Safety and Health at Work 8 (2017) 183–188

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Original Article

Cardiorespiratory Fitness Is Associated with Gait Changes among Firefighters after a Live Burn Training Evolution

Deanna Colburn [1], Joe Suyama [2], Steven E. Reis [2,3], David Hostler [2,4,*]

[1] *Department of Rehabilitation Sciences, University at Buffalo, Buffalo, NY, USA*
[2] *Department of Emergency Medicine, University of Pittsburgh, Pittsburgh, PA, USA*
[3] *Department of Medicine, University of Pittsburgh, Pittsburgh, PA, USA*
[4] *Emergency Responder Human Performance Lab, Department of Exercise and Nutrition Sciences, University at Buffalo, Buffalo, NY, USA*

A R T I C L E I N F O

Article history:
Received 25 December 2015
Received in revised form
11 October 2016
Accepted 1 November 2016
Available online 15 November 2016

Keywords:
balance
fatigue
firefighter
gait
protective clothing

A B S T R A C T

Background: Recommendations have been proposed for minimum aerobic fitness among firefighters but it is unclear if those criteria relate to performance on the fireground. Less fit individuals fatigue more quickly than fit individuals when working at comparable intensity and may have gait changes, increasing risk of falls. We evaluated the effect of fatigue during a live burn evolution on gait parameters and functional balance comparing them to aerobic fitness levels.
Methods: A total of 24 firefighters had gait and balance tested before and after a live burn evolution. Data were stratified by aerobic fitness of greater/less than 14 metabolic equivalents (METs).
Results: Analysis of gait cycles measurements before and after the live burn evolution revealed that single leg stance, cycle, and swing time decreased ($p < 0.05$) but there were no differences in the other measures. There were no differences in time to complete the functional balance test, or errors committed before or after a live burn evolution. When firefighters were sorted by fitness level of 14 METs, there were no differences for errors or time before or after the live burn evolution. Balance data were analyzed using a linear regression. Individuals with lower fitness levels required more time to complete the test.
Conclusion: A 14-MET criterion failed to distinguish gait or balance characteristics in this group. However, less fit firefighters did require more time to complete the balance test ($p = 0.003$). Aerobic fitness alone does not predict gait changes among firefighters following a live burn evolution but does appear to influence functional balance.

1. Introduction

Firefighting involves various duties that include responding to structure fires, motor vehicle accidents, search and rescue, floods, and hazardous materials response. This requires responding to novel environments with unknown hazards that can contribute to slips and falls. In addition, as part of their safety protocols, firefighters are required to wear thermal protective clothing (TPC) that includes heavy pants, coat, fire boots, gloves, helmet, and a self-contained breathing apparatus (SCBA). This ensemble can weigh up to 24 kg and can alter balance while walking [1,2].

On-duty injuries to firefighters are common, with 27,015 nonfatal injuries occurring during fireground operations in 2014 [3]. Injuries that occur while working at a fireground are frequently caused by falls, slips, and jumps, which account for approximately 28.7% of all injuries [3]. In volunteer firefighter departments, 25% of fireground injuries are caused by slips, trips, jumps, or falls and may include causes like tripping over stationary obstacles or slipping on uneven or slippery surfaces [4]. Falls account for 17.8% of nonfatal injuries in government firefighters, with an additional 5.6% of injuries caused by a slip, trip, or loss of balance [5].

Intrinsic and extrinsic factors may affect the balance of firefighters and increase fall risk at emergency incidents but it is not known which factors have a more significant effect [2]. Intrinsic factors include experience, strength, and balance, whereas extrinsic factors may include heat, walking surface, or equipment worn by firefighters. Wearing TPC is known to affect gait speed and step length in addition to contributing to decreased performance on gait assessed with standard tests [1]. Postural and functional balance are negatively affected by wearing TPC, especially the SCBA,

* Corresponding author. Department of Exercise and Nutrition Sciences, SUNY University at Buffalo, 212 Kimball Tower, Buffalo, NY 14214, USA.
E-mail address: dhostler@buffalo.edu (D. Hostler).

2093-7911/$ – see front matter
http://dx.doi.org/10.1016/j.shaw.2016.11.001

and these deficits are greater in firefighters who are older [6]. Decreased postural balance due to decreased visual and somatosensory input may increase the risk of falls on the fireground [6]. In addition to the weight alterations from wearing TPC, SCBA, and carrying any additional gear, fire boots themselves can have deleterious effects on balance [7,8].

Little is known about the effect of physical fitness on gait patterns in healthy younger adults [9]. Muscle fatigue negatively affects gait patterns by increasing gait cycle variability, which has been linked to increased risk of falls [10]. Less fit individuals show signs of fatigue more quickly when working at the same intensity compared with more fit individuals. Therefore, less fit individuals may have more gait cycle changes increasing risk of falls. Various recommendations have been proposed for minimum aerobic fitness based on maximal oxygen consumption (VO_{2max}) among firefighters but it is not clear if those criteria are related to performance on the fireground. It has been reported that the most strenuous fireground activities required sustained effort of 12 metabolic equivalents (METs) and therefore, a peak aerobic capacity of 14 METs is required to be able to successfully meet these demands [11]. Studies have reported that aspects of fitness such as aerobic capacity and strength training are more likely to predict performance on certain tests used to ascertain firefighter job readiness [12,13]. These tests include activities such as a hose pull, stair climb, simulated victim drag, but to our knowledge, there are no studies examining the effect of aerobic fitness on gait or functional balance among firefighters after participating in a live burn evolution. We hypothesized that firefighters with higher levels of fitness would have fewer changes in gait and balance after a live burn evolution.

2. Materials and methods

The University of Pittsburgh's Institutional Review Board (Pittsburgh, PA, USA) approved the procedures in this study. All firefighters (study participants) provided written, informed consent prior to participating. Study participants included male and female local volunteers and career firefighters certified to a level that allowed them to participate in live fire training.

All participants underwent a physical examination by a study physician before participation. Participants were free of chronic health conditions including cardiovascular and pulmonary disease, metabolic disease, or orthopedic injury. Participants completed a Bruce protocol treadmill test using open circuit spirometry (Parvo Medics TrueOne 2400; Parvo Medics, Sandy, UT, USA) to determine individual VO_{2max}. Electrocardiogram was recorded at rest and during the VO_{2max} test and reviewed by a study physician to ensure there were no cardiac abnormalities.

Gait measurements were videotaped (50 frames/s) on the day of the live burn evolution. The camera was positioned perpendicular to the walking lane to allow multiple steps to be analyzed. Gait was analyzed using Dartfish Connect 6.0 software (Dartfish USA, Alpharetta, GA, USA). A single technician analyzed gait speed, single and double stance time, step frequency, stride length, and cycle time.

Participants also completed a functional balance test developed for firefighters and used previously by our group [12,14]. A practice test was administered in the laboratory wearing gym clothes and tennis shoes. Participants start the test by standing on a platform at ground level with marked placement for their feet. Participants were required to walk across a 4.4-cm thick beam 9.5 cm wide and 2.45 m long. The participants initially walked forward, then turned in the middle 0.50 m of the beam and continued walking backward and stepping off the end of the beam onto another platform. They would repeat this process to end on the initial starting platform. Participants were to complete this balance task as quickly as they could without making errors. Errors were defined as stepping off the beam, touching the ground, failing to turn in the designated area, or not stepping on the designated platform area. The time to complete the test was measured with a digital stopwatch and the amount of errors were recorded by a single observer.

Participants reported to the Allegheny County Fire Academy and participated in a live burn training evolution. All data were collected in the morning over 4 consecutive days. Participants used their department-issued protective clothing and breathing apparatus. Participants were instructed to eat a normal breakfast and to avoid alcohol, caffeine, and exercise 12 hours prior to the training. All participants were given an indigestible pill (HQ Inc., Palmetto, FL, USA) to monitor core temperature and asked to take it 8 hours prior to arrival.

Participants provided a urine sample to assess euhydration (urine specific gravity $\leq$ 1.025). Participants who were not euhydrated were instructed to drink water and were rechecked for hydration status and began participation after euhydration was achieved. Each participant's protective ensemble was inspected by Allegheny County Fire Academy (Allison Park, PA, USA) instructors to ensure it met the required standards for use in a live fire training exercise. Participants donned their protective clothing and SCBA before completing the balance and gait tests. The full protective ensemble included boots, heavy pants, heavy coat, helmet, gloves, flame-resistant hood, and SCBA.

The scenario required the participant to enter a concrete block building and advance a 4.4-cm charged hose line up an interior stairwell to the second floor of the structure. Participants participated in repeated fire suppression and ventilation of room and contents as part of the training exercise and worked in pairs for approximately 20 minutes. Participants then cleared themselves and equipment including fire hose from the training building. Immediately after participating in the live fire exercise, each participant repeated the gait and functional balance test procedures.

2.1. Statistical analyses

Gait and functional balance data before and after the live burn evolution were compared with paired *t* test for the entire cohort. Participants were then stratified by maximal METs measured during their VO_{2max} assessment. A two-way analysis of variance was performed with the conditions before and after the live burn evolution and greater/lesser than 14 METs aerobic capacity. A regression analysis was also performed and conditioned on fitness. Data were considered significant if $p \leq 0.05$. All analyses were performed using Prism 5 for Mac OS X (version 5.0f) (GraphPad Software, La Jolla, CA, USA).

3. Results

A total of 24 participants participated. Morphometric measurements were obtained and are presented in Table 1. Full gait information was collected from 20 participants but video quality was not sufficient to accurately determine heel strike or toe off in the remaining six participants. Data for the functional balance testing were available for all 24 participants. For analysis of participants

Table 1
Morphometrics of the cohort

Criterion	Male/Female	Age (y)	Height (cm)	BMI (kg/m^2)	VO_{2max} (mL/kg/min)
$<$ 14 METs	10/2	26.9 $\pm$ 7.5	176.6 $\pm$ 10.3	29.2 $\pm$ 6.0	41.7 $\pm$ 6.4
$>$ 14 METs	11/1	29.1 $\pm$ 4.4	176.5 $\pm$ 7.8	26.9 $\pm$ 2.9	52.4 $\pm$ 3.7*

* $p < 0.001$ when compared with the "less than 14 METs" group.
BMI, body mass index; MET, metabolic equivalent; VO_{2max}, maximal oxygen consumption.

where data could be analyzed there are similarities in the gait cycle findings that were independent of fitness levels. Analysis of gait before and after the live burn evolution revealed that single leg stance time, cycle time, and swing time decreased ($p < 0.05$) but there were no differences in the other measures of the gait cycle (Fig. 1).

The live burn evolution lasted 25.1 ± 6.1 minutes each interval with participants extinguishing and ventilating multiple wood-fueled room fires. Pre- and postvalues for heart rate and core temperature are reported in Table 2 and are consistent with previous studies using a live burn evolution protocol conducted by our group [15,16].

The functional balance test outcomes included the time to complete the test and the number of errors that occurred during the test. Overall, there were no difference in time to complete the test, or errors committed during the test performed before the live burn evolution in TPC and after evolution conditions (Fig. 2). Similarly, when participants were sorted by fitness level of 14 METs, there were no differences for errors or time between testing conditions (Fig. 3). However, when balance data were analyzed using a

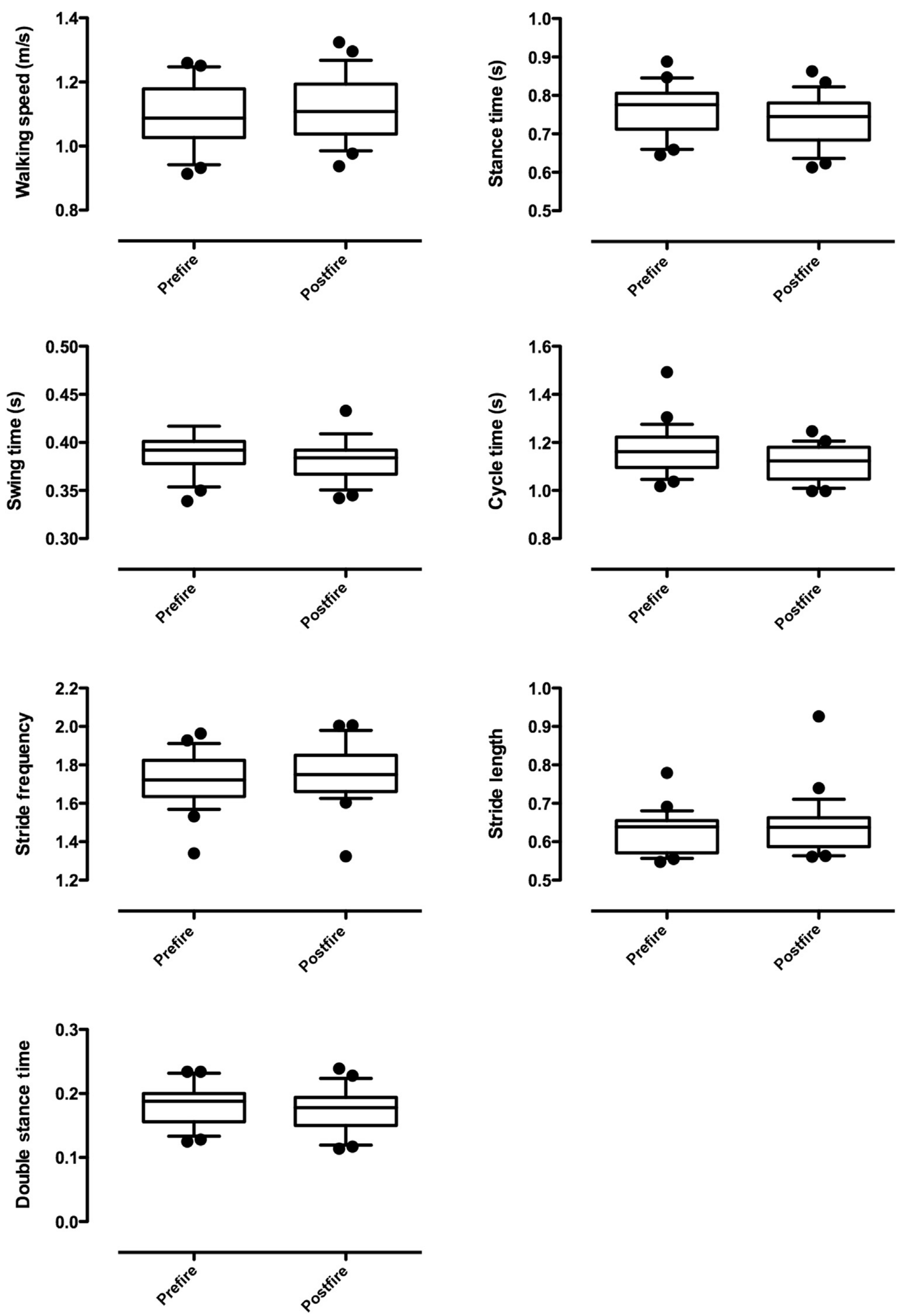

Fig. 1. Spatiotemporal gait variables measured before and after the live burn evolution interval. Whiskers on the plots indicate the 10th and 90th percentiles. Black circles represent outliers beyond the 10th percentile and 90th percentile.

Table 2
Change in heart rate (HR) and core temperature (T_c) and final values after the fire suppression interval

HR change pre–post fire suppression	HR after fire suppression	T_c change pre–post fire suppression	T_c after fire suppression
72 ± 21 bpm	177 ± 17 bpm	1.04 ± 0.6°C	38.3 ± 0.7°C

bpm, beats per minute.

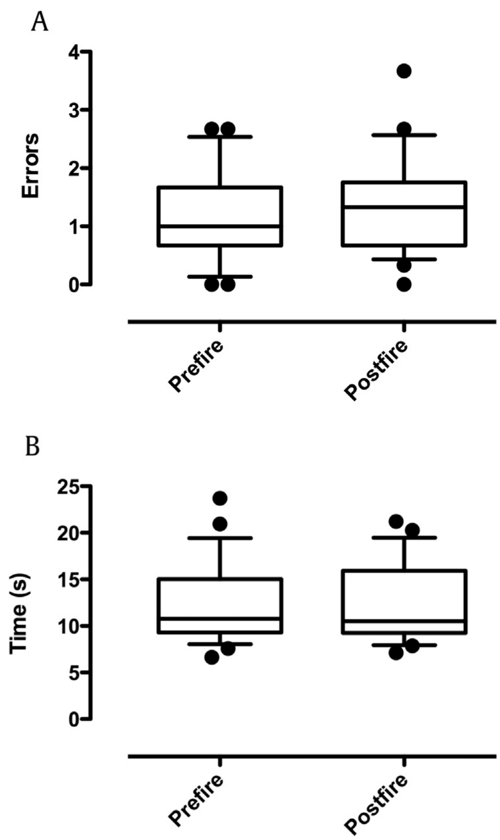

Fig. 2. Number of errors committed (A) and time required (B) to complete the functional balance test before and after the live burn evolution. Whiskers on the plots indicate the 10th percentile and 90th percentile.

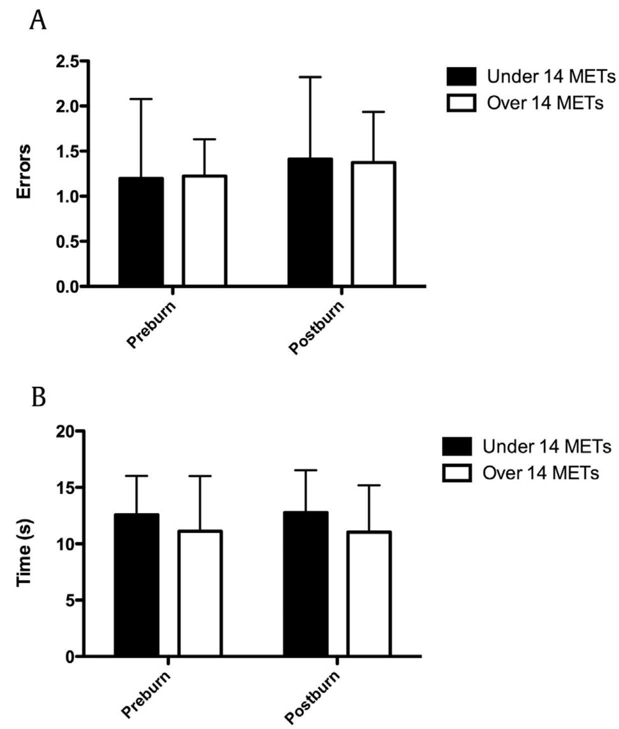

Fig. 3. Number of errors committed (A) and time required (B) to complete the functional balance test before and after the live burn evolution stratified by aerobic fitness above or below 14 metabolic equivalents (METs). Data are shown as mean ± standard deviation.

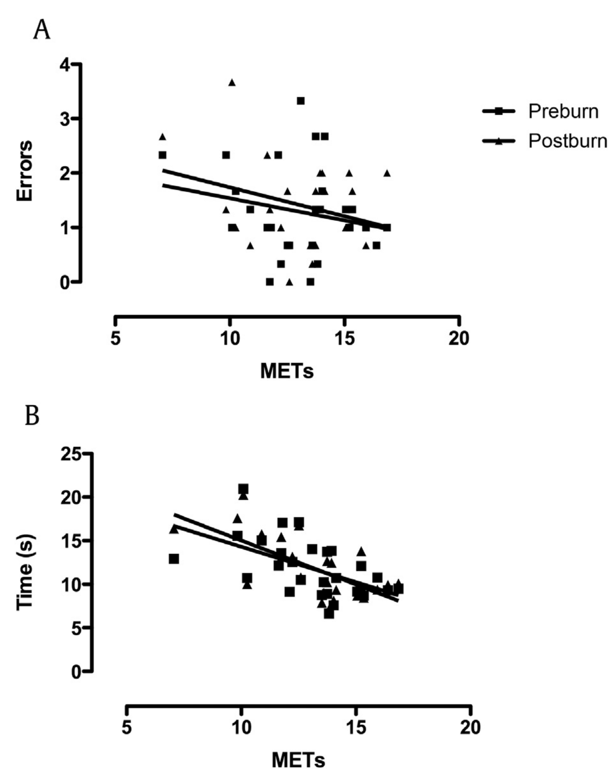

Fig. 4. Regression lines fitted to the errors committed (A) and time required to complete (bottom panel) stratified by aerobic fitness before (square symbols) and after (triangle symbols) the live burn evolution interval. For errors committed, $r^2 = 0.04$ (before the test) and 0.09 (after the test). For time, $r^2 = 0.30$ (before the test) and 0.45 (after the test). METs, metabolic equivalents.

linear regression of fitness, individuals with lower fitness levels required more time to complete the test before and after the live burn evolution (Fig. 4).

4. Discussion

This is one of the few studies to describe the association of protective firefighting gear, physical exertion, and aerobic fitness on changes in the gait cycle and functional balance. Few gait variables were altered by the exertional heat stress associated with participation in a single live burn evolution when firefighters were wearing full TPC despite substantial rise in heart rate and core body temperature. Fitness levels of the participants did not affect the results of the functional balance test when participants were separated into two groups by ability to perform 14 METs or greater of work. However, a linear regression analysis indicated that higher fitness levels allow firefighters to complete the test in less time. Participants were allowed to self-select their speed during the functional balance test. It is unknown if falls would increase if participants were required to complete the testing more quickly and we have previously reported that firefighters employ a slowing strategy on the test when the gear configuration becomes heavier and more complex [12]. Less physically fit firefighters may have a higher risk of falls in conditions that dictate the need to work at a faster pace than they would normally select for gait.

Analysis of live burn evolution gait data (before and after the test) revealed that single leg stance time, cycle time, and swing time decreased after firefighting activities but there were no differences in the other measures of the gait cycle. Identifying changes in these gait measures is novel and may indicate that firefighters are altering their gait with a slightly shortened stride and may be an unconscious attempt to compensate for their fatigue. Another possibility is that participants were aware they were being filmed and may have altered their gait while on camera to disguise markers of fatigue. It is possible that other unmeasured aspects of gait such as foot clearance, hip, knee, ankle, and foot joint kinematics, or forces produced by heel strike or toe off may reveal adaptive changes associated with fatigue, which could increase risk of slips, trips, and falls.

Other investigations have examined the relationship between wearing protective firefighting equipment and balance in an effort to decrease slips and falls with mixed results. A laboratory study of participants walking in the heat while wearing TPC and SCBA reported that the gait spatiotemporal variables such as step length and frequency were not different when comparing the rested and fatigued conditions [17]. Other investigations have reported changes in the gait cycle when participants wore TPC of different types compared with baseline conditions [1,18]. One of these studies found that wearing TPC caused the participants to have slower gait and shorter step length, and shorter single leg stance [1]. The wide discrepancy in effects of gear on gait variables may be attributed to a variety of factors including the use of treadmills to control gait speed, the use of obstacles positioned during testing, or possibly an unappreciated factor such as firefighter experience, body mass index, or the type and style of TPC.

In addition to altering the timing of the gait cycle, wearing TPC and SCBA increases postural sway, especially when visual input is eliminated. Functional balance is impaired by wearing personal protective equipment with SCBA as the single most detrimental piece of equipment [6]. Wearing SCBA has been associated with increased fall risk on the fireground [19]. Increased errors in functional gait tests have been reported when participants were fatigued after activity in TPC but this was not seen with the study conditions used in the present report [1].

A previous study of firefighters conducted in our laboratory used the balance test from the present study to examine the effect of wearing different combinations of TPC and SCBA versus regular clothing [12]. Generally, participants in that study decreased gait speed and had more errors on the balance test when wearing TPC and SCBA. The exception was the group that reported regular participation in strength training and aerobic exercise; they maintained gait speed and number of errors across testing conditions. The present study found that participants with higher fitness levels required less time to complete the balance test using linear regression, but did not find a significant difference in time or errors when comparing pre- with postwork conditions.

Minimum aerobic fitness recommendations have been made for the fire service personnel ranging from 10 METs to 14 METs and should be incorporated into firefighter screening and rescreening programs, given the high rates of obesity and the prominence of cardiac death within the fire service [20]. However, there is little evidence that aerobic fitness alone predicts performance on occupation-specific tasks. Persons who have increased fitness levels will experience fatigue less quickly than those who have lower levels of fitness. Fatigue has been noted to impair gait characteristics such as step width and hip and trunk range of motion; gait alterations can increase fall risk [12,17,21]. The regression analysis results in the present report indicate that firefighters with lower fitness levels may have decreased functional balance when compared with their more fit colleagues. However, simple stratification by the 14-MET criterion did not reveal differences in functional balance. It is possible that using a lower criterion would have revealed differences but there were not enough low-fit firefighters in the study to perform additional stratifications. These results support decreased risk of falls in firefighters who adhere to recommended standards for cardiovascular fitness.

This study was limited by the lack of low fitness levels among participants. Of 24 participants, only four had aerobic capacity measured under 12 METs, indicating a relatively high level of aerobic fitness when compared with the fire service reports overall. We did not measure muscular strength and do not have data regarding aerobic or strength training programs that the participants participated in outside of the study. A wider sample of aerobic fitness levels in firefighters that are approved for active duty may provide more insight into fitness, balance, and risk of falls.

In conclusion, differences were seen in gait when comparing data before and after the live burn evolution among experienced firefighters who were accustomed to wearing fire protective gear, indicating that some combination of TPC and fatigue affects gait. A 14-MET fitness criterion failed to distinguish gait or balance characteristics in this group of firefighters although there is an association with aerobic capacity and time to complete the functional balance test. Using this standard, aerobic fitness alone does not predict performance with regard to gait and balance among firefighters following a live burn evolution but does appear to influence functional balance when self-selection of gait speed is compatible with surrounding conditions.

Conflicts of interest

The authors have no conflicts of interest to report.

Acknowledgments

This study was funded in part by a grant from the Federal Emergency Management Agency Fire Protection & Safety Program (EMW-2009-FP-00921).

References

[1] Park K, Rosengren KS, Horn GP, Smith DL, Hsiao-Wecksler ET. Assessing gait changes in firefighters due to fatigue and protective clothing. Saf Sci 2011;49:719–26.
[2] Kong PW, Suyama J, Hostler D. A review of risk factors of accidental slips, trips, and falls among firefighters. Saf Sci 2013;60:203–9.
[3] Haynes H, Molis JL. US firefighter injuries: 2014. NFPA J 2015;109:52–9.
[4] Haynes Hylton JG. U.S. volunteer firefighter injuries 2012–2014. 2016. p. 1–14. http://www.nfpa.org/news-and-research/fire-statistics-and-reports/fire-statistics/the-fire-service/fatalities-and-injuries/an-analysis-of-volunteer-firefighter-injuries-2009-to-2011.
[5] Kurlick GM. Stop, drop, and roll: workplace hazards of local government firefighters, 2009. Monthly Labor Review 2012;135:18–25.
[6] Punaxallio A, Lusa S, Luukkonen R. Protective equipment affects balance abilities differently in younger and older firefighters. Aviat Space Environ Med 2003;74:1151–6.
[7] Chiou SS, Turner N, Zwiener J, Weaver DL, Haskell WE. Effect of boot weight and sole flexibility on gait and physiological responses of firefighters in stepping over obstacles. Hum Factors 2012;54:373–86.
[8] Garner JC, Wade C, Garten R, Chander H, Acevedo E. The influence of firefighter boot type on balance. Int J Ind Ergonomics 2013;43:77–81.
[9] Niang AE, McFadyen BJ. Effects of physical activity level on unobstructed and obstructed walking in young male adults. Gait Posture 2005;22:75–81.
[10] Parijat P, Lockhart TE. Effects of lower extremity muscle fatigue on the outcomes of slip-induced falls. Ergonomics 2008;51:1873–84.
[11] Gledhill N, Jamnik VK. Characterization of the physical demands of firefighting. Can J Sport Sci 1992;17:207–13.

[12] Kong PW, Suyama J, Cham R, Hostler D. The relationship between physical activity and thermal protective clothing on functional balance in firefighters. Res Q Exerc Sport 2012;83:546–52.
[13] Rhea MR, Alvar BA, Gray R. Physical fitness and job performance of firefighters. J Strength Cond Res 2004;18:348–52.
[14] Punakallio A. Trial-to-trial reproducibility and test-retest stability of two dynamic balance tests among male firefighters. Int J Sports Med 2004;25:163–9.
[15] Colburn D, Suyama J, Reis SE, Morley JL, Goss FL, Chen YF, Moore CG, Hostler D. A comparison of cooling techniques in firefighters after a live burn evolution. Prehosp Emerg Care 2011;15:226–32.
[16] Hostler D, Colburn D, Rittenberger JC, Reis SE. Effect of two work-to-rest ratios on cardiovascular, thermal, and perceptual responses during fire suppression and recovery. Prehosp Emerg Care 2016:1–7.
[17] Kong PW, Beauchamp G, Suyama J, Hostler D. Effect of fatigue and hypohydration on gait characteristics during treadmill exercise in the heat while wearing firefighter thermal protective clothing. Gait Posture 2010;31:284–8.
[18] Park K, Hur P, Rosengren KS, Horn GP, Hsiao-Wecksler ET. Effect of load carriage on gait due to firefighting air bottle configuration. Ergonomics 2010;53:882–91.
[19] Heineman EF, Shy CM, Checkoway H. Injuries on the fireground: risk factors for traumatic injuries among professional fire fighters. Am J Ind Med 1989;15:267–82.
[20] Kales SN, Soteriades ES, Christoudias SG, Christiani DC. Firefighters and on-duty deaths from coronary heart disease: a case control study. Environ Health 2003;2:14.
[21] Qu X, Yeo JC. Effects of load carriage and fatigue on gait characteristics. J Biomech 2011;44:1259–63.