Applied Ergonomics 46 (2015) 168–175

Contents lists available at ScienceDirect

Applied Ergonomics

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

Use of body armor protection with fighting load impacts soldier performance and kinematics

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ARTICLE INFO

Article history:
Received 25 September 2013
Accepted 28 July 2014
Available online 21 August 2014

Keywords:
Torso load
Gait
Obstacle negotiation

ABSTRACT

The purpose of this evaluation was to examine how increasing body armor protection with and without a fighting load impacted soldiers' performance and mobility. Thirteen male soldiers performed one performance (repeated 30-m rushing) and three mobility tasks (walk, walk over and walk under) with three different body armor configurations and an anterior fighting load. Increasing body armor protection, decreased soldier performance, as individual and total 30-m rush times were significantly longer with greater protection. While increasing body armor protection had no impact on mobility, i.e. significant effect on trunk and lower limb biomechanics, during the walk and walk over tasks, greater protection did significantly decrease maximum trunk flexion during the walk under task. Adding fighting load may negatively impact soldier mobility, as greater maximum trunk extension was evident during the walk and walk over tasks, and decreased maximum trunk flexion exhibited during the walk under task with the fighting load.

1. Introduction

During combat, soldiers wear body armor for protection against ballistic injury. Depending on the nature and threat of injury, different combinations of body armor and ballistic plates may be worn. At a minimum, soldiers wear 'soft body armor', a fabric based vest, in the field. The U.S. Army has two soft armor types in use: the improved outer tactical vest (IOTV, Fig. 1A) and the scalable plate carrier system (PC, Fig. 1B). The IOTV provides full coverage of the torso while allowing for mobility of the shoulder, hips, and neck. The PC affords increased shoulder, hip, and neck mobility at a lesser weight, but covers less of the torso as compared to the IOTV. To increase protection with either armor system, ballistic (hard) plates can be inserted into front, back and/or side pockets of the fabric vest, adding up to 7.3 kg of body borne load. Generally, as the protection increases, so does the body borne load. For instance, the IOTV can weigh up to 12.1 kg with front back and side ballistic plates, while PC only weighs 9.8 kg for a similar ballistic configuration (Table 1).

Body armor is just one component of soldiers' total body borne load. During dismounted operations, soldiers are encumbered with a combat load that typically includes a body armor, weapon, helmet, ammunition, rucksack (i.e. backpack), and other essentials. Depending on the operation, a combat load can add between 9 kg and 60 kg of weight, in addition to the body armor worn by the soldier (*FM 21-18*. 1990). However, during short duration missions, where enemy contact may be expected, soldiers must remain mobile and keep the body borne load to a minimum. For these missions, soldiers use a 'fighting load' which minimizes body borne load, but still provides the essential equipment, such as ammunition, via a fighting load carrier attached on the anterior of their body armor. To ensure optimal soldier performance and agility during such operations, the fighting load, including body armor, is recommended not to exceed 21 kg (*FM 21-18*. 1990).

In order to optimize soldier performance during dismounted operations, researchers have examined the effect that body borne loads (i.e. body armor and essential military equipment) has on soldier performance. Previous experimental evidence has shown that both a posterior load (Knapik et al., 2004) and body armor (Hasselquist et al., 2012) decrease performance on timed physical maneuvers, such as long runs, sprints, agility tasks, and obstacle courses. Holewijn and Lotens (1992) found that on average, physical performance decreased by 1% for every additional kilogram of load.

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http://dx.doi.org/10.1016/j.apergo.2014.07.015
0003-6870/

Fig. 1. Soft body armor types: A) Improved Outer Tactical Vest (IOTV). B) Scalable Plate Carrier (PC).

Recently, Dempsey et al. (2013) found that police officers decrease performance on average 13–42% while loaded with body armor and a utility belt (~10 kg), compared to no load, during a variety of mobility tasks. However, Peoples et al. (2010) reported no performance differences during a 5-m rush (i.e. sprinting) task between closely weighted (two and three kg difference) body armor configurations. A longer sprinting task like the repeated 30-m rushing task used by Hasselquist and colleagues (2012, 2013) found that both the addition of extremity body armor and posterior backpack loads do, in fact, decrease performance.

Reductions in soldier performance may stem from significant biomechanical alterations that occur during load carriage, such as trunk and lower limb kinematic (Attwells et al., 2006; Harman et al., 2000b; Kinoshita, 1985) or spatiotemporal adaptations (Birrell and Haslam, 2010). While these biomechanical adaptations reportedly increase walking stability (Harman et al., 1999), it may also impair the mobility of the soldier, especially during complex locomotor tasks such as when negotiating or avoiding an obstacle. To date load carriage research has limited its biomechanical analysis to continuous straight-line ambulation (i.e. walking) (Attwells et al., 2006; Hasselquist et al., 2013, 2012), static standing (Rugelj and Sevšek, 2011; Schiffman et al., 2006), or vertical jump performance (Fallowfield et al., 2012). Therefore, biomechanical assessments of load carriage, especially configurations recommended for dismounted operations, during a wide range of complex locomotor tasks is warranted.

Table 1
Body Armor Protection (BA) configuration descriptions and total weights.

Configuration	Description	No FL (kg)[a]	+FL (kg)[a]
IOTV light	IOTV w/soft armor only (4.8 kg)	12.1	23.1
PC heavy	PC w/front, back, and side plates (9.8 kg)	17.1	28.1
IOTV heavy	IOTV w/front, back, and side plates (12.1 kg)	19.4	30.4

[a] Weight includes of helmet, boots, and weapon donned for all configurations (7.3 kg).

Biomechanical assessments of load carriage have focused primarily on posterior torso borne, combat loads (16 kg–60 kg). Recently, Park and colleagues (2013) reported that participants increased stance time and decreased stride length to improve stability while walking with police body armor and varied anterior loads. Anteriorly loaded participants also demonstrated trunk (Rietdyk et al., 2005) and lower limb (Perry et al., 2010) kinematic adaptations to aid stability (but potentially at the detriment of mobility), when avoiding and negotiating an obstacle. Both Rietdyk et al. (2005) and Perry et al. (2010), however, examined small handheld, non-militarily relevant, anterior loads (2 kg–10 kg). Heavier anterior loads may have a significant, and potentially larger, impact on soldiers performing complex locomotor tasks. Therefore, research is needed to examine the effects of body armor and militarily-relevant anterior fighting load on avoiding and negotiating (i.e. walking over and under) an obstacle.

The main purpose of this evaluation was to examine if the addition of the fighting load had a greater impact on soldiers' mobility with every increase in body armor during complex locomotor tasks. It was hypothesized that adding the fighting load would produce a significantly larger reduction in mobility with every increase in body armor. Our second purpose was to examine how increases in body armor when worn with the anterior fighting load, would impact soldiers' 30-m rushing performance. It was hypothesized that with increases in the armor protection soldiers would perform the task more slowly.

2. Methods

2.1. Participants

Thirteen male soldiers (age: 21.2 ± 2.5 yrs, height: 1.8 ± 0.6 m, weight 83.4 ± 9.8 kg) participated in this evaluation. Potential participants were excluded if they had any lower extremity injury that would inhibit their ability to complete the study. The evaluation was completed at the Center for Military Biomechanics (Natick, MA) in accordance with the Natick Soldier Research Development and Engineering Center (NSRDEC) Assurance for the Protection of