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Gender differences of sagittal knee and ankle biomechanics during stair-to-ground descent transition

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ABSTRACT

Background: Falls on stairs often result in severe injury and occur twice as frequently in women. However, gender differences in kinetics and kinematics during stair descent are unknown. Thus, this study aimed to determine whether gender differences of knee and ankle biomechanics exist in the sagittal plane during the stair-to-ground descending transition. It was hypothesized that 1) women would reveal higher ground-toe-trochanter angle and lower ground-toe length during stair-to-ground descent transition than men; and 2) women would reveal lower peak knee extension moment during stair-to-ground descent transition than men.
Methods: Fifteen men and fifteen women were recruited and performed a stair descent activity. Kinetic and kinematic data were obtained using a force plate and motion capture system.
Findings: The women performed the stair descent with a lower peak knee extension moment and a peak knee power at the early weight acceptance phase. The women also revealed a higher ground-toe-trochanter angle and a lower ground-toe length, which indicated a more forward position of the lower extremity relative to the toe contact point at both the initial contact and at the time of peak kinematic and kinetic events.
Interpretation: This study found that knee and ankle kinematics and kinetics differed significantly between the genders due to differences in ground-toe-trochanter angle. Women have a different stair descending strategy that reduces the demand of the lower extremity muscle function, but this strategy seems to increase the risk of falls.

1. Introduction

Gender differences in the lower extremity including muscle strength (Barber-Westin et al., 2006; Danneskiold-Samsoe et al., 2009), muscle activation pattern (Bencke and Zebis, 2011; Flaxman et al., 2014), quadriceps angle (Horton and Hall, 1989), and joint laxity (Uhorchak et al., 2003) have been reported. Since such differences can result in different ambulatory strategies between the genders, gender differences in kinematics and kinetics in various daily activities have been studied. For example, an effect of gender on joint kinematics and kinetics during walking (Kerrigan et al., 1998), running (Ferber et al., 2003), and landing (Decker et al., 2003) have been reported. However, gender differences in the lower extremity kinematics and kinetics during stair descent have not been well established.

Although a common daily activity, stair descent is more strenuous than other daily activities. Previous kinematic and kinetic studies have shown that stair descent requires a large range of motion as well as large moments on the knee and ankle joints (Andriacchi et al., 1980; McFadyen and Winter, 1988; Protopapadaki et al., 2007; Reeves et al., 2008). Since descending stairs requires a large range of motion (Protopapadaki et al., 2007) and large muscle force (Reeves et al., 2008), it is often difficult for individuals to control their balance while performing it. Thus, muscle function is highly required to descend stairs safely. The quadriceps and gastrocnemius muscles play important roles during stair descent. Modulation of the electromyographic (EMG) amplitude of the rectus femoris and gastrocnemius muscles is higher than that of the semitendinosus and soleus muscles during stair descent (McFadyen and Winter, 1988). Gender differences in muscle strength have already been reported in many studies. Lower extremity muscle strength is generally stronger in men than in women. In particular, women have weaker knee (Barber-Westin et al., 2006; Lephart et al., 2002) and ankle (Danneskiold-Samsoe et al., 2009) extensor muscle strengths.

The incidence of falls on the stairs is high, and such incidents often result in hospitalization. Approximately 11.3% of the total accidents requiring hospital treatment were the result of a fall on the stairs in the United Kingdom (Department of Trade and Industry, DTI, 2003). Falls on the stairs, which have a high incidence as well as high injury risk, comprise 10% of all fall-related severe injuries (Startzell et al., 2000). Women were at higher risk of stair-related injury than men (Hemenway et al., 1994; Nagata, 1991; Stevens and Sogolow, 2005; Templer, 1992). Thus, we assume that gender differences of kinematics and kinetics may exist and that these factors could cause gender

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differences in movement characteristics that contribute to the higher incidence of fall injury in women. The previous studies, which have reported the incidence of fall on the stairs, did not differentiate the stair-to-ground descent transition from the stair-to-stair descent. Therefore, it is difficult to know which state has more incidence of fall on stairs. However, it is worthy to investigate the stair-to-ground descent transition. Because the transition requires higher neuromuscular recruitments from the supporting limb to precisely control body movement (James and Parker, 1989). Furthermore stair-to-ground transition has slightly higher Locomotor Risk Index score than stair-to-stair descent (Sheehan and Gottschall, 2012). Therefore, comparing the movements of the lower limbs during stair-to-ground descent transition between genders could help us understand and even prevent falls.

Despite gender disparities in various intrinsic factors and the incidence of falls on the stairs, gender differences in kinematics and kinetics during stair descent remain unknown. Previous studies reported gender differences in lower extremity movements during stair descent (Baldon Rde et al., 2013; Singhal et al., 2014). Baldon et al. studied the gender differences in hip and knee kinematics in the coronal and transverse planes during stair descent at specific knee flexion angles (30°, 40°, 50°, 60°). Singhal et al. reported the kinetic comparison of older men and women during walk-to-stair descent transition. However, both studies did not report relations between kinematics and kinetics. It is important to study the relations between kinematics and kinetics to investigate the human movement of any motion.

Toe contact makes it easier to control the forward momentum of the body than heel contact due to more anterior position of center of pressure relative to center of mass (Grabiner et al., 1993; Pijnappels et al., 2004; van Dieen et al., 2008). Forward momentum of the body could increase the risk of fall during stair descent (Hof et al., 2005; van Dieen et al., 2008). Thus, the relation between the contact point and center of mass position is important to understand the risk of fall on stairs during stair descent. Also, this relation could change the knee and ankle joint kinetics. Center of mass position closer to the contact point could reduce the knee joint moment (Hahn and Chou, 2004; McFadyen and Winter, 1988; Protopapadaki et al., 2007). In this study, the relation between the contact point and center of mass position can be inferred from the sagittal ground-toe-trochanter angle (GTT angle) and sagittal ground-toe length (GT length). Higher GTT angle and lower GT length represent lesser anterior position of center of pressure relative to center of mass. The purpose of this study was to determine whether the gender differences in knee and ankle kinematics and kinetics exist in the sagittal plane during stair-to-ground descent transition. It was hypothesized that 1) women would reveal higher GTT angle and lower GT length during stair descent than men; and 2) women would reveal lower peak knee extension moment (PKEM) during stair-to-ground descent transition than men.

2. Methods

2.1. Subjects

Thirty healthy subjects, 15 male (age: 24.1 (SD: 1.5) years, mass: 72.4 (SD: 6.8) kg, height: 1.75 (SD: 0.05) m, BMI: 23.0 (SD: 2.5)) and 15 female (age: 22.6 (SD: 1.0) years, mass: 55.2 (SD: 8.2) kg, height: 1.62 (SD: 0.05) m, BMI: 20.9 (SD: 2.5)), participated in this study after signing an informed consent form approved by the university's institutional review board. Subjects were excluded from the study if they have any current pain or injury or a history of lower limb musculoskeletal injuries requiring surgery.

2.2. Experimental protocol

The experimental two-step staircase (step height: 30 cm, width: 70 cm, depth: 35 cm) was designed with force platform embedded on the floor. The step height of 30 cm was designed, since high stair is a risk factor of fall and it could give subjects extreme condition to increase the sensitivity in detecting gender differences during stair descent. Subjects were instructed to perform stair descent using self-selected dominant limb and speed. Dominant limb is defined as the preferred limb when kicking a ball. After subjects were accustomed to stair descent activity with several trials, the data collection was performed. All subjects descended the stairs (one foot on each step) as naturally as usual stair descent. Two valid trials were collected. Between the trials, the subject had a 3-minute break time to rest. The force plate was embedded into the ground after the last stair. Data were collected from initial contact on the floor to toe off. The initial contact was defined when the vertical ground reaction force exceeded 20 N. Fifteen retro-reflective markers were placed to calculate the knee and the ankle joints motion on the following locations: the skin over the sacrum, right and left anterior superior iliac spine, greater trochanter, thigh, lateral and medial femoral epicondyles, lateral and medial edges of the tibial plateau, shank, lateral and medial malleoli, and first and fifth metatarsal head. The kinematic data were recorded at 400 Hz using a motion analysis system equipped with five infrared cameras (Eagle; Motion Analysis Corp., Santa Rosa, CA). A force plate (9260AA6; Kistler, Winterthur, Switzerland) was used to obtain ground reaction force at a sampling frequency of 1200 Hz.

2.3. Data analysis

Kinematic data were calculated using marker coordinate data and an anatomical coordinate system. A previously described method (Dyrby and Andriacchi, 2004) was used to define the femoral and tibial coordinate systems. The foot coordinate system was defined using a similar procedure. The superior–inferior (SI) axis was the cross-product of the two vectors, which are from heel to first metatarsal head and from heel to fifth metatarsal head as a normal to the sole and origin from the heel. The temporary medial–lateral (ML) axis was the cross-product of the two vectors, which are from heel to mid-point of a line between the medial and lateral malleoli and from heel to any point that lies on the SI axis. The SI axis and the temporary ML axis produced the anteroposterior (AP) axis. Finally, to complete the orthogonal coordinate system, the cross-product of the AP and SI axes was performed. The knee joint center was estimated to be at the mid-point of a line between the medial and lateral tibial plateau. The ankle joint center was calculated to be at the mid-point of markers placed on the medial and lateral malleoli. Knee and ankle joint angles were calculated using Euler angle rotations of the tibia relative to the femur and of the foot relative to the tibia.

Knee and ankle kinetic parameters were obtained by combining the kinematic and ground reaction force data with the anthropometric data and solving the Newton–Euler equations using inverse dynamics (Winter et al., 1990). The sagittal GTT angle was defined as the angle between the line connecting the trochanter marker and the toe marker and the line connecting the toe marker and ground point as the horizontal line through the toe (Fig. 1). The GTT angle can remove the influence of stature. This concept of GTT angle was adapted from the previous study (Lee and Chou, 2007). Lee and Chou (2007) proposed a method, namely, COM-COP inclination angles, which removed the influence of stature. Sagittal GT length was defined as the distance between the ground point and the toe marker (Fig. 1). The kinematics and ground reaction force data were digitally smoothed using a zero-lag fourth-order Butterworth low-pass filter at a cutoff frequency corresponding to 15 Hz (Bisseling and Hof, 2006).

Stair descent was analyzed using three phases: initial contact, first half of stance, and second half of stance. The early weight-acceptance phase was defined as the first half of the stance, and the late weight-acceptance phase was defined as the second half of the stance. For the knee and ankle joints, angles, moments, forces, power, and work in the sagittal plane were calculated and analyzed. Joint power was defined as the product of joint angular velocity and moment. Joint work