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Effects of ramp negotiation, paving type and shoe sole geometry on toe clearance in young adults

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ABSTRACT

Trips are a major cause of falls and result from involuntary contact of the foot with the ground during the swing phase of gait. Adequate toe clearance during swing is therefore crucial for safe locomotion. To date, little is known about the effects of environmental factors and footwear on toe clearance. This study reports on modulation of toe clearance and toe clearance variability in response to changes in ground inclination, paving type, and shoe sole geometry. Toe clearance and toe clearance variability for ten healthy young adults were calculated two-fold: a) for the commonly-used position on the foremost part of the sole of the shoe and b) for the lowest of a total of 7 sole positions, located between the metatarsals and the toe tip across the entire width of the sole. Utilizing a full-factorial design we found that toe clearance was affected by ground inclination, paving type, and sole geometry regardless of the computational method used (with p-values < 0.01) but the use of the foremost part of the sole for toe clearance calculation results is an overestimation of this value. Our findings highlight the importance of considering footwear and environmental factors when assessing the risk of tripping. Future work needs to investigate to which extent the same factors affect toe clearance in more vulnerable parts of the population.

1. Introduction

Trips are a major cause of falls in older adults (Berg et al., 1997) and falls-related injuries are associated with significant medical and socio-economic costs (Heinrich et al., 2010). Trips are the result of involuntary contact of the swing foot either with the ground, the stance leg, or with an obstacle above ground level. Hence, to avoid tripping and subsequent loss of balance and falling, adequate lifting of the foot during the swing phase is crucial. Previous research concerned with falls has hence investigated the effects of ageing on minimum toe clearance during the swing phase for level-ground walking (Khandoker et al., 2008; Mills et al., 2008). It has also been shown that minimum toe clearance and its variability are related to the probability and risk of tripping (Best and Begg, 2008, Barrett et al., 2010). However, while useful insights can be gained for unperturbed level-ground walking, modulation of minimum toe clearance in response to environmental factors is likewise of interest to gain a better understanding of the circumstances that may lead to a trip under various real-life relevant conditions.

Little is known about minimum toe clearance in response to environmental factors. A small number of studies have shown that toe clearance is modulated during walking on inclines and declines (Prentice et al., 2004; Khandoker et al., 2010) and in response to obstacles (Schulz, 2011). We recently investigated minimum toe clearance for walking on smooth and uneven 'blister' paving commonly used at pedestrian crossings, to assess the effects of urban design on risk of tripping and falling in older adults (Thies et al., 2011). Data were collected over level ground followed by a declining slope and, on the level ground only, we observed an increase in minimum toe clearance on uneven tactile paving, as compared to smooth paving. These studies highlight the importance of multiple factors (i.e. surface inclination, ground irregularity) in the assessment of toe clearance modulation and risk of tripping. Furthermore, while we used standardized footwear in our study for all the subjects, we suspect that the geometry of the shoe sole may likewise affect minimum toe clearance. In particular the amount of toe height of the sole with respect to the ground (see Fig. 1) may affect toe clearance, i.e. a larger toe height may well reduce risk of tripping. In this paper we report on the effects of ramp negotiation, paving type, and shoe sole geometry on minimum toe clearance and its variability

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