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Evaluating Firefighters' Joint Mobility and Muscular Activity during Load Carriage ⋆

Shi-Tan Wang [a,b,c,*]

[a] *Shanghai Yangzhi Rehabilitation Hospital (Shanghai Sunshine Rehabilitation Center), School of Medicine, Tongji University, Shanghai 201619, China*

[b] *The Clinical Research Center of Intelligent Rehabilitation, Tongji University, Shanghai 201619, China*

[c] *College of Fashion and Design, Donghua University, Shanghai 200051, China*

Abstract

This study aimed to quantify the firefighters' joint mobility and muscular activity during self-contained breathing apparatus (SCBA) carriage and evaluate the effectiveness of shoulder strap length variation. Three varying-strapped SCBAs and a control condition with no SCBA equipped were evaluated. Joint range of motion (ROM) and surface electromyography (sEMG) signals were synchronously collected when twelve male subjects walked in four test samples. Results showed that carrying SCBA had more pronounced impacts on the joint ROM and sEMG around the proximal torso, suggesting that the training of firefighters focuses on the coordinated movement of muscles and joints in the trunk. The length of the SCBA strap was suggested to be set at 98–105 cm for firefighters who are 172-178 cm.

Keywords: Firefighters; Biomechanical Evaluation; Personal Protective Equipment; Muscular Activity

1 Introduction

Self-contained breathing apparatus (SCBA) provides an external air supply that is essential for the safety of firefighters at a fireground. However, as the heaviest item of personal protective equipment (PPE), frequent use of SCBA can cause an excursion of the centre of mass (COM) [1, 2]. As a result, the lower limb range of motion (ROM) is altered, and the metabolic cost and spine muscle activities are increased [3, 4]. It has been reported that heavy SCBA resulted in discomfort, fatigue, and even injury, for example, rucksack palsy and low back problems (LBP) [5-7]. Especially, the prevalence of LBP in firefighters is at 19.3% and is highest in the emergency service (31.8%) sector.

The SCBA is a single-piece, cylinder-shaped equipment made of carbon fibre and aluminium. It has a frame with a shoulder strap, hip-belt, and chest-belt. The weight of SCBA is acknowledged

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*Corresponding author.
Email address: wangshitan@tongji.edu.cn (Shi-Tan Wang).

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as having the greatest impact on a firefighter's movement. To alleviate the biomechanical strain of SCBA, several strategies were developed, such as reducing the size and mass of the SCBA cylinder or redesigning the cylinder shape [7, 8]. However, a lighter SCBA cylinder only offers a little amount of breathing air capacity, and a low-profile SCBA is expensive and impractical. For firefighters using a traditional cylindrical SCBA with a certain weight and shape, the adjustment of shoulder strap length has been reported in a survey that could influence firefighters' perceived fatigue and comfort by shifting loads from one body region to another [9]. Our previous survey indicated that the adjustment of strap length by firefighters was primarily based on their convenience or habit, and 32.5% of firefighters preferred to adjust the shoulder strap in tight-fitting condition [10]. However, no quantitative data has been recorded about the biomechanical impacts of the strap length of SCBA systems, and an "optimal" arrangement for strap length has not yet been reached.

According to backpack studies, the strap design was a feasible solution to modify the soldiers' joint kinematics and interface pressure by moving the backpack's centre of gravity and changing the load transfer patterns [11, 12]. Both the backpack and the SCBA are built on back weight-bearing patterns, with the shoulder strap, hip belt, and chest belt supporting the carried load. The load distribution and transfer pattern of the SCBA is, in principle, compatible with the backpack. As an alternative, adjusting the weight distribution on the body and the SCBA's carrying techniques, such as strap lengths, may be chosen to enhance firefighters' joint and muscular reactions.

Nevertheless, some controversial statements and findings were observed regarding the "optimal" strap length of the backpack. According to the [12], a loose strap produced 40% less total shoulder pressure and 37% less strap tension forces than a tight strap, indicating that shoulder strap in backpacks should be looseness. On the contrary, several studies discovered that walking with a looser shoulder strap resulted in a bigger postural forward and more restricted joint mobility [13, 14]. These contradictory findings may attribute to a single test variable. While it was easier to examine either variable in exclusivity, those studies ignored the fact that the variables interact and were not mutually exclusive. From a biomechanical perspective, muscle contraction and joint movement is an integrated complex that is operating in a coordinated manner [15]. Examining the kinematic or kinetic variable alone just provided an isolated point that may restrict the comparability of the study to others. Therefore, a thorough assessment of joint mobility and muscle activity is required.

Firefighters' joint mobility and muscle activity have frequently been evaluated using a range of motion (ROM) and surface electromyography (sEMG) techniques [16, 17]. Typically, a decrease in range of motion (ROM) indicates a loss of mobility, whereas an increased sEMG value indicates muscular fatigue [18]. ASTM F3031 (2017) specified the standard test protocol for measuring ROM and subjective perceptions while subjects wear protective garments. In the early stage, ROM was mainly measured using a variety of goniometers and flexometers [19]. However, these methods only measured the maximal ROM of a certain joint in standard static postures and did not assess the dynamic changes of body movement over time in real working situations. Researchers have recently employed a 3D motion capture system to investigate the impacts of firefighters' PPE on joint ROM at the hip, knee, and ankle joints [20, 21]; however, these were only focused on lower limb mobility. Because the SCBA is positioned on the firefighter's back; theoretically, the upper body mobility will be affected.

By addressing the literature gaps mentioned above, the purpose of this study was to calculate