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Evaluating the physical demands on firefighters using track-type stair descent devices to evacuate mobility-limited occupants from high-rise buildings

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ABSTRACT

The physical demands on firefighting personnel were investigated when using different types of track-type stair descent devices designed for the emergency evacuation of high rise buildings as a function of staircase width and evacuation urgency. Twelve firefighters used five track-type stair descent devices during simulated urgent and non-urgent evacuations. The devices were evaluated under two staircase width conditions (1.12, and 1.32 m), and three devices were also evaluated under a narrower staircase condition (0.91 m). Dependent measures included electromyographic (EMG) data, spine motion, heart rates, Borg Scale ratings, task durations and descent velocities. Stair descent speeds favored the devices that had shorter fore/aft dimensions when moving through the landing. EMG results indicated that there were tradeoffs due to design features, particularly on the landings where the physical demands tended to be greater. On the landings, devices that could be rolled on four wheels reduced the deltoid and bicep activation levels.

1. Introduction

Firefighters/paramedics and emergency medical service (EMS) providers are frequently engaged in transporting patients down flight of stairs. In fact, when asked to indentify frequently performed strenuous work activities, Conrad et al. (2000) found that several of the identified activities included transporting patients down flights of stairs using various pieces of equipment, including stair chairs. In addition to the routine transporting of patients out of residences, fire service personnel are typically among the first responders called to assist in evacuating large multi-story buildings during both emergency and non-emergency conditions, for example, extended power outages. During such evacuations, the first responders may need to transport building occupants with mobility impairments down several flights of stairs. Clearly, the transporting of people can be very physically demanding (Lavender et al., 2000; Fredericks et al., 2002) and there is epidemiological evidence that such tasks performed by EMS workers are often associated with injury development (Gershon et al., 1995; Hogya and Ellis, 1990; Karter and Molis, 2011; Maguire et al., 2005). Furber et al. (1997) in their study of 477 workers compensations claims, specifically found that stair transport within private residences was a strong factor contributing to injuries reported by ambulance officers.

Different types of equipment are available to assist first responders in transporting individuals down flights of stairs. Most common are hand-carried stair chairs. These are minimally carried by two individuals, and depending on staircase width, patient weight, and first responder availability, carried by as many as four individuals. Prior work in this field has documented stair descents with such hand-carried chairs to be a physically demanding task (Lavender et al., 2000; Fredericks et al., 2002; Lavender et al., 2013). Specifically, Lavender et al. (2013) reported Erector Spinae activations for the “follower” position during two-person stair descents that included two landings using three hand-carried devices to evacuate a 73 kg occupant. The mean values on the stairs, averaged

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across participants, ranged between 25 and 34 percent MVC. The 90th percentile values obtained on the landing, averaged across participants, ranged between 33 and 43 percent MVC. The heart rates measured at the completion of these stair descents ranged from 36 to 48 percent of the participant's age-adjusted maximum heart rate. Moreover, hand-carried evacuation devices, particularly those where the lead evacuator must descend the stairs walking backwards, have stair descent velocities that are slow relative to published pedestrian evacuation speeds (Peacock et al., 2012) and therefore may disrupt evacuation flow in emergency situations (Lavender et al., 2013).

Within the last decade, track-type stair chairs have become more prevalent. These pieces of evacuation equipment eliminate the need for lifting/carrying and instead have evacuators gliding or rolling the chairs down the stairs on long tracks that bridge two, possibly three stair nosings, thereby reducing the load experienced by the evacuator (Fredericks et al., 2002) and improving the evacuation speed (Adams and Galea, 2010). While several track-type devices are currently on the market for emergency evacuation of individuals with motor disabilities from high rise buildings, little empirical data exists that indicates their relative impact on the physical demands experienced by the first responders across the different track-type stair chair designs. Previously, Fredericks et al. (2002) showed that the use of track-type devices reduced the risk to back injury relative to hand-carried devices. Moreover, subtle changes in the track-type stair chair design had substantial effects on the physical demands, as evidenced by the variations they observed in their compressive and shear force estimates (Fredericks et al., 2006). However, Fredericks et al. (2006) did not obtain data as the chairs were maneuvered through a landing. Previously, Lavender et al. (2007) reported greater physical demands were experienced by the research participants while on the landing as compared to when they were on the flight of stairs. Evacuation conditions including the staircase width and the urgency of the evacuation may also impact the physical demands on the first responders, particularly if the stair descent involves landings where the direction of travel changes. Drury (1985) provided evidence that task performance measures, for example task duration or movement speed, are dependent upon the available space, at least up to the point where space no longer potentially restricts movement. Likewise, Karwowski and Hashim (1991) reported a trend toward a lower acceptable weight of lift with more restricted lifting spaces. This implies that staircase dimensions could impact performance measures and muscle recruitment levels as track-type stair chairs are maneuvered through smaller versus larger landings. As for urgency, several studies have shown increases in biomechanical loading as movement speed increases (Marras, 2008). Under urgent evacuation conditions, one could expect more rapid motions, and perhaps more co-contraction of antagonistic muscles as the body is stabilized under the increased dynamic external loads.

Therefore, the objectives of this study were to compare the physical demands experienced by seasoned fire service personnel and their usability experiences when using five existing evacuation chairs with track systems, each representing a different design approach that has been developed to transport individuals who are ill or who have ambulatory disabilities down multiple flights of stairs of varying widths. Specifically, the following hypotheses were tested:

1. There are significant differences among existing evacuation device designs with regards to the physical demands placed on firefighters as measured with objective heart rate and electromyographic measures, as well as with subjective measures of perceived exertion.
2. There are differences in occupant evacuation times across evacuation devices.
3. The physical demands on the evacuator increase with narrower staircases.
4. The physical demands on the evacuator increase when there is a sense of urgency.

Additionally, the study assessed usability issues with each of the evaluated devices through video analysis and a structured interview process.

2. Methods

2.1. Participants

Twelve male professional firefighters between the ages of 24 and 61 (mean = 36 years) were recruited for this study. Mean height and weight were 1.83 m (1.75–1.96 m) and 87.7 kg (70.7 kg–111.1 kg). The fire service experience ranged from 1.5 to 23 years (mean = 9 years). All participants signed a consent document approved the The Ohio State University's Institutional Review board.

2.2. Experimental design

A repeated measures randomized block experimental design was used in which participants experienced all tested combinations of the five evacuation devices (Fig. 1), the three staircase widths, and the two urgency conditions (urgent and non-urgent). Participants were asked to descend three flights of stairs and proceed through two landings under each experimental condition. As participants performed this task, dependent measures were obtained that included task performance measures, levels of muscle recruitment, spine kinematics, and physiologic demands. Task performance measures were comprised of overall task duration, stair descent velocity, and time required for strapping the occupant in the chair. Muscle recruitment was assessed using surface electromyographic (EMG) signals sampled bilaterally from the Erector Spinae, Latissimus Dorsi, Deltoid, Biceps and Triceps muscles. Three-dimensional spine postures while the participants descended the stairs and moved through the landings were assessed using a Lumbar Motion Monitor (LMM) (Chattanooga Group, Chattanooga, TN, USA). Physiological demands were obtained by sampling the heart rate and ratings of perceived exertion (Borg Scale) at the completion of each condition. Maneuverability, one aspect of usability, was assessed using a camera mounted above one of the landings requiring a 180° turn. In addition, other usability issues were assess through structured post-study interviews.

NFPA 101-2009 code specifies staircase widths based on building occupant load. Specifically, this study evaluated stair descent tasks performed under the following stair case widths: 0.91 m (building occupancy < 50), 1.12 m (building occupancy < 2000), and 1.32 m (approximates the 1.42 m required for ≥2000 occupants). Data collection in the experiment was blocked on the three staircase widths. However, two chairs, the Long-track and the Rear-facing, were not used during the 0.91 m condition on account of their overall length. Within each staircase width, the order that the chairs were used was randomized. The sequence of “urgent” versus “non-urgent” conditions with the stair descent devices was counter-balanced across participants.

2.3. Apparatus

The chair occupant was a training mannequin having a mass of 73 kg. The five chairs selected for this study are shown in Fig. 1.