Original Article

Effects of body mass and sex on kinematics and kinetics of the lower extremity during stair ascent and descent in older adults

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ARTICLE INFO

Keywords:
Joint moment
Range of motion
Obesity
Overweight
Joint angles

ABSTRACT

The effects of body mass and sex on lower limb biomechanics during ascent and descent were examined in participants aged 50 to 75 with normal weight (n = 19), overweight (n = 18), and obese (n = 8). Peak joint angles and joint moment of the lower limb were analyzed with the VICON motion analysis system. Results from multivariate analysis of variance showed that during descent, the overweight participants had significantly higher knee extensor moment (0.98 ± 0.30 N-m/kg) than the normal-weight participants (0.70 ± 0.29 N-m/kg). The obese group had significantly higher ankle abductor moment (0.21 ± 0.11 N-m/kg) than the normal weight (0.12 ± 0.08 N-m/kg) and overweight groups (0.09 ± 0.06 N-m/kg). During ascent, the obese participants had significantly higher hip flexor moment (0.42 ± 0.20 N-m/kg) than overweight participants (0.22 ± 0.17 N-m/kg). Significant sex differences were found in knee extension angles (4.2 ± 3.4° vs 7.0 ± 3.3°) during descent, plantar flexion angles during ascent (23.7 ± 5.3° vs 15.6 ± 3.7°) and descent (29.9 ± 5.0° vs 22.1 ± 7.9°), and ankle adduction angles (6.8 ± 4.8° vs 2.5 ± 2.5°) during ascent. It is concluded that body mass has significant impact on joint loading of lower limbs during stair walking. Being overweight and obese increased hip joint loading during ascent, and knee and ankle joint loading during descent in older adults. Sex difference in joint kinematics was presented during stair walking regardless of the body mass.

Introduction

Stair climbing is a common daily locomotion and is challenging for some individuals as it has high demands on the musculoskeletal and cardiovascular systems. In the past two decades, biomechanics studies on stair walking that utilized simulated staircase set-ups in gait laboratories have been performed in adults with normal body weights. During ascent, the knee and hip joints extend forward in the early stance phase to overcome the force of gravity. Therefore, more joint moments are required during stair ascent than during walking and the joints experience higher loadings in the former activity. In contrast to ascent, flexion occurs at the hip and knee during descent to control the force of gravity.

Stair climbing may be more challenging for people with larger body masses, such as obese and overweight individuals, because the forces on the lower extremities can be higher compared with leveled walking. The understanding on the lower extremity biomechanics in people with larger body mass, such as obese or overweight, is severely limited. To the author's knowledge, only a few studies on the kinetic aspects of stair climbing in obese individuals have been published. Mazlan and co-workers studied biomechanics of the lower limb in young obese individuals (23.65 ± 2.26 Years) during ascent. They found that obese individuals adopted an altered movement pattern with higher hip joint moments during ascent than normal-weight individuals along the three movement planes. Strutzenberger et al. studied joint biomechanics of the lower limb in obese and normal-weight children during stair climbing and found that obese children had a significantly larger knee extensor moment during descent. The above study findings are from young people and children, whether obesity or overweight causes changes in the lower extremity biomechanics in older people is unclear. Moreover, it is unknow whether there is sex difference in kinematics and kinetics of lower limb during stair walking as fat tissue distribution pattern are different between older man and women that might influence biomechanics of lower limb.

Research data indicate that the altered joint biomechanics, such as increased joint loading acting on weight-bearing joints, significantly contribute to osteoarthritis (OA) onset and progression. Lohmander et al. found that all obesity measures, including body mass, body mass index (BMI), and waist circumference, were associated with the development of knee and hip OA. Evidently, our knowledge on the lower
extremity mechanics of obese or overweight people during challenged locomotion, such as stair climbing, is lacking. Moreover, whether sex differences in lower limb biomechanics during stair ascent and descent in the population is unknown. Therefore, it is needed to understand whether older obese or overweight adults change their lower extremity biomechanics during stair climbing compared with normal-weight people and whether there is sex difference in the lower limb biomechanics during stair climbing. The purpose of this study was to examine the effects of body mass and sex on the kinematics and kinetics of the lower limb of normal-weight, overweight, and obese participants during stair ascent and descent. The findings from this study could add understanding to the joint biomechanics of obese and overweight people during stair climbing.

Materials and method

Participants

Participants were recruited through distributing information letter and posters in local community centers, university campus, and local clinics. An introductory presentation about the study was given to the people who were involved in programs of local community centers, such as reading, cooking, dancing and exercise. The following participants were recruited for the study: 20 normal-weight individuals, with 9 males and 11 females (61.2 ± 6.0 years; 163.8 ± 7.7 cm; 59.5 ± 7.9 kg); 21 overweight individuals, with 14 males and 7 females, (59.4 ± 6.0 years; 170.4 cm ± 9.8; 78.9 ± 11.4 kg); and 11 obese individuals, with 3 males and 8 females (58.1 ± 6.0 years; 166.7 ± 8.6 cm; 93.8 ± 12.8 kg). Table 1 presents the demographical data of the participants. The participants were classified into three groups, the normal weight, overweight, and obese group, based on their BMIs. Those with BMI of 18.5–24.9 kg m\(^{-2}\) were classified as normal weight, whereas individuals with BMI of 25.0–29.9 kg m\(^{-2}\) were classified as overweight. Moreover, those with BMI of 30.0–34.9 kg m\(^{-2}\) were classified as obese class I. The participants were eligible to participate in the present study if they were between the ages of 50 years to 75 years and have BMI of 18.5–34.9 kg m\(^{-2}\). Prior to the experiment, the participants were asked to complete a questionnaire of their medical history to ensure that they did not experience any neuromuscular disorders, musculoskeletal injuries, cardiopulmonary diseases, and weight fluctuations in the past 6 months. This study was approved by the University of Ottawa research ethics committee, and all participants were required to sign an informed consent form.

Data collection

The experimental staircase illustrated in Figure 1 comprised of three steps at 17.8 cm high and 28 cm deep, with the first and second steps built with portable force plates (Model 9286AA, Kistler Instruments Corp, Winterthur, and Switz). Four force plates, two portable Kistler built with portable force plates (Model 9286AA, Kistler Instruments), were placed on the ground. Each of the participants was asked to ascend and descend the staircase at a comfortable speed for five trials with their right legs as lead leg.

Table 1

| Group       | Participants | Age (years) | BM (kg) | BH (cm) | BMI (kg m\(^{-2}\)) |
|-------------|--------------|-------------|---------|---------|---------------------|
| Normal      | n = 19 (M:8; F:11) | 61.4 ± 7.1 | 59.5 ± 7.9 | 163.8 ± 8.0 | 22.1 ± 1.8 |
| Overweight  | n = 18 (M:14; F:4) | 59.7 ± 7.0 | 81.3 ± 6.0 | 172.1 ± 9.5 | 27.4 ± 2.6 |
| Obese       | n = 8 (M:3; F:5)   | 60.3 ± 6.0 | 93.3 ± 6.0 | 167.6 ± 8.0 | 33.3 ± 6.0 |

M, male; F, female; BM, body mass; BH, body height; BMI, body mass index.
\(^a\), \(p < 0.05\), indicates a significant difference between the three groups.
Results

Kinematics

No significant interaction was found between mass and sex in the peak joint angles \( F(48) = 1.072, p = 0.387 \) and ROM \( F(24) = 0.716, p = 0.815 \) during ascent and descent. The participants’ sex had a significant effect on the peak joint angles \( F(24) = 4.393, p = 0.002 \) and ROM \( F(12) = 4.386, p = 0.001 \) at the knee and ankle, whereas the participants’ body mass did not influence these variables. Table 2 presents means and standard deviations of the peak joint angles and ROM in the sagittal and frontal plane during stair climbing for females and males.

For ascent, a significant difference was found in ROM of ankle dorsiflexion/plantarflexion. Females presented significantly bigger ROM of ankle \( p = 0.007 \) and peak plantar flexion angles \( p < 0.001 \) than males. And females showed significantly bigger ROM of hip abduction/adduction \( p = 0.006 \) and ROM of ankle abduction/adduction \( p = 0.007 \) than males. For the descent, significant differences were found in the ROM of knee and ankle in sagittal motion. Female participants had a significantly smaller peak knee extension angle \( p = 0.012 \) compared with the males. The females’ overall ROM at the knee was significantly larger \( p < 0.001 \) than that of the males. At the ankle, the female participants plantarflexed their ankles more than the males during descent \( p = 0.004 \). The females’ sagittal ROM at the ankle was significantly larger than that of the males during descent \( p = 0.003 \). And during descent, the females showed significantly smaller knee abduction angle \( p = 0.002 \) than the males.

Kinetics

The MANOVA results revealed no significant interaction between sex and mass \( F(34) = 0.594, p = 0.943 \). Body mass had a significant
The obese group had a significant increase in the sagittal and frontal plane during stair climbing for females (n = 20) and males (n = 25).

Table 2

|       | Ascent | Female | Male | p-value |
|-------|--------|--------|------|---------|
| Hip   | Flexion| 70.2 ± 7.3 | 67.4 ± 4.7 | 0.066 |
|       | Extension| 8.8 ± 6.1 | 7.9 ± 6.2 | 0.385 |
|       | ROM    | 62.8 ± 4.2 | 60.0 ± 4.8 | 0.092 |
| Knee  | Flexion| 99.1 ± 6.3 | 95.7 ± 5.1 | 0.138 |
|       | Extension| 2.3 ± 5.4 | 7.6 ± 6.5 | 0.753 |
|       | ROM    | 92.3 ± 8.6 | 88.2 ± 5.6 | 0.088 |
| Ankle | DF     | 11.3 ± 4.1 | 14.5 ± 5.6 | 0.366 |
|       | PF     | 23.7 ± 5.3 | 15.6 ± 3.7 | < 0.001 |
|       | ROM    | 35.9 ± 5.2 | 31.2 ± 5.7 | 0.007 |
| Hip   | Adduction| 7.8 ± 4.6 | 4.6 ± 4.6 | 0.076 |
|       | Abduction| 9.1 ± 3.4 | 8.4 ± 3.6 | 0.702 |
|       | ROM    | 17.3 ± 3.2 | 13.2 ± 4.5 | 0.006 |
| Knee  | Abduction| 2.7 ± 4.7 | 2.3 ± 4.3 | 0.150 |
|       | Adduction| 8.6 ± 17.0 | 15.7 ± 15.3 | 0.064 |
|       | ROM    | 17.3 ± 9.4 | 19.1 ± 10.9 | 0.564 |
| Ankle | Adduction| 6.8 ± 4.8 | 2.5 ± 2.5 | 0.001 |
|       | Abduction| 1.9 ± 1.0 | 1.6 ± 1.7 | 0.329 |
|       | ROM    | 9.5 ± 4.3 | 6.8 ± 2.7 | 0.017 |

Table 3

|       | Ascent | Normal | Overweight | Obese | p-value |
|-------|--------|--------|------------|-------|---------|
| Hip flexor | 0.26 ± 0.18 | 0.22 ± 0.17 | 0.42 ± 0.20 |
| Hip extensor | 0.72 ± 0.17 | 0.70 ± 0.17 | 0.61 ± 0.20 |
| Knee extensor | 0.94 ± 0.29 | 1.05 ± 0.35 | 0.99 ± 0.33 |
| Ankle PF | 1.20 ± 0.23 | 1.25 ± 0.15 | 1.11 ± 0.12 |
| Hip abductor | 0.44 ± 0.18 | 0.35 ± 0.14 | 0.32 ± 0.18 |
| Knee abductor | 0.44 ± 0.19 | 0.40 ± 0.21 | 0.29 ± 0.13 |
| Knee adductor | -0.15 ± 0.11 | -0.13 ± 0.13 | -0.09 ± 0.08 |
| Ankle adductor | – | – | – |
| Ankle abductor | 0.14 ± 0.10 | 0.16 ± 0.07 | 0.20 ± 0.06 |

Influence on the joint moment (F (34) = 1.836, p = 0.026), irrespective of sex (F (17) = 1.730, p = 0.110). Considering that no interaction or effect of sex was found, the joint moment data for the males and females were pooled for the ANOVA and post-hoc tests. Table 3 lists the means and standard deviations for the peak joint moment of force during stair ascent and descent. The females had significantly larger ankle plantar flexion angles during ascent and descent. However, their knee extension angles were smaller compared with the males. The sex differences in the peak knee extension and plantar flexion angles might be related to the body height difference between males and females. Livingstone et al. studied impact of body height, shorter 155.9 ± 21 cm, medium (163.5 ± 2.2 cm) and tall (171.6 ± 2.1 cm) on knee joint angles during stair climbing. They found that shorter participants would use larger knee flexion angles (92° to 105°) than taller participants whose angles would range from 83° to 96°, when climbing stairs. In the study females’ body height was shorter than males. They may have been required to flex their knees more during descent to compensate for their shorter height. This activity resulted in a larger ROM at the knee during descent.

In the frontal plane, the differences in the frontal peak joint angles and ROM may reflect the changes in the participant's center of mass relative to the base of support. During ascent, the females would adduct their ankles more than the males. And during descent, the females would not only adduct more in their ankles, but also in the knees compared with the males. These findings on the peak knee abduction angles were clinically important because they could provide a possible mechanism for knee OA development and may explain why women older than 50-year-olds are at a higher risk of OA than men. Researchers believed that the valgus malalignment (knock knees) at the knee, which resulted because of the larger Q angle in females, may lead to knee pain.21 The present study revealed that the peak joint moments of force for the hip, knee, and ankle were influenced by the body mass. Sex did not have a significant influence on the peak joint moment of force. During ascent, the obese group demonstrated significantly greater hip flexor peak joint angles and ROM at the hip, knee and ankle in ascent and at the knee and ankle in descent. The females had significantly larger ankle plantar flexion angles during ascent and descent. However, their knee extension angles were smaller compared with the males. The sex differences in the peak knee extension and plantar flexion angles might be related to the body height difference between males and females. Livingstone et al. studied impact of body height, shorter 155.9 ± 21 cm, medium (163.5 ± 2.2 cm) and tall (171.6 ± 2.1 cm) on knee joint angles during stair climbing. They found that shorter participants would use larger knee flexion angles (92° to 105°) than taller participants whose angles would range from 83° to 96°, when climbing stairs. In the study females’ body height was shorter than males. They may have been required to flex their knees more during descent to compensate for their shorter height. This activity resulted in a larger ROM at the knee during descent.

The purpose of this study was to examine the effects of body mass and sex on the kinematics and kinetics of the lower limb in normal weight, overweight, and obese participants during stair ascent and descent. The main findings from the study are 1) sex had a significant influence on peak joint angles and ROM during stair ascent and descent in older adults, whereas body mass did not have a significant influence on these variables; and 2) the peak joint moment of the lower limb was significantly influenced by the body mass during stair ascent and descent, irrespective of the effects of sex.

Concerning the kinematic findings, sex differences were found in the
moment than the overweight group. This finding is consistent with findings that young obese participants had higher hip flexion moment in ascent than young normal-weight participants. The possible reason for the difference may be the position of the trunk. Gilleard and Smith (2007) studied body posture and hip joint moment in obese people during standing. They found that obese adults had a more flexed trunk posture during standing and had increased hip joint moment compared to normal-weight people. The higher hip flexor moment in obese people in this study might be influenced by trunk posture and body mass, and will need to be considered in future analysis. At the knee level, the sagittal knee moments of the normal weight, overweight, and obese groups were consistent with the findings from other studies on stair ascent based on normal-weight population. In contrast to ascent, body mass had significant impact on joint moment at the knee and ankle in both sagittal and frontal planes in descent. The descent required a second peak extensor moment at the knee toward the lower body through flexion control at the knee. Descent may place more loading at the knee, resulting in a higher moment caused by the force of gravity acting on the descending participant. Both overweight and obese participants had higher peak knee extensor moments than normal-weight participants. Notably, the overweight group had a significantly higher peak knee extensor moment than the normal weight group during descent (Table 3). And the overweight group showed significant higher knee abductor moment than the obese group. The significant differences between the overweight and normal group and between overweight and obese group might be related to altered muscle contractile function and body mass. Bollinger discussed the contribution of the muscle contractile dysfunction to biomechanics alterations in obesity based on the research evidences in the field. Decreased relative muscle strength and altered contractile properties of the muscle is associated with obesity, which is linked to muscle contractile dysfunction. Recently, Valenzuela and co-workers further provided supporting evidence to Bollinger’s explanation. Their study in 111 obese participants aged 45 to 74 with BMI 35–64 kg m\(^{-2}\) demonstrated a high prevalence of poor muscle quality (the expression of muscle function per unit of muscle mass) in obese people. And BMI was positively associated with the prevalence of poor muscle quality. In this study, the significantly higher knee abductor moment in the overweight group than obese group might be related to their differences in BMI level and subsequently in the extent of poor muscle quality. The obese group might experience more negative changes in muscle quality than the overweight group and their muscles were unable to generate strong contractile force. When scaled to the body weight, the higher moments are strong indications of the higher loading of the musculoskeletal structures in obese individuals compared with normal-weight individuals. The higher joint loading at the knee may have several implications on the amount of stress acting on the articular cartilage of the knee. Cartilages in the knee joint are responsible for reducing the friction between the articular surfaces of the knee. Although necessary loads are needed to stimulate the bone to obtain stronger and excessive bone tissue. However, these higher loads may also cause microdamage to the musculoskeletal tissues and lead to OA development.

A limitation of this study is that it was conducted in a laboratory setting, which may not be conducive for stair climbing in the real world. The experimental staircase used consisted of only three steps, indicating the experimental staircase may not be representative of real-world staircases. The experimental staircase used by previous studies may have different effects on joint moments and muscle forces compared to real-world staircases. The study was conducted in a laboratory setting, which may not be conducive for stair climbing in the real world. The experimental staircase used consisted of only three steps, indicating the experimental staircase may not be representative of real-world staircases. The experimental staircase used by previous studies may have different effects on joint moments and muscle forces compared to real-world staircases. The study was approved by the University of Ottawa research ethics committee, and all participants were required to sign an informed consent form. Our study reported in the manuscript was done in accord with the Helsinki Declaration of 1975.

**Ethical approval statement**

This study was approved by the University of Ottawa research ethics committee, and all participants were required to sign an informed consent form. Our study reported in the manuscript was done in accord with the Helsinki Declaration of 1975.

**Submission statement**

Authors declare that this work has not been published before and is not being considered for publication in another journal.

**Conflict of interest**

Authors confirm that there are no conflicts of interest associated with this publication.

**Acknowledgement**

The study was supported by the Faculty of Health Sciences, University of Ottawa, Ontario, Canada.

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