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Neuromuscular and cardiovascular responses of Royal Marine recruits to load carriage in the field

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Cardiovascular and neuromuscular responses of 12 male Royal Marine recruits (age 22 ± 3 years, body mass 80.7 ± 6.8 kg, $\dot{V}O_2$max 52.3 ± 2.7 ml kg^{-1} min^{-1}) were measured during 19.3 km of load carriage walking at 4.2 km h^{-1} and carrying 31.0 kg. Heart rate during load carriage was 145 ± 10 beats·min^{-1} (64 ± 5 %HRR) and showed a negative relationship with body mass ($r = -0.72$, $P = 0.009$) but no relationship with $\dot{V}O_2$max (ml kg^{-1} min^{-1}; $r = -0.40$, $P = 0.198$). Load carriage caused a decrease in vertical jump height (8 ± 9%) and power (5 ± 5%) ($P < 0.001$). Change in vertical jump power showed a positive relationship with body mass ($r^2 = 0.40$, $P = 0.029$) but no relationship to $\dot{V}O_2$max (ml kg^{-1} min $^{-1}$; $r^2 = 0.13$, $P = 0.257$). In conclusion, load carriage caused a reduction in vertical jump performance (i.e. decreased neuromuscular function). Lighter individuals were disadvantaged when carrying absolute loads, as they experienced higher cardiovascular strain and greater decreases in neuromuscular function.

1. Introduction

Load carriage using backpacks is a requirement of military (Knapik et al., 1996) and emergency service personnel (McLellan and Selkirk, 2004) and can be a recreational pursuit (Lobb, 2004). In these settings individuals typically carry absolute loads, prescribed by the requirements of the task (e.g. required equipment) rather than based on an individual's physical capability, and are completed at a sustained pace rather than best effort performance (Haisman, 1988; Lobb, 2004; McLellan and Selkirk, 2004). The physical demands during and fatigue following exercise are both important considerations for military and emergency service personnel undertaking load carriage as these could impair physical and cognitive performance (Blacker et al., 2010; Mahoney et al., 2007), which are important when completing a range of occupational tasks (Nindl et al., 2002).

The physiological responses during load carriage have been shown to depend upon a combination of load mass, speed of movement, gradient, terrain, situational factors and environmental conditions (Ainslie et al., 2005; Knapik et al., 1996; Pandolf et al., 1977). For example, a typical military load carriage task in the field at a set pace (4 km h^{-1}) carrying 41 kg over mixed terrain has been shown to elicit a heart rate of 117 ± 13 beats min^{-1} (Scott and Ramabhai, 2000).

The most accurate assessment of muscle fatigue after exercise is to measure changes in the force producing capability of a muscle or muscle groups (i.e. neuromuscular impairment) (Warren et al., 1999). Knapik et al. (1991) observed no change in muscle function (vertical jump power) for military personnel following a maximal effort 20 km road march carrying 46 kg. Ainslie et al. (2003) showed no decrease in vertical jump performance for recreational walkers following a self-paced 21 km hill walk carrying 9.5 kg (duration mean 448 min, range 351–656 min). These findings are surprising as neuromuscular function has been shown to be impaired for trained individuals following prolonged running, cycling and skiing events (i.e. >1 h) (Millet and Lepers, 2004). Also, Clarke et al. (1955), showed decreases in strength of the knee, trunk and ankle flexors and extensors and the shoulder elevators in college students (i.e. naive load carriers) following a 12.1 km road march at 4 km h^{-1} carrying 13, 18 and 27 kg loads. Both previous studies that administered the vertical jump to assess changes in neuromuscular function have allowed participants to be self-paced (Ainslie et al., 2003; Knapik et al., 1991), rather than the typical forced pace movement commonly associated with load carriage in many occupational settings.

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The relationship between physiological strain and body mass during load carriage in the field has not been studied. In a laboratory-based study, Bilzon et al. (2001) showed when participants carried an absolute load of 18 kg during 4 min of treadmill running (9.5 km h^{-1}) there was an inverse relationship between oxygen uptake (relative to body mass) and body mass ($r = -0.87$, $P < 0.01$) but no relationship when running unloaded. It has been suggested that this relationship means that heavier individuals are better performers of occupational tasks such as load carriage, where the load mass is determined by task constraints, presumably as the load represents a lower proportion of body mass. This has implications for selection of individuals working in occupations where performance of load carriage tasks is critical to job performance (Vanderburgh, 2008). These findings suggest the physical strain experienced during load carriage would be greater for lighter individuals. However, the relationship between body mass and changes in neuromuscular function following load carriage is unknown.

The aims of this study were to; (1) Quantify the cardiovascular strain and changes in neuromuscular function of Royal Marine recruits during 19.3 km of load carriage (absolute load of 31.0 kg) in the field, (2) Investigate the relationship between body mass and cardiovascular strain during the load carriage task. (3) Investigate the relationship between body mass and changes in neuromuscular function following the load carriage task.

2. Methods

2.1. Participants

Twelve male Royal Marine recruits (age 22 ± 3 years, height 1.78 ± 0.05 m, body mass 80.7 ± 6.8 kg, body fat 11.8 ± 3.0%, $\dot{V}O_2$max 52.3 ± 2.7 ml kg^{-1} min^{-1}) volunteered to participate in the study. The recruits were in week-25 of a 32-week initial training course at the Commando Training Centre Royal Marines (CTCRM), Lympstone, UK. Ethical approval for all procedures was provided by the UK Ministry of Defence Research Ethics Committee (MODREC). All protocols were performed in accordance with the ethical standards laid down in the 2004 Declaration of Helsinki.

2.2. Preliminary measures

2.2.1. Body composition

Body mass (Seca Model 880, Seca Ltd., Birmingham, UK) and height (Invicta Stadiometer Model IP1465, Leicester, UK) were measured whilst wearing shorts and underwear. Skinfold measurements were taken at the *Biceps*, *Triceps*, *Sub Scapular* and *Iliac Crest* on the right side of the body to measure body composition using Harpenden Skinfold Callipers (Body Care, Southam, UK). Two measurements were taken at each site and if there was a difference >5 mm the measurements were repeated. Percentage body fat was estimated following the assessment of skinfold thickness at four anatomical sites using previously described methods (Durnin and Womersley, 1974; Siri, 1956).

2.2.2. Multistage fitness test

Participants completed a Multistage Fitness Test (MSFT) to exhaustion to estimate their maximal aerobic capacity (Ramsbottom et al., 1988). Participants ran between two parallel lines 20 m apart, in time to an audio signal to provide pacing; the time between the audio signals progressively decreased therefore increasing the required pace of each shuttle. The end of the test for each individual was determined if they failed to complete three consecutive shuttles or voluntarily stopped. Each participants' estimated maximal oxygen uptake ($\dot{V}O_2$max) was calculated from their MSFT score (i.e. the number of the last completed shuttle) using a previously validated equation (Ramsbottom et al., 1988).

2.3. Experimental protocol

Participants were monitored during a 19.3 km load carriage event (duration 270 min). Participants carried a total load of 31.0 kg on the shoulders (21.5 kg backpack, 9.5 kg webbing) whilst wearing boots (1.8 kg) and helmet (1.7 kg), and carrying a rifle in the hands, supported by a sling across the shoulders (5.0 kg) (Fig. 1). Participants all wore the same backpack and webbing and load distribution was similar between participants, Fig. 1 shows an example of the load carriage system. The straps were adjusted by the individuals so that they felt they were carrying the load in a position with maximum comfort. The load carried and walking speed was prescribed by CTCRM, as this event was a criterion assessment during the recruit training course. This event was selected for investigation in the present study as it was identified as a typical load carriage task that this population are required to complete.

The load carriage event started at 0600, approximately 1 h after participants had consumed breakfast. All participants walked as a group and the speed was paced by instructors from CTCRM.

2.3.1. Heart rate (HR)

Participants wore heart rate monitors (Polar Team System®, Polar, Kempele, Finland) for the duration of the load carriage. Maximum heart rate (HR_{max}; peak heart rate during the MSFT) and resting heart rate (HR_{rest}; lowest value during a 30 s rolling average during an overnight sleep) were recorded using heart rate monitors. Heart rate was recorded every 5 s during load carriage and expressed as an absolute value, a percentage of maximum heart rate (%HR_{max}), and percentage of heart rate reserve (%HRR) (Eq. (1)) (Howley, 2001).

$$\%HRR = (\text{Mean HR during exercise} - HR_{rest})/(HR_{max} - HR_{rest}) \quad (1)$$

The level of cardiovascular strain was classified using Howley (2001) recommended zones for physical activity (very light <20 %HRR, light 20–39 %HRR, moderate 40–59 %HRR, hard 60–84 %HRR, very hard ≥85 %HRR).

2.3.2. Global positioning system (GPS)

One participant carried a GPS (Garmin® eTrex Legend™, Garmin International Inc, Kansas, USA) which recorded the position of the whole group every 5 s to provide information on speed of movement, altitude and distance covered. Data were downloaded on completion of load carriage using Map Source software (Map Source™, Garmin International Inc, Kansas, USA).

2.3.3. Vertical jump test

A vertical jump test was conducted indoors, the evening before and immediately after load carriage to determine the effects of load carriage on neuromuscular performance. The vertical jump technique was demonstrated by the investigator prior to the pre- and post-load carriage assessments. During pre-testing only, the participants were coached while completing five maximal jumps as a familiarisation (pilot data showed this was the optimal number of jumps for volunteers to become familiar with the technique without causing a decrement in performance). Participants completed three maximal effort jumps and the mean score was recorded for the performance in each session. No warm up other than the practice jumps was performed prior to the test, which was in keeping with the protocols used to develop Eqs. (2) and (3) (Bosco et al., 1983; Sayers et al., 1999). Participants stood on