evident, albeit in reverse, in this study, where participants generally walked at a slower speed on the self-paced treadmill. This slower speed was also associated with a slower cadence. This finding was independent of the presence of pain, although the mean speed and cadence of the control group was higher than the pain group across both conditions.

The present options for treadmill interaction require that either the treadmill speed is preset, which may decrease immersion and increase anxiety, or the treadmill can respond to the participants speed, which may result in slower walking speeds. As noted previously, modulation of audio and visual frequency cues may improve movement speed, and if these are correctly referenced to individual gait then this may compensate for the slower speeds noted on treadmill walking. Therefore, if studies are to be conducted using gait-referenced visual and audio frequency cues to improve movement speed in virtual reality, the baseline measures should be calibrated to treadmill walking and not to the standard overground walk tests.

4. Conclusion

This is the first study to demonstrate that gait characteristics of treadmill walking are significantly different to overground walking when participants are allowed to self-select their walking pace in both conditions. Given the magnitude of the decrease in gait velocity and cadence from OVR to TR walking, visual (optic flow) or auditory cues (stepping beats) included in a VR environment to improve walking must be calibrated to TR based walk assessment measures.

Further work is required to examine the gait characteristics of the remaining treadmill type (self-driven), and to develop a standardized treadmill assessment protocol comparable to the current overground tests.

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