International Journal of Industrial Ergonomics 44 (2014) 615–620

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Fatigue-induced balance alterations in a group of Italian career and retained firefighters

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ARTICLE INFO

Article history:
Received 2 July 2013
Received in revised form
2 April 2014
Accepted 29 June 2014
Available online 28 August 2014

Keywords:
Firefighters
Postural sway
Balance
Fatigue
Multiscale entropy
Aging

ABSTRACT

Firefighters (FFs) often work in hazardous and physically-demanding environments, and injuries related to loss of balance are common among them. This study examined the postural balance of FFs with different levels of experience and training, both before and after simulated physically-demanding and fatiguing firefighting and rescue activities. Balance was assessed in two FF groups (career and "retained", $n = 13$ each), on the basis of center-of-pressure (COP) time series that were acquired using a pressure platform during quiet upright stance. Several traditional COP-based measures (mean COP velocity and sway area) were derived. In addition, and to quantify the dynamical properties of postural control, complexity of the COP time series was determined using the multiscale entropy (MSE) method. Both age and the annual number of working days were higher for career FFs, though both groups had comparable levels of pre-activity balance. Post-activity changes in balance were also generally comparable between the groups, except that retained FFs exhibited a significantly higher post-activity loss of COP complexity in the medial-lateral direction. These results suggest that experience and training may serve to offset age-related decrements in postural balance, and implications for the risk of balance-related injuries during firefighting operations are discussed.

Relevance to industry: Objective assessment of physical capacities in firefighters may be of value to design training programs suitable to meet job demands and avoid injury.

1. Introduction

Firefighters (FFs) are often required to work in fast-paced, physically demanding, and/or unpredictable environments. Maintaining postural balance can be essential to safely performing a FF's required tasks, such as when using a ladder, walking on a roof, or during interior structural firefighting (aka "smoke diving"). Yet, maintaining balance in such situations can be challenging to achieve. In fact, slips, trips, and falls are collectively the major cause of non-fatal injuries among FFs, and account for roughly 28–40% of all non-fatal injuries in the US (Karter, 2012a) and the UK (Health and Safety Executive, 2014). Moreover, a recent study (Petrucci et al., 2012) indicated that FFs report a need for specific prevention programs aimed to reduce the risk of slips, trips, and falls.

Postural balance of FFs has been assessed in several studies during upright stance. These studies have demonstrated that balance can be affected by the use of personal protective equipment (PPE), age, fatigue, and extended work shifts. Specifically, standing balance performance has been found to be inconsistently affected by the use of PPE (Punakallio et al., 2003; Sobeih et al., 2006), and to decline generally for older vs. young FFs (Punakallio et al., 2003, 2005), as well as after fatiguing exercise (Kincl et al., 2002) and a long working period (Sobeih et al., 2006). These findings, however, are limited to either of two categories of FFs – career (or professional/fulltime) or volunteer – and have not considered retained (or on-call/part-time) FFs. The latter are common in some European countries, accounting for ~30% of the total workforce in the UK (Fire Brigades Union, 2004) and ~20% in Italy (Corpo Nazionale dei Vigili del Fuoco, Italia, 2011).

Retained FFs provide a full-time service (e.g., fire and emergency cover) with regularly scheduled and on-call shifts, though only on certain days and while maintaining other full- or part-time work. However, they undertake the same basic training as career FFs and follow a regular training program at the fire station when not busy with emergency services. Based on FF reports, this training usually consists of 1–2 two daily sessions that are self-administered for a total of ~2 h. Such training involves either general resistance exercises or more specific "work-like" routines composed of tasks

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http://dx.doi.org/10.1016/j.ergon.2014.06.010
0169-8141/

List of abbreviations:

AP	Antero-Posterior
BMI	Body Mass Index
CEA	Confidence Ellipse Area
CI	Complexity Index
FFs	Firefighters
ML	Medio-Lateral
MSE	Multiscale Entropy
MV	Mean Velocity
PPE	Personal Protective Equipment
SCBA	Self-Contained Breathing Apparatus

similar to those performed during real firefighting and rescue services (e.g., stairclimbing, hose unrolling and rolling, fire suppression, etc.).

Further, service requests and emergency duties are the same for the two categories, as are hourly pay rates. With only a part-time commitment, though, retained FFs typically have a fewer number of shifts and less opportunities to attend in-station training than career FFs, leading to different levels of experience and training between different categories of FFs. Importantly, postural control can be affected by the level of expertise/experience (Min et al., 2012; Noé and Paillard, 2005; Schmit et al., 2005) or improved with physical training (Di Stefano et al., 2009; Nagy et al., 2007; Van Ooteghem et al., 2009). A recent report by Karter (2012b) indicated that volunteer FFs have more injuries at the fireground than career FFs, with falls, jumps, slips, and trips being the major causes of injuries. Hence, it can be speculated that career and retained FFs are exposed to different levels of injury risks at the fireground that are related to differences in postural balance.

The purpose of this study was thus to examine whether there is difference in the postural balance between FFs with different levels of experience and training (i.e., career and retained FFs), particularly after firefighting and rescue operations. Such operations likely induce physical fatigue, and extensive evidence demonstrates that both general and localized muscle fatigue compromise postural balance (e.g., see Paillard, 2012 for a review). Less-trained and less-experienced personnel might be more susceptible to fatigue-induced adverse effects and subsequent risk of balance-related injuries during firefighting and rescue operations. Therefore, it is considered of practical importance to understand how postural balance changes post-fatigue for FFs with different levels of training and experience. This study was designed to address two central questions: 1) do career and retained FFs have a similar baseline level of postural balance in the absence of fatigue induced by training activities? and 2) does fatigue differentially impair the postural balance of career and retained FFs?

2. Methods

2.1. Participants

Twenty-six active male FFs in two groups (13 career and 13 retained) participated voluntarily, all from the Fire Department of the City of Oristano (Sardinia, Italy). Note that participation was not limited to males, though only males volunteered. All participants provided informed consent prior to experimentation, and the study procedures were conducted in compliance with the ethical principles for research involving human subjects expressed in the Declaration of Helsinki (World Health Organization, 2001). Participants completed a short questionnaire containing questions addressing physical training outside the fire station (frequency and hours per week) and any musculoskeletal problems within the prior month. In particular, the participants reported that aerobic training such as swimming, cycling and jogging/running were their preferred activities while not on duty.

None of the participants reported any such musculoskeletal problems. No significant difference (two-sided Fisher's Exact Test, $p = 0.39$) was found between groups in whether physical training was done outside the fire station; among participants who did such training, both the frequency and duration of training were comparable between groups (Table 1). Anthropometric measures were obtained by direct measurement, and annual service days were provided by the Human Resources Office of the Oristano Fire Station (summary statistics are provided in Table 2). Using an existing classification (NHLBI, 1998), the mean Body Mass Index (BMI) of the two groups was above the normal weight category ($18.5 \leq$ BMI < 25), 60% of the participants were overweight ($25 \leq$ BMI < 30), and 20% were in class I obesity ($30 \leq$ BMI < 35). According to the official time sheet supplied by the Department Command, career FF participants completed more working days in 2010 than retained FFs, and were also older. The latter was not unexpected, as it is usual to spend a long period as a retained FF before formal enrollment as a career FF. Such enrollment occurs as a result of passing examinations provided for the public selection periodically issued by the Italian Ministry of Internal Affairs.

2.2. Experimental design and procedures

A pretest-posttest design was used, in which participants performed a single trial of quiet upright standing both before and after simulated firefighting and rescue activities (i.e., fatiguing protocol; see below for the details). Postural balance was measured during these trials, all of which were performed in a dedicated quiet room at the fire station during a regular shift. During the standing trials, participants stood on a pressure platform (Footscan™ 0.5 system, RS Scan International, Belgium) composed of a pressure-sensitive plate (4096 7.62 $\times$ 5.08 mm sensing elements based on piezoresistive technology arranged in a 64 $\times$ 64 matrix). Each trial lasted 30 s, during which participants were asked to stand as still as possible with their gaze fixed at a target image placed at a distance of 3 m at eye level, their arms at their sides, and their feet placed on two 30° oriented shapes drawn on a paper sheet. These procedures ensured a common reference position, and foot placement followed recommendations of the International Society of Posturography (Kapteyn et al., 1983). Participants wore protective clothing (Nomex™ jacket, brush pants, gloves, and helmet produced by Alfredo Grassi S.p.A., Italy) during both the balance trials and the simulated activities. The total mass of protective clothing was 21.5 kg.

Table 1
Summary of questionnaire results regarding physical training outside the fire station.

	Response	Career FFs	Retained FFs
1. Do you perform physical training outside the fire station?	Yes	80%	90%
	No	20%	10%
2. If yes, with what frequency (sessions per week)?	Sporadic	0%	11%
	At least once per week	0%	11%
	At least twice per week	38%	44%
	More than twice per week	62%	34%
3. How many hours do you spend for training on a weekly basis?	up to 2 h	13%	0%
	2-4 h	25%	44%
	4-6 h	63%	44%
	>6 h	0%	11%