AGE-RELATED EFFECTS OF VARYING STEP GEOMETRY & BIOMECHANICAL FALLS RISK DURING STAIR DESCENT

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Stair-related falls remain persistently high, leading to hospitalization, admission to long-term care and even death in those at greater risk of injury. The current study aims to address knowledge gaps regarding stair design by providing a more comprehensive biomechanical assessment of user behaviour during stair descent on steps of varying dimensions. Data were collected from healthy young and healthy older adults as they descended 3 custom-built staircases (each with a different riser height of 7, 7.5 and 8 inches). The tread run length varied between 8 and 14 inches in one-inch increments. Measures of foot trajectory and whole body dynamic balance control were determined. Preliminary analysis demonstrates a linear relationship with measures of safety and increased run length. Riser height appears to influence biomechanical indicators of falls risk to a lesser degree during stair descent. This empirical evidence supports the work of others and highlights the definite need for safer standards to minimize the risk of falls given the relatively huge costs of injuries on stairs.

Introduction

Falls are one of the leading causes of unintentional injuries and deaths among Canadians. Falls account for the majority of injury-related hospitalizations among older adults (Centre for Disease Control and Prevention, 2011; Public Health Agency of Canada, 2011). It has been estimated that approximately 40% of nursing home admissions can be attributed to a fall in the older adult population. Although a fall can occur when one ambulates many surfaces and obstacles, research consistently identifies stairs, particularly those found in homes, as the primary location of falls (Startzell et al., 2000; Templer, 1992; Johnson & Pauls, 2010). This is not surprising. As stated by Roys (2001), when exposure is taken into account, stairs are one of the most hazardous locations of any home.

In Canada, stair-related falls remain persistently high, leading to hospitalization, admission to long-term care homes and even death in those at greater risk of injury. A recent analysis of Canadian injury data (Barss, 2012) has indicated that stair-related falls account for 25% of all known deaths related to falls. Traumatic brain injury occurs in approximately 12% of stair falls (Barss, 2012). Although stair-related falls can happen across the lifespan they are most prevalent in advanced age, where a fall-related injury for an older adult can have severe, disabling and fatal consequences. If physical impairment is superimposed on normal aging, the ability to negotiate stairs safely may be seriously compromised (Novak & Brouwer, 2012), which in turn could be a critical factor in the loss of independence. Older adults are increasingly living longer and choose to live in community settings. To maintain healthy aging within the home and community is it critical to address falls prevention on stairs.

Although many other strategies have been proposed to address the issue of stair-related falls, changing environmental codes and standards may be the most effective way to have an impact on injuries because environmental risk factors are amenable to correction and do not require modifications in behaviour or physical function. A large injury surveillance study in the UK has identified that by increasing the minimum run length several inches, stair-related falls could be reduced by a factor of 4 (Wright & Roys, 2008). Ergonomics-based research has also emphasized that stair injuries can be prevented by improved stair design (Roys, 2001; Tse, 2005). Despite the available evidence, there is still debate amongst decision makers regarding the optimal step geometry design to minimize falls during stair ambulation. This is likely attributable to the lack of comprehensive studies aimed at understanding step dimensions and falls. For example, research-to-date has focused on understanding how only certain biomechanical measures, such as toe clearance and foot overhang percentage, are influenced by changes in step rise and run in healthy young adults (Kose et al., 1985; Wright & Roys, 2005). More comprehensive empirical evidence is required to provide further insight to user behavior and subsequent risk of falls on stairs of varying step geometry. This research would then be the basis to advocate for changes in codes and standards and improve stair safety.

The current study aims to address knowledge gaps regarding stair design by providing a more comprehensive biomechanical assessment of user behaviour in young and older adults during stair descent on steps of varying dimensions. Laboratory-derived biomechanical measures permits investigation of small differences in the performance of specific built environment features, such as rise/run dimensions and the mechanisms underlying increased risk of falls on steps of varying geometry.

Methods

Subjects

For this pilot work, data were collected from 6 healthy young adults and 6 healthy older adults. All subjects were able to ascend and descend stairs independently without the use of handrail. All subjects had normal or corrected-to-normal vision (self-report). Subjects were excluded from the study if they presented with any neurological or orthopaedic condition affecting walking ability.

Staircase apparatus

Three customized staircases, freestanding staircases were built to accommodate the testing protocol. Each staircase consisted of 6 steps which permitted adjustments of the run length (from 8 inches to 14 inches in one-inch increments). The riser height for each staircase was constant (7 inches, 7.5 inches, and 8 inches, respectively). Handrails were present for all testing. However, subjects were instructed to descend the stairs without the use of the handrail. Figure 1 below illustrates the staircase apparatus.

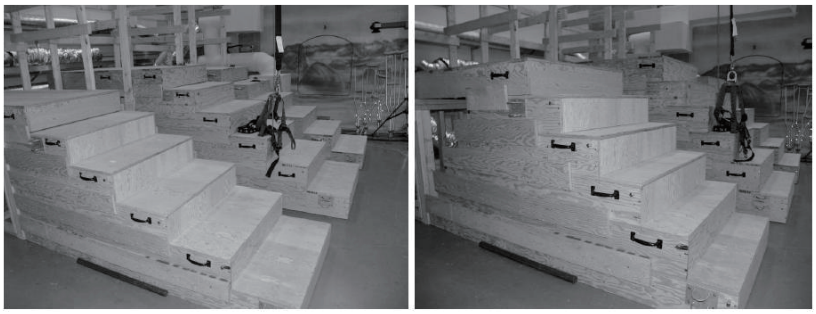

Figure 1. Custom-built stairs highlighting the maximum (left) and minimum (right) run lengths used for the study. Of note, a handrail (not present in the figure) was present for all testing. However, subjects were instructed to negotiate stairs without the handrail.

Subject instrumentation and procedure

Data collection took place at Toronto Rehab Institute's Challenging Environments Assessment Laboratory. All testing took place during a single testing session, lasting approximately 2 hours. Ethics approval was provided by the hospital's ethics board and all subjects provided informed consent prior to participation in the study.

The focus of the current work was not to determine incidence of falls, but rather to assess biomechanical measures that are known to increase risk of falling either by (a) increasing the risk of missteps or (b) increasing the degree to which the body's COM approaches the limits of stability. To gather this kinematic information, a cluster of four infrared emitting diodes (IREDs) were secured bilaterally on the subject's shoes and tracked the shoe assuming the foot to be a rigid segment. A pointed probe instrumented with IREDs permitted identification of a virtual point on the midpoint of the front of the shoe and midpoint of the heel of the shoe relative to the cluster of tracking markers. To quantify segmental motion and measures of dynamic balance, IREDs were also secured at the sacrum (level of S2, providing a proxy measure of whole body centre of mass (COM)) and the upper body at the thoracic level of T12. Finally, IRED markers were secured on the steps of each staircase and the instrumented probe was used to identify the edge of the stairs in the global coordinate system relative to the tracking step markers.

Following instrumentation, subjects were instructed to ascend and descend the stairs at a self-selected pace using a reciprocal stepping pattern, under normal lighting conditions. For this work, only stair descent is reported. All subjects were instructed to complete two trials for each staircase configuration while performing a secondary dual task (serial subtraction mental arithmetic task), where the subjects were asked to count backwards by 3's starting with a randomly selected number from the initiation to completion of the stair walking task. Previous work has shown the addition of a secondary dual-task reveals more natural motor behavior patterns thus minimizing any associated effects of laboratory testing (Miyasike & McIlroy, 2012). A total of 21 conditions were tested (7 run lengths x 3 riser heights). The step geometry configurations were randomized to ensure that fatigue, practice effects or carry-over effects did not affect interpretation of the data. An overhead, passive safety harness system was used for all testing.

Data Analysis

All kinematic data were collected at 60Hz, filtered using a second-order Butterworth filter (cut-off frequency = 6 Hz) and processed using Visual 3D (C-Motion, Inc.). In order to quantify measures of dynamic balance, a margin of stability was determined. This was computed as the instantaneous distance between the vertical extrapolation of the COM marker and the anterior boundary of the base of support. The distance between the upper body and the anterior boundary of the base of support was also determined. To quantify risk of missteps during descent, biomechanical indicators are represented by the horizontal and vertical distance between the hindmost point on the bottom of the shoe relative to the edge of the nosing and face of the riser. Measures of heel clearance were extracted at several instances to assess the risk of a misstep, including foot contact, and during swing when the heel is at the same vertical height as the step edge. For this paper, all measures of interest were determined for the steady state phase of stair descent only, which was considered as the middle (third) step.

The small sample size limited the statistical analyses that could be performed. Ongoing data collection and analysis will provide a larger sample size. Therefore, only preliminary results are reported.

Results & Discussion

Foot-to-step clearance during steady state stair descent

Figure 2 (below) illustrates the clearance of the heel during swing (measure taken when the heel is at the same vertical height of the step) and at foot contact with respect to the step edge during steady state stair descent. As indicated by the data, there is a linear relationship with increased clearance of the foot relative to the step edge as a function of increased run lengths in both the older and young adults. A limited effect of riser height is evident in the young subjects. However, the older adults appear to have a smaller heel-to-step clearance with the largest riser height (8 inches) as the foot passes the step edge. The older group also presents with a reduced slope of the curve compared to their younger counterparts as the run length increases at foot contact, placing them at greater risk of unexpected contact with the step. Despite the increased step length provided, it appears as though the older group adopt a strategy by which to maintain a greater proportion of their foot on the step. This is reflected in the Figure 3, which highlights the proportion of the foot placed on the step during flat foot (ie. Midstance). The strategy likely provides the older group with greater stability because of the opportunity to generate greater moments about the ankle to arrest forward momentum in the event of a fall. Also, following a "heel scuff" or unanticipated contact with the step edge, a more anteriorly placed step will typically occur on subsequent steps. Given that older adults do not permit very much distance between the step edge and their foot, it follows that a longer step should be provided to accommodate the potential variability in the foot placement following unexpected contact with the step.

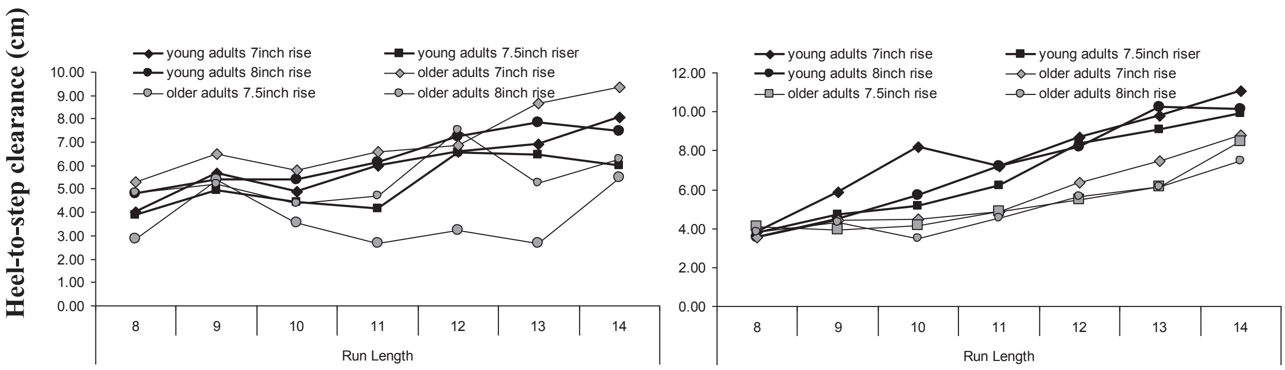

Figure 2. Foot-to-step clearance (cm) during swing across various run lengths, when the foot is at the same vertical height as the step edge (left), during steady state stair descent. Foot-to-step clearance (cm) at foot contact across various run lengths, during steady state stair descent (right). Black lines = Young adults; Gray lines = Older adults; Riser heights are indicated by the symbols in the legend.

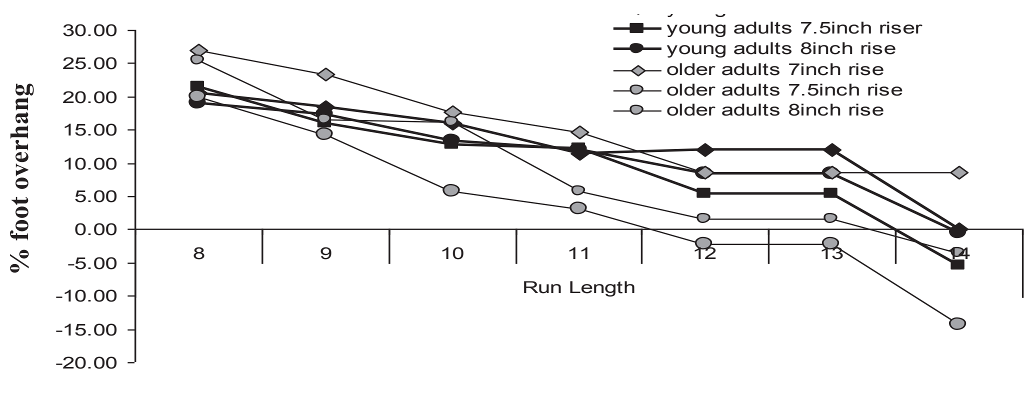

Figure 3. Percentage of foot overhang across various run lengths during steady state stair descent. Black lines = Young adults; Gray lines = Older adults; Riser heights are indicated by the symbols in the legend.

Whole body balance control during steady state stair descent

Figure 4 (below) illustrates the whole body COM and upper body position relative to the step edge in the sagittal plane during steady state stair descent. As demonstrated by the data, both young and older adults always position their COM and trunk behind the step at foot contact, despite the differences in step geometry. With an increase in run length, however, there is a general increase in the margin of stability where a greater distance between the anterior limits of the individual's base of support and the COM/upper body is noted. This does not appear to be differentially affected by aging. Riser height does not appear to affect measures of dynamic postural control during stair descent. Of note, an upward shift in the curve representing the older adults is seen, reflecting the general challenge of the task in terms of dynamic balance control (Reid et al., 2011). Specifically, at foot contact the individual must control the momentum generated by the forward pitching motion of the upper body and COM. If the individual is unable to control this momentum it places them at a much greater risk of falling during stair descent. The increased run length provides individuals with an opportunity to adopt a biomechanically more stable posture at the critical point when the body's mass is being transferred to the anteriorly placed limb.

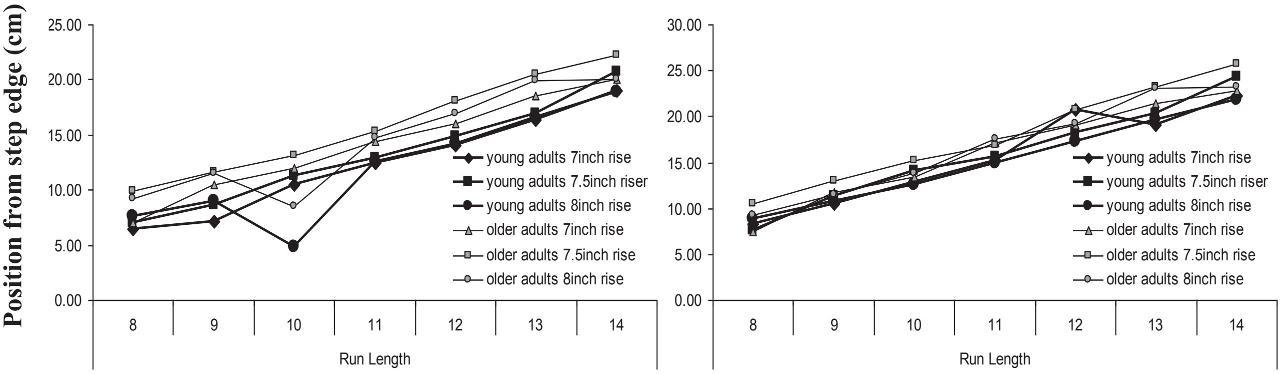

Figure 4. Position of the COM (left) and upper body (right) relative to the step edge (cm) at foot contact during steady state stair descent. Zero degrees represents a position aligned with the step edge. Positive values indicate the segment is positioned behind the step. Negative values indicate the segment is positioned ahead of the step edge.

Conclusions

The current pilot work provides a descriptive evaluation of the biomechanical risk factors of falls during stair descent in the healthy young and healthy older adults and the effect of varying rise/run dimensions. Despite available evidence (Roys, 2001; Wright & Roys, 2005; Wright & Roys, 2008), safer stair standards have not been adopted globally. The empirical evidence presented highlights the linear relationship with increased run length consistent with previous injury surveillance data (Wright & Roys, 2008). The results provide an understanding of the biomechanical mechanisms underlying increased falls risk and movement control and the relationship with step geometry. Ongoing data analysis will permit statistical analyses which will be used to advocate for improved stair safety and formulate effective recommendations for changes to current building codes in Canada and world-wide.

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