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Minimum foot clearance during walking: Strategies for the minimisation of trip-related falls

Rezaul Begg *, Russell Best, Lisa Dell'Oro, Simon Taylor

Biomechanics Unit, Centre for Ageing, Rehabilitation, Exercise & Sport, Victoria University, City Flinders Campus, PO Box 14428, MCMC, Melbourne, Vic. 8001, Australia

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Abstract

This paper models minimum foot clearance (MFC) data during steady-state gait to investigate how the various descriptive statistics of the MFC distribution differ in healthy young and elderly females. A minimum of 20 min of treadmill walking was analysed for 17 young and 16 elderly females using a Peak Motus motion analysis system. The results indicated that none of the 33 participants' MFC data sets were Normally distributed. The deviation from a Normal distribution was systematic (always skewness > 0 and kurtosis > 0). Skewness and kurtosis in MFC data was highly correlated (young: $r = 0.60$, $p = 0.01$; elderly: $r = 0.95$, $p < 0.01$). MFC descriptive statistics provide useful information about basic strategies used by individuals to minimize the likelihood of tripping. Possible strategies to minimize tripping include: (a) increasing MFC height central tendency, (b) reducing MFC variability, and/or (c) increasing right skewness. A low median MFC was often associated with a low IQR or high skewness to compensate. Further research is required to establish how, or if at all, these strategies are modified in populations that are more at risk of falling.

Keywords: Gait; Minimum foot clearance; Descriptive statistics; Tripping

1. Introduction

Falls in the elderly are a major public health issue because of their associated morbidity and mortality rates, social cost and financial cost [1–3]. Most falls in older adults are reported during locomotion and tripping while walking is a commonly reported cause of falls [4,5] responsible for 53% of falls in healthy older adults [6].

Researchers have documented ageing effects on gait with the aim of identifying variables linked to falls. Some research has looked at basic gait variables such as step length, walking speed and stance/swing times [7,8] while others have looked at joint moments/powers [9] to investigate differences between young and old populations. The literature is consistent in supporting the overall slow down in walking performance in the elderly, including reduced step length and walking speed, increased single/double support time, reduced angular range of motion and less propulsive joint power. These gait adaptations are viewed as a safety strategy employed by the elderly during walking [10].

Minimum foot clearance (MFC) is a critical event in the gait cycle as the foot travels with maximum horizontal velocity around this instant [11]. MFC has been reported to be low in young adults (1.29 cm) and Winter [11] recorded a reduced mean MFC = 1.12 cm in healthy elderly. Karst et al. [12] reported a mean MFC = 1.29 cm in elderly participants. Group standard deviation (SD) in MFC has been reported as 0.62 cm for young and 0.5 cm for elderly adults by Winter [9] and 0.68 for elderly adults by Karst et al. [12]. A low mean MFC combined with MFC variability could potentially cause tripping during walking.

In the above studies [9,11,12] the low number of participant trials (5–10) and varying placement of markers may have contributed to the different results. Markers placed on the shoe cannot themselves represent the part of the shoe closest to the ground at MFC. Two- or three-dimensional

* Corresponding author. Tel.: +61 3 9919 1116; fax: +61 3 9919 1110.
E-mail address: rezaul.begg@vu.edu.au (R. Begg).

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foot/shoe modelling techniques are required to accurately represent MFC [13,14].

Mean and group SD only give a basic representation of MFC data and the literature does not report whether MFC data is Normally distributed or not. Moreover, there is neither literature on individual MFC distribution statistics during walking, nor how ageing influences distribution statistics. For a better understanding of MFC central tendency in a sample distribution and MFC variability, other descriptive statistics and longer data sets are required to explore fully the implications of MFC data and how it is controlled for each individual than the 5–10 gait cycles frequently reported [11,12].

The objectives of this research were, firstly, to study MFC variability and, secondly, to investigate ageing effects on MFC statistics and the extent to which ageing affects the risk of tripping. Only female participants were tested because they are more prone to injurious falls [15] and to eliminate gender effects.

2. Method

2.1. Participants

Seventeen young females (age 26.4 ± 4.9 years) and 16 elderly females (age 72.1 ± 4.4 years) were studied. Population demographics are presented in Table 1. Participants were free of conditions impairing normal locomotion, as determined from a self-reported health and fitness questionnaire. Participants wore their own flat, comfortable shoes suitable for walking. The study was approved by Victoria University's Human Research Ethics Committee.

2.2. Experimental set-up and procedure

Each participant's foot clearance data was collected using the Peak Motus system (Peak Technologies, USA) after at least 20 min of steady-state walking at a self-selected speed on an Austradex 683M treadmill (Austradex, Australia). Standard principles for 2D filming were followed [16]. A 50 Hz Panasonic F15 video camera (shutter speed 1/1000 s) positioned 9 m from the treadmill, perpendicular to the plane of treadmill belt motion, recorded unobstructed treadmill walking. Three spotlights were arranged behind the video camera to illuminate reflective markers. Two, 2.5 cm spherical markers were attached to the left shoe at the great toe and fifth metatarsal head (P1 and P2 in Fig. 1). Two markers were also attached to the treadmill (1.6 m apart) as a distance calibration.

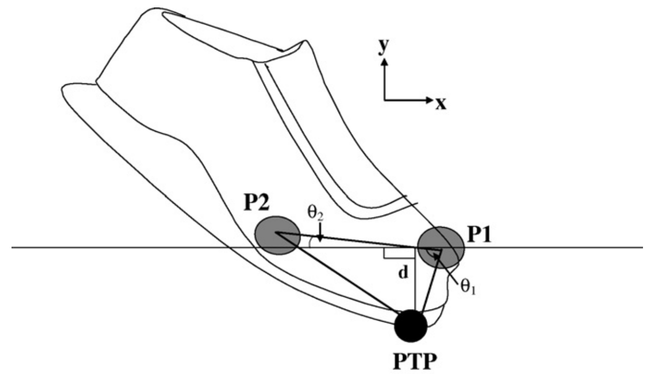

Fig. 1. Geometric model of the foot used to calculate the y coordinate of the lowest point of the shoe (PTP) from great toe (P1) and metatarsal head (P2) markers using constant triangle geometry.

Digital conversion of the location of reflective markers and calculation of 2D marker trajectories were performed using Peak Motus. Raw data was smoothed using a Butterworth filter (cut-off frequency 4–8 Hz).

2.3. Geometric model

Marker positions and shoe dimensions were used to predict the lowest point on the shoe (PTP) using a geometric model (Fig. 1; PTP is a virtual point, the most distal and inferior edge of the shoe at MFC).

The following equations demonstrate how y(PTP) was calculated from the constant geometry triangle in Fig. 1. Mean distances for d_1 (P1–P2), d_2 (P2–PTP) and d_3 (P1–PTP) were calculated for each individual before the main data analysis using Pythagoras and manually digitized

Table 1
Comparison of young and elderly participant demographics, walking speed and relative walking speed

Variables	All ($N = 33$), mean (SD)	Young ($N = 17$), mean (SD)	Elderly ($N = 16$), mean (SD)	p-Value
Age (years)	49.7 (23.0)	26.36 (4.89)	72.10 (4.42)	0.00*
Body mass (kg)	65.39 (8.59)	65.11 (9.91)	65.71 (7.12)	0.84
Stature/height (m)	1.63 (0.07)	1.66 (0.06)	1.59 (0.06)	0.00*
Walking speed (m/s)	1.01 (0.25)	1.15 (0.21)	0.88 (0.19)	0.00*
RWS (statures/s)	0.62 (0.15)	0.69 (0.14)	0.54 (0.13)	0.00*
Strides measured	1295 (581)	1480 (708)	1065 (246)	0.03*

RWS, relative walking speed.
* $p < 0.05$.