Applied Ergonomics 50 (2015) 147–152

Contents lists available at ScienceDirect

Applied Ergonomics

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

Effects of flooring on required coefficient of friction: Elderly adult vs. middle-aged adult barefoot gait

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A R T I C L E I N F O

Article history:
Received 13 April 2014
Accepted 28 February 2015
Available online 1 April 2015

Keywords:
Gait
Elderly
Barefoot

A B S T R A C T

The aim of this study was to investigate the effect of flooring on barefoot gait according to age and gender. Two groups of healthy subjects were analyzed: the elderly adult group (EA; 10 healthy subjects) and the middle-aged group (MA; 10 healthy subjects). Each participant was asked to walk at his or her preferred speed over two force plates on the following surfaces: 1) homogeneous vinyl (HOV), 2) carpet, 3) heterogeneous vinyl (HTV) and 4) mixed (in which the first half of the pathway was covered by HOV and the second by HTV). Two force plates (Kistler 9286BA) embedded in the data collection room floor measured the ground reaction forces and friction. The required coefficient of friction (RCOF) was analyzed. For the statistical analysis, a linear mixed-effects model for repeated measures was performed. During barefoot gait, there were differences in the RCOF among the flooring types during the heel contact and toe-off phases. Due to better plantar proprioception during barefoot gait, the EA and MA subjects were able to distinguish differences among the flooring types. Moreover, when the EA were compared with the MA subjects, differences could be observed in the RCOF during the toe-off phase, and gender differences in the RCOF could also be observed during the heel contact phase in barefoot gait.

1. Introduction

The causes of falling are multifactorial and can be due to individual limitations, environmental conditions or the interaction of both effects. Among the individual limitations that can increase the probability of falls are balance and gait disorders, side effects of certain medications and the effects of aging (Salzman, 2010; Silva-Smith et al., 2013). In particular, many falls experienced by older adults occur when a change in body position is required, such as walking on different flooring (Soriano et al., 2007).

Previous research has investigated the effects of age on the ability to walk on different flooring, e.g., carpet versus vinyl (Willmott, 1986; Dickinson et al., 2001). However, contradictory results were found depending on the gait velocity adopted while walking on these flooring types (Willmott, 1986; Dickinson et al., 2001). Willmott (1986) found that elderly people walk faster on carpet than in vinyl flooring, and the Dickinson et al. (2001) had the opposite conclusion. Changes in gait speed and step length during ambulation over different floorings may influence the outcome of slips and falls, especially for the elderly. Understanding how older adults adapt to walking on different flooring types may provide useful information for the design of interventions to reduce falls in older people.

The surface roughness of the shoe and floor surfaces affects slipperiness significantly (Kim et al., 2013; Kim and Nagata, 2008, Chang et al., 2012; Lockhart et al., 2003), and dangerous slips are most likely to occur when the required coefficient of friction (RCOF) at the shoe–floor interface exceeds the available coefficient of

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http://dx.doi.org/10.1016/j.apergo.2015.02.010
0003-6870/

friction of the floor (Kim et al., 2013; Kim and Nagata, 2008). The RCOF is one of the most critical gait parameters in predicting the risk of slipping (Chang et al., 2012). It is defined as the minimum coefficient of friction necessary at the shoe–floor interface to support walking, and its value relative to the available coefficient of friction is used to assess the probability of slipping (Chang et al., 2012; Redfern et al., 2001; Hanson et al., 1999). Consequently, slip severity increases as the RCOF increases above the available coefficient of friction of a floor surface (Kim et al., 2013; Kim and Nagata, 2008; Chang et al., 2012; Lockhart et al., 2003; Hanson et al., 1999).

At the interface between the foot and the ground, footwear is likely to influence balance control and the risk of experiencing slips and trips while walking. The shoe type and sole material affect the available friction between the foot and the support surface. Because many falls occur when older adults walk barefoot inside their home or in a familiar environment (Menz et al., 2006), understanding their behavior while walking barefoot on different flooring should provide new insights about the risk of falls in the elderly population.

In general, elderly adults walk slower than young adults, with a higher heel contact velocity and a shorter step length (Lockhart, 1997; Lockhart et al., 2003; Burnfield and Powers, 2003; Kim and Lockhart, 2006; Menz et al., 2006; Seo and Kim, 2013a,b). It has been suggested that these age-related gait adaptations influence the likelihood of slip-induced falls (Lockhart et al., 2003). Another factor that should be taken into account is gender differences. According to Lach (2005), gender is the most important covariant associated with the fear of falling. Women with balance and gait difficulty resulting in unsteadiness, multiple falls, and low self-rated health are at greatest risk (Lach, 2005).

Although fall risk factors among the elderly have been well studied (Lockhart, 1997; Lockhart et al., 2003; Burnfield and Powers, 2003; Kim and Lockhart, 2006; Menz et al., 2006; Seo and Kim, 2013a,b), it could be interesting to understand the strategies adopted by middle-aged and elderly adults when walking over different flooring. We are interested in comparing older adults (60–70 years old) (O'Loughlin et al., 1994), whose risk of falling is relatively high, with a group of adults close in age (40–50 years old) with a lower risk of falling (Rubenstein and Josephson, 2002).

Previous studies (Lockhart, 1997; Lockhart et al., 2003; Burnfield and Powers, 2003; Kim and Lockhart, 2006; Menz et al., 2006; Seo and Kim, 2013a,b) have assessed the gait parameters under slippery conditions and compared RCOF strategies in the elderly with control groups of young adults (20–30 years old). In this study we are considering the barefoot gait in the day-by-day flooring without slippery conditions and the aging process comparing middle aged individual with elderly individuals.

The aim of this study was to investigate the effect of flooring on the RCOF during barefoot gait according to age (middle-aged versus elderly adults) and gender. We expect in this study: (a) to find differences in the RCOF variables in barefoot gait on different dry flooring; (b) differences can be observed in the RCOF when elderly adults are compared with middle-aged adults; and (c) gender differences in the RCOF can be observed during barefoot gait.

2. Material and methods

2.1. Participants

The Research Ethics Committee of the University of Campinas approved this study (UNICAMP protocol No. 319/2011), and the volunteers gave written informed consent to participate. Twenty healthy subjects volunteered in this study, and they were divided into two age groups: elderly adults (EA, $n = 10$) and middle-aged adults (MA, $n = 10$). Table 1 shows the anthropometric data for each group. The subjects recruited for this study were healthy (without known musculoskeletal, neurologic, cardiac, or pulmonary diagnoses), community dwelling, and ambulatory without an assistive device.

Table 1
Anthropometric data.

Group	*N*	Age (years)	Body mass (kg)	Height (cm)
EA males	5	67.4 ± 5.02	74.52 ± 14.21	164.04 ± 11.44
EA females	5	67.8 ± 6.05	69.80 ± 16.34	162.5 ± 6.64
MA males	5	48.2 ± 6.22	78.75 ± 8.23	166.58 ± 9.28
MA females	5	47.6 ± 3.32	70.76 ± 11.98	166.24 ± 8.21
EA	10	67.6 ± 5.25	72.17 ± 14.66	166.41 ± 8.26
MA	10	47.90 ± 5.47	74.76 ± 10.57	163.27 ± 8.85
Males	10	57.7 ± 11.92	70.28 ± 13.52	164.37 ± 7.3
Females	10	57.8 ± 11.43	76.64 ± 11.17	162.31 ± 9.91

EA = Elderly Adult group; MA = Middle-aged Adult group; *N* = sample size.

2.2. Flooring classification

Three flooring types under four experimental conditions were used to evaluate the study volunteers:

- *Homogeneous vinyl (HOV):* Homogeneous single-layer vinyl flooring (Pavifloor Prisma tile, 2 mm thickness, 2 × 8 m, ref. 909, charcoal, Tarkett Fademac);
- *Heterogeneous vinyl (HTV)*: Compact flexible vinyl floor covering (Chinese Teak natural, 2.50 mm thickness, 2 × 8 m, Imagine Wood, Tarkett Fademac);
- *Carpet:* Needle-punch carpet (plain quality needle-punch carpet, 100% pet fiber, 2 mm thickness, 2 × 8 m, Flortex Eco Inylbra);
- *Mixed:* To simulate a person walking from one room to another room with different flooring, a mixed condition was included. As illustrated in Fig. 2d, in a walkway with 9 m and 2 force plates strategically embedded in the floor on the middle of it; the first 4.5 m of the pathway and the 1st force plate were covered by HTV, and the second 4.5 m of the pathway and the 2nd force plate were covered by HOV.

To characterize the flooring used in this study, the static coefficient of friction (μ_e) was calculated using a pulley test. Fig. 1a illustrates the test and the resulting μ_e. The chosen flooring was positioned on a force platform (Kistler 9286BA), and over this flooring a halter (H1) was positioned weighing 18.42 kg. Halter H1 was pulled by another halter (H2) weighing 17.32 kg. H1 was connected to H2 by a steel cable that slid on a system of three rollers, one fixed on the floor (R1) and two on the laboratory roof (R2 and R3). From the plot of the coefficient of friction of the force plate as a function of time, μ_e was determined as the maximum friction prior to the start of movement. The μ_e values for all the flooring chosen for this study were approximately 0.5, which is within the standards of safety according to Templer (1992) and Miller (1983) (see Fig. 1b–e).

2.3. Experimental procedures

The RCOF is typically measure on dry surfaces with a force plate. The force plate consists of a board in which four sensors of piezoelectric are distributed to measure the three ground reaction forces components Fx, Fy and FY; the medial-lateral, the anterior-posterior and the vertical directions respectively. In this study two force plates (Kistler 9286BA) were used.

The participant was asked to walk barefoot, at his or her self-selected speed, along a 9 m pathway of the experimental flooring material, beneath which two force platforms were embedded in the