

Electromyographic Activity of Soleus and Tibialis Anterior Muscles during Ascending and Descending Stairs of Different Heights

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ABSTRACT

Background: The aim of this study was to evaluate the electromyographic (EMG) activity of the two leg muscles (Tibialis anterior [TA] and Soleus [SOL]) during ascending and descending stairs with different heights (10 cm, 15.5 cm and 18 cm).

Methods: Eighteen female university students aged between 20 and 36 yr participated in the study. Data were collected using a ME6000 Biomonitor EMG System (revision MT-M6T16-0) and surface electrodes.

Results: The EMG activity of the SOL muscle was significantly higher than the TA muscle activity ($P = 0.001$). Besides, the muscle activity level of the SOL muscle was significantly higher when ascending compared to descending condition ($P = 0.001$). The stair height had no significant effect of the EMG activity of the two muscles.

Conclusion: These findings highlight that the two muscles are not equally affected by the stair height during ascending and descending condition. The results also indicate that there is no preference between different stair heights in terms of muscular effort.

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Introduction

Stairs may be a frequently encountered obstacle in our daily life. Due to their abundance, the ability of people to ascend and descend stairs without difficulty or pain is an important consideration to improve the quality of life. According to the Consumer Product Safety Commission, there has been an estimated two million injuries and 1000 deaths each year associated with stair falls.¹ Moreover, stair and step fall increased by over 70% over a decade between 1993-2002 in Australia.² In the U.S, about 85% of

stair falls occurred in residential settings, and falls on stairs accounted for 60% of slip, trip and fall deaths in buildings.³ Stairs may also be one of the common factors involved in low (below two meters) fall accidents.^{1,4,5} Falling on stairs has been suggested as a common source of injury, and occasionally this may result in fatalities to stair users. Stairs seems also to be one of the most serious accident dangers that people encounter in usual activities.⁴ A number of different aspects of stairway design have been identi-

fied as important items of stairway safety. These include steepness, step height, step depth, stair width, tread overhang and configuration, lighting, landings, surface materials, and handrails. Additional concerns are related to people who use stairways and include age, anthropometry, physical condition, and task attention.¹

Jackson and Cohen,⁶ concluded that the main problem with stair-related accidents was dimensional inconsistency, not individual (user) or external variables in some stairways.

Larger riser heights may be one of the major design factors associated with stair-related accidents.⁷

So far, much of the research on stairway design has focused on physiological and performance variables such as energy expenditure, gait and missteps and (dis)comfort, safety or hazard that users experience in ascending or descending stairs.¹

Ascending/descending stairs and level walking are generally rhythmic activity which may involve the same muscles and producing similar joint angles in stair gait.⁸ However, the main differences between level walking and stair climbing may be manifested in a significant increase in the range of motion of the lower limbs during stair climbing as well as in muscle activity levels.⁸ a number of studies have shown that how muscles provide support and propulsion in over stair gait.⁹⁻¹⁵ Winter reported higher leg muscle activity levels for ascending as compared to descending stairs.⁹ Ascending stairs involves (during the supporting phase) an elevation of the human body on to the stair. This may be achieved by the concerted and powerful contraction of the soleus, quadriceps femoris, hamstrings and gluteus maximums muscles of the leg. The soleus and the quadriceps femoris muscles act as controlling muscles, during the supporting phase of ascending stairs.¹⁰ There is evidence that the magnitudes of the flexion-extension moments at the hip and knee may be greater during stair ascent compared to walking.¹¹

The purpose of this study was, therefore, to investigate the EMG activity of the leg

muscles involved in ascending and descending stairs with different heights.

Materials and Methods

Participants

Eighteen females with a mean age of 29 ± 5.02 year, height of 161.33 ± 4.3 cm, and body weight of 59.66 ± 5.57 kg, and with no history of neuromuscular disorder and injury to the lower extremities participated in this study. This study was cross-sectional and descriptive analyzing conducted in 2013. They were all students or members from the Tabriz University of Medical Sciences, Tabriz, Iran.

Ethical Considerations

Written informed consent form was obtained from all subjects, and the study protocol was approved by the Tabriz University of Medical Sciences Ethics Committee.

Apparatus

Three heights of stairs were specially designed and built for the purpose of this study. The custom-built steel and wood staircase of 4 steps with the dimensions of 18 cm, 15.5 cm, 10 cm (riser), 30 cm (tread), and 30 deg (the total slope of the stairs) were used. No hand railings were available (Fig. 1).^{1,4,16,17}

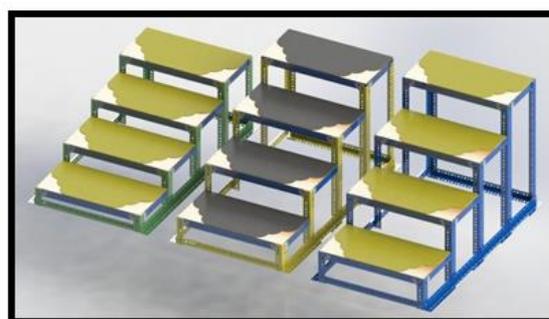


Fig. 1: Custom-built steel and wood staircase

Procedure

Subjects were asked to ascend and descend a staircase of four steps. They tested 3 sets of stairways with different riser dimensions, with the order of presentation of the

stair conditions randomized across the participants. Subjects ascended and descended the staircases in a step-over-step (SOS) manner with a steady pace (e.g. ascended or descended each stair in one second) (Fig. 2). The staircase was independently mounted on the floor. Each test consisted of three consecutive activities including ascending and descending, the average of them was used for analysis, and tests were separated by a 2-min rest interval. Therefore, participants performed nine ascending and nine descending trials leading with the dominant leg. Stair ascent was initiated in front of the staircase on ground level, whereas stair descent started on the fourth stairs. To ascend the stairs, participants stood in front of the staircase and took an initial step on level ground; their next step was onto the staircase. To descend, participants took an initial step on top fourth stairs before stepping onto the staircase. Within the ascent and descent conditions, the order of the stepping pattern trials was randomized. The trial ended when the subject was either on the top fourth stair or on the ground level with the two feet together.

EMG measurements

Muscle activity was measured using ME6000 Biomonitor EMG System (revision MT-M6T16-0). EMG recordings were made using a pair of surface electrodes (silver-silver chloride, 55 mm) placed over the TA muscle (at proximal one third of the line between the tip of the fibula and the tip of the lateral malleolus) and over the SOL muscle (on the inferior and lateral aspects of the leg) of the dominant leg. A reference electrode was placed over the tibial tubercle. Surface electrodes were secured onto the shaved and cleaned skin above muscles. EMG signals were amplified and band-pass filtered (20–500 Hz). EMG signals were collected at a sampling frequency of 1000 Hz. Root mean square (RMS) of the EMG was obtained using a time window of 5 ms sliding average.

Experimental testing

Before the beginning of the experiment, participants were given time (5-10 minutes) for

warm-up, practicing ascending and descending stairs and familiarizing themselves with experimental tasks until they were able to make steady manipulation.

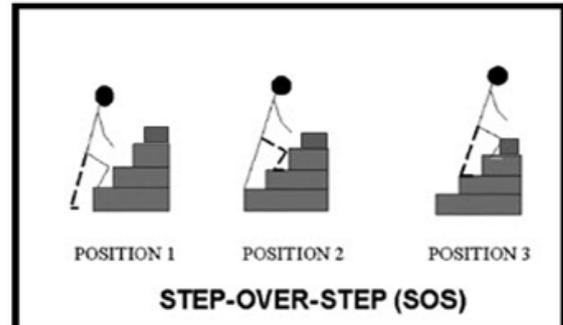


Fig. 2: Step-over-step (SOS) manner

EMG activity was measured during stair ascent and descent, and during maximal voluntary contraction (MVC) from the two muscles of the dominant leg. Before placing the electrode pairs, the skin was shaved and cleaned by alcohol swab to increase conductivity and to reduce electrode-skin impedance. The skin impedance was less than 5 K Ω .¹⁸⁻¹⁹ Skin preparation and electrode placement were carried out in accordance with the standard recommendations in the literature.²⁰ Each participant performed three MVC efforts for each muscle and the average value from these measurements was used for normalization of the EMG data. For MVC measurements, the participants were asked to start slowly increasing the force, reach the maximum effort within 3–5 seconds, and hold it for 3 seconds and then calm down within 3 seconds.^{18-19,21-23} A 2 minute rest break was given between the successive MVC measurements.²⁴ The EMG measurements were then normalized to the maximum EMG exertion for each muscle.

Statistical analysis

Data were analyzed using SPSS version 15.0 (SPSS Inc, IL, Chicago, USA). Significantly different conditions between stairs were included in subsequent analyses as covariance structure (linear mixed model). A univariate analysis of co-variance compared differences between high stairs for each

EMG variable. Normality was assessed for each of the dependent variables (EMG amplitude and high stair) by the Kolmogorov–Smirnov (K-S) test.

A covariance structure (linear mixed model) was used for evaluation of the effect of different heights of stairs on EMG activity of the muscles during ascending and descending stairs based on Autoregressive (1) covariance structure. The parameters were estimated using the Restricted Maximal Like-

lihood (REML) Method. The Intraclass Correlation Coefficient (ICC) was calculated and all cases were confirmed. A significance level of 0.05 was applied for all statistical tests.

Results

The main findings of the study are shown in Fig. 3 and 4 and Table 1.

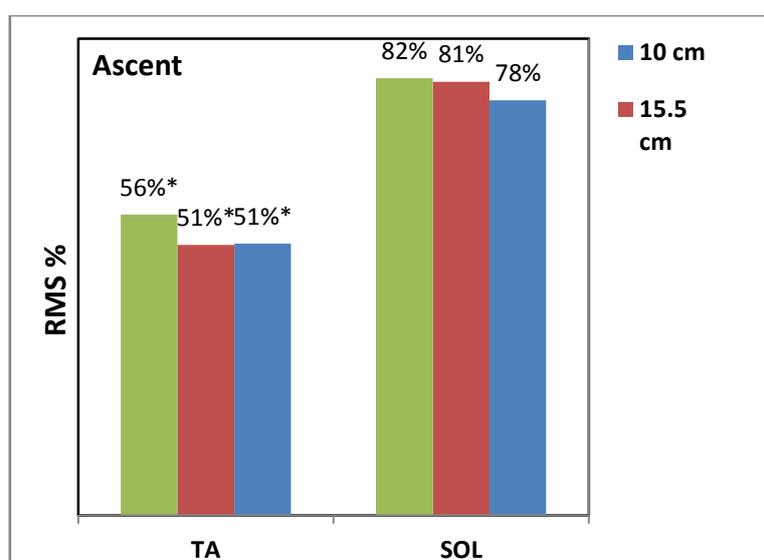


Fig. 3: Effect of stair height on the RMS muscle activity (% MVC) levels of soleus (SOL) and tibia (TA) muscles while ascending stairs. * indicates significant difference between the two muscles

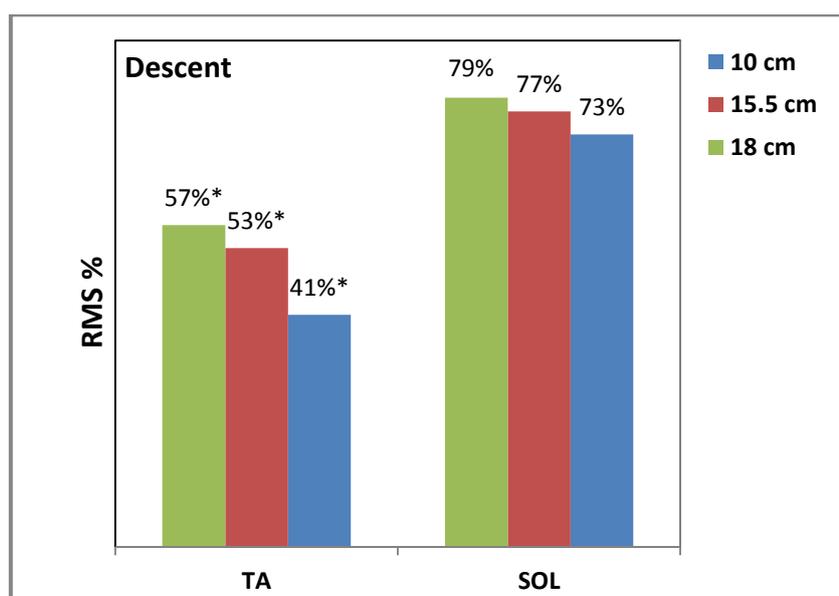


Fig. 4: Effect of stair height on the RMS muscle activity (% MVC) levels of soleus (SOL) and tibia (TA) muscles while descending stairs. * indicates significant difference between the two muscles

Accordingly, the muscle activity levels of the soleus (SOL) muscle were significantly higher than those of the tibia (TA) muscle for both ascending and descending conditions ($P = 0.000$). The results also showed significant differences in the muscle activity levels of the SOL muscle between ascending and descending conditions ($F(1,210) = 18.406, P = 0.000$). However, the results showed no

significant difference in the muscle activity levels of the TA between ascending and descending conditions ($F(1,194) = 2.22$). The results showed no significant effect of stair height on the muscle activity levels of SOL ($F(2,122) = 0.073, P = 0.930$) or TA ($F(2,156) = 2.271, P = 0.107$) muscles.

Table 1: Results for electromyography (EMG), during stair ascend & descent

Muscle	Stair height (cm)	Ascending & Descending	RMS EMG (%)	
			Mean	Standard Deviation
SOL	10	Ascending	85.53	9.80
		Descending	74.70	18.41
	15	Ascending	80.79	12.89
		Descending	81.01	19.57
	18	Ascending	80.37	10.67
		Descending	83.29	17.00
TA	10	Ascending	51.71	28.45
		Descending	41.11	20.90
	15	Ascending	51.48	24.73
		Descending	53.37	24.22
	18	Ascending	56.70	25.63
		Descending	58.32	25.72

Discussion

The findings of the present study add to the understanding of the EMG activity of the two leg muscles involved in ascending and descending stairs with different heights (e.g. 10 cm, 15.5 cm and 18 cm). The TA and SOL muscles were studied because of their involvement when ascending and descending stairs. The main findings of the study were that the EMG activity of the SOL muscle was significantly higher than the TA muscle activity and that the muscle activity level of the SOL muscle was significantly higher when ascending compared to descending condition, although the stair height had no significant effect of the EMG activity of the two muscles. These findings provide an insight that how the muscles of the leg are influenced by stair height during ascending and descending stairs.

The findings of this study are consistent with the findings of the study conducted by

Hall et al.,²⁵ and Bradford et al.,²⁶ which reported EMG activity levels of muscles were significantly greater during stair ascent as compared to stair descent and other study indicated that the EMG data of muscles was found to increase as speed increased, as well.²⁷ The RMS values reflect better the levels of muscle activity at rest and during contraction, and that is why this parameter has been used widely in previous research.²⁸⁻³¹ The result of the present study showed a trend in the RMS values of the EMG signals and stair height during descending stairs, so that the EMG activity levels of both muscles were increased by increasing the height of stairs, although this difference was not so large as to be statistically significant. The highest EMG levels for the TA and SOL muscles during descending were recorded for 18 cm and 10 cm stair heights, respectively. However, the results did not show such a trend for the EMG activity levels while ascending stairs.

As shown in this study, the EMG activity level of the SOL muscle was higher than that recorded for the TA muscle for both ascending and descending conditions and for the different heights of the stairs. These findings indicate that the two muscles are not equally affected by the stair height during ascending and descending. In addition, a higher level of EMG activity was recorded for both TA and SOL muscles during ascending compared to descending condition, which is perhaps not surprising. This result highlights that a higher level of muscular activity is expected while ascending compared to descending stairs.

With regard to the effect of stair height, the results showed no significant main effect of stair height on the muscle activity levels of the SOL or TA muscles. This means that there is preference between the stairs with different heights when it comes to selection of an appropriate stair height. However, there are other recommendations than stair height that should be taken into account. For example, ergonomic staircases should have steps that provide full heel support for all sizes of feet. This can help to relieve pressure on toes, thereby reducing fatigue and discomfort. Another recommendation is for rise (e.g. height of each step) diameter to be between 152 mm and 165 mm¹.

Conclusions

The results showed a clear difference in the muscular activity levels of the two leg muscles (e.g. TA and SOL) while ascending and descending stairs with different heights. The results indicated that the EMG activity of the SOL muscle was significantly higher than the TA muscle activity, which highlights the increased muscular effort of the SOL muscle compared to the TA muscle while climbing or descending stairs. It was also indicated that the muscle activity level of the SOL muscle was significantly higher when ascending compared to descending condition. However, the stair height had no significant effect of the EMG activity of the

two muscles, which shows that there is no preference between different stair heights in terms of muscular effort.

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Competing interests

The authors declare that there is no conflict of interests.

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