MINIMAL FOOT CLEARANCE IN STAIR DESCENT: APPLICATION OF A SIMPLE, ROBUST EMPIRICAL METHODOLOGY

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INTRODUCTION

Debilitating stair falls motivate researchers to understand the factors that predispose both young and elderly populations to falling. Foot clearance has received considerable attention as such a factor (Cavanagh and Higginson, 2002; Hamel et al, 2005). Foot clearance quantifies the distance between the stair edge and the foot during swing phase. To date, the majority of research focused on clearance in descent since falls in descent are three times more numerous than those incurred in ascent (Cohen, 2000). In short, it appears clearance might be refined to progressively smaller values as the individual descends stairs and accomplishes a steady-state descent pattern.

METHODS AND PROCEDURES

Healthy males (n=9) and females (n=9) participated in the study. All subjects were free of neurological and musculoskeletal conditions. Subjects performed 10 trials in forwards (FD) and backwards descent (BD). Trials were initiated with the subject's preferred limb and performed at a self-selected pace. Condition presentation was counterbalanced across subjects. Stair dimensions were 30 cm tread and 20 cm riser according to local building codes. Seven Vicon MX-13 cameras sampled displacement data of four foot marker--hallux, calcaneus, 1st and 5th metatarsal-phalangeal joints --at 200 Hz. Analog data were low-pass filtered with a 4th-order Butterworth digital filter with 6 Hz cutoffs. Filtered marker trajectories were imported to MATLAB and analyzed with a custom script. Marker clearance was computed according to the formula:

$$d = \frac{\left|(\underline{x}_2 - \underline{x}_1) \times (\underline{x}_1 - \underline{x}_0)\right|}{\left|(\underline{x}_2 - \underline{x}_1)\right|}$$

where d is the minimal distance between a marker and the line that defines the stair edge; $\underline{x}_1$ and $\underline{x}_2$ are points at the corners of the stair edge; and $\underline{x}_0$ represents the coordinates of a foot marker. Data were ensemble averaged and subjected to 2 × 5 repeated-measures ANOVA with descent condition and stair (number) as factors.

RESULTS

There were significant stair ($F_{(4, 13)} = 51.43$, $p<0.001$) and condition ($F_{(1, 16)} = 109.57$, $p<0.001$) main effects and a stair × condition interaction ($F_{(4, 13)} = 37.22$, $p<0.001$) for the dependent variable, minimal clearance. Figure 1 shows ensemble averaged minimal clearances over five consecutive stairs during the swing phases of FD and BD. In addition, Figure 1 demonstrates that clearance was dependent upon levels of both stair and condition so that neither main effect was relevant. In other words, clearance increased and stabilized in the mid-stair region in BD and was subsequently larger than that demonstrated in FD. However, there was no discernible difference in transition (first stair). In both conditions, subjects demonstrated a tendency to increase clearance at stair 5, the transition to level walking.

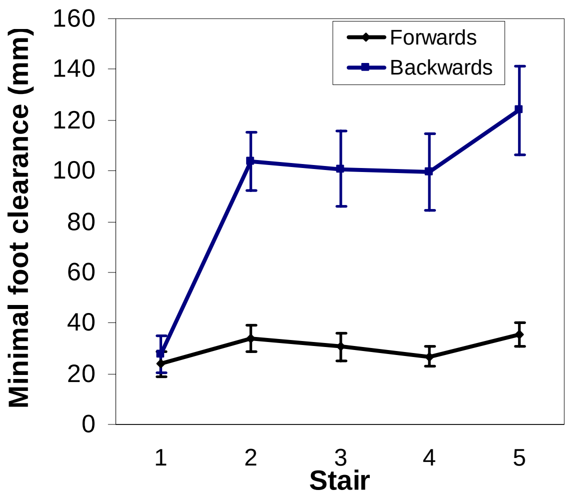

Figure 1. Ensemble averaged minimal foot clearance over five consecutive stairs in forwards and backwards descent. Error bars represent ±1 SD.

DISCUSSION

As demonstrated in Figure 1, clearance was substantially larger in BD than FD, except for the transition at stair 1. Transition represents the initiation of descent where the foot need only clear one step. Therefore, it seems the constraints imposed during transition to stair descent reduced foot clearance as compared to subsequent stair step-downs; making it the most dangerous. This phenomenon was especially pronounced in backwards descent, where clearance over stair 2 saw a fivefold increase in contrast to that of stair 1. Aside from the apparent transition effect and despite greater intra- and inter-subject variability, clearance in BD was markedly larger than that of FD. As a result, there is significantly less likelihood of contacting a stair in the swing phase of BD than FD. In conjunction with kinetic analyses conducted in our laboratory, BD might be suggested as an alternative to FD since the peak knee extensor moment and dissipative power are substantially reduced, while subjects are less likely to sustain contact with the stair edge during the swing phase of the descent gait cycle.

Moreover, the minimal clearance results shown in Figure 1 agree well with the literature (Hamel *et al.*, 2005), in that clearance became progressively smaller as the individual descended the stairs and achieved a steady-state pattern. Therefore, the methodology presented here appears to be robust and suitable for application in clinical and research settings.

SUMMARY

Minimal foot clearance revealed that the first gait cycle represented a transition in stair descent. In transition, clearance was markedly smaller than during steady-state progression. However, as an individual descends, clearance progressively decreased. In steady-state progression, clearance was substantially greater in backwards as compared to forwards descent. Future research should consider the feasibility of backwards descent in elderly and clinical populations.

REFERENCES

Hamel, K.A. *et al.* (2005). *Gait Posture* 21: 135-140.

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