International Journal of Industrial Ergonomics 41 (2011) 410–417

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

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

Existence of an optimum dynamic coefficient of friction and the influence on human gait variability

Tomás Zamora [a,*], Enrique Alcántara [a], Miguel Ángel Artacho [b], Marta Valero [a]

[a] Instituto de Biomecánica de Valencia, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain
[b] Departamento de Proyectos de Ingeniería, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain

ARTICLE INFO

Article history:
Received 2 June 2009
Received in revised form
6 April 2011
Accepted 27 May 2011
Available online 16 June 2011

Keywords:
Chaos
Friction
Floor
Entropy
Ceramics
Gait
Falls
Comfort

ABSTRACT

The existence of a range of optimal coefficient of friction that encompasses safety and comfort has not been addressed before. This paper assesses the existence of such a range and its relationship with the variability of human gait. Six women walked for 15 min over five ceramic tile floorings with friction coefficients (DCOF) ranging from 0.19 to 0.63. Subjective opinions (pain, comfort, etc.) and biomechanical parameters including sagittal plane knee angle, tibia acceleration, and ground reaction forces were gathered. The required coefficient of friction (RCOF) was calculated from ground reaction forces. The results show that as DCOF increases so do reports of pain in the knees and under the metatarsal heads and toes; whereas a low DCOF relates to pain in the thighs and perception of low friction. RCOF showed a quadratic relationship with DCOF indicating the existence of a range of optimal coefficient of friction outside of which walking strategy is modified either to avoid slipping (DCOF < 0.25) or reduce pain (DCOF > 0.55). This result is supported by the results of the analysis of gait variability using non-linear methods. Floors inside the optimal range of friction yielded statistically significant higher entropy for tibia acceleration and knee angle, confirming the hypothesis that gait is more constrained outside that range (i.e. natural variability is reduced).

Relevance to the industry: Floor friction is one of the main concerns for the floor industry and for decision makers when choosing public space paving (indoor and outdoor). The false concept 'the more friction the better' can induce manufacturers and technicians to make wrong decisions. This paper can assist the industry produce and select solutions encompassing safety and comfort.

1. Introduction

Several reports describe slips, trips, and falls as one of the most important causes of fatal injuries (Grönqvist et al., 2001a; Haslam et al., 2002). Many factors combine in a complex way to provoke a fall (Grönqvist et al., 1999; Leamond and Murphy, 1995; Leclercq, 1999; Redfern and Bloswick, 1997; Strandberg and Lanshammar, 1981). Floor friction is one of these factors and it has been profusely studied in an attempt to prevent and reduce the incidence of slipping and falling.

The traditional approach is to establish the minimum level of floor friction necessary to avoid accidents (Grönqvist et al., 2001b; Redfern et al., 2001; Redfern and Bidanda, 1994). It is normally assessed by the dynamic coefficient of friction (DCOF) measured using various testing methods (Ricotti et al., 2009).

The required coefficient of friction (RCOF) is a different parameter that measures the friction demanded by people for a safe and comfortable gait (Buczek et al., 1990; Redfern et al., 2001). RCOF is calculated as the ratio between shear and normal ground reaction forces during normal locomotion over dry and clean surfaces. RCOF depends on individual characteristics and terrain inclination. Different studies establish RCOF for able people at around 0.25 for horizontal surfaces, and around 0.33 for inclined surfaces (Lockhart and Pai, 2001; Redfern et al., 2001). Some studies show that mobility-disabled people require more friction (greater RCOF) than able-bodied people (Buczek et al., 1990; Durá et al., 2005).

In this way, the difference between the floor friction (DCOF) and the friction that people need (RCOF) for a safe and comfortable gait can be used to estimate the probability of suffering a slip and/or a fall (Hanson et al., 1999).

Following this rationale, it would seem appropriate that, once that minimum is achieved, the more friction, the better. However, there is evidence that too much friction can give rise to a variety of problems. Fatigue, discomfort, trips, and even serious injuries have been

* Corresponding author.
E-mail address: tomas.zamora@ibv.upv.es (T. Zamora).

0169-8141/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.ergon.2011.05.004