

Comparison of stair walking mechanics between adult males and females

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Background

Stair negotiation is a daily functional activity that poses greater mechanical burden as compared with level walking. Few studies have investigated the biomechanical demands of stair walking tasks. However, sex-based biomechanical differences of such tasks, in terms of joint movement and muscle activity, have not been previously reported.

Purpose

The aim of this study was to investigate sex-based differences in lower extremity joint kinematics and muscular electromyography (EMG) in healthy adults during stair ascent and descent.

Materials and methods

A total of 20 participants (10 males and 10 females), with mean±SD age of 21.7±2.7 years, ascended and descended a two-sided staircase. Sagittal movements of the hip, knee, and ankle joints were measured using a Qualisys motion analysis system. Peak amplitude of surface EMG activity for gluteus medius, rectus femoris (RF), vastus lateralis, and soleus muscles was collected using a Biopack EMG system. Each participant performed three repetitions, and an average was calculated for analysis.

Results

Female participants demonstrated significantly higher hip and knee angles ($P=0.01$) during stair ascent and higher hip angles and ankle dorsiflexion ($P=0.01$) during stair descent than male participants. Female participants also exerted higher normalized muscular activity than male participants for RF, vastus lateralis, and soleus muscles during ascent. However, only RF muscle had significantly higher readings for female participants during stair descent.

Conclusion

Female participants perform stair negotiation using greater angular excursion and muscle activation than male participants. This could impose greater mechanical burden on lower extremity structures and, consequently, increase energy consumption. Therefore, sex-based differences should be considered when planning a stair-negotiation rehabilitation program.

Keywords:

electromyography, kinematics, lower extremity, sex, stair negotiation

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Introduction

Stair negotiation is a daily functional activity performed by almost every human being. Compared with level walking, it poses a physical challenge to individuals with reduced functional capacity such as the elderly, pregnant women, or those with muscle or joint disease. A thorough understanding of stair-negotiation mechanics and motor control mechanisms could support clinicians' effort at designing an intervention approach that best suits individual needs. The importance of individualized needs is clear on considering sex-based differences.

Sex-based differences have been the scope of many studies, particularly those concerned with incidence of lower extremity (LE) injury. However, most previous

studies have been primarily focused on athletic activities and how the injury rate could be sex dependent. A number of studies have reported that LE injury incidence rate is greater in female than male individuals [1–3]. It has been postulated that sex-based structural differences may cause differences in running mechanics [2,4]. In addition, previous studies have reported a relationship between sex-based structural changes in LE joints and their movement patterns [5–7]. Despite receiving great attention in athletic activities, sex-based differences

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have not received a similar attention regarding other common daily activities such as stair negotiation.

The biomechanics and motor control mechanisms underlying stair negotiation have been examined previously. Kinematics and kinetics of the LE have been compared for stair ascent and descent, revealing interchangeable patterns of joint movements and forces [8] and muscular coordination [9]. Stair ascent caused eight-time higher patellofemoral contact force compared with level walking [10]. Joint power has shown a significant dependency on staircase inclination [11]. Furthermore, the physical and functional demands of stair negotiation have been shown to be age dependent, as older adults negotiate stairs with different joint motion patterns compared with their younger counterparts [12] and with greater muscular exertions [13]. Recently, researchers have been studying stair negotiation with dual tasking [14–16] and in pathological conditions [17–19]. Although different studies examined the biomechanical mechanisms of stair negotiation, few studies are available on sex-based differences in stair negotiation. A study compared muscular activation characteristics, in terms of timing and amplitude, of the vastus medialis and medial hamstring muscles of both sexes during stair ascent and descent. However, LE kinematics were not reported [20]. Lower extremity kinematics and dynamic postural stability were compared between male and female individuals during stair descent only [21,22]. Kinematics and kinetics of the LE were compared during stair ascent and descent. However, sex-based comparison was not considered [8].

Thus, it appears that a comprehensive examination for comparison between male and female individuals, in terms of LE movement and muscular performance, during both stair ascent and descent is still needed. Therefore, the objective of this study was to investigate the differences between both sexes regarding LE joint sagittal movements and magnitude of muscular activity during performing stair ascent and descent. It was hypothesized that sex-based differences exist in kinematics and muscle activity of the LE when walking up and down the stairs.

Materials and methods

Design

A between-subject study design was used in this pilot study. The independent variable was sex (male vs. female). The dependent variables were maximum and minimum joint excursion angles of the hip, knee, and

ankle joints and peak normalized electromyography (EMG) amplitude of the gluteus medius (GM), rectus femoris (RF), vastus lateralis (VL), and soleus muscles (SL) of the dominant lower extremity during stair ascent and descent. Each participant performed three trials. All experimental data were collected in the same session.

Sample

A total of 20 healthy adult individuals, 10 males and 10 females, were conveniently recruited from the local community. Participants' age and BMI ranged between 18–30 years and 18–25 years, respectively. Participants were nonathletes, with no history of injury to the lower extremities or spine for at least 6 months before the study and having normal LE joint flexibility. All participants signed a consent form approved by the ethical committee of the Faculty of Physical Therapy, Cairo University.

Instrumentation

A Qualisys motion analysis system was used to capture the participant's movement. This system had three ProReflex infrared cameras with a capturing frequency of 120 Hz; a wand kit used for system calibration; and a computer installed with a Q trac, Q view, and Q tools software used for data capturing and processing and equipped with an ACB-530 serial adaptor for analog-to-digital data conversion. A total of eight 9-mm passive reflective skin markers were used for detecting lower extremity movement.

A wooden two-sided staircase was used in the study. It consisted of four steps on each side connected at the top by a short walkway. The slope of the staircase was 33° with a step height of 18 cm, tread depth of 28 cm, and a width of 107 cm [8,23,24]. A Biopack EMG system with Acknowledge MP 100 data acquisition software was used to record the muscular activity of the lower extremity muscles during stair ascent and descent. Each channel was composed of active, passive, and ground silver–silver chloride surface electrodes. The EMG data collection unit was synchronized with that of motion capture system.

Procedures

All individuals were barefoot and wore shorts to allow attachment of the reflective markers and EMG surface electrodes. Weight, height, BMI, and LE length of each individual were measured before starting data collection. Before electrode placement, the participant's skin was shaved and wiped with alcohol. EMG surface electrodes were

attached over the following muscles of the dominant lower limb: GM, VL, RF, and SL. Surface EMG electrodes were placed according to the protocol of Delagi and Perotto [25]. Maximum voluntary isometric contractions (MVIC) were first obtained for each of the four tested muscles before performing the stair-climbing trials. A total of three MVICs were carried out. The highest of the three measurements was used for EMG normalization. Reflective markers were then placed on the second metatarsal head, posterior calcaneus, lateral malleolus, tibial tuberosity, center of the lateral knee joint line, proximal border of patella, greater trochanter, and acromion process of the shoulder.

For stair-climbing assessment, each individual was asked to stand on ground level in front of the stairs before ascending. All participants were instructed to place only one foot on each step and to move at the speed they feel most comfortable. Participants practiced before collecting data until they felt that they perform the task naturally [24]. Participants were instructed to perform stair ascent from one side of the staircase and continue to descend on the other side of the staircase. Each participant carried out three repetitions. Participant's movement and muscular activity were synchronously recorded.

Data processing

During stair ascent, all parameters were measured from foot contact on the second step to foot contact of the same foot on the fourth step (a complete cycle). During stair descent, parameters were measured from foot contact on the second step and ended with the same foot contact on the floor [8].

Kinematic data were analyzed using Q view and Q tools programs. Timing of the beginning and the end of stair ascent and descent cycles was first detected for each trial. Then the maximum and minimum flexion joint angles for the hip, knee, and ankle were detected at each of the cycles of stair ascent and descent for each trial. The average values for the joint angles were then calculated for the three trials for each participant [26]. As hip and knee joints do not go into full extension during stair walking, their maximum joint angles represented

the greatest flexion position and the minimum represented the least flexion position.

EMG data were analyzed using AcqKnowledge MP100 software version 3.7.0 (BIOPAC Systems Inc., California, USA). EMG data were band-pass filtered at 10 to 500 Hz and processed with a root mean square (RMS) algorithm. Peak muscular activity was then identified [27,28]. To enable comparison between individuals, the RMS amplitude data for each muscle were normalized to MVIC% [27].

Data analysis

Data were analyzed using SPSS, version 21. Descriptive statistics, including mean±SD, were calculated for all variables. Because of the small sample size of this pilot study, Mann-Whitney test was used to detect significant difference between groups for participants' demographics; the maximum and minimum sagittal angles of LE joints; and MVIC % of GM, RF, VL, and SL muscles during stair ascending and descending activities. SPSS software was used for statistical analysis. Because we used a nondirectional hypothesis, two-tailed test was conducted, and the level of significance was set at *P* value less than 0.025 (0.05/2).

Results

Sample characteristics

Participant's demographic data are shown in Table 1. It can be noticed that no significant differences were detected between the study groups.

Kinematics

Results revealed that LE sagittal angles were affected by sex during stair ascent, except the ankle joint. Female participants demonstrated significantly greater hip maximum (21%), hip minimum (40.5%), knee maximum (13%), and knee minimum (22.4%) angles than male participants. Regarding stair descent, female participants also exhibited significantly greater hip maximum angle, hip minimum angle, and ankle dorsiflexion by ~32, 55, and 23%, respectively, than their male counterparts. However, for knee joint angles, and ankle planter flexion, no significant differences were found between the groups (Table 2).

Table 1 Mean±SD of participants' demographic data

	Age (years)	Height (cm)	Weight (kg)	Lower limb length (cm)	Lower limb/height (%)	BMI
Male participants	23.9±3.8	171.8±4.1	73.6±11.6	94.3±6.6	0.54±0.03	24.9±3.5
Female participants	20.1±1.5	164.8±4.2	59.1±4	88.3±4.1	0.54±0.02	21.9±2.3
<i>P</i> value	0.16	0.07	0.04	0.06	0.92	0.45

Electromyography activity

Statistical analysis showed that, during stair ascent, female participants exerted significantly greater muscular activity than male participants. Female participants' RF, VL, and SL muscles had 36, 27, and 26% greater RMS amplitude, respectively. However, during stair descent, only RF (31%) muscle had significantly greater readings in female participants as compared with male participants (Table 3).

Discussion

This study demonstrated a comparison between adult male and female individuals during stair negotiation for lower limb sagittal angle and muscular activity. Findings reveal that female individuals use greater hip and knee angular excursion than male individuals to use stairs, particularly during ascent. In addition, female individuals also exert greater muscular activity than male individuals to ascend stairs. The increased muscular activity is clearly detected in the knee and ankle joint muscles more than the hip joint.

To the best of the author's knowledge, there is no published work that compared sagittal plane LE angles between sexes in the up and down stairs activity. However, a study reported higher nonsagittal (frontal and transverse) LE angles among female than male individuals during stair descent only, which is consistent with the greater LE sagittal angles among female individuals recorded in the current study [21]. In agreement with that sex bias, several previous studies have reported sex differences in other physical activities and in other

planes of movement. It has been shown that women exhibit greater LE motion during landing than men [1,27]. Furthermore, female individuals have demonstrated greater LE angles than male individuals during walking [29] and in single-leg squat [30]. Interestingly, it has been reported that female individuals have significantly greater nonsagittal hip and pelvis motion during walking and running across a range of speeds and inclines than male individuals [31]. In contrast to the present study, Ferber *et al.* [2] have shown that sex differences of the sagittal hip and knee motion were not observed during running. However, they have reported greater frontal hip motion for female participants and attributed their findings to the structural difference between both sexes. It is suggested that differences in the physical activities examined among studies may account for the different findings.

Overall, hip and knee joint movements have been affected by sex. Nevertheless, female individuals have shown a trend of higher dorsiflexion angles than male individuals while ascending stairs, but the difference was not statistically significant. Although not measured in the current study, anterior pelvic tilt is known to be greater in female than male individuals during standing [32] and walking [33]. Female individuals tend to utilize more anterior pelvic tilting and more hip flexion angles. These changes might be attributed to sex-related structural differences [33]. In addition, the reported weaker abdominal muscles in female than male individuals or the persistent use of high heeled

Table 2 Mean±SD of the average peak joint angles as a function of sex during stair negotiation

Angle	Stair ascent (deg.)			Stair descent (deg.)		
	Male participants	Female participants	<i>P</i> value	Male participants	Female participants	<i>P</i> value
Hip (Max.)	49.3±7.7	62.5±6.6	0.01	25.68±8.01	37.26±4.41	0.01
Hip (Min.)	8.5±5.8	14.3±4.0	0.01	8.10±4.93	17.89±3.99	0.01
Knee (Max.)	85.8±9.2	98.7±5.9	0.01	87.05±7.23	89.52±18.10	0.74
Knee (Min.)	17.0±6.6	21.9±5.2	0.02	18.12±6.27	18.58±5.31	0.87
Ankle DF	21.3±8.3	27.6±11.9	0.09	33.59±4.19	44.13±8.85	0.01
Ankle PF	10.7±6.5	6.8±5.8	0.08	19.13±8.08	14.06±9.41	0.15

Bold values indicate significant difference at $P < 0.025$. DF, dorsiflexion; Max., maximum angle; Min., minimum angle; PF, plantar flexion.

Table 3 Mean±SD of the average peak root mean square amplitudes as a function of sex during negotiation

Muscle	Stair ascent (MVIC%)			Stair descent (MVIC%)		
	Male participants	Female participants	<i>P</i> value	Male participants	Female participants	<i>P</i> values
GM	39±12	53±18	0.07	30±15	36±8	0.54
RF	32±21	50±10	0.01	27±7	39±16	0.01
VL	58±18	79±1	0.01	50±16	63±13	0.09
SL	67±11	90±6	0.01	66±27	65±25	0.87

Bold values indicate significant difference at $P < 0.025$. GM, gluteus medius; MVIC, maximum voluntary isometric contraction; RF, rectus femoris; SL, soleus; VL, vastus lateralis.

shoes among female individuals could affect the angle of hip flexion [33,34]. This may account for the sex bias in LE sagittal joint angles during stair ascent and descent in the current study. Moreover, difference between sexes may be related to the fact that women have different dimensional proportions of lower extremity than men, which could affect hip and knee movement [26,35,36].

Mean values recorded for the different angles of hip, knee, and ankle joints during stair ascent and descent were in close agreement with the work of Livingston *et al.* [26], but slightly less than the values reported by Protopapadaki *et al.* [8]. The differences in the joint angles readings among the studies may be attributed to the use of different equipment such as different motion analysis systems, marker placement, stair dimensions, or subject characteristics. Results have shown that female individuals had significantly greater knee joint peak flexion angles than male individuals during stair ascent. However, that was not the case during descent. This could be supported by the previous reports that the maximum angles and moments of the lower limb occur during stair ascent as compared with stair descent [8].

Muscular activity

The ability of the participants to ascend and descend stairs requires activation of various muscles of the lower limb. In the current study, normalized muscular activity data of female participants were always higher than those of male participants. Significant differences were found for RF, VL, and SL muscles while ascending the stairs. RF muscle works concentrically in the swing phase of stair ascent, and eccentrically to control the body against gravity during stair descent. The SL muscle contracts during stair ascent in the pull-up phase (in which the limb placed on the upper step is extended to bring the body up to that step). The lower leg moves posteriorly through planter flexion of the ankle to increase the vertical position. In the forward propelling stage (in which the limb on the lower step pushes up to the next step), the greatest ankle power is generated in this phase in which the ankle pushes off with the planter flexors active as the body is pushed up to the next step [35]. The different kinematic profile of female participants compared with male participants may account for the female's higher muscular activity. To elaborate, the greater tendency toward greater hip, knee, and ankle joint angles in female than male individuals to climb stairs would induce more external moment

and thereby enhancing the muscles to contract more to overcome the higher external torque developed. In the current study, female participants needed significantly greater muscular exertion than male participants to ascend the stairs. In contrast, this difference was not evident during stair descent. Generally, it seems that female individuals need more muscular effort than male individuals to accomplish the same task. Interestingly, knee musculature has been used to a greater extent by female individuals more than male individuals (RF and VL showed a 36 and 26% more amplitude than male individuals, respectively) followed by hip (26%), and lastly ankle muscles (25%). The same trend was found during stair descent although the differences were not significant (RF 31%, VL 20%, GM 17%, and SL 1.5%). Such overuse of knee musculature by female individuals in performing a daily activity such as going up and down the stairs might account for the high incidence of knee injuries among female individuals as compared with male individuals [2,3].

The current study suffers some limitations. The sample size is small, which necessitates cautious interpretation of the findings. The EMG examination was limited to four available channels only, and thus, only four muscles were examined. Furthermore, analysis of other planes of motion together with kinetic data in future research would add more comprehensive analysis of the differences in stair locomotion between both sexes.

Conclusion

Adult female individuals perform stair ascent and descent with greater LE sagittal angles and muscular activity than male individuals. The greatest difference between sexes was found at the knee musculature, which puts more risk on the knee joint. These sex-based differences should be considered when planning a stair-negotiation rehabilitation program by giving more attention to strengthening the LE muscles specially the knee muscles to guard against overuse injuries, which are more prevalent in female individuals.

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Conflicts of interest

There are no conflicts of interest.

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