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Effect of shoe type on descending a curb

Juff George[a,*], Michelle Heller[a] and Michael Kuzel[b]
[a] *Exponent, Inc., 3401 Market Street, Suite 300, Philadelphia, PA 19104, USA*
[b] *Exponent, Inc., 23445 N. 19th Ave., Phoenix, AZ 85027, USA*

Abstract. The aim of this study was to evaluate the effect of shoe type on the performance of women during curb descent. Performance during curb stepping may be explained by biomechanical research that has evaluated the kinematics of overground walking and stair ascent and descent. Studies have reported that women exhibit performance differences when wearing high heels, flip flops and sneakers during overground walking and stair ascent and descent. Thus, in addition to features of the curb, the type of shoe being worn may also affect performance. Although several studies have investigated curb stepping, no known studies have investigated the effects of different types of footwear on curb descent performance. This research was conducted in a real-world environment where participants wore three different types of shoes and performed a series of activities that involved curb stepping. The subjects were videotaped while descending a curb, allowing for observation of changes in gait parameters. Results of this study indicate that wearing high heels leads to performance differences as compared to wearing flip flops or sneakers.

Keywords: walking, real-world environment, single step, shoes

1. Introduction

Curbs are commonly encountered environmental features that can be found in urban, suburban, and rural settings. Due to the change of height between present ground level and future ground level, curbs present a potential obstacle for walkers. Curbs have been found to be a potential trip hazard for those walking in the direction of ascent [1,4]; however, few studies have investigated performance during curb descent [3,8].

Research studies have also shown that shoe type affects performance during overground walking and stair negotiation [5,6,9,11]. A literature review did not identify any studies that investigated the effect of shoe type on curb descent in a real-world environment.

Navigating a curb can prove to be a challenging task due to the combination of overground and stair gait required to successfully complete the task. Since curbs are typically encountered when transitioning between two areas of the environment, the walker may encounter the curb while in full stride. Biomechanical studies of overground walking and stair descent demonstrate that kinematics, especially ankle and knee motions, are different in both timing and joint angle magnitude. This is shown in Figures 1 and 2 [7]. Due to the probable area of encounter, curb descent is likely to require a combination of kinematics from these two gait patterns. Examples of why an individual may lose his/her balance during curb descent include catching his/her heel on the nosing (edge) of the curb and/or over/under stepping the curb [12]. Parameters related to falls occurring for these reasons may include heel-to-curb clearance for the swing limb and toe-to-curb position of the stand limb.

The aim of this study was to observe the effect of different shoe types on the kinematics of curb descent in young, healthy women in a real-world environment. The results are compared to the findings of previously published studies that have involved more controlled environments and/or did not evaluate the effects of shoe type.

* Corresponding author. Tel.: +1 215 594 8866; Fax: +1 215 594 8898; E-mail address: jgeorge@exponent.com

2. Methods

2.1. Subjects

Ten female subjects participated in a study to evaluate changes in gait during curb descent. Participating subjects were required to be 18 years or older and the study was restricted to women who (1) were feeling well and healthy on the day of the study, (2) had no previous history of lower torso or back injuries, and (3) were not knowingly pregnant at the time of the study. Participants were compensated for their time, and participation was voluntary. Participants were recruited through family and friends and were asked to bring a pair of flip-flop sandals, high heel shoes and sneakers with them to the study location. Table 1 provides summary information regarding the ten subjects' age, height, weight, shoe size, and step length.

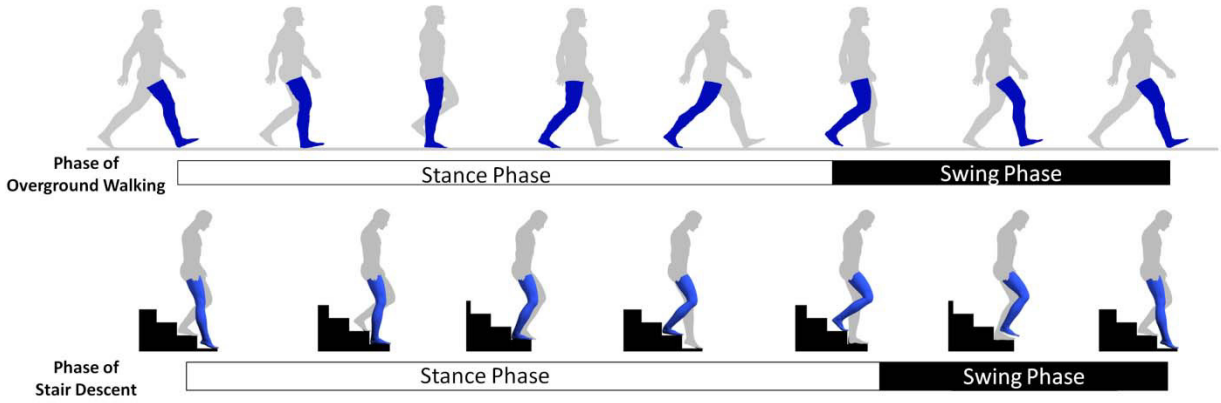


Fig. 1: Phases of gait for overground walking (top) and stair descent (bottom) (adapted from Heller et al., 2011)

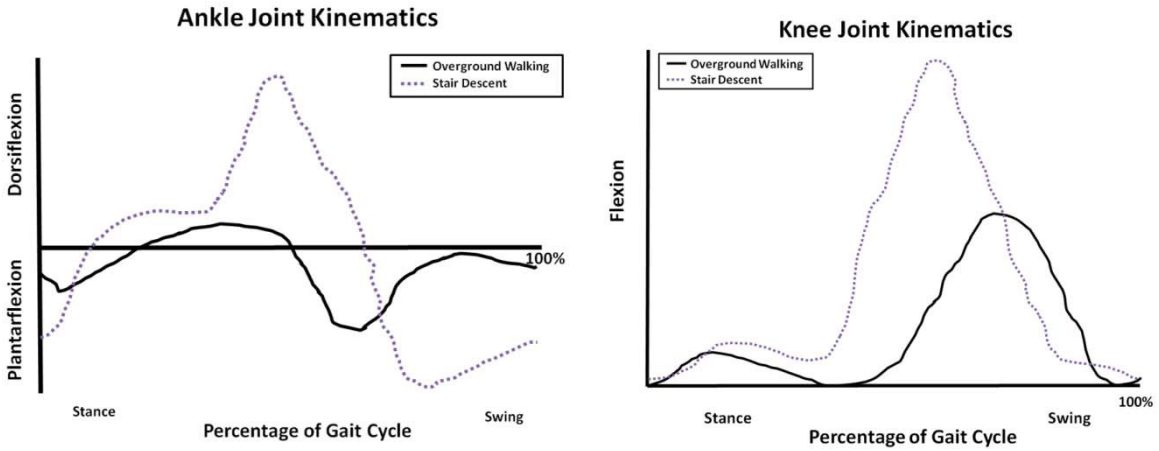


Fig. 2: Ankle and knee joint kinematics in overground walking and stair descent (figure adapted from Heller et al., 2011)

Table 1: Subject Data

	Age (years)	Height (meters)	Weight (kilograms)	Shoe Size (US)	Step Length (meters)
Mean	33	1.6	65	8	0.8
Maximum	45	1.8	88	9	1.0
Minimum	20	1.5	50	6	0.7

2.2. Settings and materials

The study was conducted at an elementary school that offered an approximately 4 m wide cement walkway leading to a 14 cm curb at the edge of the parking lot. Video cameras were placed on either side of the walkway, approximately 11 m from walkway centerline, and approximately 1 m above the curb to capture movement during approach to the curb and curb negotiation. Two additional video cameras (high speed) were placed on either side of the walkway at the curb. All testing was conducted during daylight hours in dry weather. Prior to testing, an Institutional Review Board evaluated and approved the research protocols.

2.3. Procedure

Each volunteer was asked to sign a consent form, after which a researcher collected information regarding the subject's age, height, weight, and shoe size. The volunteers were fitted with circular, adhesive, cross-hair joint markers. The order in which the shoe types were worn was randomized and pre-determined for the subjects. A folding chair was placed in the parking lot and on the walkway, approximately 6 m from the curb. Objects were placed on each chair and participants were informed that their task was to swap the objects between the chairs. Hence, while wearing each pair of shoes, a subject started walking from one of the chairs (chair A) and walked to the opposing chair (chair B), during which she ascended/descended the curb; upon reaching chair B, the subject would deposit the object obtained from chair A, retrieve a new object from chair B and return to the chair A, again descending/ascending the curb. The order of ascent/descent was counterbalanced. Subjects were allowed to walk at a self selected pace during each of the trials and each subject completed three trials of curb ascent and descent while wearing each type of shoe.

Following the first test series, the subject was asked to don her sneakers. In a separate location of the parking lot, a researcher measured the average step length of the subject. A point corresponding to approximately 1 ½ step lengths was marked on both sides of the curb. The subject was then asked to begin at each point and ascend/descend the curb. Initiation from each of these points was intended to disrupt the normal gait for the subject as she approached the curb. Each subject performed three trials of curb ascent and descent from this short start position.

2.4. Data analysis

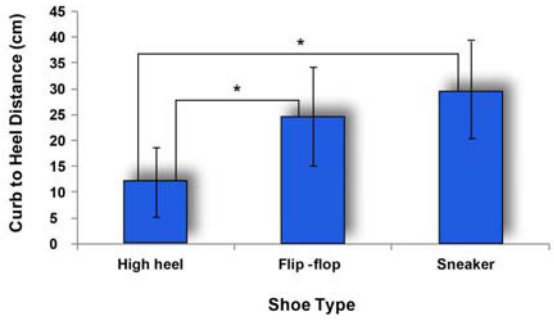
The video data were reviewed for each subject and trial during curb descent. Photogrammetric and qualitative methods were utilized to obtain the heel-to-curb clearance during the swing phase of the trailing leg (measured as the distance from the back of the heel to the leading edge of the curb as the shoe was in plane with the curb), position of the shoe toe box of the stance leg relative to the curb (on walkway or overhanging), landing orientation of the swing foot (toe or heel leading), and the number of steps taken prior to the step initiation when starting from 1 ½ step lengths from the curb edge.

The mean values of the heel-to-curb and toe-to-curb measures were calculated across trials for each shoe type and subject. To test for statistically significant differences between means, a one-way ANOVA with a Bonferroni adjustment was utilized. The significance level was set at $p < 0.05$. Overhang of the toe box over the curb (yes/no) was tabulated for each trial and analyzed using a Chi-Square test.

3. Results and discussion

Analysis of the video allowed for determination of the heel position relative to the curb during the swing phase of curb descent. The mean clearance distances for each shoe type are shown graphically in Figure 3. The differences in heel-to-curb clearance were found to differ statistically between shoe types [$F(2, 18) = 26.03$, $p << .001$]. Specifically, when subjects were wearing sneakers or flip-flops, their heel-to-curb clearance was found to be significantly greater than when they were wearing high heels [$F(1, 9) = 48.00$, $p << .001$ for flip-flops vs. high heels; and $F(1, 9) = 44.53$, $p << .001$ for sneakers vs. high heels]. Although this parameter has not previously been investigated in curb stepping, comparison to measures obtained in other studies may explain this difference in performance. In a previous study, George *et al.* reported performance differences of women wearing different shoe types during overground walking, specifically noting that women reduce their stride length when walking in heels. A reduction in stride length during either the approach phase and/or the step phase may be apparent in the current study, resulting

in reduced heel-to-curb clearance during curb descent. The reduction in stride length may also result from women adapting a more conservative approach when wearing the high heels. Chen *et al.* investigated whether older adults use different strategies than young adults while avoiding obstacles of heights. Results of that study indicated that older adults adopted a more conservative strategy that included shorter heel-to-obstacle distance after crossing. The conservative strategy employed by older adults also resulted in shorter step lengths, in turn causing unintended stepping on the obstacle and thus an increased risk of tripping [2]. During curb stepping, if women wearing high heels adopt a conservative approach that leads to a reduced heel-to-curb clearance, the potential for unintended interaction with curb nosing could lead to a loss of balance, and potentially a fall.



*Statistically significant comparison (p << .001)

Fig. 3: Effect of shoe type on curb to heel distance. Error bars denote one standard deviation.

The placement of the toe of the stance foot relative to the curb was also analyzed. As with heel-to-curb clearance, there were significant differences among shoe types in the placement of the toe relative to the curb [$F(2, 18) = 3.89$, $p < .05$]. However, in contrast to heel-to-curb clearance, only the difference between sneakers and high heels proved significant [$F(1, 9) = 2.63$, $p = .14$ for flip-flop vs. high heel; and $F(1, 9) = 6.47$, $p < .05$ for sneaker vs. high heel]. This finding would indicate that when wearing high heels, subjects made purposeful adjustments about foot placement in anticipation of stepping off the curb. Similar adjustments were not made when wearing tennis shoes. Previous research studies including research evaluating curb descent, have reported that adjustments were made to a person's stride to ensure that the foot would land short of or over an obstacle [3,10]. In the subject case, adjustments may have resulted in the stance foot landing near the curb edge (max distance 0.3 m from edge), without allowing for an uncomfortable amount of overhang (max overhang 0.1 m). Whereas the curb presented an obstacle limiting placement of the stance foot, there was no similar obstacle on the landing surface. Hence the subject could adjust their stride as desired, resulting in larger ranges in heel-to-curb clearance (0.53 m maximum to 0.03 m minimum).

Corresponding to the significant differences in toe-to-curb position, there was also a statistically significant difference across shoe types in the frequency of the toe overhanging the curb [$X^2(2, N = 90) = 7.20$, $p < .05$]. A comparison of the distributions of overhang versus non-overhang for each shoe type revealed that when wearing high heels, subjects significantly less often allowed the toe box to overhang the curb than not [$X^2(1, N = 30) = 4.80$, $p < .05$]. When wearing flip flops or sneakers, the toe box overhung the curb more often than not, although these differences did not prove statistically significant for either shoe type [$X^2(1, N = 30) = 1.20$, $p = .27$ for both flip-flops and sneakers]. Figure 4 illustrates this result. Lythgo *et al.* studied the stepping responses of elderly and young female adults during step ascent and descent. Results of the study demonstrated that step descent was hazardous for elderly participants because of smaller foot clearances and closer placement of the stance foot from the step. The study also showed that approximately 23% of individuals placed the stance foot such that it was only partly supported [8]. Again, for this parameter, the differences between performance when wearing high heels and flip-flops or sneakers may be explained by more cautions behavior when subjects were high heels. Allowing the toe to overhang the curb edge reduces the amount of the stance leg shoe that is supported, and increases the potential for a loss of balance.

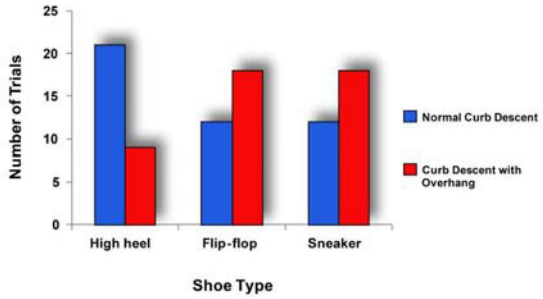


Fig. 4: Effect of shoe type on curb descent mode (normal and overhang)

Video data was analyzed to determine whether subjects landed on their heel or toe. Among all subjects, in all shoe conditions and all trials (90 foot landings in total), the toe landing strategy was utilized. van Dieen and Pijnappels (2009) evaluated the landing position for 25 women stepping down from curbs of three different heights at three different walking velocities and reported that although heel landings were predominant, toe landing was preferred for larger step heights and lower walking velocities. Walking velocity was not controlled in the present experiment, and the 14 cm step height was similar to the largest step height (15 cm) evaluated by van Dieen and Pijnappels. A toe landing would be preferred with high heels as it provides the largest surface area for support of the landing foot. The reasoning for all of the women using only the toe landing strategy in both other shoe types is not as intuitively clear and was not obvious from the video data available.

Qualitative video analysis of the second test series was performed to determine the number of steps taken by each subject prior to curb descent from a starting point of 1 ½ step lengths prior to the curb. When starting from this position, which would require modification of normal stride length, all participants made the appropriate adjustments to avoid a potentially hazardous position during curb descent. As shown in Figure 5, more subjects preferred a 2-step approach to curb descent versus using a single step from the 1 ½ step length starting position. This observation was found to be similar to results reported by Crosbie and Ko (2001), who studied step adjustments made by individuals during curb negotiation. They reported that subjects adopted a conservative step adjustment during curb descent, and ensured that the foot was either well short, or well over the curb.

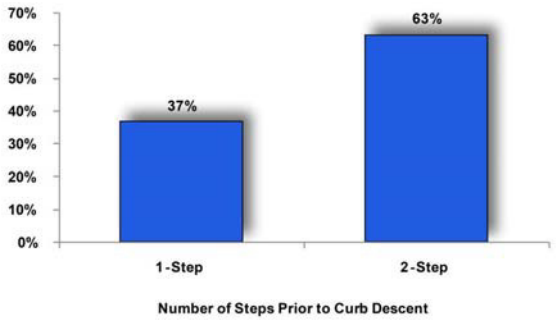


Fig. 5: Number of steps prior to curb descent from 1 ½ step lengths

4. Conclusions

The current study evaluated the effect of shoe type on performance of women descending a curb in a real-world environment. Curbs can present a trip hazard if an individual fails to successfully negotiate the change in level. Biomechanical literature extensively discusses walking on level ground and stair ascent and descent. However, less attention has been focused on performance during curb descent/ascent and no known efforts have evaluated the effects of shoe type on curb descent in a real world environment. As demonstrated by the results of this convenience sample study, women appear to adopt a more conservative gait pattern while wearing high heels as compared to sneakers or flip-flops. This approach may reduce the likelihood of a loss of balance in some ways (*e.g.*, toe box of stance foot is placed on the curb rather than overhanging) but may also make the walker more prone to falls in other ways (*e.g.*, heel-to-curb distance of swing foot is decreased increasing likelihood of contact). Similar results have been shown in studies evaluating the effect of footwear on level ground walking and stair ascent and descent, which demonstrate that women exercise additional effort, caution, and attention while wearing high heels. Not surprisingly, surveys conducted at the conclusion of the current study indicate that women are generally less comfortable and admittedly exert more caution in high heels when compared to other shoes types. Further research is required to determine how footwear can affect ankle and knee kinematics during curb negotiation in healthy young women.

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