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Cardiorespiratory responses to heavy military load carriage over complex terrain☆

David P. Looney[a,*], William R. Santee[a,b], Laurie A. Blanchard[a], Anthony J. Karis[a], Alyssa J. Carter[a], Adam W. Potter[a]

[a] US Army Research Institute of Environmental Medicine (USARIEM), 10 General Green Ave, Natick, MA, 01760, USA
[b] Oak Ridge Institute for Science and Education (ORISE), 1299 Bethel Valley Rd, Oak Ridge, TN, 37830, USA

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ABSTRACT

This study examined complex terrain march performance and cardiorespiratory responses when carrying different Soldier loads. Nine active duty military personnel (age, 21 ± 3 yr; height, 1.72 ± 0.07 m; body mass (BM), 83.4 ± 12.9 kg) attended two test visits during which they completed consecutive laps around a 2.5-km mixed terrain course with either a fighting load (30% BM) or an approach load (45% BM). Respiratory rate and heart rate data were collected using physiological status monitors. Training impulse (TRIMP) scores were calculated using Banister's formula to provide an integrated measure of both time and cardiorespiratory demands. Completion times were not significantly different between the fighting and approach loads for either Lap 1 ($p = 0.38$) or Lap 2 ($p = 0.09$). Respiration rate was not significantly higher with the approach load than the fighting load during Lap 1 ($p = 0.17$) but was significantly higher for Lap 2 ($p = 0.04$). However, heart rate was significantly higher with the approach load versus the fighting load during both Lap 1 ($p = 0.03$) and Lap 2 ($p = 0.04$). Furthermore, TRIMP was significantly greater with the approach load versus the fighting load during both Lap 1 ($p = 0.02$) and Lap 2 ($p = 0.02$). Trained military personnel can maintain similar pacing while carrying either fighting or approach loads during short mixed terrain marches. However, cardiorespiratory demands are greatly elevated with the approach load and will likely continue to rise during longer distance marches.

1. Introduction

Military load carriage planning involves determining which items are crucial to mission success and sustainment. Items necessary during contact with enemy forces are considered part of a Soldier's fighting load and constitute ~30% body mass (US Department of the Army, 2017). Non-combat related mission essential items such as extra clothing or water are added to the fighting load as part of a Soldier's approach load and increase loading up to ~45% body mass (US Department of the Army, 2017). The physiological consequences of dismounted movements while carrying fighting versus approach loads are not agreed upon despite their widespread use.

Laboratory studies have isolated physiological effects of load carriage by controlling confounders such as walking surface conditions (i.e. terrain factors), grade, and pace (Ludlow and Weyand, 2016; Pandolf et al., 1977; Santee et al., 2003; Beekley et al., 2007; Crowder et al., 2007; Quesada et al., 2000). Heavy loads increase metabolic costs (Santee et al., 2001a, 2003; Richmond et al., 2015; Potter et al., 2013, 2017), and cardiovascular responses (Simpson et al., 2010; Pihlainen et al., 2014; Evan's et al., 1983). Respiratory rate also increases with heavier loads (Phillips et al., 2016) while inspiratory volume is limited with higher compression from backpack constrains (Brown and McConnell, 2012; Faghy and Brown, 2014; Tomczak et al., 2011). These findings would seem to support cautionary guidelines for additional loads and the importance of physiological status monitoring.

Unfortunately, Army foot march guidelines have changed little over the last three decades (US Department of the Army, 1990, 2017). This is perhaps related to concerns that laboratory studies do not reflect the realities of current military operations. While laboratory studies have collected high quality data, they seldom replicate the variable surfaces (Richmond et al., 2015), steep grades (Minetti et al., 2002; Jacobson et al., 2000), and downhill segments (Santee et al., 2001a, 2001b)

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* Corresponding author. Biophysics and Biomedical Modeling Division, U.S. Army Research Institute of Environmental Medicine, 10 General Greene Avenue, Natick, MA, 01760, USA.
E-mail address: david.p.looney4.civ@mail.mil (D.P. Looney).

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encountered during dismounted marches. Field experiments have mainly evaluated cardiorespiratory responses to road marches on uniform terrain (Fallowfield et al., 2012; Santee et al., 1992). There is a considerable gap in the literature regarding complex terrain which is defined by diverse topography, surface conditions, and physical obstacles such as vegetation (Richmond et al., 2015). The few complex terrain march investigations have only briefly described trail conditions (Yokota et al., 2005, 2012; Cuddy et al., 2008) or lacked study interventions to determine causal factors (Welles et al., 2013). Therefore, it is unclear if these complex terrain features will obscure or augment differences between military load configurations in marching performance or cardiovascular strain.

Setting a fixed complex terrain marching pace is largely impractical since speed depends on the grade (Giovanelli et al., 2016) and terrain (Pandolf et al., 1976; Richmond et al., 2015) of the trail. On the other hand, self-paced marches are difficult to evaluate if neither pace and physiological strain are controlled. For example, volunteers may slow pace when fatigued to reduce physiological strain or march at a high pace but experience severe physiological strain. Load effects must be large enough to overcome any confounding interactions between pace and cardiorespiratory strain.

Banister's Training Impulse (TRIMP) is a common athlete monitoring metric used to determine training demands based on time and heart rate (Banister, 1991; Foster et al., 2001; Banister et al., 1999). The TRIMP score is the product of exercise time, heart rate, and a multiplying factor based on the predicted blood lactate rise at higher intensities (Banister, 1991). The TRIMP method has been used to evaluate exercises without a fixed pace or level of physiological strain such as fencing (Turner et al., 2017), soccer (Scott et al., 2013), swimming (Garcia-Ramos et al., 2015), and triathlons (Foster et al., 2001). However, TRIMP scores have only recently been used to evaluate military load carriage performance (Wang et al., 2017).

Cardiorespiratory responses to military-specific loads need to be examined during conditions reflective of current dismounted military movements. We investigated whether the difference between the fighting and approach loads would significantly increase completion times and cardiorespiratory demands during complex terrain marching by active military personnel.

2. Materials and methods

2.1. Design

Volunteers completed two marches over a complex terrain course carrying a load equivalent to either a fighting load (30% body mass) or an approach load (45% body mass). We scaled the loads to each individual's body mass to simulate the cardiorespiratory stresses endured by the average Soldier when carrying the average fighting and approach loads (US Department of the Army, 2017). The marches were separated by a minimum of five days to allow for adequate recovery and the order of the load conditions was randomized.

2.2. Volunteers

Nine (8 male, 1 female) active duty US Army Soldiers (age, 21 ± 3 yr; height, 172 ± 8 cm; body mass, 83.4 ± 13.7 kg; VO_2 max, 47.9 ± 4.4 ml kg^{-1}·min^{-1}) volunteered to participate in this research. A sample size of 9 volunteers is sufficient to detected significant within-subject differences in cardiorespiratory responses to load carriage (Lloyd and Cooke, 2000; Tseng and Liu, 2011; Lloyd et al., 2010; Kawahara et al., 1998; Macias et al., 2007). Each Soldier had completed US Army Basic Combat Training and their Advanced Individual Training where they had gained specific experience in load carriage in outdoor training environments. All volunteers were medically cleared and signed an informed consent agreement prior to participation in this investigation. Selection criteria included general good health as determined during clearance procedures, passing their most recent Army Physical Fitness Test (APFT), and no recent musculoskeletal injuries or other pre-existing conditions which would preclude their participation in the study. The APFT consists of the push-up, sit-up, and two-mile run tests (US Department of the Army, 2012). The study was approved by both the Scientific Review Committee and Institutional Review Board (SRC and IRB) at the U.S. Army Research Institute of Environmental Medicine (USARIEM; Natick, MA).

2.3. Procedures

2.3.1. Familiarization

Volunteers were familiarized with testing equipment, procedures, and the complex terrain course prior to data collection during an initial visit. Maximum heart rate was determined during a standard laboratory VO_2 peak treadmill running test in which volunteers wore their PT uniform with athletic shoes and the Equivital™ Life Monitor EQ-02 Physiological Status Monitor (PSM). Familiarization also included fitting and carrying both the fighting and approach loads over a short distance (~150 m) on a level surface. Each volunteer walked one clockwise lap while accompanied by a research team member around the ~2.5 km complex terrain course (Fig. 1). The complex terrain course was divided into forty segments (60.1 ± 45.6 m) based on grade (0.4 ± 6.6%), and terrain type.

2.3.2. Test visits

Test visits started with preliminary measurements and instrumentation before a short unloaded warm-up walk. Volunteers were then fitted with the EQ-02 PSM and donned either the fighting or approach load. The fighting load included the Army Combat Uniform Trousers worn with the Army Combat Shirt, personal boots, body armor, replica rifle, water, and simulated munitions. The approach load combined the fighting load with a Modular Lightweight Load Carrying Equipment frame rucksack. Additional loads were added to the vest pouches and/or rucksack if the fighting load or approach load was below its target mass (either 30% or 45% body mass respectively).

Volunteers were then required to march two laps around the complex terrain course in the shortest time without running, jogging, or shuffling. The first lap was completed in the clockwise direction while the second lap was completed counterclockwise. Five-minute rest intervals were allotted between laps during which volunteers were allowed to sit down and drink water ad libitum. Each volunteer was provided a Radio Frequency Identification tag (SportIdent; Scarborough Orienteering; Huntington Beach, CA) which communicated with timing gates (SportIdent; Scarborough Orienteering; Huntington Beach, CA) placed between the 40 trail segments to record completion times and speeds along the course.

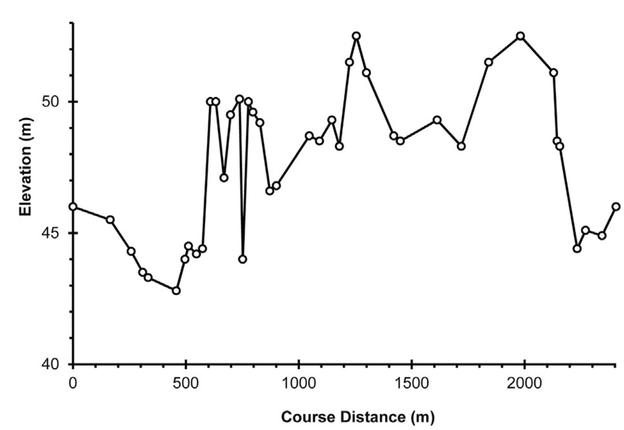

Fig. 1. Elevation over Natick Soldier System Center Fitness Trail (Natick, MA). White circles, timing gate locations.