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SCIENCE DIRECT

Gait & Posture 21 (2005) 388–394

www.elsevier.com/locate/gaitpost

Push-off reactions in recovery after tripping discriminate young subjects, older non-fallers and older fallers

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Received 20 February 2004; accepted 20 April 2004

Abstract

Tripping is a major cause for falls, especially in the elderly. This study investigated whether falls in the elderly can be attributed to inadequate push-off reactions by the support limb in the recovery after a trip. Twelve young (20–34 years) and eleven older (65–72 years) men and women walked over a platform and were tripped several times over an obstacle that suddenly appeared from the floor. Kinematics and ground reactions forces of the support limb during push-off were measured of falls and successful recoveries. Young subjects did not fall. The older subjects were divided into a group of four non-fallers and seven fallers. Older fallers showed insufficient reduction of the angular momentum during push-off and less proper placement of the recovery limb. This was due to a lower rate of change of moment generation in all support limb joints and a lower peak ankle moment. Onset of knee moment generation was slightly delayed in older fallers. Improvement over trials was ascribed to better positioning of the recovery limb, as no clear differences were seen in the joint moments of the support limb. In conclusion, the contribution of the support limb to prevent a fall after tripping is decreased in older adults. Lower limb strength could be an underlying factor and strength training might help to reduce fall risk.

Keywords: Fall prevention; Postural control; Perturbation; Angular momentum; Strength

1. Introduction

Identification of factors reducing the ability to prevent a fall in the elderly can be used to define intervention targets in fall prevention programs [1]. As tripping is one of the main causes for falls [2–4], several authors have investigated recovery reactions after tripping in young adults [5–13]. Pavol and co-workers investigated recovery after tripping in a group of older adults [14–18]. They found that a decreased lower extremity strength on the one hand increases fall-risk by limiting the ability to execute the required motor response, but on the other hand decreases fall-risk as less strong people walk slower, which makes recovery after a trip less demanding.

The essence of preventing a fall after tripping is to reduce the angular momentum, which the body acquired from impact with the obstacle. Eng et al. [5] described two strategies for recovery after tripping. An elevating strategy is observed after a perturbation in early swing and consists of an elevation of the obstructed (ipsilateral) swing limb to overtake the obstacle. A lowering strategy is seen during late swing and consists of an immediate placement of the obstructed foot on the ground, followed by a step of the contralateral limb to overtake the obstacle. For both strategies, the foot that is positioned forward after the trip is defined the recovery foot. In this paper, we focus on the elevating strategy.

Placing the recovery limb anteriorly of the body to generate force is one means to reduce the angular momentum [6,7,16]. In addition, the support limb (stance limb at time of tripping) plays an important role, before the recovery limb hits the ground [12,13]. During the push-off phase (from the instant that contact of the swing foot with the obstacle ends until support limb toe-off), the support limb can contribute to recovery by generating adequate forces.

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0966-6362/$ – see front matter
doi:10.1016/j.gaitpost.2004.04.009

This way, the support limb can provide time and clearance for proper recovery limb positioning, but can also reduce the angular momentum of the body. This can contribute to recovery success, because the more angular momentum is taken away by the support limb, the less remains to be accomplished by the recovery limb. During push-off, young subjects generate fast and large ankle and hip extension moments [13]. Generating such reactions could be a problem for the elderly, since lower extremity strength, rate of force generation and reaction speed decline with age [19,20].

The purpose of this study was to investigate (1) whether older adults react less adequately than young adults during the primary phase of recovery after tripping and (2) why some older adults fall more often than others. For this purpose, we had 12 young and 11 older subjects walk over a platform, and tripped them several times over an obstacle. Kinematics and ground reactions forces during push-off were measured. We expected older subjects to react more slowly and generate lower joint moments (relative to body mass) than young subjects during push-off. Consequently, the support limb would contribute less to reduction of the angular momentum during push-off, resulting in a higher frequency of falling.

2. Methods

2.1. Subjects

Twelve young and eleven older subjects voluntarily participated in this study (Table 1). Subjects were informed on the research procedures before they gave informed consent in accordance with the ethical standards of the declaration of Helsinki. Protocol, data collection, and part of the results of the young subjects were described previously [12,13].

2.2. Experimental setup and protocol

Subjects were instructed to walk at a self-selected speed over a 12 m × 2.5 m platform. A force plate was mounted in the platform and 21 aluminum obstacles (15 cm height) were hidden over a total distance of 1.5 m. In about 10 out of 50 walking trials, one obstacle appeared from the ground unexpectedly to catch the subject's swing limb. Online kinematic data were used to calculate where and when an obstacle had to appear to initiate a trip at mid-swing. A full-body safety harness, attached to a ceiling-mounted rail, prevented subjects from falling on the floor. The safety ropes provided enough slack for free motion, and a spring, in series with the ropes, ensured smooth restraint in case of an imminent fall. For the young subjects, video data allowed visual detection of harness assistance. For the older subjects, a force transducer (AMTI M3-1000), in series with the safety ropes, measured the force exerted on the ropes. Trials were classified as falls when the vertical force in the ropes exceeded 200 N, at which point the slack in the ropes was taken up and the compression spring, that had a pretension of 200 N, started to stretch out.

2.3. Data collection and analysis

Gait kinematics were recorded using four Optotrak camera arrays (Northern Digital). Motions of 12 infrared-light emitting markers, placed on joints bilaterally, were tracked and seven body segments were defined. Ground reactions forces and centre of pressure of the support limb were measured with a custom-made strain gauge force plate. All data were collected and synchronized at a sample frequency of 100 Hz.

For each subject, five trials of normal walking were selected that had complete kinematic and dynamic data. For the young subjects, five tripping trials at mid-swing were selected. For the older subjects, available tripping trials ranged from 1 to 6, as some subjects also performed a lowering strategy at mid-swing, which could not be used for these analyses.

Heel strike, toe-off and obstacle-foot contact were detected, based on kinematic data [21]. For the older subjects, this method of detecting timing of obstacle-foot contact was evaluated using the signal of an accelerometer on the obstacles, sampled at 1000 Hz. The detection method based on kinematic data resulted in an acceptable mean error of 1.61 ms (S.D. 5.82). Data were analyzed in the sagittal plane after smoothing with a fifth order filter [13]. To investigate the contribution of push-off by the support limb on control of the angular momentum, we calculated the external moment (M_{ext}), which equals the rate of change in the angular momentum of the entire system. M_{ext} was calculated as the sum of the moments about the body centre of mass, generated by ground reaction force and obstacle-foot contact force [12]. In addition, we investigated the

Table 1
Subject characteristics; group averages (and S.D.)

Group	# subjects	Gender	Age (y)	Height (m)	Weight (kg)
Young	12	6 ♂, 6 ♀	27.1 (4.3)	1.78 (0.07)	75.1 (8.9)
Old					
Old overall	11	4 ♂, 7 ♀	67.6 (2.7)	1.72 (0.11)	77.0 (9.6)
Non-fallers	4	3 ♂, 1 ♀	66.5 (3.3)	1.72 (0.15)	75.4 (11.5)
Fallers	7	1 ♂, 6 ♀	67.9 (2.6)	1.71 (0.08)	74.2 (7.8)