ANALYSIS OF FOOT CLEARANCES IN FIREFIGHTERS DURING ASCENT AND DESCENT OF STAIRS

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INTRODUCTION

Slip, trip and fall (STF) injuries are the leading cause of moderate to severe injuries and the second leading cause of minor injuries to firefighters on the fireground [1]. Ascending and descending stairs is generally regarded as a common everyday activity, however the U.S. Consumer Product Safety Commission estimated that there were approximately one million stair related accidents in 1990. Results from a 2008 survey of 148 firefighters showed stairs as the fifth most prevalent cause of fireground injury [2]. Firefighters routinely traverse stairs in heavy firefighting personal protective equipment following significant amounts of work and fatigue, often while carrying heavy asymmetrical loads. The prevalence of STF injuries on the fireground, and the inherent risks associated with ascending and descending stairs indicate a need to examine stair ascent and descent in firefighters.

METHODS

Twenty-four firefighters (23 male, 1 female, age 28.6±7.9 years, height 1.8±0.1 m, weight 90.7±14.9 kg) participated in this study. All provided informed consent and IRB approval was obtained. All firefighters participated in three different fatiguing protocols, though only one, simulated firefighting in a burn building, is used in this analysis. Simulated firefighting was comprised of four activities done on a two-minute work-rest cycle: (1) a stair climb in which the subject climbed to the second step on a three-step, 1.2 m wide staircase, touched both feet to the second step, then stepped backward down to ground level, (2) a simulated hose advance, in which a section of hose was fixed to a modified weight pull machine that required pulling weight from overhead. For activities (2) and (4), 9.1 kg (20 lb) of weight were used to simulate the load of advancing a hose or pulling ceiling.

Before and immediately after the fatiguing protocol, each subject went through a course consisting of six obstacles. The second obstacle was a 1.2 m wide, three step tall staircase where firefighters ascended one side and descended the opposite, always facing forward. Subjects then proceeded to the remaining four obstacles. Subjects passed through the full obstacle course twice and then twice through the first three obstacles carrying an 11.3 kg hose load on the right shoulder for a total of four trials before and four trials after the fatiguing protocol.

Toe and heel clearances over the edges of the stairs were recorded using three-dimensional motion capture data sampled at 200 Hz (OQUS 100, Qualisys, Sweden). Reflective passive markers were placed on the boot in the vicinity of the heel, first metatarsal, fifth metatarsal and on the tip of the boot. A calibration trial was conducted to determine distance from the marker placement to the ground and to determine the angle of the foot during flat stance. The vertical offset was used to determine the bottom of the boot so true vertical clearance could be calculated. Vertical clearance of the toes (VCT) during ascent and vertical clearance of the heel (VCH) during descent were examined. VCT was calculated as the average vertical clearance of the “true” first and fifth metatarsals when each marker was vertically aligned with the stair edge. VCH was determined as the vertical clearance of the “true heel” and the stair edge when the two were vertically aligned. Considering subjects did not
always begin traversing the stairs using the same foot, ‘leading’ and ‘trailing’ limbs for landing and passing stairs were compared. The first foot on stair one was considered the leading limb and used to determine the Stair 1 Landing (S1L) clearance, with the first foot on stair two considered the trailing limb and used to determine the Stair 1 Passing (S1P) clearance (see Figure 1). For descent the same naming convention was used. The first foot on stair four was considered the lead descending limb, with the first foot to touch stair five considered the trailing descending limb. This naming convention was presented in [3].

**Figure 1**: Illustration of stair edges and definition of landing and passing limbs during ascent. The left image shows landing clearance over stair one. The right image shows passing clearance over stair 1. Note that Stair 4 Landing (S4L) would indicate the clearance over edge 3b of the foot proceeding to land on stair 4.

**RESULTS AND DISCUSSION**

There was a significant Time main effect for stair clearances on five out of the 12 variables examined (SPSS 20, IBM, New York; Table 1). These included S1L (p=0.005), S3L (p=0.003), S4P (p=0.039), S5P (p=0.002) and FL (p=0.048). During ascent, clearances decreased across five of the six parameters examined, although only two were statistically significant (S1L and S3L). Clearances for S4L also decreased following fatigue. All other descent parameters (S4P, S5P, S5L, FL and FP) increased in clearance after fatigue, three of which were significant.

Previous studies have examined the negative effects of fatigue on postural control [4], stability [5,6] and gait [7]. Effects of fatigue also resulted in decreased sense of limb position [8]. The fatigue induced by simulated firefighting resulted in significant decreases in clearances while ascending and increases in clearances while descending stairs. The firefighters’ lessened postural control and reduced sense of limb position may have carried them into the stairs during ascent and carried them away from the stair edges during descent.

**CONCLUSIONS**

The impact of fatigue on clearance over stair edges, especially the decrease seen during stair ascent could lead to increased risks of trips and falls while navigating stairs. An examination of the horizontal clearances could further the hypothesis that reduced postural control and sense of limb position due to fatigue carried the firefighter into the stair edges during ascent and away from the edges during descent. Further investigations into the effects of asymmetrical load carriage and different fatiguing conditions are still necessary.

**REFERENCES**


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<table>
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<th>Ascent</th>
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<th>S1 Passing</th>
<th>S2 Passing</th>
<th>S2 Landing</th>
<th>S3 Landing</th>
<th>S3 Passing</th>
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<th>S5 Landing</th>
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Table 1: Stair Clearances (Mean±SE) over Stair Edges given in mm. Parameters indicated with a star (*) showed significant differences between pre- and post-fatiguing trials (p<0.05).