



Original Article

## Muscle activation pattern during self-propelled treadmill walking

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**Abstract.** [Purpose] To examine muscular demands during self-propelled treadmill walking to provide a potential option for fitness training. [Participants and Methods] Eleven healthy college students were recruited. Participants walked under three conditions: over-ground walking at a self-selected speed, treadmill walking at a self-selected speed, and treadmill walking at a speed comparable to that of over-ground walking. Step lengths and lower extremity muscle activations were recorded while participants walked under the three conditions. [Results] Step lengths were significantly shorter when participants walked on a self-propelled treadmill than when walking over-ground. The spatiotemporal and muscle activations of the gaits varied among the different walking conditions. Muscular demands at the moment of heel-strike were higher around the hip and knee when walking on the self-propelled treadmill than when walking over-ground. [Conclusion] During heel-strike, the lower extremity extensors were activated more on the self-propelled treadmill with an incline, especially at faster speeds, than during over-ground walking. A low-cost, self-propelled treadmill may be a modality for training specific muscles.

**Key words:** Self-propelled treadmill, Gait, Muscular demands

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### INTRODUCTION

Motorized treadmills are used by clinicians, researchers and general populations for gait and fitness training. Previous studies have compared the spatiotemporal parameters and muscle activation patterns of gaits occurring over ground and on motorized treadmills<sup>1-8)</sup>. Several studies have reported higher cadence and shorter stance time during treadmill walking than during over-ground walking at comparable speeds<sup>5, 7, 8)</sup>, whereas others reported no such differences or showed a longer double-limb-support period on the treadmill<sup>3, 6, 9)</sup>. Nonetheless, treadmill walking is considered a viable rehabilitation and fitness training method.

Unlike motorized treadmills, non-motorized (or self-propelled) treadmills are cheaper and more compact. Without motors, self-propelled treadmills contain an inclined surface that requires the user to propel the belt with each stride. While many studies have examined motorized treadmill walking, literature assessing the muscular demands of gait on a self-propelled treadmill remains scarce. Therefore, this study examined muscle activations during walking on a self-propelled treadmill with an inclined surface. Previous studies have shown that knee extensors are activated more at greater slopes<sup>10, 11)</sup>. Based on these findings, we hypothesized that the lower body extensor muscles would activate more during self-propelled treadmill walking than during over-ground walking. Step lengths of gait were also compared for different walking conditions.

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## PARTICIPANTS AND METHODS

A convenience sample of 11 healthy college students (six females and five males) aged  $22.3 \pm 2.4$  years were recruited. Their average height was  $175 \pm 9.8$  cm and average weight was  $68.2 \pm 16.5$  kg. This study was approved by the Institutional Review Board of the University of Massachusetts Lowell (IRB No.: 13-181-WU-XPB). Informed written consent was obtained before the experiment.

Participants were asked to walk under three conditions. Participants first walked over level ground (OGW) for 10 meters three times to determine their preferred walking speed. Participants were then asked to walk on a self-propelled treadmill (Fig. 1) at a fixed speed (FTW) equivalent to the OGW speed or to walk on a self-propelled treadmill at a self-selected speed (STW) for 30 seconds. FTW and STW were performed three times in random order after the participants became familiar with walking on the self-propelled treadmill. Wireless surface electromyography (EMG) (Trigno, Delsys, Natick, MA, USA) was used to record muscle activities during the three walking conditions. Twelve surface EMG sensors were placed on the anterior tibialis (TA), medial gastrocnemius (GA), rectus femoris (RF), biceps femoris (BF), gluteus maximus (GMax), and gluteus medius (GMed) of both legs. A digital camera, synchronized with the data acquisition system, was placed parallel to the sagittal plane of the participants' motion with a 1-meter scale also placed near this plane. ImageJ<sup>12)</sup> was used to analyze the step lengths under the three walking conditions.

EMG signals were sampled at 1,000 Hz and stored for offline analyses. Recorded EMG data were filtered using a band-pass filter (20–400 Hz), and a linear envelope was obtained by full-wave rectification and low-pass filtering at 10 Hz<sup>13)</sup> using MATLAB (MathWorks, Natick, MA, USA). One-way repeated-measures ANOVA was used to test for differences in overall muscle activation, muscle activation at heel-strike, and step length during the three walking conditions (OGW, FTW, and STW). Statistical significance was set at  $p < 0.004$  after the Bonferroni correction. Tukey's Honestly Significant Difference (THSD) post hoc test for pair-wise comparisons was used if a main effect (e.g., conditions) was detected. A paired t-test was used to examine the difference in preferred speeds on the treadmill and over the ground (STW and OGW) with statistical significance set at  $p < 0.05$ . All statistical analyses were performed in JMP, version 13.0.0 (SAS Institute, Inc., Cary, NC, USA).

## RESULTS

The average preferred speed on the self-propelled treadmill was significantly slower than the self-selected over-ground speed ( $1.08 \pm 0.27$  versus  $1.26 \pm 0.15$  m/s,  $p = 0.01$ ). The average step lengths during OGW, FTW and STW were  $0.764 \pm 0.098$  m,  $0.558 \pm 0.064$  m and  $0.583 \pm 0.0512$  m, respectively. Step lengths were statistically significant among the three tasks ( $p < 0.001$ ). THSD showed that the step lengths during FTW and STW were significantly shorter than those for OGW, and the step length during STW was longer than that during FTW. Table 1 summarizes the overall muscular demands as well as muscle activations at heel-strike. Overall muscular demands throughout one gait cycle differed statistically in the Gmed and GA ( $p < 0.0001$  and  $p = 0.003$ ). THSD further showed that the Gmed was activated more during OGW than during FTW or STW; however, the GA was activated less during OGW than during FTW and STW. When comparing muscle activations at heel-strike, significant differences were noted in the RF, BF, and Gmed of the leading leg as well as in the RF, TA and BF of the trailing leg ( $p < 0.0001$ ,  $p < 0.0001$ ,  $p < 0.0001$ ,  $p < 0.0001$ ,  $p = 0.003$  and  $p < 0.0001$ , respectively). THSD showed that RF and BF activations in the leading leg were higher during treadmill walking than during OGW. Furthermore, activations of those two muscles were higher during FTW than STW. The Gmed of the leading leg, as well as the RF and BF of the trailing leg,



**Fig. 1.** A participant walking on the self-propelled treadmill with surface EMG sensors on the leg muscles. The walking surface is about 1.05 m in length with 15% incline.

were activated significantly less during OGW than during FTW or STW, while FTW and STW did not differ. The TA of the trailing leg was activated significantly more during FTW than STW.

## DISCUSSION

This study explored whether a low-cost self-propelled treadmill could be a modality for training specific muscles while walking. As expected, the spatiotemporal characteristics and muscle activations of the gaits varied among the different walking conditions. In the study, the preferred over-ground walking speed often differed from that used for treadmill walking. This finding is consistent with the observation reported by Malatesta et al. that the preferred treadmill walking speed is slower than the preferred over-ground walking speed<sup>14</sup>). In addition, step lengths were shorter while walking on the treadmill than when walking over-ground, which is similar to motorized treadmill findings<sup>7</sup>). Other literature shows that with sufficient practice, the participants walked on the motorized treadmill with the comparable step lengths as overground walking<sup>14</sup>). Nonetheless, most of the treadmills used in the previous literature were with tread belt longer than the self-propelled treadmill used in the current study. The limitation of the tread belt in the current study might restrict the step lengths of the participants. Moreover, it may have been due to the challenges of maintaining balance on the self-propelled treadmill's inclined, slippery surface, as shorter step lengths bring the center of mass to the front foot to prevent losing balance<sup>15</sup>).

Shorter step lengths might also explain the lower gluteus medius activation observed during treadmill walking than that observed during over-ground walking. The gluteus medius plays an important role in single-leg support to stabilize the pelvis. When step lengths became shorter, the time spent on single-leg support was reduced; therefore, overall gluteus medius activation during a gait cycle was less than during treadmill walking. In addition, participants held handrails while walking on the self-propelled treadmill for safety. This could also reduce muscle activations, although participants were instructed to not put weight on the handrails. Nonetheless, the gastrocnemius was activated more during treadmill walking than during over-ground, indicating the gastrocnemius may be the major muscle propelling the self-propelled treadmill belt. A previous study showed that lower extremity extensor muscle activities increased while walking uphill<sup>10</sup>). Although the self-propelled treadmill used in this study had an inclined surface, participants mostly generated force to propel the treadmill belt, assisted by their body weight. This differed from incline walking on a motorized treadmill or hiking uphill where individuals generate force to lift the body upward. We further examined the EMG output during heel-strike, specifically at the moment before the leading leg propelled the belt downward. The results demonstrated that walking on the self-propelled treadmill requires greater muscular demand around the knee and hip, including the rectus femoris and biceps femoris of both legs, and the gluteus medius of the leading leg. These results are similar to previous findings that hip and ankle extensors were exerted more when walking uphill<sup>10, 11, 14</sup>).

**Table 1.** The overall muscle activations and muscle activations at heel-strike

Tasks		OGW	FTW	STW
Overall muscle activations in V				
	RF	1.59 ± 0.71	1.3 ± 0.95	1.24 ± 0.63
	TA	1.74 ± 0.67	1.83 ± 0.86	1.93 ± 0.92
	BF	2.35 ± 1.32	2.32 ± 0.81	2.24 ± 1.08
	GA	<b>1.49 ± 0.96</b>	<b>1.69 ± 1.47</b>	<b>1.73 ± 1.66</b>
	Gmed	<b>1.76 ± 0.61</b>	<b>0.99 ± 0.35</b>	<b>1.13 ± 0.66</b>
	Gmax	1.61 ± 1.02	1.05 ± 0.65	1.25 ± 0.94
Muscle activations in mV at heel-strike				
Leading leg	RF	<b>4.27 ± 1.69</b>	<b>16.77 ± 2.43</b>	<b>5.23 ± 2.31</b>
	TA	20.58 ± 4.65	17.79 ± 5.79	20.04 ± 4.93
	BF	<b>8.51 ± 5.17</b>	<b>17.44 ± 12.36</b>	<b>13.50 ± 7.47</b>
	GA	22.54 ± 14.3	17.78 ± 15.21	22.89 ± 11.1
	Gmed	<b>6.84 ± 2.7</b>	<b>16.98 ± 3.56</b>	<b>8.54 ± 2.41</b>
	Gmax	19.79 ± 32.79	18.18 ± 15.97	15.66 ± 26.3
Trailing leg	RF	<b>4.51 ± 1.95</b>	<b>18.36 ± 2.65</b>	<b>5.55 ± 2.26</b>
	TA	30.87 ± 8.8	<b>28.20 ± 7.57</b>	<b>20.84 ± 11.08</b>
	BF	<b>6.25 ± 1.5</b>	<b>18.34 ± 5.5</b>	<b>11.12 ± 5.82</b>
	GA	18.70 ± 7.59	20.94 ± 7.79	18.89 ± 7.56
	Gmed	11.68 ± 12	15.26 ± 9.85	10.53 ± 5.81
	Gmax	15.62 ± 14.64	15.63 ± 35.6	13.25 ± 18.29

Bolded numbers indicate significant muscle activation differences.

Walking speed can alter muscle activations<sup>16, 17</sup>). In the current study, when participants walked on the treadmill, muscular demands on the rectus femoris and biceps femoris of the leading leg were higher during FTW, as the speed was faster than STW. Similarly, the tibialis anterior of the trailing leg was activated more during FTW. The higher muscular demands found in this study were consistent with a previous study on level over-ground walking<sup>16</sup>).

Overall, the findings demonstrated increased muscular demands around the hip and knee at heel-strike during self-propelled treadmill walking, but similar total muscular demands were required across the gait cycle except for the gluteus medius and gastrocnemius. These comparisons could reflect the human gait of healthy individuals adapting to changes in both walking surface and space constraints<sup>6, 18</sup>). Using a low-cost, self-propelled treadmill may be a potential modality for training specific muscles during functional movements such as walking, jogging and running.

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### *Conflict of interest*

None.

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