Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Gait & Posture 27 (2008) 564–571
GAIT POSTURE
www.elsevier.com/locate/gaitpost

Kinetic analysis of forwards and backwards stair descent

François G. D.Beaulieu [a], Lucie Pelland [b], D. Gordon E. Robertson [a,*]

[a] School of Human Kinetics, University of Ottawa, Ottawa, Ontario, Canada
[b] School of Rehabilitation Therapy, Queen's University, Kingston, Canada

Received 3 June 2006; received in revised form 24 June 2007; accepted 13 July 2007

Abstract

The activity of descending stairs increases loading at the joints of the lower extremities as compared to walking, which may cause discomfort and or difficulties in completing the task. This study compared and contrasted the kinematics and kinetics of both forwards and backwards stair descent to those of level walking. We compared the support moments and moment powers of the lower limb joints while descending stairs forwards at a self-selected pace, backwards at a self-selected pace and forwards at the same pace as backwards. Participants were 10 healthy young adults (6 men and 4 women) aged 20–35 years. Sagittal plane kinematics and ground reaction forces were collected and moments of force computed using inverse dynamics. The ratio of stance/swing phase changed from 59:41 for normal level walking to between 65:35 and 70:30 for forward stair descent but backwards descent was 58:42. Stair descent produced larger double-peak support moments with reduced ankle plantar flexor and increased knee extensor moments as compared to level walking (>±95th-percentile confidence interval). The hip moments during stair descent were relatively small and highly variable. We observed significantly larger distances between the centres of pressure and the stair edges for backwards stair descent versus forwards stair descent. These results demonstrate that stair descent, even at a slower pace, requires greater power from the knee extensors than level walking but that backwards stair descent significantly reduced the peak knee power during midstance and provided a potentially safer means of descending stairs than forwards stair descent.

Keywords: Gait; Mechanical power; Support moment; Inverse dynamics; Falls

1. Introduction

Daily, we encounter stairs at the workplace, during leisure activities, pedestrian travel and at home. For those with muscle weakness or joint dysfunction, such as arthritis, ascending and particularly descending stairs can be a difficult, risky and painful task. One solution that occasional long-distance runners and athletes use to deal with the difficulty of descending stairs after heavy exercise is to descend them backwards. Backwards stair descent is also commonly used when stairs are very steep such as on ladders or ships where forward descent can easily result in a fall. Falls on stairs are a leading cause of accidental deaths and of morbidity [1] and have therefore attracted attention concerning injury prevention [2,3]. Backwards stair descent may offer a less stressful and safer means of descending stairs under certain circumstances. Since stairs are an integral part of our societal architecture, the ability to manage stairs in a safe and independent fashion is important. For people injured [4] or physically [1,5,6] or cognitively impaired [7] and for the elderly [8,9], stair descent can be strenuous, painful and even dangerous [10]. Suitable strategies should therefore be available to permit safe and comfortable stair descent.

The purpose of this study was to investigate backwards stair descent as an alternate strategy for descending stairs. We wanted to quantify the differences in the patterns of the joint kinetics of the lower extremity to better understand the energetic and loading demands of backwards compared to forwards descent and level walking. We will use the data

* Corresponding author. Tel.: +1 613 562 5800x4253; fax: +1 613 562 5149.
E-mail addresses: fdbeauli@uOttawa.ca (F.G. D.Beaulieu), Lucie.Pelland@Queensu.ca (L. Pelland), dger@uOttawa.ca (D.G.E. Robertson).

0966-6362/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.gaitpost.2007.07.010

compiled and reported by Winter [11] for comparisons with level walking. Furthermore, we wished to examine whether backwards stair descent was potentially safer in terms of preventing falls caused by being too close to the stair edge.

2. Methods

Lower extremity mechanics during forward and backward stair descent were analyzed for 10 able-bodied subjects 20–35 years old (6 males and 4 females). Prior research on stair climbing has demonstrated the effects of leg length on lower extremity mechanics [5,7,12,13] and as such, a stratified recruitment approach was used to ensure a range of heights in our subject group from 165 to 184 cm (see Table 1 for relevant subject information). A questionnaire screened subjects to exclude people with histories of lower extremity joint and muscle impairment. Prior to data recording, subjects provided written informed consent as approved by the responsible ethics committee.

Subjects completed blocks of five stair descent trials under three experimental conditions: forward stair descent at self-selected speed (NF), backward stair descent at self-selected speed (NB) and slower forward stair descent at the same speed as each subject's backward stair descent (SF). External pacing by metronome ensured that speed of descent remained constant within conditions. Stair descent trials were completed on a three-step laboratory staircase (Fig. 1), with step dimensions: 20 cm riser and 30 cm tread [10,12–14]. Subjects started at the landing at the top of the staircase and stepped down onto a force platform (Kistler model 9281C) on the first step. The contralateral leg, which was not analyzed, stepped down to the second step, followed by the ipsilateral leg stepping down to floor level. Subjects continued walking at floor level. The contribution of the arms was eliminated by asking subjects to keep their arms folded across their chest during stair descent.

Segmental motions of the lower limb were recorded on digital video at 60 Hz. The camera was placed perpendicular to the plane of motion so that the right side was filmed during forward stair descent but the left side was filmed during backwards stair descent. Reflective markers were affixed to the iliac crest, greater trochanter, lateral condyle of the tibia, lateral malleolus, lateral calcaneus, base of the 5th-metatarsal and the hallux. Segmental positions were captured offline (Ariel Performance Analysis System), low-pass filtered (6 Hz) and time normalized over the stride cycle from foot-strike (FS) on the second step to the foot-strike on the floor. Ground reaction forces were acquired (at 240 Hz) with Kistler BioWare software and low-pass filtered with a 20 Hz cutoff. Forces were then synchronized with the segmental positions using Biomech Motion Analysis Software [22]. Inverse dynamics [15,16] computed the net moments of force and then their powers at the three joints of the lower extremity were calculated. Moments of force at the three lower extremity joints were summed to determine the support moment [17]. Each subject's trials (5) for each condition were normalized to body mass, time normalized and ensemble averaged. Then, each subject's ensemble average data were ensemble averaged to obtain a grand ensemble for each condition for comparisons among stair descent conditions and for contrasts with published level walking data [11].

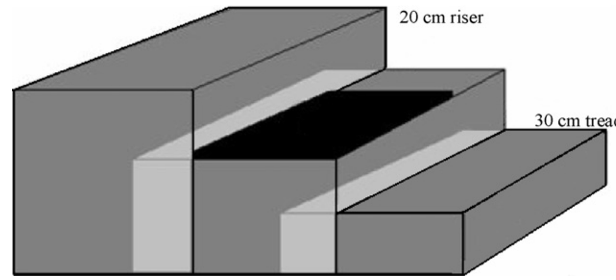

Fig. 1. Schematic of laboratory staircase with force platform on step two.

A repeated-measures ANOVA was performed to identify differences in peak knee moments and powers during the period when the knee extensors performed negative work during midstance (label K3). This event was selected because the powers during this event were largest and it occurred at a period of stair descent where failure could result in collapse. *Post hoc* tests were performed by dependent-groups *t*-tests. In addition, to quantify the risk of slipping down the stairs, time integrals of the horizontal distances between the centres of pressure and the edge of the stair were computed for the SF and NB descents. Differences between the two groups were evaluated by a dependent-groups *t*-test.

3. Results

Fig. 2 compares the support moments and the hip, knee and ankle moments for backwards stair descent and the two speeds of forwards stair descent compared to those reported by Winter [11] for normal-speed level walking. The moments were plotted so that extensor moments were

Table 1
Subject information

	Subject									
	1	2	3	4	5	6	7	8	9	10
Mass (kg)	72.0	81.0	72.0	81.0	85.0	54.1	69.0	57.0	66.0	65.8
Height (cm)	172	181	179	184	180	163	172	164	178	168
Normal forwards (NF) descent time (s)[a]	1.10	1.18	1.23	1.01	1.12	1.17	1.08	1.39	1.05	0.98
Normal backwards (NB) descent time (s)[a,b]	1.35	1.45	1.19	1.47	1.52	1.41	1.39	1.13	1.54	1.05
Normal backwards (NB) distance–time integral (cm·s)[c]	10.5	8.5	8.6	9.9	7.9	8.6	9.1	9.1	Not done	8.1
Slow forwards (SF) distance–time integral (cm·s)[c]	5.7	7.1	5.0	8.7	3.5	4.0	5.4	3.9	Not done	7.5

[a] Average duration from foot-strike of the second step to the next foot-strike of same foot (i.e., two steps).
[b] Slow forwards (SF) descent times were approximately the same as normal backwards.
[c] Average time integrals of the horizontal distance from the stair edge to the centre of pressure of the ground reaction force.