Applied Ergonomics 62 (2017) 77–82

Contents lists available at ScienceDirect

Applied Ergonomics

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

Required friction during overground walking is lower among obese compared to non-obese older men, but does not differ with obesity among women

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ARTICLE INFO

Article history:
Received 1 August 2016
Received in revised form
21 December 2016
Accepted 13 February 2017

Keywords:
Required friction
Obesity
Aging

ABSTRACT

Obesity and aging have been independently associated with altered required friction during walking, but it is unclear how these factors interact to influence the likelihood of slipping. Therefore, the purpose of this study was to determine whether there are differences related to obesity and aging on required friction during overground walking. Fourteen older non-obese, 11 older obese, 20 younger non-obese, and 20 younger obese adults completed walking trials at both a self-selected and hurried speed. When walking at a hurried speed, older obese men walked at a slower gait speed and exhibited lower frictional demands compared both to older non-obese men and to younger obese men. No differences in required friction were found between non-obese and obese younger adults. These results suggest that the increased rate of falls among obese or older adults is not likely due to a higher risk of slip initiation.

1. Introduction

Slipping is responsible for a substantial proportion of occupational falls across many industry sectors, including 55% of falls among healthcare workers (Courtney et al., 2010), and 24% of falls among manufacturing plant workers (Amandus et al., 2012). In a specific example within the construction sector, slips caused 85% of falls to the floor and 30% of falls to a lower level during construction of the Denver International Airport between 1989 and 1994 (Lipscomb et al., 2006). Falls on the same level, many of which are caused by slips, are ranked as the second leading cause of disabling workplace injuries after overexertion—accounting for 16.4% of all workplace injuries and $10.1 billion in direct costs (Liberty Mutual, 2015). A slip occurs when the required friction to prevent slipping at the shoe/floor interface exceeds the available friction. Required friction is dependent upon individual and gait characteristics (Anderson et al., 2014; Burnfield et al., 2005; Cooper et al., 2008; Moyer et al., 2006; Redfern et al., 2001), while available friction is dependent upon the tribology of shoe sole and supporting surface characteristics (Chang et al., 2014; Kim et al., 2013; Li et al., 2006; Tsai and Powers, 2009). The likelihood of slipping increases when either the required friction increases, or when the available friction decreases (Burnfield and Powers, 2006; Hanson et al., 1999; Tsai and Powers, 2009).

A growing number of studies suggest a higher rate of falling among individuals who are obese (Chau et al., 2004; Fjeldstad et al., 2008; Himes and Reynolds, 2012). This is problematic because obesity afflicts over 35% of adults in the United States (Ogden et al., 2012). The higher rate of falling among individuals who are obese may be due, in part, to more slip-induced falls. There are two possible mechanisms by which obesity may result in more slip-induced falls, including a greater likelihood of slipping (i.e. propensity for slip initiation), or greater difficulty recovering balance once a slip is initiated (Allin et al., 2016). This study will focus on the former. Only two studies to our knowledge have investigated obesity-related differences in required friction while walking. Results of these studies were somewhat consistent in that both reported a higher required friction in a directional component of the overall required friction among obese or overweight younger adults. Wu et al. (2012) reported a 40% higher required friction in the medial-lateral direction during overground walking among

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http://dx.doi.org/10.1016/j.apergo.2017.02.010
0003-6870/

younger obese compared to healthy-weight men, but no difference in the overall (combined anterior-posterior and medial-lateral directions) required friction. Liu (2010) reported an 18% higher required friction in the anterior-posterior direction during treadmill walking among younger overweight compared to healthy-weight adults.

Advanced age is also associated with a higher rate of falling (Talbot et al., 2005), and may be due, in part, to a higher likelihood of slipping. Several studies have investigated differences between older and younger adults in required friction while walking, but with inconsistent results. Some have reported 13–21% lower required friction among older compared to younger adults (Anderson et al., 2014; Kim et al., 2005; Lockhart et al., 2007), while others have reported no age-related differences (Burnfield and Powers, 2003; Burnfield et al., 2005; Lockhart et al., 2003, 2005). It should also be noted, though, that older adults typically walk at slower speeds (Burnfield et al., 2005; Kim et al., 2005; Lockhart et al., 2003, 2005) and/or with decreased step lengths (Lockhart et al., 2003, 2005), both of which decrease the required friction (Anderson et al., 2014; Burnfield et al., 2005; Cooper et al., 2008; Fendley and Medoff, 1996; Moyer et al., 2006).

Given the large obese and aging populations in the United States, the prevalence of slip-induced falls, and the potential for obesity and age to interactively influence slip-induced falls, the purpose of this study was to investigate obesity and age-related differences in the required friction while walking. We hypothesized that the required friction would be: 1) higher among obese compared to non-obese adults; 2) lower among older compared to younger adults; and 3) influenced by an obesity $\times$ age interaction, in that obesity-related differences would differ with age (or vice versa). The third hypothesis was based upon the possibility that the opposing effects of obesity and age described in the first two hypotheses would offset each other. Results from this study were intended to help clarify how obesity and age influence the likelihood of slipping while walking, as well as the higher rate of falls among these individuals. A better understanding of how individual factors such as obesity and age contribute to slip-induced falls can inform future fall prevention efforts.

2. Materials and methods

Sixty-five adults completed this study (Table 1), including four groups of subjects: 14 older (age 60–80 years) non-obese (body mass index, or BMI 18–29.9 kg/m^2) adults (6 women), 11 older obese (BMI 30–40 kg/m^2) adults (5 women), 20 younger (age 18–30 years) non-obese adults (10 women), and 20 younger obese adults (9 women). Subjects were screened to exclude those with self-reported musculoskeletal, neurological, or balance disorders that could influence their gait or safety. This study was approved by the local Institutional Review Board, and written consent was obtained from all subjects prior to participation.

Subjects completed a single experimental session involving four walking trials at a self-selected speed and four walking trials at a "hurried" speed. Trials were completed along a 9-m walkway covered in vinyl flooring. A hurried speed was investigated because required friction has been shown to increase with increasing gait speed (Anderson et al., 2014; Burnfield and Powers, 2003; Chang et al., 2014; Fendley and Medoff, 1996), and obesity/age differences may only exist at higher gait speeds. At no point during the experiment were subjects told there was a chance they would be slipped or perturbed in any way to elicit a fall. All subjects wore athletic clothing, and the same brand of athletic shoes in their requested size to avoid any differences in footwear between subject groups (Menant et al., 2009; Tsai and Powers, 2009). Walking trials at a self-selected speed were completed first. After a short rest, walking trials at the hurried speed were completed by instructing subjects to walk slightly faster than their self-selected speed. Gait speed was estimated after every trial by averaging the anterior-posterior speed of a reflective marker on the right scapula, and subjects were instructed to alter their speed depending on this measurement. The acceptable speed range for the hurried speed trials was 1.7–2.0 m/s. Some subjects could not reach this speed, in which case they were told to simply walk as fast as possible.

During all trials, foot kinematics and ground reaction forces under the dominant (preferred to kick a ball) foot were collected. Foot kinematics were sampled at 100 Hz using a motion capture system (six MX T10 cameras, Vicon Motion Systems, Inc., Los Angeles, CA, USA) and reflective markers placed bilaterally on the heel, lateral malleolus, and fifth metatarsal head. Ground reaction were sampled at 1000 Hz using a force platform (Bertec Corporation, Columbus, OH) embedded in the walkway. Foot kinematics and ground reaction forces were respectively low-passed filtered at 5 and 40 Hz (eighth-order, zero-phase-shift Butterworth filter), prior to further processing.

Required friction was defined as the peak required coefficient of friction (RCOF) during the weight acceptance portion of the stance phase of gait (Anderson et al., 2014; Burnfield and Powers, 2006; Burnfield et al., 2005; Cham and Redfern, 2002; Redfern et al., 2001). RCOF throughout the stance phase was first determined by dividing the magnitude of the shear ground reaction force (resultant of the anterior-posterior and medial-lateral components) by the vertical ground reaction force (Anderson et al., 2014; Burnfield and Powers, 2006; Burnfield et al., 2005). The local peak in RCOF during weight acceptance was found when the anterior-posterior component of the ground reaction force was directed posteriorly (indicating the foot would tend to slip anteriorly), and when the vertical component of the ground reaction force was greater than 50 N. Using these criteria, spurious peaks in RCOF at the beginning and end of stance, that occur due to a small vertical ground reaction force, were ignored (Anderson et al., 2014; Burnfield and Powers, 2006; Burnfield et al., 2005). The peak RCOF used here typically occurred at 10–20% of stance time, although this range was not used as an explicit criterion to identify the peak. To better understand any differences in peak RCOF, we also determined the vertical and resultant shear ground reaction force at the time of peak RCOF during weight acceptance, and normalized these to body mass. Step length was determined as the anterior-posterior distance between heel markers on the left and right feet during consecutive stance phases.

Separate three-way repeated measures analyses of covariance were used to investigate differences in peak RCOF, vertical GRF at peak RCOF, shear GRF at peak RCOF, and step length between

Table 1
Subject Characteristics (mean ± standard deviation).

	N	Men	Women	Age (yrs)	Height (cm)	Mass (kg)	BMI (kg/m^2)
Older Non-Obese	14	6	8	66.6 ± 4.9	171.8 ± 14.1	72.0 ± 13.8	24.2 ± 1.7
Older Obese	11	6	5	70.5 ± 7.4	170.2 ± 12.0	93.5 ± 12.3	32.2 ± 2.0
Younger Non-Obese	20	10	10	24.5 ± 3.5	171.3 ± 6.8	65.3 ± 7.5	22.3 ± 2.3
Younger Obese	20	11	9	23.5 ± 3.2	172.2 ± 8.7	99.1 ± 13.9	33.4 ± 3.4