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Original Article

Effects of pelvic range of motion and lower limb muscle activation pattern on over-ground and treadmill walking at the identical speed in healthy adults

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Abstract. [Purpose] Many studies have compared over-ground and treadmill walking, but the biomechanical relationship between the two gait modes is unclear. The aim of this study was to analyze differences in pelvic range of motion and lower limb muscles activity during over-ground and treadmill walking in healthy adults. Moreover, we aimed to analyze differences according to gender. [Subjects and Methods] Twenty-three healthy adults (9 men, 14 women) between 25 and 35 years of age walked at the identical speed for 30 seconds each in two difference gait modes. The pelvic range of motion were obtained by using three-axis accelerometer and lower limb muscle activation data were obtained by using wireless surface EMG. [Results] The results showed that pelvic obliquity showed a greater angular range of women than men, and the pelvic rotation decreased more in treadmill walking than over-ground walking. In the muscles activity, vastus lateralis and tibialis anterior increased, and gastrocnemius medialis decreased in treadmill walking than over-ground walking. [Conclusion] We conclude that treadmill walking reduces the range of motion of the pelvic and increases lower limb muscles activity therefore, when using treadmill for the purpose of rehabilitation at the clinic, consider this difference.

Key words: Gait analysis, Over-ground, Treadmill

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INTRODUCTION

Kinematic kinetic, and muscle activations are affected by gait speed during gait analysis[1)]. Therefore, walking should be evaluated at the same speed when performing the walking analysis. Recently, gait analysis using treadmill has been actively used in clinical practice. When using treadmill in gait analysis, not only can gait be evaluated at the same speed but also the treadmill can be used as a training device because it can control the inclination and secure a continuous walking cycle in a small space. However, the debate about whether a long time how close the over-ground walking (OW) and treadmill walking (TW) the plains has been continued[2–4)]. Many studies have compared OW and TW, but the relationship between the two gait modes is unclear[4)]. At the beginning, when the speeds of OW and TW are constant, the gait pattern should be mechanically the same[5)]. Similarly, many studies have shown that kinematic and kinetic parameters are similar in OW and TW in healthy adults, elderly people[4, 6–10)]. These show that TW analysis results can be generalized to those of OW analysis[9)].

Many studies have investigated the difference in motion pattern of joints during OW and TW, but most focus on the ankle, knee, and hip joints, and few studies have analyzed the range of motion (RoM) of the pelvic[4, 9, 11, 12)]. However, the pelvic plays an important role in walking. Pelvic motions control whole-body balance, transmit force between the lower and upper limbs, and increase the energy efficiency of gait[13–16)]. The pelvic RoM was affected by gender, but studies on pelvic RoM

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according to gender and gait mode were rarely performed. Recently Chockalingam et al.[17] analyzed the pelvic movement according to gender in heel strike and toe off during OW and TW. However, this study showed the pelvic movement at certain events (heel strike and toe off) and did not analyze the pelvic RoM according to gait cycle.

In the analysis of muscle activity during gait, Nymark et al.[18] reported the characteristics of muscle activity according to gait velocity during OW and TW. Stoquart et al.[1] reported similar patterns of muscle activities with reference to the gait cycle. However, previous studies reported results from the gait cycle without distinguishing the stance and swing phase. In addition, many studies did not distinguish between gender-related differences.

Thus, the purpose of this study was to analyze differences in pelvic RoM and muscle activity during OW and TW in healthy adults. Moreover, we aimed to analyze differences according to gender. This information will provide data that can be considered when designing clinical protocols using the treadmill in the future.

SUBJECTS AND METHODS

In this study 9 healthy men adults (age: 33.00 ± 5.41 years, height: 169.89 ± 5.09 cm, weight: 72.00 ± 10.12 kg) and 14 healthy women adults (age: 28.36 ± 5.60 years, height: 162.71 ± 6.41 cm, weight: 54.36 ± 5.62 kg) participated. We excluded any subjects with any gait abnormalities or musculoskeletal and neurological disorders. The participants provided signed consent after receiving verbal and written information about the study. All the procedures performed in this study that involved human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

All the subjects wore their own gym shoes and underwent a 5-minute walking familiarization process under the same conditions as the evaluation before this test. For OW the subjects walked in a straight line for 30 seconds at their self-selected walking speeds inside the laboratory. OW was performed first and gait speed measured during OW was applied to TW for assessment[19]. For TW the subjects walked on the treadmill for 30 seconds at the same speed as that in OW.

Data were collected with three-axis accelerometers (G-Sensor, BTS Bioengineering, Milano, Italy) and wireless surface EMG (FreeEMG1000, BTS Bioengineering, Milano, Italy). OW was performed in a gait analysis laboratory of 15-m and TW was used of treadmill (Zebris Medical GmbH, Isny, German).

The three-axis accelerometer (TAA) was used to measure pelvic RoM in two gait modes. The TAA was attached to the S_1 (sacrum first spine) level of the subjects by using a special velcro strap. The sampling frequency was set to 100 Hz. The pelvic RoM were obtained by using analysis software G-Studio (BTS Bioengineering, Milano, Italy).

The wireless surface EMG (sEMG) was used to measure muscle activity in two gait modes. Eight wireless sEMG electrodes were attached to the following four major muscle groups of both lower limbs: vastus lateralis (VL), tibialis anterior (TA), biceps femoris (BF), and gastrocnemius medialis (GM), with a sampling frequency of 1,000 Hz[1]. To minimize skin resistance we removed skin hair at the site of the attachment, cleaned the site with alcohol, and attached the electrodes according to the direction of the muscle fibers[20]. Muscle activation data were obtained by using analysis software EMGAnalyzer v2.9.37.0 (BTS Bioengineering, Milano, Italy). For the distinction between stance and swing phase during gait cycle a TAA was used in synchronization with the sEMG. The collected sEMG raw data were band-pass filtered at 20–500 Hz to remove artifact and high-frequency noise. The root mean square (RMS) values were computed over a time constant of 50 ms. Muscle activation data were measured three times and averaged. To normalize the sEMG signal the OW values were set to reference voluntary contraction (RVC), and TW values were expressed as %RVC[20, 21].

Descriptive statistics (means and SD) were calculated for all outcome measures. An independent t-test was performed to examine the effect of two gait modes (OW and TW). Two-way analysis of variance was performed to examine the effect of two gait modes (OW and TW) and gender on each dependent variable. All analyses were performed using SPSS (version 18.0) and a significance level of $p<0.05$ was adopted.

RESULTS

Table 1 represents the values and statistical results for the pelvic RoM. A significant difference ($p<0.05$) was evident between the gender for pelvic obliquity only, and the women had greater pelvic obliquity than the men. When comparing OW with TW, significant differences ($p<0.05$) were identified for pelvic rotation. However, there was no significant difference in the interaction between gender and the two gait modes at the pelvic parameters (Table 1).

Table 2 represent the values and statistical results for the muscle activation. When comparing OW with TW we found significant differences ($p<0.05$) in muscle activation except BF. VL and TA activities during the stance phase were significantly increased but GM activity significantly decreased during TW in comparison with those in OW. VL, TA, and GM activities during the swing phase were significantly increased ($p<0.05$) during TW in comparison with those during OW. Muscle activation showed no significant difference in gender and interaction between gender and the two gait modes (Table 2).

Figure 1 represents the %RVC value as a radar plot. The %RVC analysis results showed that muscle activity increased with TW except GM in the stance phase. The %RVC of VL was 1.45 times higher in the stance phase and 2.45 times higher in the swing phase. In BF and TA was increased during the stance phase in comparison with those during the swing phase (Fig. 1).

Table 1. Mean (1 SD) values of pelvic range of motion parameters values and results for statistical comparisons

Pelvic movement	Parameters (degrees)	Group	Over-ground	Treadmill	Comparison (p-value)		
					Male vs. Female	Over-ground vs. Treadmill	Gender × Walking mode
Tilt	Minimum	Male	−1.44 (1.50)	−1.36 (1.15)	0.373	0.727	0.920
		Female	−1.20 (0.78)	−1.06 (0.67)			
	Maximum	Male	0.87 (0.81)	0.66 (0.64)	0.131	0.355	0.926
		Female	1.17 (0.80)	1.00 (0.47)			
	Range	Male	2.30 (1.91)	2.03 (1.42)	0.889	0.420	0.963
		Female	2.37 (0.73)	2.06 (0.67)			
Obliquity	Minimum	Male	−1.68 (0.44)	−1.62 (0.43)	0.001***	0.813	0.890
		Female	−2.29 (0.57)	−2.27 (0.72)			
	Maximum	Male	1.69 (0.45)	1.61 (0.42)	0.001***	0.727	0.887
		Female	2.30 (0.57)	2.26 (0.72)			
	Range	Male	3.39 (0.89)	3.23 (0.85)	0.001***	0.763	0.875
		Female	4.58 (1.14)	4.53 (1.44)			
Rotation	Minimum	Male	−5.40 (1.84)	−3.36 (1.13)	0.304	0.015*	0.503
		Female	−5.63 (2.68)	−4.45 (2.05)			
	Maximum	Male	5.47 (1.93)	3.38 (1.16)	0.271	0.011*	0.555
		Female	5.80 (2.69)	4.47 (2.02)			
	Range	Male	10.86 (3.77)	6.74 (2.29)	0.285	0.013*	0.533
		Female	11.43 (5.37)	8.92 (4.06)			

*p<0.05, ***p<0.001.

Table 2. Mean (1 SD) muscle activity parameters values and results for statistical comparisons

Gait phase	Parameters (μV)	Group	Over-ground	Treadmill	Comparison (p-value)		
					Male vs. Female	Over-ground vs. Treadmill	Gender × Walking mode
Stance	Vastus lateralis	Male	17.25 (3.60)	22.55 (12.50)	0.078	0.029*	0.765
		Female	11.56 (6.05)	18.49 (10.82)			
	Biceps femoris	Male	21.12 (7.14)	22.75 (12.10)	0.190	0.180	0.420
		Female	22.66 (9.67)	29.14 (9.96)			
	Tibialis anterior	Male	28.07 (9.16)	33.93 (6.16)	0.616	0.023*	0.909
		Female	29.54 (7.63)	34.85 (8.09)			
	Gastrocnemius medialis	Male	76.89 (13.38)	67.89 (15.13)	0.818	0.044*	0.879
		Female	76.52 (15.57)	66.10 (16.79)			
Swing	Vastus lateralis	Male	11.11 (1.83)	24.26 (11.27)	0.208	0.000***	0.988
		Female	7.77 (3.15)	20.99 (12.11)			
	Biceps femoris	Male	23.14 (13.86)	21.41 (7.19)	0.741	0.454	0.183
		Female	20.19 (6.34)	26.29 (10.25)			
	Tibialis anterior	Male	48.92 (10.87)	55.63 (11.30)	0.076	0.016*	0.770
		Female	42.52 (9.77)	51.02 (8.73)			
	Gastrocnemius medialis	Male	10.08 (5.60)	14.92 (4.16)	0.626	0.038*	0.640
		Female	11.86 (7.75)	14.96 (5.64)			

*p<0.05, ***p<0.001.

DISCUSSION

This study aimed to determine differences in pelvic RoM and muscles activity when comparing OW and TW. In addition we analyzed difference according to gender.

The women's pelvic obliquity was significantly greater than that of men (Table 1). This result is consistent with those of

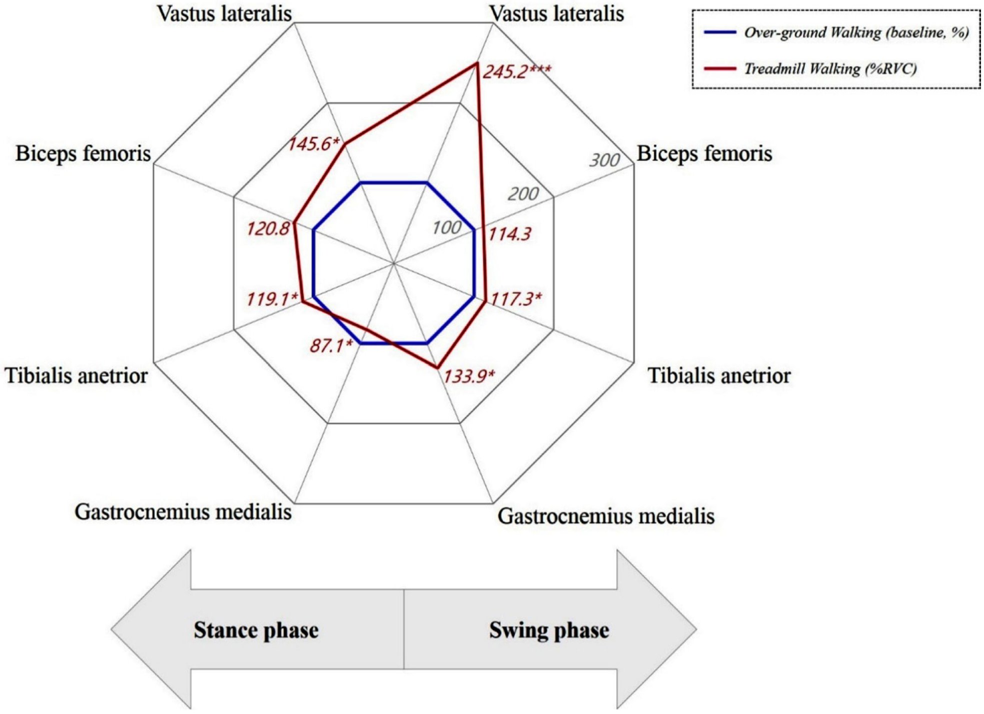

Fig. 1. The radar plot of %RVC for all 23 participants for each muscle activation when on a over-ground and on a treadmill walking. *p<0.05, ***p<0.001.

previous studies[22, 23]. Lim et al.[22] reported that this results are due to the attachment method of motion analysis markers and the location of the anatomical landmarks were different. However, in this study TAA that attatched S1 level was used instead of motion analysis markers. This is because the pelvic of the women is larger than the men in anatomically, therefore it is considered that the up and down is greater when walking based on the S1 level. There have been studies that reported contrasting results. Alton et al.[6] reported that the hip and knee were affected by OW and TW according to gender but did not report any differences in pelvic RoM. Crosbie et al.[24] reported that pelvic obliquity did not differ between the gender in adults aged 20 and 50 years. Also, Barrett et al.[25] also reported that gender-related differences were inconsistent. These contradictory results will help to consider gender characteristics when setting up a treatment plan based on a walking mode. Pelvic rotation was significantly smaller with TW than with OW (Table 1). This result is consistent with those of previous studies. Chockalingam et al.[17] reported that pelvic rotation was most affected by the walking mode. Vogt et al.[12] reported that this reduction in pelvic rotation during TW was due to the stiffness of the kinematic chain. These changes in pelvic RoM can change the gait pattern[17]. Although this study did not assess patients, it may be more helpful to improve understanding of pelvic motion as compared with previous studies.

The comparison of muscle activities between OW and TW showed significant differences in VL, TA, and GM activities in both the stance and swing phases (Table 2). This result is consistent with those of previous studies. The %RVC of the VL (knee stabilizer in stance phase, knee extensor in swing phase) increased in the stance and swing phases in TW in comparison with those in OW (Fig. 1). Also we confirmed that the muscle activity of VL was higher in the swing phase than in the stance phase (Fig. 1). This means that TW requires more stability and more contribution to knee extension than OW. The %RVC of the TA (ankle dorsi-flexor) increased in the stance and swing phases in TW (Fig. 1). Vogt et al.[12] reported that the TA shows eccentric contraction (EC) and concentric contraction (CC) in the gait cycle. The TA creates an EC to reduce ankle plantar flexion following heel strike in the stance phase. In the swing phase, it creates a CC as an agonist muscle for dorsi-flexion to prevent the heel from being dragged on the ground. In our study, the TA showed heightened activity in the swing phase in comparison with that in the stance phase, which may have been influenced by the properties of the sEMG (Table 2). The CC activity was higher than the EC activity even when the forces of the muscles were equal[26]. Such a feature of EC when measured with surface EMG could have played a role in producing lower muscle activities during the stance phase than during the swing phase in our study. The %RVC of the GM decreased in the stance phase and increased in the swing phase with TW in comparison with those with OW (Fig. 1). The %RVC of the GM (ankle plantar flexor) is mostly activated in the stance phase of the gait cycle. It mainly acts when one plantar flexes the ankle and pushes against the ground to move the body forward. Our results showed a significantly lower muscle activity in the stance phase during TW than during OW (Table 2). As the treadmill belt runs continuously at a constant speed, the subjects quickly lifted their legs to create a new gait cycle instead of sufficiently pushing against the ground. This can be interpreted with the fact that the VL muscle activity during the TW stance phase is greatly activated in comparison with that during OW (Fig. 1). BF (knee flexor) showed an increasing trend in TW in comparison with that in OW, but the difference was insignificant. This is in line with the findings of past studies where OW and TW did not show significant differences in BF activity[27].

Our study had a few limitations. We had a small sample size and we only examined healthy adults. The other limitation could be from the variety of footwear used, which has an influence on gait. All the subjects wore their own gym shoes, which had varying designs and material properties. However, we expect that conducting additional studies in patients based on our results would produce meaningful data regarding the effects of TW.

The present study identified differences in pelvic RoM and muscle activation when comparing OW and TW and between the genders. Rehabilitation training and evaluation using a treadmill are increasingly popular in clinical practice. However, this study showed significant differences in pelvic RoM and muscle activity between OW and TW. The differences in the values of the parameters in this study should be considered in rehabilitation training using the treadmill.

Conflict of interest

None.

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