ASSESSING GAIT CHANGES IN FIREFIGHTERS DUE TO FATIGUE AND ASYMMETRIC LOAD CARRIAGE

1Julian F. Sy, 1,2Gavin P. Horn, 1Richard M. Kesler, 1Matthew N. Petrucci, 3Kiwon Park, and 1Elizabeth T. Hsiao-Wecksler

1University of Illinois at Urbana-Champaign, Urbana, IL, USA
2Illinois Fire Service Institute, Champaign, IL, USA
3Trine University, Angola, IN, USA

email: ethw@illinois.edu, web: http://mechse.illinois.edu/research/hsiao-wecksler/

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 8200, or over 21%, of all fireground injuries [1]. Previous studies have found correlations between gait characteristics and STF risk [2]. Thus, understanding the changes in gait characteristics after firefighting activities may aid developments in preventing STF-related injuries on the fireground.

Fatigue and load have been found to significantly impact gait characteristics [3-6]. Various fatiguing protocols have been used to assess the effects of fatigue on gait in firefighters [3,4] and it is therefore difficult to compare results from different studies in the current literature. One goal of this study was to compare the effects of different fatiguing protocols on gait to determine whether results from previous studies can be compared with one another.

Firefighters commonly carry asymmetric loads while traversing the fireground (e.g. air bottle, hose). Several studies have examined the effects of load on human gait [5,6], but no studies have been found that examine asymmetric loads on gait symmetry when subjects are fatigued. The second goal of this study was to investigate gait changes due to asymmetric load while fatigued, which may deepen the current understanding of risk factors in STF-related injuries.

METHODS

A total of 24 healthy male (n = 23) and female (n = 1) firefighters participated in this study (age 28.6 ± 7.9 years, height 182.1 ± 7.2 cm, weight 90.7 ± 13.9 kg). Each subject signed an informed consent and approval was obtained from the University of Illinois Institutional Review Board. Firefighters underwent three different fatiguing activities: (1) simulated firefighting activities in a live fire burn building (BBFF), (2) simulated firefighting activities in a temperature and humidity controlled environmental chamber (ECFF), and (3) treadmill walking in the environmental chamber (ECTM). Temperature in the live fire burn building varied from top to bottom due to the buoyant nature of the hot gasses generated by fire, but was kept at 82º C at 1.2 m from the floor. Temperature and humidity throughout the environmental chamber was set at 49º C and 30% humidity, respectively. The simulated firefighting activities consisted of 16 minutes of alternating work/rest cycles (with 2 minute intervals) and consisted of climbing stairs, overhead ceiling pulls, a room search, and advancing a hose. Treadmill walking consisted of 16 minutes of continuous walking at 4.5 km/h at 2.5% incline. The firefighters wore National Fire Protection Association (NFPA-1971) compliant structural firefighting personal protective equipment.

Gait performance was evaluated for each fatiguing activity at two separate time periods (pre/post-activity) under two different load conditions (with/without an 11.3 kg hose load over the right shoulder). Participants were instructed to look straight ahead and walk at fireground pace. Data were collected using a 29 foot long pressure sensitive gait mat (GAITRite Platinum, CIR Systems Inc., Havertown, PA). Six parameters were measured: step length (SL), stride length (STR_L), step width (SW), gait speed (GS), single leg support
time (SLST), and double leg support time (DLST). SL, STR_L, and SW were normalized to each subject’s corresponding leg length (greater trochanter to foot). SLST and DLST were measured as a percentage of gait cycle. Gait symmetry was quantified using the following symmetry index:

\[
SI = \frac{P_L - P_R}{0.5(P_L + P_R)} \times 100\%
\]

where \( P_L \) is the value of a measured gait parameter on the left side of the body and \( P_R \) is the value of the same parameter on the right side of the body.

Descriptive statistics were calculated for all measured gait parameters and a series of three-way repeated-measures analysis of variance tests were performed with time, activity, and load carriage as main effects. Statistical significance was set at \( p < 0.05 \). SPSS 20.0 (SPSS Inc., Chicago, IL, USA) was used for all analyses.

**RESULTS AND DISCUSSION**

Significant time main effects were found for SL (\( p = 0.038 \)), STR_L (\( p = 0.032 \)), SLST (\( p < 0.001 \)), DLST (\( p < 0.001 \)), and SW (\( p = 0.037 \)), with shorter SL, STR_L, SLST, SW, and longer DLST after firefighting activity. Significant load main effects were found for SL (\( p < 0.001 \)), GS (\( p = 0.001 \)), STR_L (\( p < 0.001 \)), SLST (\( p < 0.001 \)), and DLST (\( p < 0.001 \)). The addition of the hose load resulted in shorter SL, slower GS, shorter STR_L, longer DLST, and shorter SLST. A significant activity \times time interaction was found for SL (\( p = 0.001 \)), STR_L (\( p = 0.002 \)), SLST (\( p < 0.001 \)), and SW (\( p < 0.001 \)). Post-hoc analysis revealed significant differences post-activity for these parameters between BBFF and ECTM and between ECFF and ECTM, but no significant differences between BBFF and ECFF. Significant time \times load interactions were also found for SL (\( p = 0.015 \)), GS (\( p < 0.001 \)), STR_L (\( p = 0.006 \)), SLST (\( p = 0.042 \)), and DLST (\( p < 0.001 \)), with the differences between pre- and post-activity measures larger when carrying the hose load than without.

No significant main effects were found for symmetry index for STR_L, SLST, or DLST. A significant load main effect was found for SL symmetry (\( p = 0.003 \)) with the right foot taking longer SL when carrying an asymmetric load. Additionally, a significant load \times time interaction was found for SW symmetry with the right foot taking wider steps when carrying an asymmetric load, but only when fatigued (\( p = 0.001 \)).

**CONCLUSIONS**

The effects of ECFF and BBFF conditions resulted in larger pre- to post-firefighting changes in various gait parameters when compared to the effects of ECTM. Additionally, no significant differences between the effects of ECFF and BBFF were found. These results suggest that studies employing fatiguing protocols using long term, low intensity treadmill walking may not be able to be directly compared with studies employing intermittent work/rest cycles similar to typical firefighting activities for evaluating changes in gait parameters.

Increased asymmetry in was found for SL and SW when firefighters were carrying the additional hose load. Larger SWs were found for the right foot when carrying a load while fatigued, which suggests that firefighters veer to the direction of the shoulder that is carrying the load. Additional load over the right shoulder might lead to hasty right heel strike in gait since the whole body center of mass is toward the right in the frontal plane. In order to compensate for this, subjects might use cautious strategies such as wider SW for reducing STF risk. In addition, this asymmetric load carriage requires additional hip moment which might result in fatigue of muscles related to hip joint.

**REFERENCES**


**ACKNOWLEDGEMENTS**

This project was funded by the Department of Homeland Security Fire Prevention & Safety Grant #EMW-2010-FP-01606. The authors thank David Li, Michael Angelini, Lela DiMonte, and Dan Warner for their assistance.