Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Clinical Biomechanics 22 (2007) 203–210
CLINICAL BIOMECHANICS
www.elsevier.com/locate/clinbiomech

Hip, knee, ankle kinematics and kinetics during stair ascent and descent in healthy young individuals

Anastasia Protopapadaki [a], Wendy I. Drechsler [a,*], Mary C. Cramp [a], Fiona J. Coutts [b], Oona M. Scott [a]

[a] School of Health and Biosciences, University of East London, Romford Road, Stratford, London E15 4LZ, UK
[b] School of Health Sciences, Queen Margaret University College, Edinburgh, UK

Received 12 January 2006; accepted 19 September 2006

Abstract

Background. Few studies have reported the biomechanical aspects of stair climbing for this ergonomically demanding task. The purpose of this ethically approved study was to identify normal functional parameters of the lower limb during stair climbing and to compare the actions of stair ascent and descent in young healthy individuals.

Methods. Thirty-three young healthy subjects, (16 M, 17 F, range 18–39 years) participated in the study. The laboratory staircase consisted of four steps (rise height 18 cm, tread length 28.5 cm). Kinematic data were recorded using 3D motion analysis system. Temporal gait cycle data and ground reaction forces were recorded using a force platform. Kinetic data were standardized to body mass and height.

Findings. Paired-samples *t* tests showed significantly greater hip and knee angles (mean difference standard deviation (SD): hip 28.10° (SD 4.08), knee 3.39° (SD 7.20)) and hip and knee moments (hip 0.25 N m/kg (SD 0.18), knee 0.17 N m/kg (SD 0.15)) during stair ascent compared to descent. Significantly greater ankle dorsiflexion angles (9.90° (SD 3.80)) and plantarflexion angles (8.78° (SD 4.80)) were found during stair descent compared to ascent. Coefficient of variation (mean (SD)) in percentage between repeated tests varied for joint angles and moments, respectively (2.35% (SD 1.83)–17.53% (SD 13.62)) and (4.65% (SD 2.99)–40.73% (SD 24.77)).

Interpretation. Stair ascent was shown to be the more demanding biomechanical task when compared to stair descent for healthy young subjects. The findings from the current study provide baseline measures for pathological studies, theoretical joint modelling, and for mechanical joint simulators.

Keywords: Stair climbing; Motion analysis; Kinematics; Kinetics

1. Introduction

Stair climbing is a common activity of daily life. Kinematic and kinetic studies have shown that, in comparison to level walking, larger ranges of knee flexion angle and knee flexion moment are required during stair climbing (Andriacchi et al., 1980; Jevsevar et al., 1993). Andriacchi et al. (1980) found the maximum external knee flexion moment during stair ascent to be three times greater than level walking and maximum hip flexion moments during stair descent to be a maximum of 1.5 times greater than level walking. Jevsevar et al. (1993) found an average of 98.6° (SD 6.5°) of knee flexion was required to ascend stairs, 90.3° (SD 4.9°) of knee flexion to descend stairs and 64.6° (SD 6.7°) of knee flexion to walk on level ground. Analysis of the biomechanical requirements involved in stair climbing can add to our understanding of the diverse demands of this common activity in human locomotion.

In comparison to level walking, only a small number of studies have investigated normal human stair ascent and

* Corresponding author.
E-mail address: w.drechsler@uel.ac.uk (W.I. Drechsler).

0268-0033/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.clinbiomech.2006.09.010

descent (Andriacchi et al., 1980; Costigan et al., 2002; Kowalk et al., 1996; Livingston et al., 1991; McFadyen and Winter, 1988; Riener et al., 2002). Researchers have also used stair climbing to describe changes in a patient's functional performance following knee arthroplasty (Andriacchi et al., 1982; Andriacchi and Galante, 1988), anterior cruciate ligament deficiency (Berchuck et al., 1990; Andriacchi and Birac, 1993) transtibial amputations (Powers et al., 1997) and patellofemoral pain (Salsich et al., 2001; Brechter and Powers, 2002). Understanding the biomechanics and pathomechanics of the lower limb during stair climbing is important for therapists attempting to integrate scientific findings into clinical examination and management of patients with lower extremity dysfunction.

Andriacchi et al. (1980) investigating hip, knee, ankle joint angles and moments in ten young healthy male subjects during stair climbing found maximum external knee flexion moments during stair descent to be 2.7 times greater than during ascent. They used the ground reaction method for the calculation of joint moments. This method involves calculation of joint moment by calculating the product of the ground reaction force vector and the perpendicular distance from the joint center to that vector (Winter, 1991). Wells (1981) found that the ground reaction method is a good predictor of net joint moments for slow gait, but increasing the velocity of gait results in increased errors, especially at the hip. Therefore for healthy populations, the linked segment method is preferable to calculate joint moments; the linked segment method takes into consideration the mass-acceleration products of the foot, leg and thigh, that the ground reaction method neglects (Winter, 1991). McFadyen and Winter (1988) used the linked segment method for the calculation of joint moments during stair climbing. However, the small sample size ($n = 3$) in their study limits the power and usefulness of the results. Kowalk et al. (1996) reported external abduction–adduction moments at the knee joint in young adults ($n = 10$) ranging in age from 22 to 40 years, while Costigan et al. (2002) reported only external hip, knee moments ($n = 35$, mean age = 24.6). Further studies that include larger numbers of subjects and more developed analysis of joint moments are required before definitive conclusions can be made.

Livingston et al. (1991) investigated stair climbing kinematics of the hip, knee, and ankle joints on stairs of differing dimensions. Fifteen young healthy women were divided into short, medium, and tall subject groups with five subjects in each group ranging in age from 19 to 26 years. Subject height appeared to influence knee motion during stair climbing. Short subjects used greater maximum knee flexion angles than taller subjects during stair ascent and descent. Riener et al. (2002) investigating how stair inclination affects the kinematic and kinetic patterns of stair climbing ($n = 10$, mean age = 28.8 years) found joint ranges and maximum flexion angles to increase with increasing inclination of the staircase.

So far, few if any studies have provided a comprehensive set of data on biomechanics of the hip, knee and ankle joint in healthy young subjects during stair-climbing; either the subject populations were small or a limited number of parameters were reported. The purpose of the present study was to identify normal functional parameters in the hip, knee and ankle joints during stair climbing in healthy individuals.

2. Methods

2.1. Subjects

Thirty-three healthy subjects, 16 men and 17 women, ranging in age from 18 to 39 (mean age 28.09 years; standard deviation 6.08) mean height 1.69 m (SD 0.08) and mean mass 67.48 kg (SD 12.12), recruited from the staff and student population of the University of East London participated in this study. Subjects were excluded from the study if they presented with: history of injury to the lower limbs in the previous 6 months, any type of lower extremity surgery, pathology of the back and pelvis, systematic disease, neuromuscular disease, or balance problems. Eleven subjects from the above population, seven men and four women, (range 19–36 years), mean age 27 years (SD 6.62), mean height 1.72 m (SD 0.07) and mean mass 70 kg (SD 10.66) were tested on two separate occasions to test variability of the data recorded. This study was approved by the University of East London Research Ethics Committee and all subjects gave their written informed consent to participate.

2.2. Equipment

The experimental staircase consisted of four steps (step height 18 cm, tread length 28.5 cm). Kinematic and kinetic recordings were collected from an 8-camera, three-dimensional motion analysis system (Vicon M3 camera system, Oxford Metrics Ltd, UK) and force platform (Bertec Model 4020 H, MIE Ltd, Leeds, UK) positioned in the second stair step. Kinematic data were collected at a sampling rate of 120 Hz and ground reaction forces were collected at a rate of 1080 Hz. Both kinematic and kinetic data were recorded simultaneously on a personal computer.

2.3. Subject preparation and procedure

All subjects were barefoot and wore shorts to allow attachment of reflective markers on the skin of the lower limbs. Reflective markers (14 mm spheres) were placed on: second metatarsal head, lateral malleolus, posterior calcaneus at the same level as the second metatarsal marker, lateral surface of tibia, lateral aspects of the knee joint, lateral surface of the thigh below hand swing, and over both anterior and posterior superior iliac spines. To enable calculation of hip, knee, and ankle joint angles and external joint moments, anthropometric measures were obtained including bilateral leg length, knee width, ankle width, height, and body mass. All participants were instructed