INTRODUCTION

Falls are the leading cause of unintentional injuries in almost every age group [1], with tripping over an object identified as the leading cause of falls in older adults [2]. Over the last 20 years there has been extensive research on minimum foot clearance (MFC) in both young and older adults during overground walking, obstacle crossing, level changes, and stair negotiation – the primary locomotor tasks during which trips and slips often occur.

The results of these studies have yielded a wide range of MFC results both within and across locomotor tasks. This may be due to the lack of standard MFC measurement methods or/and poor consideration of marker placement for different tasks. The purpose of this study was to compare minimum foot clearance across the primary locomotor tasks during which falls often occur using multiple points on the surface of the shoe. The primary aims were to: 1) examine the difference in overall MFC across all tasks for both leading and trailing limbs; 2) examine the differences between the leading and trailing limbs within each task; 3) determine which region of the shoe experienced the majority of minimum clearances for each task; and 4) determine whether or not the use of minimum toe clearance overestimates the overall MFC.

METHODS

Ten healthy young adults (6 female, 4 male 24.5±2.9yrs) participated in the study. Participants completed three trials of nine locomotor tasks: single large obstacle (SOB) crossing (17x91x3.5cm (h x w x d)), double large obstacle crossing (first=1OB and second=2OB) (spaced 1.5m apart), single small (threshold-height) obstacle (TOB) crossing (1.3x91x3.5 cm) a tape (zero-height) obstacle (TAPE) crossing (0x91x3.5cm), stair ascent (AST), stair descent (DST) (7 steps with a rise/run 17/26cm), up level change (ULV), down level change (DLV) (obstacle h x w w/a 3.5m landing) and level overground (OG) walking. Participants were asked to walk at a self-selected pace.

Each participant wore the same model of shoes with five reflective tracking markers attached to the upper of each shoe and 72 points virtually digitized on the bottom, front and rear portions of the shoe. All obstacles, stairs, and level changes were also digitized in the global coordinate system. An 8 camera VICON® MX motion capture system was used to track the markers and a custom model in Visual 3D® 4.75.11 was used to visualize virtual markers and calculate MFC. 3D distances were calculated from each point on the shoe to each region of the obstacle, step or stair. Minimums were calculated for each region of the shoe (5 regions- toe, fore, mid, rear and heel) and overall MFC for both lead and trail limbs. Location of the overall minimum among the 72 virtual points on the shoe was recorded.

Three factor, mixed model ANOVAs were used to analyze the effects of task and trial order on MFC of both the lead and trail limbs. Additional two-way ANOVAs were used to test for differences between the lead and trail limb MFC within each task. Tukey’s HSDs were used for post-hoc analysis

RESULTS AND DISCUSSION

There was a significant main effect of task for both the leading and trailing limbs (p<.001). Lead limb MFC was smallest in the overground walking condition (0.4±0.2cm) and largest in the large obstacle crossing conditions (Fig. 1). There was no
significant difference in lead limb MFC between single or double large obstacle crossing conditions. Overall lead limb MFC was reduced with decreasing obstacle height (SOB>TOB>TAPE), but the TAPE MFC was significantly larger than overground walking. There was no significant difference in lead limb MFC between crossing an obstacle (SOB) and going up a level change (ULV) of the same height. MFC going up a level change is larger than MFC ascending stairs of the same height (AST1-7) and larger than going down a level change (DLV). There were no significant differences in MFC between going down a level change (DLV) and going down stairs (DST7-2) except for the last stair (DST1). MFC during DLV and DST was equivalent to the MFC during zero height obstacle crossing (TAPE).

![Figure 1: Overall minimum foot clearance for each task and each limb.](image)

There was no significant difference in trail limb MFC between single or double large obstacle crossing conditions or between large obstacle crossing and negotiating the first stair during stair ascent (AST1). Overall trail limb MFC was reduced with decreasing obstacle height (SOB>TOB>TAPE). The overall MFC of the trail limb during TAPE crossing was equal to the MFC going up a level change and up all stairs (AST 2-7) except the first stair.

When comparing the lead limb MFC to the trail limb MFC within a task, the trail limb MFC was significantly larger than lead limb clearance for all obstacle conditions and the bottom step (AST1) during stair ascent. Lead limb MFC was significantly larger than trail limb MFC when going up a level change and when ascending the top stair (AST7). There were no significant differences between the lead and trail limb MFC during mid-stair ascent (AST2-6).

Nearly all lead limb MFCs and ~50% of all trail limb MFCs during obstacle crossing occurred in the rear and heel regions of the shoe. For stair and level change ascent, the lead limb MFC primarily occurred in the toe - midfoot regions while the trail limb MFC was nearly always located in the toe region. When descending the stairs, the MFC always occurred in the rearfoot and heel regions while during level change descent, the MFC occurrences were spread throughout all shoe regions. During overground walking over 80% of MFCs occurred in the rearfoot region of the shoe.

In fact, use of the MFC from just the toe region of the shoe overestimated the actual MFC anywhere between 33-126% for lead limb obstacle crossing, 28% and 50% for ULV and DLV lead limb MFC respectively, 76-409% for stair descent and 128% for overground walking. For the lead MFC during stair ascent and all trail limb MFC however, the toe region MFC was adequate (0-5.75% overestimation of overall MFC).

These results indicate that marker placements typically used for MFC research (marker on toe, virtual marker on sole of toe, etc.), do not provide the actual minimum foot clearance for most tasks and use of these marker placements may affect MFC results – especially when comparing across locomotor tasks. Further research is needed utilizing this methodology to examine MFC in young and older adults during these high risk locomotor tasks to determine if, as previously reported, there are minimal age-related changes in MFC, or if the lack of differences in previous studies was due to methodological inadequacies.

REFERENCES

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