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Assessing gait changes in firefighters after firefighting activities and while carrying asymmetric loads

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ABSTRACT

One of the most common causes of injuries among firefighters is slips, trips, and falls on the fireground. Acute fatigue from firefighting activities and/or carrying asymmetric loads might impact gait characteristics increasing slip, trip, and fall risk. The purpose of this study was to examine the effects of fatigue from simulated firefighting activities and carrying asymmetric loads (fire hose over one shoulder) on firefighters' gait behavior. Both firefighting activities and asymmetric hoseload carriage led to shorter step lengths, stride lengths, single leg support time, and longer double leg support time, suggesting firefighters adopted cautious gait strategies. Simulated firefighting activities performed in either a live-fire training tower or laboratory-based environmental chamber using a firefighting activity simulator resulted in nearly identical effects on gait kinematics. This result suggests that gait assessment in a laboratory-based environmental chamber can be used as effective simulations in place of specialized burn facilities.

1. Introduction

One of the most common causes of firefighter injury on the fireground is slips, trips, and falls (STF). Every year STF events account for over 22% of all fireground injuries (Hylton and Molis, 2015). In addition, STF injuries have been found to be the leading cause of firefighter work absences (Cloutier and Champoux, 2000) and result in an average worker compensation claim that is significantly above the mean of all other claims (Walton et al., 2003).

One factor that also relates to STF is physical fatigue. Fatigue resulting from acute exertion has been found to negatively impact balance and gait (Kong et al., 2010; Nardone et al., 1997; Park et al., 2011). Compared to gait performance in a rested state, gait performance assessed immediately after performing a firefighting activity was significantly reduced, with firefighters exhibiting reduced single leg stance times while crossing obstacles and a greater number of instances of contacting the obstacle (Park et al., 2011). Kong et al. reported that physical fatigue from prolonged (~50 min) walking while wearing firefighting equipment led to increased gait variability of double support time (Kong et al., 2010). In addition, body sway increased after performing strenuous physical exercise (Nardone et al., 1997). All of these fatigue-induced changes in balance and gait increase the potential for STF.

Previous studies have employed several different exercise/activity protocols to induce acute physical fatigue, including bicycling (Nardone et al., 1997), treadmill and indoor running (Fox et al., 2008; LaFiandra et al., 2003; Nardone et al., 1997), and sit-to-stand tasks (Helbostad et al., 2007). In studies that investigated the effect of acute exertion on firefighters' gait, at least two experimental protocols have been employed. Park et al. utilized a protocol consisting of 18 min of simulated firefighting activities (climbing stairs, advancing a hose, a room search, and overhead ceiling pull on a 2 min work-rest cycle) in a live-fire burn tower, whereas Kong et al. used a 50-min treadmill walking protocol in a heated room (Kong et al., 2010; Park et al., 2011).

Past research examining the impact of acute fatigue on gait has not provided entirely consistent results likely due to the different fatigue and assessment protocols used by different research groups and that these different protocols affect different muscles leading to diverse influences in gait (Qu and Yeo, 2011). Specifically, Kong et al. found gait variability of the double-support time increased at the end of exercise, but no change was observed for other variables (Kong et al., 2010). On the other hand, using an obstacle crossing task, Park et al. found

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significant reduction in obstacle clearance and increased obstacle crossing errors after completing simulated firefighting activities, suggesting an increase in risk for trips after typical physical fatigue that might be experienced on the fireground (Park et al., 2011). In order to understand the impact of different protocols more fully, one of the goals of the current study was to determine whether the various activity protocols designed to simulate firefighting conditions used by different research teams are equivalent substitutes for realistic firefighting tasks. Further, we were interested in whether different protocols have similar effects on gait. To our knowledge, this study was the first direct comparison of different protocols to have been conducted.

Another factor that might impact gait performance and be impacted by fatigue is carrying an asymmetric load. Asymmetric load carriage is quite common on the fireground due to the necessity of carrying a variety of tools and equipment (e.g., axe, haligan, pike pole, hose). Carrying an asymmetric load has been found to significantly impact gait performance in the general population (DeVita et al., 1991; Özgül et al., 2012; Zhang et al., 2010). DeVita et al. has shown that asymmetric sidepack carriage resulted in increased hip and knee extensor moments of the unloaded leg (DeVita et al., 1991). Zhang et al. reported that asymmetric load carriage increased the gait asymmetry in ground reaction forces during walking (Zhang et al., 2010). Ozgul et al. suggested that asymmetrical backpack carriage affected both the unloaded and loaded side of body, and led to changes in knee biomechanics (Özgül et al., 2012). Changes in gait due to asymmetric load carriage may increase the risk of STF and these risks may increase as a function of fatigue. However, most studies on asymmetric load carriage have focused on the general population, and to our knowledge there have not been any studies that have examined the potential interactive effect of asymmetric loads and fatigue on firefighters' gait.

The goal of this study was to examine how fatigue from completing simulated firefighting activities and asymmetric hose load carriage can influence gait in ways that could place firefighters at increased STF risk. We hypothesized that both acute fatigue after firefighting activity and asymmetric load carriage would result in decreased gait performance, i.e., reduced step length, stride length, single leg support time, longer step widths, gait speed and double leg support time, and increased gait asymmetry. In addition, we employed three different exercise protocols such that a secondary aim of this study was to test the efficacy of two laboratory-based exercise protocols (simulated firefighting tasks vs. inclined treadmill walking) to replicate the changes in biomechanics measured after working in live-fire conditions to assist in developing a standard test protocol. It was hypothesized that the effect on gait, after simulated firefighting activity in two different types of environments (a temperature and humidity controlled environmental chamber vs. a live-fire burn building) would be similar, but different than after treadmill walking in an environmental chamber.

2. Methods

2.1. Subjects

A total of 24 healthy firefighters (age 28.6 ± 7.9 years, height 182.1 ± 7.2 cm, weight 90.7 ± 13.9 kg, leg length 96.5 ± 5.2 cm) participated in this study (23 male, 1 female). Each subject signed an informed consent and approval was obtained from the University of Illinois Institutional Review Board.

2.2. Experimental procedure

This assessment represents one part of a larger study of firefighter functional movement behavior using a complex obstacle course, which is shown in its entirety in Fig. 1. Before and immediately after finishing acute exercise protocols designed to simulate typical structural fireground exertion levels in full firefighting personal protective equipment (PPE), firefighters completed a six-station balance and gait evaluation

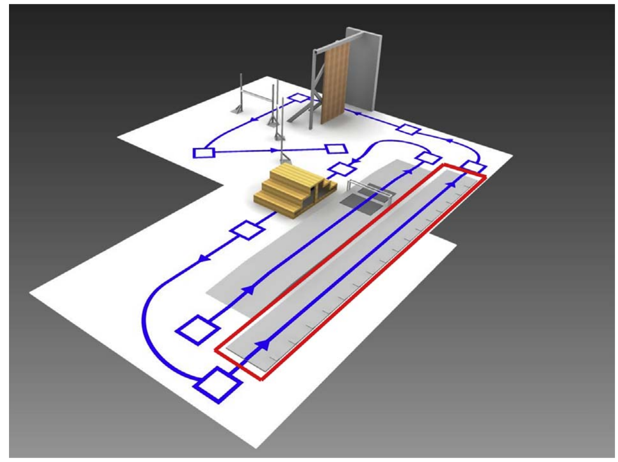

Fig. 1. Overall layout of the entire experimental setting with obstacle crossing station.

course. Subjects passed through the full course twice, resting between each trial, and then repeated the first three stations two more times carrying an 11.3 kg hose load on the right shoulder for a total of four trials before and four trials after the exercise protocol. This load is typical of one that a firefighter would carry on the fireground.

This manuscript focuses on the third station in which gait performance was evaluated using an 8.8 m-long pressure sensitive gait mat (GAITRite Platinum, CIR Systems Inc., Havertown, PA). During the gait assessment, participants were instructed to look straight ahead and walk at a pace that he or she would use on the fireground, without running. The number of steps collected for analysis was 7.55 ± 0.53 steps (maximum: 9 steps, minimum: 5.5 steps) for each condition per subject. Six gait parameters were assessed using the GAITRite software: step length (SL), stride length (STR_L), step width (SW), gait speed (GS), single leg support time (SLST), and double leg support time (DLST) (Fig. 2). The step width parameter calculated by the GAITRite software and used in this study was defined as the Euclidean distance from the midpoint of the current footprint to the midpoint of the previous footprint on the opposite foot (CIR Systems Inc., 2013). SL, STR_L, and SW were normalized to each subject's corresponding leg length (greater trochanter to floor). SLST and DLST were calculated and presented as a percentage of gait cycle. Gait symmetry was quantified using the symmetry index proposed by Robinson et al. (1987):

$$SI = \frac{P_L - P_R}{0.5(P_L + P_R)} 100\%$$

Where P_L is the value of a measured gait parameter on the left side of

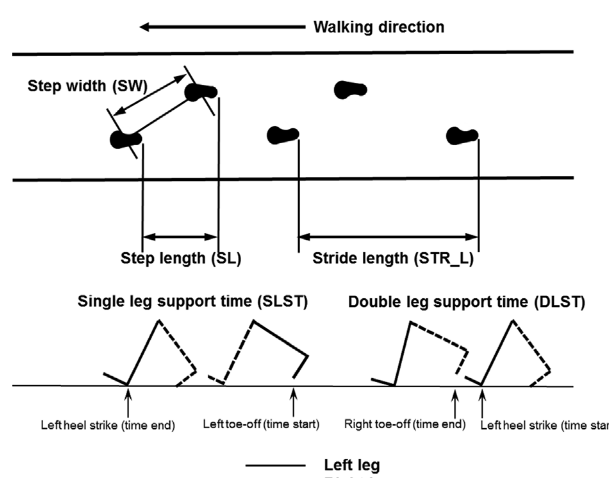

Fig. 2. Kinematic gait parameters.