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Original research

Sex differences in neuromuscular fatigability in response to load carriage in the field in British Army recruits

Thomas J. O'Leary*, Samantha C. Saunders, Stephen J. McGuire, Rachel M. Izard

Department of Occupational Medicine, HQ Army Recruiting & Training Division, UK Ministry of Defence, UK

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ABSTRACT

Objectives: Women are resistant to neuromuscular fatigue compared to men in response to a range of exercise tasks. The sex differences in the neuromuscular responses to load carriage have yet to be investigated.
Design: Prospective cohort study.
Methods: Twenty-three male and 19 female British Army recruits completed a 9.7 km loaded march within 90 min, with the weight carried dependent on military trade (16 ± 2 kg for men and 15 ± 1 kg for women). Isometric maximal voluntary contraction (MVC) force of the knee extensors and vertical jump (VJ) height were examined pre- and post-loaded march to examine neuromuscular fatigue. Heart rate (HR) was recorded throughout and ratings of perceived exertion (RPE) was recorded following the march.
Results: HR was higher for women (173 ± 9 b min^{-1}, $83 \pm 6\%$ heart rate reserve) than men (158 ± 8 b min^{-1}, $72 \pm 6\%$ heart rate reserve) ($p \leq 0.001$). RPE following the march was also higher for women than men (6 ± 2 vs 4 ± 2, respectively, $p < 0.001$). The loss in MVC force was greater for men than women ($-12 \pm 9\%$ vs $-9 \pm 13\%$, respectively, $p = 0.031$), however VJ height was impaired to a similar extent ($-5 \pm 11\%$ vs $-5 \pm 6\%$, respectively, $p = 0.582$).
Conclusions: The greater physiological stress during load carriage for women compared to men did not translate to a greater severity of knee extensor muscle fatigue, with women demonstrating fatigue resistance.

1. Introduction

The ability to carry load over long distances is fundamental for many roles in the military. All male and female standard entry (SE) British Army recruits are required to complete 9.7 km within 90 min carrying either 15 or 20 kg in order to pass initial training. The load carried is determined by each recruit's chosen job role with the more arduous roles requiring 20 kg to be carried. A limited number of studies have demonstrated that load carriage in the laboratory[1–3] and field[4,5] induces impairments in knee extensor function for men. For example, 120 min treadmill walking at 6.5 km h^{-1} with 25 kg resulted in a 14–15% reduction in isometric maximal voluntary contraction (MVC) force for men, taking a minimum of 48 h to recover.[1,2] Additionally, a 19.3 km loaded march carrying 31 kg, completed within 270 min, reduced vertical jump (VJ) height by 8% in male Royal Marine recruits.[5] Although considered one of the most physically arduous tasks during SE British Army initial training, the neuromuscular responses to the 9.7 km loaded march, and the differences between men and women, have yet to be examined.

Women have shown to be resistant to neuromuscular fatigue during isolated muscle contractions compared to men,[6–8] however few studies have examined the sex differences in the neuromuscular responses to locomotor endurance exercise. The reduction in MVC torque of the knee extensors at slow but not fast contraction speeds is less in women than men after prolonged running.[9] However, similar reductions in isometric MVC force are seen between sexes following prolonged cycling.[10] Temesi et al.[11] recently demonstrated that the reduction in isometric MVC force of the knee extensors was greater in men than women in response to a 110 km ultra-marathon, however women completed the ultra-marathon in a slower time. The sex comparison studies to date have been conducted during fatiguing tasks at relative intensities (*i.e.* contractions performed relative to MVC, endurance exercise performed relative to aerobic fitness or self-paced time trials) and the relevance of these findings for populations such as the military where men and women must often complete the same absolute task remains unknown. Consequently, the aim of the present study

* Corresponding author.
E-mail address: thomas.oleary100@mod.uk (T.J. O'Leary).

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Table 1
Participant characteristics. Data are mean ± SD.

	Men (n = 23)	Women (n = 19)
Age (years)	21 ± 3	22 ± 4
Height (m)	1.77 ± 0.09	1.65 ± 0.03*
Body mass (kg)	77.0 ± 11.8	64.0 ± 7.2*
2.4-km run time (s)	632 ± 59	721 ± 47*
HR_{min} (b min^{-1})	47 ± 6	51 ± 6
HR_{max} (b min^{-1})	202 ± 6	198 ± 8
MDLS (kg)	72 ± 15	46 ± 10*
Lean mass (kg)	58.2 ± 8.2	42.2 ± 3.5*
Body fat (%)	21.0 ± 7.1	29.4 ± 5.6*

HR_{max}, maximum heart rate; HR_{min}, minimum heart rate; MDLS; maximal dynamic lift strength.
* $p < 0.05$ vs men.

Table 2
Physiological responses to the loaded march. Data are mean ± SD.

	Men	Women
Time taken (min:s)	87:46	85:56
Absolute load carried (n 15 kg/n 20 kg)	5/18	1/18
Mean absolute load carried (kg)	16 ± 2	15 ± 1
Mean relative load carried (kg^{-1} BM)	0.22 ± 0.04	0.25 ± 0.03*
Mean relative load carried (kg^{-1} LBM)	0.28 ± 0.05	0.36 ± 0.03*
Mean HR (b min^{-1})	158 ± 8	173 ± 9*
Mean HR (%HRR)	72 ± 6	83 ± 6*
RPE (0–10)	4 ± 2	6 ± 2*

b min^{-1}, beats per minute; kg^{-1} BM, kilogram carried per kilogram of body mass; kg^{-1} BM, kilogram carried per kilogram of lean body mass; HR, heart rate; HRR, heart rate reserve; RPE, ratings of perceived exertion.
* $p < 0.05$ vs men.

was to examine the sex differences in neuromuscular fatigability in response to the 9.7 km loaded march completed during British Army SE initial training. It was hypothesised a greater degree of physiological strain for women would negate any fatigue resistance, and therefore men and women would demonstrate a similar level of neuromuscular fatigue.

2. Methods

Twenty-three male and 21 female British Army recruits volunteered to take part in this study. Two women failed to complete the march and therefore data are presented from 23 men and 19 women (Table 1). All participants were recruited during week 1 of their 14-week British Army SE Phase One training at the Army Training Centre, Pirbright. The men and women formed two single-sex training platoons that commenced training on the same day and completed an identical training programme (Common Military Syllabus (Standard Entry), CMS(SE)). All participants passed an initial medical assessment and were therefore declared medically fit to train. Each participant had the study procedures and risks fully explained in writing and by oral brief before providing written informed consent. This study was approved by the Ministry of Defence Research Ethics Committee (ref:753/MODREC/16) and was completed in accordance with the Declaration of Helsinki.

Each participant took part in three trials (two preliminary and one experimental). The first preliminary trial took place in week 1 of training and involved familiarisation to the neuromuscular testing protocol, assessment of body composition, determination of maximal lifting strength and a maximal effort 2.4 km run to provide an estimate of aerobic fitness. The second preliminary trial took place in week 9 of training and neuromuscular function was tested prior to, and following, a 6.4 km loaded march which served as a familiarisation trial. The experimental trial involved completion of a 9.7 km loaded march during week 11 of training with neuromuscular function tested pre- and post-exercise. All exercise tests were completed wearing a heart rate (HR) monitor (Polar Team Pro, Polar, Finland).

Whole-body fat and lean mass (Lunar iDXA, GE Healthcare, UK) were assessed with participants wearing shorts and a t-shirt. Aerobic fitness was estimated from time taken to complete a 2.4 km maximal effort run with maximum HR (HR_{max}) taken as the highest recorded HR during the run. Minimum HR (HR_{min}) was taken as the lowest rolling 30 s average recorded during sleep in week 1.[12,13] Maximal dynamic lift strength (MDLS) was assessed with a lift machine that simulated the power clean. Participants attempted to lift the vertically moving weight stack from a resting height of 0.30 m to 1.45 m with the weight starting at 20 kg and increased in 5 kg increments until a lift was failed or 100 kg was lifted. If a lift was failed twice, participants attempted a weight 2.5 kg heavier than the previous successful lift.

Knee extensor neuromuscular function was measured with isometric MVC force and VJ height. Isometric MVC force of the right knee extensor was determined using a strain gauge (MIE Digital Myometer, MIE Medical Research, UK) attached to a plinth and wrapped ~2 cm above the malleolus.[14,15] The hip and knee were kept at 90° and force was measured in the direction of knee extension. Lever length and knee angle were recorded to standardise position of measurement. Three MVCs of 3 s in duration separated by ~15 s rest were performed at each time-point. VJ height was determined with a belt fitted around the waist which was attached to a rubber mat on the floor by a cord (Takei 5406, Takei Scientific Instruments, Japan).[5] Participants were instructed to descend to 90° knee flexion and immediately jump as high as possible with hands placed on the hips and feet a shoulder width apart. MVC force and VJ height were taken as the peak of the three recorded values at each time-point. In order to reduce any learning effect, additional attempts were permitted if peak MVC force or VJ height was achieved in the third effort at the pre-exercise time-point only (for MVC force 2 women and 5 men, and for VJ height 7 women and 9 men, required up to an additional two attempts to ensure a plateau). All measures of neuromuscular function were taken whilst wearing socks, trousers and t-shirt.

All participants completed a 9.7 km loaded march carrying either 15 or 20 kg (11 or 16 kg backpack and 4 kg rifle) during week 11 of training. A breakdown of the absolute and relative loads carried are shown in Table 2. The weight carried was determined by the requirements of each recruit's career employment group (20 kg for Royal Artillery, Royal Armoured Corps, Royal Engineers and Household Cavalry and 15 kg for all other military trades) and each participant carried an identical standard issue British Army backpack with a rifle in their hands and wore standard issue boots and clothing. All participants completed the same course at the same walking speed, which is prescribed by CMS(SE) and was paced at 6.4 km h^{-1} by experienced physical training instructors to ensure completion in 90 min. The loaded march is an assessed test of combat fitness as part of CMS(SE) and must be completed in 90 min in order to pass training. The men and women completed the march as part of their respective platoons at the same time of day separated by 24 h. HR was expressed relative to heart rate reserve (%HRR)[12,13] using the equation: $\%HRR = (HR - HR_{min})/(HR_{max} - HR_{min}) \times 100$. Ratings of perceived exertion (RPE) for the march was measured within 30 min post-exercise using the Borg 0–10 scale.

All data are presented as mean ± standard deviation (SD) and were analysed using SPSS (v.23, SPSS Inc., USA). Data were initially tested for normality. Participant demographics, relative load carried and HR were compared between men and women using independent samples t-tests. Absolute load carried and RPE was compared between sexes with a Mann–Whitney U test. MVC force and VJ height were compared using a 2 × 2 (sex [men vs women] × time [pre-exercise vs post-exercise]) mixed-measures

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