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A contribution to understanding the impact of variations in body mass on fractionating the metabolic burden of military load carriage

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Abstract

Purpose: The oxygen cost associated with load carriage is dependent upon both its mass and its placement about the body. For occupations in which load carriage is routinely performed, and involves identical loads for all individuals, the relative metabolic cost varies inversely with body mass. However, whilst we understand the average impact of varying load placement, our appreciation of its impact on a morphologically diverse, contemporary workforce is very limited. Methods:The relationship between load placement and body mass was evaluated in 65 men (23.0 y [SD 3.0]; 80.5 kg [SD 1.7]: range 56.0-109.8 kg), matched for height-adjusted adiposity (59.3 mm [SD 25.4]) and height-adjusted body mass (65.9 kg [SD 22.0]). Participants were grouped into mass categories (55-65 kg [N = 12]; 66-76 kg [N = 15]; 77-87 kg [N = 19]; 88-98 kg [N = 12]; 99-110 kg [N = 7]) and walked at 4.8 km h−1 (0% gradient) for five, 15-min stages, separated by 5-min rests. Each stage involved a unique load configuration presented in a balanced order: unloaded (battle dress and running shoes); head loading (1.38-kg helmet); torso loading (25-kg weighted vest); hand loading (2 kg each wrist); and foot loading (2 kg each foot [boot plus ankle]). Data were collected using open-circuit respirometry, sampled over the last 5 min. Results: Within each condition, gross oxygen consumption increased in parallel with body mass ($p < 0.05$). However, when net data were normalised for the external load (change score divided by the added mass), a body mass-dependency of the oxygen cost was not realised within any condition. When averaged across the mass categories, the oxygen consumed per kilogram of mass carried was greater for foot loading (44.8 mL kg−1 min−1 [±2.0]; $p < 0.05$) compared to all other locations (head: 7.0 mL kg−1 min−1 [±4.9]; torso: 8.6 [±0.3]; hands: 8.0 [±1.3]). The gross oxygen costs of torso (1211.8 mL min−1 [±21.0]) and foot loading (1179.8 mL min−1 [±20.7]) were both greater than the other three conditions (unloaded: 999.2 mL min−1 [±20.5]; head: 1005.8 mL min−1 [±19.2]; hands: 1038.4 mL min−1 [±19.0]; $p < 0.05$), but did not differ from one another ($p > 0.05$). Conclusion:Whilst the relative impact of fixed load carriage was greater for smaller individuals, no relationship was found between body mass and the nett mass-specific, ambulatory oxygen cost of these added loads, regardless of their location. This is important, for it shows that whilst loads have greater impact on smaller individuals, that impact appears not to be position dependent.

Keywords

understanding, impact, variations, body, mass, contribution, fractionating, metabolic, load, carriage, military, burden

Disciplines

Medicine and Health Sciences | Social and Behavioral Sciences

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Thematic Oral Poster Session 4 – Load carriage

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The effects of body armour and load carriage on respiratory function and physical performance during a simulated military task in male and female soldiers

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Purpose: This study investigated the effect of wearing body armour and loads of varying masses on respiratory function and physical performance during prolonged marching, in male and female soldiers.

Methods: Twelve male and ten female soldiers conducted four 12.25 km treadmill marches (4.9 km/h in 3 × 50 min sessions) in different load configurations (21 kg, 26 kg, 33 kg and 43 kg), followed by a 2.4 km best time test wearing assault order load (26 kg). Respiratory mechanics, gait and movement analysis were measured before, during and/or after the tests.

Results: Only 50% of male and 10% of female participants were able to complete all conditions; statistical analysis was not possible for women wearing 43 kg. The main limiting factor for completing trials was self-reported discomfort, e.g. blisters and muscle discomfort. Women carried a significantly greater percentage of their lean body mass (44–93%) than men (36–74%). Time to complete the best effort test was unaffected by the load carried during the march. Women marched at a significantly increased percentage of $\dot{V}O_2$max compared to men (women: 36–55%; men: 31–41%). $\dot{V}O_2$ did not exceed the Gas Exchange Threshold (GET) in either group, indicating a moderate exercise intensity; percent GET was similar in both sexes (women: 50–73%; men: 50–62%). $\dot{V}O_2$ increased with load and over time ($\dot{V}O_2$ drift). $\dot{V}O_2$ drift was first observed in loads of 33 kg within 50 minutes of marching in women, and 110 minutes in males. Load carriage caused a restrictive ventilatory impairment in both sexes indicated by a reduction in lung volumes at rest (women: up to 15%; men: up to 17%). Increases in ventilation observed with load and over time were similar in men and women (women: 7–54%; men: 8–35%) and were achieved by increased breathing frequency, but not tidal volume. Breathing frequency was significantly greater (11–18%) in women than men throughout the march. Inspiratory and expiratory muscle fatigue was evident (7–22%) within the first 50 min of marching in all loads in both sexes.

Conclusions: Physical performance decrements during prolonged loaded marching are evident in both sexes, but occur in lighter loads and earlier during marching in women compared to men. This finding may reflect differences in body size between sexes; however, further analyses are required to understand the independent mediators of these findings. These data highlight the need to investigate, and improve, the load carriage ability of women.

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A contribution to understanding the impact of variations in body mass on fractionating the metabolic burden of military load carriage

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Purpose: The oxygen cost associated with load carriage is dependent upon both its mass and its placement about the body. For occupations in which load carriage is routinely performed, and involves identical loads for all individuals, the relative metabolic cost varies inversely with body mass. However, whilst we understand the average impact of varying load placement, our appreciation of its impact on a morphologically diverse, contemporary workforce is very limited.

Methods: The relationship between load placement and body mass was evaluated in 65 men (23.0 y [SD 3.0]; 80.5 kg [SD 1.7]: range 56.0–109.8 kg), matched for height-adjusted adiposity (59.3 mm [SD 25.4]) and height-adjusted body mass (65.9 kg [SD 22.0]). Participants were grouped into mass categories (55–65 kg [*N* = 12]; 66–76 kg [*N* = 15]; 77–87 kg [*N* = 19]; 88–98 kg [*N* = 12]; 99–110 kg [*N* = 7]) and walked at 4.8 km h^{-1} (0% gradient) for five, 15-min stages, separated by 5-min rests. Each stage involved a

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unique load configuration presented in a balanced order: unloaded (battle dress and running shoes); head loading (1.38-kg helmet); torso loading (25-kg weighted vest); hand loading (2 kg each wrist); and foot loading (2 kg each foot [boot plus ankle]). Data were collected using open-circuit respirometry, sampled over the last 5 min.

Results: Within each condition, gross oxygen consumption increased in parallel with body mass ($p < 0.05$). However, when net data were normalised for the external load (change score divided by the added mass), a body mass-dependency of the oxygen cost was not realised within any condition. When averaged across the mass categories, the oxygen consumed per kilogram of mass carried was greater for foot loading (44.8 mL kg^{-1} min^{-1} [±2.0]; $p < 0.05$) compared to all other locations (head: 7.0 mL kg^{-1} min^{-1} [±4.9]; torso: 8.6 [±0.3]; hands: 8.0 [±1.3]). The gross oxygen costs of torso (1211.8 mL min^{-1} [±21.0]) and foot loading (1179.8 mL min^{-1} [±20.7]) were both greater than the other three conditions (unloaded: 999.2 mL min^{-1} [±20.5]; head: 1005.8 mL min^{-1} [±19.2]; hands: 1038.4 mL min^{-1} [±19.0]; $p < 0.05$), but did not differ from one another ($p > 0.05$).

Conclusion: Whilst the relative impact of fixed load carriage was greater for smaller individuals, no relationship was found between body mass and the nett mass-specific, ambulatory oxygen cost of these added loads, regardless of their location. This is important, for it shows that whilst loads have greater impact on smaller individuals, that impact appears not to be position dependent.

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The physiological demand of a loaded march at five incremental speeds

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Purpose: The primary purpose of this study was to determine the physiological demand of a loaded march at five incremental speeds. The second purpose was to assess if the number of steps taken had an impact on the physiological demand.

Methods: 31 participants from the RAF Regt undertook five walking speeds (3 km/h, 4.2 km/h; 5 km/h; 6 km/h and 7 km/h) for 5 min. Participants performed the speeds in groups of four in an aircraft hangar on a flat concrete surface, each group was paced by the same tester. Participants wore standard fatigues, boots and Complete Equipment Fighting Order (31.5 kg). During the last minute at each speed steady state oxygen consumption (VO_2) was measured using Douglas bag collections of 1 min. The total number of steps taken by each participant during the final minute of exercise for each speed was counted. Heart rate (HR) was measured for the duration of the trial at 5 s intervals. Rating of Perceived Exertion (RPE) was recorded after each march, ten minutes rest was provided between each speed.

Results: The relationship between body mass and absolute VO_2 (L/min) was assessed at each speed, weak (R^2 ranged from 0.095 at 3 km/h to 0.298 at 4 km/h; 5 km/h and 6 km/h reported lower R^2 than 4 km/h) and moderate ($R^2 = 0.327$ at 7 km/h) relationships were found. Mean (SD) VO_2 (mL/kg/min) was 12.1 (2.6) mL/kg/min; 14.4 (2.1) mL/kg/min; 17.2 (2.6) mL/kg/min; 23.9 (2.9) mL/kg/min and 33.5 (3.5) mL/kg/min for each of the speeds in ascending order. A positive polynomial relationship was found between walking speed and relative VO_2 (mL/kg/min) ($y = 1.2395x^2 - 7.1769x + 22.071$; $R^2 = 0.9617$) and walking speed and HR ($y = 4.4438x^2 - 31.758x + 16.6$; $R^2 = 0.7954$). Expressing the data as number of steps per km demonstrated a negative polynomial relationship with speed ($y = 29.906x^2 - 436.6x + 2773.9$; $R^2 = 0.8985$) and VO_2 (mL/kg/km) demonstrated a positive polynomial relationship with speed ($y = 13.078x^2 - 119.1x + 473.63$; $R^2 = 0.5387$).

Conclusions: The polynomial nature of the relationships exhibited suggests that walking at 3 km/h is less efficient than faster speeds. An independent contributing factor to this may be the relatively higher number of steps taken, thus the additional physical work of lifting a load more times over the same distance.

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Backpack and body-armour ensembles reduce pulmonary function according to the mass carried and its distribution around the thorax

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Introduction: Soldiers carry loads as backpacks, body armour and as combined (backpack and body amour) arrangements. Such thoracic loading contributes to the existing pulmonary restrictive and inertial forces, and may impede ventilation. Therefore, we evaluated the impact of thoracic load carriage upon lung function by varying both the mass (0–54 kg) and its thoracic distribution.

Methods: Twelve males (age 24.0 y [SD 4.1], mass 81.6 kg [SD 9.5], height 1.82 m [SD 0.07]) participated in 12, within-subjects treatments, conducted on separate days. These included a control condition (clothing only), combined backpack and armour (15, 25, 35, 41, 54 kg; 75% rear distribution), backpack only (15, 25, 35 kg: 100% rear distribution) and body armour only (15, 25, 35 kg: 50:50 distribution). For each condition, pulmonary function was evaluated during standing rest, including forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), maximal voluntary ventilation (MVV) and inspiratory airway occlusion pressure ($p_{0.1}$).

Results: Increasing mass in the combined load arrangement significantly reduced both FVC (control: 6.24 L [±0.16]; 15 kg: 5.88 [±0.14]; 25 kg: 5.62 [±0.16]; 35 kg: 5.40 [±0.17]; 41 kg: 5.60 [±0.15]; 54 kg: 5.51 [±0.14]; $p < 0.05$) and FEV_1 (control: 4.86 L [±0.15]; 15 kg: 4.56 [±0.19]; 25 kg: 4.39 [±0.15]; 35 kg: 4.19 [±0.11]; 41 kg: 4.3 5[±0.18]; 54 kg: 4.35 [±0.18]; $p < 0.05$). Inspiratory occlusion pressure was augmented while carrying 41 kg and 54 kg ($p < 0.01$), but there was no impact of mass on either FEV_1/FVC (%) or MVV (L/min). When the load was distributed to solely the body-armour, there was no additional change to pulmonary function for any given mass. In contrast, when the load was distributed solely to the backpack, the mass-dependant reductions in FVC and FEV_1 were reduced for the 35-kg treatment ($p < 0.05$).

Conclusions: The loaded backpack and body-amour ensemble imposed mass-dependant reductions of up to 13.8% on FVC and up to 13.4% on FEV_1. Redistributing the mass to either the backpack or body-amour caused no further reductions to pulmonary function for any given load. Importantly, there was no evidence of airway obstruction for any of the treatments. However, inspiratory neuromuscular drive was elevated when carrying the very heavy loads and this may predispose some individuals to respiratory muscle fatigue.

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