Applied Ergonomics 65 (2017) 123–129

Contents lists available at ScienceDirect

Applied Ergonomics

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

Ankle restrictive firefighting boots alter the lumbar biomechanics during landing tasks

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ARTICLE INFO

Article history:
Received 21 December 2016
Received in revised form
4 June 2017
Accepted 5 June 2017

Keywords:
Firefighting boots
Lumbar
Landing

ABSTRACT

Firefighters incur high incidences of lower back and body injuries. Firefighting boots, with specific design requirements, have been shown to reduce ankle range of motion. This reduction has been associated with impaired force dissipation and lower body kinematic alterations. Thus, the aim of this study was to determine the relationship between firefighting boots, lumbar biomechanics and load carriage during landing. Our data indicates that when wearing firefighting boots, lumbar forces increased and kinematics changed in frontal and transverse planes. These changes may be occurring due to the restrictive shaft of the firefighting boot reducing ankle range of motion. Comparisons between unloaded and loaded conditions also showed increased changes in lumbar biomechanics, independent of footwear worn. Therefore, wearing firefighting boots, in addition to operational loading, may be placing firefighters at greater risk of lumbar injuries. Future research investigating firefighting boots and additional load carriage on lower body biomechanics during landing is recommended.

1. Introduction

Firefighting is a physically demanding occupation where workers are exposed to a significantly increased risk of injury (Bos et al., 2004). To address the risk of workplace injuries, technical advances in equipment, in conjunction with changes to standard operating procedures, have resulted in significant reductions in overall injury numbers in fire services (Karter and Molis, 2011). However, while injuries have reduced, injury surveillance data reporting that the majority of firefighting injuries occurring at work involved sprains and strains, with between 42 and 62% of the compensable injuries occurring in the lower lumbar and lower body regions (Bos et al., 2004; Reichard and Jackson, 2010).

According to the Global Burden of Disease study conducted in 2010, lower back pain accounted for 10.5% of years lived with disability (YLDs) and was ranked first in overall health burden in Australasia (Hoy et al., 2014). This study was based on several occupations and not specifically firefighters. In addition, the likelihood of individuals working in the labour workforce was also reduced when subjected with lower back pain (Australian Institute of Health and Welfare, 2016). As firefighters have higher physical demands at work than more sedentary occupations, it is possible that the YLDs for the firefighting population may be higher as they are at higher risk of injury, particularly during high intensity emergency responses. During any given shift, firefighters continuously complete high impact work tasks which include walking, jumping, landing, stepping over obstacles, stair climbing and alighting fire trucks (Chiou et al., 2012; Coca et al., 2010; Giguère and Marchand, 2005; K. Park et al., 2011). Thus, the impact of lower back pain would likely result in the inability for firefighters to continue work, resulting in lost work time, reduced work life and increased government costs (Australian Institute of Health and Welfare, 2016).

Firefighters are required to wear personal protective clothing (PPC) typically comprising of a coat, pants and gloves and personal protective equipment (PPE) to protect against hazardous environmental conditions. However, despite fulfilling protective requirements, PPC restricts natural movement as it adds bulkiness and rigidity. This reduced mobility, has been associated with early fatigue, reductions in physical performance and increased risk of injuries, particularly from trips and falls (Kong et al., 2013; H. Park et al., 2015a; H. Park et al., 2015b; K. Park et al., 2011). In addition to

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http://dx.doi.org/10.1016/j.apergo.2017.06.006
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PPC, firefighters wear a helmet and a self-contained breathing apparatus (SCBA), adding between 17 and 25 kg of extra load to the firefighter. During landings, carrying higher loads results in adaptive alterations of lower body and trunk mechanics (Coca et al., 2010; Haynes and Stein, 2014; Keelty, 2013; Kong et al., 2013; H. Park et al., 2015b; K. Park et al., 2011; Reichard and Jackson, 2010). Therefore, it is intuitive to expect that reduced mobility in increased loading resulting from wearing PPE and PPC may be increasing the risk of injury to firefighters as landing with additional load is a requirement to successfully completing emergency firefighting operations.

During landing, forces are transferred from the distal to proximal extremities and dissipated through the musculature of the ankle, knee then hip (Kovacs et al., 1999; Prilutsky and Zatsiorsky, 1994; Riemann et al., 2002; Self and Paine, 2001). Therefore given its location, the ankle joint has the ability to influence joint kinematic and muscle energetics further up the kinetic chain during landings (DeVita and Skelly, 1992; Kovacs et al., 1999; McNitt-Gray, 1993; Stefanyshyn and Nigg, 1998). When ankle restriction occurs, resulting in an individual landing with the absence of adequate plantar flexion, a heel toe landing (HTL) technique occurs, which has been associated with increased vertical ground reaction forces (vGRFs) and alterations in lower body kinematics. Specifically, increased hip flexion and reduced knee flexion has been observed (Kovacs et al., 1999). These alterations increase compressive forces in the surrounding lower body and lumbar soft tissues and joints (Kovacs et al., 1999). Although these compressive forces and mechanical alterations are a by-product of increased force absorption during impact movements, it is possible that chronic exposure to altered force dissipation may lead to lumbar instabilities, resulting in lower lumbar and lower body injuries (Bruening and Richards, 2006; DeVita and Skelly, 1992; Heinrich et al., 2014; McNitt-Gray et al., 1993; Panjabi, 2003; Saunders et al., 2014; Stefanyshyn and Nigg, 1998).

Compared with adopting a HTL, a forefoot landing (FFL) technique has been shown to be associated with reduced vGRFs as it utilises ankle range of motion for efficient dissipation of forces throughout the landing phase (Kovacs et al., 1999; Prilutsky and Zatsiorsky, 1994; Self and Paine, 2001). FFL sees the ankle in a plantar flexed position at the point of ground contact, followed by rapid dorsiflexion controlled through eccentric contraction of the gastrocnemius. Therefore, to reduce the amount of force absorbed into the soft tissues of the lumbar and lower body, and possible chronic loading, adopting a FFL may provide a protective mechanism for injury (Kovacs et al., 1999; Self and Paine, 2001). Given that firefighting boots have been shown to constrain ankle movement (H. Park et al., 2015a; H. Park et al., 2015b) it is plausible that the boots affect the ability of firefighters to land with an optimal technique resulting in a reduction of the body's natural ability to attenuate force through the musculature of the ankle plantar flexors.

Urban firefighters wear specially designed firefighting boots, referred to as Type 2 structural firefighting boots. These boots are designed to address specific occupational safety risks including impact protection along with heat and flame resistance. To address these risks, and meet design requirements, structural firefighting boots must have a minimum shaft height of 178 mm for an EU size 41 or 42 and up to 192 mm for size 45 and above (International Organization for Standardization, 2011) resulting in shafts finishing superior to the ankle joint creating a rigid structure that restricts movement of foot relative to the shank. This restriction has been associated with increased ground reaction forces (GRFs) and alterations in lower body kinematics during gait and landing tasks (Giguère and Marchand, 2005; Huang et al., 2009; H. Park et al., 2015a; K. Park et al., 2011; Spratford et al., 2017). Firefighters typically wear boots made of rubber or leather with restrictive movements being seen in boots made of the heavier and inflexible rubber upper (H. Park et al., 2015b). On the contrary, leather boots are lighter and have greater boot shaft flexibility, which has been associated with greater efficiency in gait behaviour as well as jump and landing performances. These have been demonstrated through greater ankle power generation and shock absorption as the shaft flexibility of the boot allowed for greater ankle movement during gait, jumping and landing tasks (Cikajlo and Matjačić, 2007; H. Park et al., 2015b).

Based on the current literature, we hypothesise that the protective nature of firefighting boots will result in compensatory changes to kinematics during landings and contribute to increased exposure to compressive forces on body joints. These alterations and greater compressive forces result in greater risk of sustaining overuse or fatigue related lower body and lumbar injuries (Chiou et al., 2012; Garner et al., 2013; Spratford et al., 2017; Snijders et al., 1998). To date, research conducted on firefighting and other high ankle related footwear such as military boots, have been limited to kinetic and kinematic variables at the hip, knee, ankle and metatarsophalangeal (MP) joints during gait. Despite the high incidences of lower back pain in firefighters, there has been no research investigating whether the ankle restricted firefighting boot influences ankle and lumbar kinematics and lumbar kinetics. In addition, no research has been conducted on the typical landing technique acquired when wearing firefighting boots. Thus, the aim of this study is to examine the relationship between firefighting boots, ankle kinematics and lumbar biomechanics during landing for both loaded and unloaded conditions, simulating alighting from a fire truck, an essential task performed numerous times throughout a shift. We hypothesised that the Type 2 structural firefighting boot will increase vGRFs resulting from incorrect landing technique, subsequently increasing forces acting upon the more proximal joints in the kinetic chain. The increases in vGRFs will therefore be compensated by kinematic and kinetic changes at the lumbar pelvic joint. It is also hypothesised that the additional load of the SCBA will further amplify the kinetics and kinematics at the lumbar.

2. Methodology

2.1. Participants

Twenty professional male urban firefighters (Mean $\pm$ SD; weight 84.4 kg $\pm$ 11.6, height 1.81 $\pm$ 0.06 m and age 41.3 $\pm$ 8.8 years) were recruited from a community fire service to participate in this study. All participants were fully operational at the time of testing and had 13.5 $\pm$ 10.9 years of operational service. Participants were excluded if they were injured or currently undertaking any form of lower limb or back rehabilitation. Ethics approval was granted and written informed consent was obtained for each participant before the commencement of the study in accordance with the requirements of the Human Research Ethics Committee at the University of Canberra.

2.2. Procedures

Data collection was conducted in a purpose built Biomechanics laboratory. Three-dimensional marker trajectories were captured using a 12-camera Vicon motion capture system sampling at 250 Hz (Oxford Metrics Ltd., Oxford, UK). GRF data were collected at 1000 Hz using two 400 $\times$ 600 mm AMTI Force plates (Advanced Mechanical Technologies, MA, USA). Prior to testing, participants had 37 retro-reflective makers placed on their lumbar and lower body consistent with previously validated methods (Crewe et al.,