Gait & Posture 34 (2011) 239–244

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

The biomechanical functional demand placed on knee and hip muscles of older adults during stair ascent and descent

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ARTICLE INFO

Article history:
Received 23 April 2010
Received in revised form 26 April 2011
Accepted 7 May 2011

Keywords:
Functional demand
Stair negotiation
Knee
Hip
Moments
Biomechanical analysis
Muscle strength
Stair ascent
Stair descent

ABSTRACT

Age-related decline in physical capabilities may lead to older adults experiencing difficulty in performing everyday activities due to high demands placed on the muscles of their lower extremity. This study aimed to determine the biomechanical functional demand in terms of joint moments and maximal muscle capabilities at the knee and hip joints while older adults performed stair ascent (SA) and stair descent (SD). Eighty-four healthy older adults aged 60–88 years were tested. A torque dynamometer attached to a purpose-built plinth was utilized to measure muscle moments at the knee and hip joints. Participants also underwent full body 3-D biomechanical assessment of stair ascent and descent using an 8-camera VICON system (120 Hz) with 3 Kistler force plates. Stair negotiation required knee extensor moments in excess of the maximum isometric muscle strength available (SA 103%, SD 120%). For the hip, the levels of demand were high, but were slightly lower than those of the knee joint. Stair negotiation placed a high level of demand on the knee extensors with demand in SA reaching maximal isometric capacity and demand in SD exceeding maximal isometric capacity. The levels of demand leave little reserve capacity for the older adult to draw on in unexpected situations or circumstances.

1. Introduction

Stair negotiation is an important functional activity for independent living. It is a physically challenging activity and peak knee flexion moments during stair ascent (SA) have been reported to be three times greater than those of level walking [1,2]. Diminishing physiological reserves and a decline in physical capacities with increasing age might predispose the older person to an increased risk of falls. The prevalence of injurious falls on stairs is high in older adults with over 60% of the accidents occurring on stairs [3].

Biomechanical analysis of stair negotiation could enhance our understanding of the requirements of this demanding task and help develop appropriate clinical interventions to improve performance on stairs. Investigations into stair ascent and stair descent (SD) have been limited to a few studies involving small sample sizes [4–7]. Andriacchi et al. [1], investigated stair negotiation ability in young males and reported that SA and SD produced large moments at the hip, knee and ankle joints and the highest external knee flexion moment during SD was 2.7 times greater than during SA. Similarly, Hortobágyi et al. [8] reported high external knee moments during SD while investigating the relative efforts during stair negotiation in young and older adults. Older adults required 1.0 Nm/kg of knee moment to go up the stairs and 0.6 Nm/kg of knee moment to perform a stair descent with high loading placed on knee extensors during stair negotiation. They focussed only on knee moments and hence information on other lower extremity joints was lacking [8]. Reeves et al. [9,10] observed that even though external moments required at the knee joint were well within the maximal limits during stair negotiation, nevertheless older adults operated at a higher proportion of their maximum values when compared to young adults. Although previous studies have highlighted the high loading placed on knee and ankle joints [8,9,11], there is a lack of data on the functional loading placed on hip muscles during stair negotiation. Furthermore no previous studies have looked at the age-related decline in performance on stairs in a large sample of non-elite older people.

The level of "Functional Demand" (FD) generated by different daily living tasks is of interest to clinicians, bioengineers, patients and their carers so as to set targets for rehabilitation [12]. FD is dependant on the external moments developed by gravity and inertia at each of the joints and the internal moments required to be produced by the muscles crossing that joint in order to counteract the external moment generated during a functional task [13]. Conventionally, the loading on the muscle group has been evaluated by comparing the peak external moment in a functional task with the maximum muscle strength. However this method is flawed because the peak external moment may occur at

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doi:10.1016/j.gaitpost.2011.05.005

a joint angle different to the position of maximal muscle strength. Muscle strength is also highly dependent on joint angle [14]. Hence, in this study we defined ''Functional Demand'' as the ratio of external moment generated during the functional task at a particular point in time for a particular joint at a specific joint angle divided by the muscle moment available at that joint for that particular joint angle [15]. Therefore, FD was calculated on an instant to instant basis for the joint and using the relevant muscle strength for that joint at that angle. The aim of the present study was to determine the level of functional demand placed on the hip and knee joints during stair negotiation in older adults.

2. Methods

Ethical approval was obtained from the Ethics Committee of the Bioengineering Unit, University of Strathclyde. All subjects gave their written informed consent prior to participation in the study.

2.1. Participants

Eighty four healthy older adults (mean age 73.2 $\pm$ 7.3; age range 60–88 years) including 41 males (mean $\pm$ SD age: 73.4 $\pm$ 7.1 years; height: 1.73 $\pm$ 0.07 m; body mass: 78.7 $\pm$ 13.7 kg) and 43 females (mean $\pm$ SD age: 72.9 $\pm$ 7.6 years; height: 1.60 $\pm$ 0.07 m; body mass: 69.1 $\pm$ 13.4 kg) were recruited from older adult organizations in the Greater Glasgow area, Stirlingshire and Ayrshire in Scotland, UK. Participants were from a wide range of social, economic and educational backgrounds. The inclusion and exclusion criteria proposed by Greig et al. [16], were adopted for inclusion of older adults and those with neurological conditions, musculoskeletal disease or systemic disorders were excluded from the study. Participants attended the Biomechanics Laboratory at the University of Strathclyde for two, 2-h sessions, one for muscle strength tests and one for whole body biomechanical assessment.

2.2. Equipment and protocol

2.2.1. Muscle strength measurements

A torque dynamometer attached to a plinth (Fig. 1) designed and built at the Bioengineering Unit, University of Strathclyde was utilised to measure isometric muscle moments. Details of the equipment utilised for testing lower extremity strength, have been reported previously [14]. Muscle strength was tested through joint range for knee extensors and flexors (at 90°, 60°, and 20° of knee flexion) and hip extensors and flexors (at 45°, 30°, and 0° of hip flexion). The joint angles were chosen to reflect the lengthened, mid and shortened positions of muscle action for the respective muscle groups. As a first approximation, muscle strength was assumed to vary linearly between data points. However, in reality the curve will be polynomial but given the limited number of joint positions tested only a linear interpolation was possible. The test positions were standardised ensuring measurements of strength at the hip and knee were consistent with regard to the whole body posture. In addition, postural restraints, namely an upper body harness system, a pelvic strap and thigh strap were utilised to isolate force measures to the individual muscle groups tested. Maximal isometric contractions were held for three seconds each, with a 30 s rest period between consecutive contractions. A sub-maximal practice trial was performed prior to actual testing and instructions provided to participants were standardised. Strong verbal encouragement using standardised instructions and visual feedback was provided to participants. The maximum value from two trials was used in the analysis. Body mass and height were measured using metric equipment. The sign convention adopted was that flexion moments were positive and extension moments were negative.

Fig. 1. Torque dynamometer.

2.2.2. Biomechanical analysis

A full body 3-D biomechanical assessment was carried out during stair ascent and descent using a VICON (Vicon v 4.4; Oxford Metrics, UK) 8-camera motion analysis system (120 Hz) with 3 Kistler forceplates (1080 Hz). Vicon BodyBuilder was used to analyze the data, calculate joint angles and external moments. A full body marker placement protocol was developed to enable identification of bony landmarks while minimising artefacts caused by soft tissue movement. The participants wore tight Lycra body suits and normal shoes during the tests. 14 mm reflective markers were attached using double-sided wig tape to the bony landmarks. Individual markers were attached bilaterally to the ASIS, PSIS, medial/lateral epicondyles of femur, medial/lateral malleoli, C7 spine, T8, jugular notch, ziphysternum, proximal/distal 3rd metacarpal, distal 5th metacarpal, ball of big toe, 5th metatarsal and mid heel. In addition, cluster of markers (4 markers) were attached to cuffs placed on the upper arm, forearm, thigh and lower leg bilaterally. A custom-built four-step instrumented stairway (step height – 185 mm; depth – 280 mm) with hand rails was utilised in order to promote normal stair climbing during the measurements. Force plate data was collected from the second step and hence was part of a complete stair climbing cycle for both ascent and descent. Participants performed three practice sessions at a self-selected speed and data were captured for three subsequent repetitions of each activity. Three trials were performed and the average of the three was taken. The trials were labelled manually and processed using a purpose written program in Vicon Body builder software. The data were output as ASCII files and imported into Excel for further analysis. A purpose written program in Excel was used to amalgamate the data on the knee and hip angles and moments produced during the above functional activities.

The muscle strength data were combined with the biomechanical moment and angle data to determine the ''functional demand'' placed on the muscles during stair negotiation. Functional demand (FD) for a muscle group was defined as the muscle moment required at a particular joint angle, divided by the maximum isometric muscle strength available at that joint angle (expressed as a percentage). In