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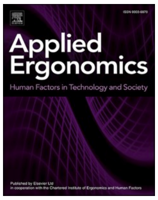

Energy cost and knee extensor strength changes following multiple day military load carriage

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ABSTRACT

Military exercises and recruit training requires soldiers, including new recruits, to undergo multiple days of substantial physical stress. The aim of this study was to evaluate the physiological impact of multiple days of military load carriage by addressing the hypothesis: A second day of load carriage increases oxygen uptake and reduces knee extensor torque compared to a single day of load carriage. A load carriage group (n = 12) (carrying 32 kg) and unloaded group (n = 14) walked on a treadmill for 2 h on two consecutive days. Knee extensor and flexor torque were assessed by dynamometry at speeds of: $0^\circ\cdot s^{-1}$,$60^\circ\cdot s^{-1}$ and $180^\circ\cdot s^{-1}$ before and after load carriage on day one and two, and 24 h following day 2. Oxygen uptake was assessed via respiratory gas assessment at the 6th and 119th minute of load carriage on day one and two. When assessed by mixed methods ANOVA (alpha: 0.05), an interaction effect was observed for oxygen uptake ($p < 0.001$), with post hoc assessment highlighting second day of load carriage significantly increased oxygen uptake compared to day one post in the loaded group (28.9(3.0) vs 25.8(3.4), $p = 0.048$). An interaction effect was observed for all knee extensor variables (all $p < 0.05$). All knee extensor peak torque variables were significantly associated to oxygen uptake at $0^\circ s^{-1}$ ($r = -0.576$, $p < 0.05$), $60^\circ s^{-1}$ ($r = -0.552$, $p < 0.05$), and $180^\circ s^{-1}$ ($r = -0.589$, $p < 0.05$). Two days of load carriage significantly increases oxygen uptake and reduces knee extensor and flexor torque compared to a single day of load carriage. Subsequently, physical training programmes aimed at increasing knee extensor strength may protect against increases in oxygen uptake.

1. Introduction

Military training requires recruits to undergo multiple days of substantial physical stress (Knapik, 2001), during which load carriage is a key occupational task. Load carriage has been characterised by high injury rates (Birrell, 2007; Knapik et al., 1992) and increased oxygen uptake(VO_2) (Blacker et al., 2009)- a commonly accepted marker energy cost (Lidstone et al., 2017). Despite recruit training involving load carriage over multiple days, the cummulative effects of multiple day load carriage are yet to be established. Understanding the mechanisms increasing the likelihood of injury incidence and fatigue, through physiological assessment of load carriage, is critical to reducing the time and financial costs to training establishments.

A number of detrimental physiological changes occurring during load carriage, which may inhibit a load carriers performance or expose them to increased injury risk. It is broadly accepted that VO_2 and heart rate drift occur during load carriage. A previously conducted study has presented drift in VO_2 with slight simultaneous changes in exhaled carbon dioxide (VCO_2) and respiratory exchange ratio (RER) during 120min walking on a treadmill with a 40 kg (Epstein et al., 1988) and replicated in a number of studies with different external loads (Mullins et al., 2015; Patton et al., 1991; Warber et al., 2000).

Previous work has presented reductions in torque producing capacity of the ankle plantarflexors and knee extensors by dynamometry before and after load carriage (Clarke et al., 1955; Scales et al., 2019; Blacker et al., 2010a). Reductions to knee extensor strength during load carriage may provide a mechanistic explanation for increased VO_2, due to a less economical gait pattern or through the increased muscular fibre recruitment required to maintain movement (Birrell and Haslam, 2009). Knee extensor torque output has been shown to be reduced up to 72 h after load carriage (Blacker et al., 2010b), suggesting a likelihood that participants would start consecutive day exercise with reduced knee

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Abbreviations: D1, Day one; D2, Day two; D3, Day three; RER, Respiratory Exchange Ratio; VO_2, Oxygen uptake; VCO_2, Expired carbon dioxide.

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extensor torque output. It is known that adaptive movement patterns emerge as a function of the organism's propensity to minimize metabolic energy expenditure (Sparrow and Newell, 1998)- of which VO_2 is a reliable proxy measure, however it is not known whether reduced knee extensor torque output will impact consecutive day VO_2. Confirming an association between knee extensor torque and VO_2 would help guide future practice by developing training programmes to mitigate reductions in muscle function most closely associated to load carriage fatigue as measured by VO_2.

The aim of this work is to evaluate whether multiple days of load carriage increases VO_2 and knee extensor strength compared to an unloaded control. It was hypothesized that the loaded group will exhibit a significant increase in VO_2 and significant reduction in knee extensor strength following the second bout of prolonged walking compared to no change in the unload walking group.

2. Material and methods

2.1. Participants

Participants were assigned to unloaded (73.8 ± 34.8 kg, 178.0 ± 17.5 cm, 21 ± 5 yrs, 11 males, 3 females) and loaded (78.3 ± 36.8, 179.2 ± 17.9 cm, 22 ± 6 yrs, 10 males, two females) groups by randomly selecting odd or even playing cards on their first visit to the laboratory. Inclusion criteria required participants to be between 18 and 32 years old, weigh more than 50 kg, taller than 1.63m, free from self-reported musculoskeletal injury. These criteria were developed to ensure that participants physical characteristics matched those of a military recruit cohort (Allsopp and Shariff, 2003). This is a frequently used model as such cohorts are representative of early stage military recruits (Blackeret al., 2013).

Twenty-six participants provided written informed voluntary consent to participate in the study. Ethical approval was attained from the university ethics committee and all procedures were performed in accordance with the Declaration of Helsinki (2013).

2.2. Protocol

The study was conducted in a randomized parallel group experimental design (loaded vs unloaded) with expired gas collected during treadmill walking and dynamometry measurements performed before and after the walking task on day 1(D1pre, D1post) and day 2(D2pre, D2post) with dynamometry measures 24 h post on day 3 (D3); both conditions ran concurrently. All participants were familiarized with the load carriage and testing systems visit prior to testing. Testing was completed at the same time of day on D1 and D2.

Participants walked on a level motorised treadmill (Woodway ELG, Birmingham, UK) (0% gradient) for 120 min, at 6.5 km h^{-1}. The unloaded group walked on the treadmill wearing their own trainers, shirt and shorts, while the loaded group wore the same but carried an external load. The load consisted of a 32 kg external load spread across: webbing (10 kg), bergen (15 kg) and a dummy rifle (7 kg).

The webbing is a collection of pouches, used to hold ammunition, 24 h of emergency rations and 2 L of water. The webbing is held on the body by a belt, and shoulder straps, which run underneath the bergen. A bergen (large military backpack) is supported on the body by shoulder straps and a hip belt. The rifle has a sling running around the neck (Fig. 1.).

Participants consumed water with no restrictions during the treadmill protocol, which reflected the occupational military setting. The bottle from which the water was consumed was not carried within the load carriage system.

Environmental temperature (ATP: UK) and humidity (RS:UK) were monitored during the walking task. No differences in environmental temperature were observed during testing between D1 (18.66 °C ± 2.83 °C) and D2 (18.17 °C ± 1.83 °C) ($p = 0.362$). No differences in humidity were observed between D1 (51.05% ± 18.15%) and D2 (49.4% ± 15.00%) ($p = 0.311$).

2.3. Dynamometry

Dynamometry variables assessed as dependent variables were knee extension at $0°\cdot s^{-1}$, knee extension at $60°\cdot s^{-1}$, knee extension at $180°\cdot s^{-1}$, knee flexion at $0°\cdot s^{-1}$, knee flexion at $60°\cdot s^{-1}$ and knee flexion at $180°\cdot s^{-1}$. Knee assessment was conducted on the right limb to facilitate comparison with previous work (Blackeret al., 2013) using a Biodex System 3 Pro (Biodex: New York: USA). The right knee and hip were secured at 90° (shank vertical) to facilitate comparison with previous work (Blackeret al., 2013), confirmed by goniometer measurement. The Biodex knee attachment arm was attached to the dynamometers point of

Fig. 1. Load carriage system carried by participants.

rotation. The dynamometers point of rotation was aligned to the participant's lateral femoral epicondyle. Before testing participants performed the test protocol at 30% of maximum effort (confirmed in subgroup analysis of 10 participants). The test protocol consisted of one maximal voluntary isometric knee extension and flexion ($0^\circ{\cdot}s^{-1}$) and then one set of eight maximal concentric contractions of the knee extensors and flexors at speeds of $60^\circ{\cdot}s^{-1}$ and $180^\circ{\cdot}s^{-1}$. A rest of 120 s occurred between each exercise cluster. Concentric knee extensor peak torque was calculated as the highest recorded score from the eight repetitions at 110° (internal knee angle). Concentric knee flexor peak torque was calculated at the highest recorded score from the eight repetitions at 130° (internal knee angle).

2.4. *Metabolic variables*

Respiratory gases were collected via continuous breath-by-breath analysis using an Oxycon Pro metabolic cart (Oxycon Pro, CareFusion: USA); calibrated using certified standardised gases of a known composition and the turbine was calibrated using a 3L syringe. All data from the Oxycon Pro (VO_2, VCO_2, RER) were interpolated and averaged over 10 s intervals. The sixth minute and the last minute of the load carriage task were used. To ensure the participant was performing in steady state intensity. The averaged output was then normalised to the participant's body mass.

2.5. *Statistical analysis*

Data were statistically analysed using SPSS for windows version 23 (SPSS, Chicago, USA) and Excel (Microsoft: USA). Before variables were normalised the data were log transformed and plotted to ensure that it did not violate any scaling guidelines (Atkinson and Batterham, 2012; Davies and Dalsky, 1997; Nevill et al., 1992). Once sphericitiy and homogeneity was assessed, a repeated measures ANOVA was used to assess for between groups (loaded vs unloaded) and for repeated measures factors (time). Tukey post hoc testing was used to further characterise differences observed by repeated measures ANOVA. Alpha level was $p = 0.05$ and corrected for repeated measures assessment. Associations between VO_2 and all knee extensor variables were examined for the loaded group only using repeated measure correlations procedures (Birrell, 2007; Knapik et al., 1992).

Using 90% power and 0.05 alpha level to test for 16% difference in oxygen uptake between first and last measurement derived from published literature (Blacker et al., 2009) a required sample of 24 participants (12 participants per group) was required and achieved to assess the primary hypothesis.

3. Results

Table 1 presents a significant interaction effect for VO_2 ($p < 0.001$). Post hoc assessment identified between group differences with the loaded group elevated at baseline (23.26 ± 3.06 ml $kg{\cdot}min^{-1}$vs 16.28 ± 1.89 ml $kg{\cdot}min^{-1}$, $p < 0.001$) and significantly increased change scores at all time points: D1post: 9.56 ± 7.14% vs 2.12 ± 3.71%, $p < 0.001$; D2pre: 4.35 ± 4.75% vs 1.48 ± 5.24%,$p < 0.001$) and D2post: 15.5 ± 7.59% vs 3.16 ± 6.97%, $p < 0.001$). VO_2 of the loaded group was significantly increased compared to baseline at D1post ($p = 0.03$), D2pre ($p = 0.05$) and D2post ($p < 0.001$). Loaded group VO_2 was significantly increased at D2post compared to D2pre ($p = 0.05$).

Table 1 presents an interaction effect for VCO_2 ($p = 0.035$). A main effect was observed between groups ($p < 0.001$) with the loaded group elevated compared to the unloaded group. Post hoc assessment identifies between group differences with the loaded group elevated at baseline (20.53 ± 3.20 ml $kg{\cdot}min^{-1}$vs 13.98 ± 1.80 ml $kg{\cdot}min^{-1}$, $p < 0.001$). No between group differences were observed at: (Loaded vs Unloaded) D1post: 0.96 ± 5.25% vs −4.41 ± 6.13%, $p = 0.35$ or D2pre: 2.96 ± 5.91% vs −1.43 ± 6.91%,$p = 0.46$. A difference was observed between groups at D2post: 3.06 ± 6.26% vs −6.23 ± 7.88%, $p = 0.04$.

Respiratory exchange ratio showed no interaction ($p = 0.40$) or main effect between groups ($p = 0.05$), but did show significant effects of time ($p = 0.05$). As there were no main effect no post hoc analysis was conducted between loaded and unloaded group at baseline (Loaded vs Unloaded): 0.88 ± 0.05 vs 0.86 ± 0.04, D1post: 8.15 ± 4.25 vs −6.14 ± 5.44, D2pre: 0.65 ± 5.43 vs-2.87 ± 6.60 or D2post: 10.13 ± 6.3 vs −8.75 ± 6.63.

Table 2 presents interaction effects for all knee extensor variables ($0^\circ s^{-1}$, $p = 0.01$; $60^\circ s^{-1}$, $p = 0.04$; $180^\circ s^{-1}$, $p = 0.02$). Post hoc assessment highlighted that significant reductions in torque occurred at D1post compared to baseline for the knee extensors at $0^\circ s^{-1}$ ($p = 0.01$), $60^\circ s^{-1}$ ($p = 0.03$) and $180^\circ s^{-1}$ ($p = 0.04$) in the loaded group with no change in the unloaded group. Differences between D2pre and baseline were observed for the loaded group but not unloaded group for $60^\circ s^{-1}$ ($p = 0.05$) and $0^\circ s^{-1}$ ($p = 0.01$) knee extensor variables. Reductions were observed at D2post compared to baseline at $0^\circ s^{-1}$($p = 0.01$), $60^\circ s^{-1}$ ($p = 0.01$) and $180^\circ s^{-1}$ ($p = 0.05$) for the loaded group but not the unloaded group. Reductions in torque from baseline for the loaded group were observed at D3 $0^\circ s^{-1}$ ($p = 0.03$) and $180^\circ s^{-1}$ ($p = 0.04$) but not at $60^\circ s^{-1}$ ($p = 0.22$) Differences for the loaded group between D2pre and D2post were observed for all knee extensor variables at $0^\circ s^{-1}$ ($p = 0.03$), $60^\circ s^{-1}$ ($p = 0.02$) and $180^\circ s^{-1}$ ($p = 0.04$). No interaction effect was observed for any knee flexion variable.

VO_2 was not associated to any knee flexion variable ($180^\circ s^{-1}$: $r = -0.40$, $p = 0.41$, $60^\circ s^{-1}$: $r = -0.386$, $60^\circ s^{-1}$: $r = 0.322$, $p = 0.56$). VO_2 was significantly associated to the knee extensors at $0^\circ s^{-1}$ ($r = -0.576$, $p < 0.05$), $60^\circ s^{-1}$ ($r = -0.552$, $p < 0.05$), and $180^\circ s^{-1}$ ($r = -0.589$, $p < 0.05$).

After initial examination of findings, VO_2 D1 and D2 percentage change scores were calculated for the loaded group (D1 9.30(2.12)% vs D2 12.78(1.61)% and were assessed for association ($r = 0.824$, $p < 0.01$). VO_2 at baseline and the D2 change score were significantly associated ($r = 0.786$, $p < 0.01$).

Table 1
Respiratory gas measures at baseline and change scores from baseline.

Variable	Condition	n	Day 1		Day 2		p-Value	Significance	Effect size
			Baseline	Post (%)	Pre (%)	Post (%)			Eta 2
VO2	Unloaded	14	16.28 (1.89)	2.12 (3.71)	1.48 (5.24)	3.16 (6.97)	<0.001	Time·Load	0.24
(ml·kg·min-1)	Loaded	12	23.26 (3.06)	9.56 (7.14)[a]	4.35 (4.74)[a]	15.5 (7.59)[a,b].			
VCO2	Unloaded	14	13.98 (1.80)	−4.41 (6.13)	−1.43 (6.91)	−6.23 (7.88)[a,b].	0.035	Time·Load	0.16
(ml·kg·min-1)	Loaded	12	20.53 (3.20)	0.96 (5.25)	2.96 (5.91)	3.06 (6.26)			
RER	Unloaded	14	0.86 (0.04)	−6.14 (5.44)	−2.87 (6.60)	−8.75 (6.63)	0.398		
	Loaded	12	0.88 (0.05)	−8.15 (4.25)	−0.65 (5.43)	−10.13 (6.3)[b]			

Baseline and Pre measures collected in 6th minute of load carriage, post measure collected in 119th minute of load carriage.

[a] Denotes statistical interaction effect($p < 0.05$).

[b] Represents statistical significance from D2 pre. Results are presented as means with standard deviations in brackets.

Table 2

Mean values knee extensor and flexor change scores, alongside statistical significance and effect sizes.

Variable	Condition	n	Day 1		Day 2		Day 3	p Value	Significance	Effect Size
			Baseline (N.m)	Post (%)	Pre (%)	Post (%)	(%)			Eta2
Knee Extension 180°s-1	Unloaded	14	135.6 (38.7)	0.8 (8.2)	3.0 (8.7)	3.5 (12.8)	5.1 (10.6)	0.022	Load·Time, Load	0.13
	Loaded	12	166.0 (49.8)	−11.1 (10.4)[a]	−0.9 (5.9)	−8.8 (14.7)[a,b]	0.1 (10.7)			
Knee Extension 60°s-1	Unloaded	14	178.3 (36.0)	−1.2 (11.9)	−5.3 (9.0)	−3.3 (7.7)	−1.3 (9.3)	0.041	Load·Time, Load	0.10
	Loaded	12	228.9 (97.2)	−15.2 (14.3)[a]	−9.6 (12.3)[a]	−15.4 (10.5)[a,b]	−11.5 (10.8)[a]			
Knee Extension 0°s-1	Unloaded	14	222.8 (67.7)	−0.5 (10.2)	−9.6 (12.3)[a]	−5.0 (12.9)	−1.2 (16.2)	0.009	Load·Time, Load	0.16
	Loaded	12	281.4 (116.1)	−9.2 (11.1)[a]	−9.6 (12.3)[a]	−18.7 (21.0)[a,b]	−11.3 (12.5)[a]			
Knee Flexion 180°s-1	Unloaded	14	76.5 (29.1)	0.2 (12.1)	3.8 (18.1)	0.5 (20.1)	6.0 (20.2)	0.930		
	Loaded	12	106.8 (41.4)	−13.0 (19.1)	−7.0 (15.3)	−18.1 (18.7)	−9.6 (19.0)			
Knee Flexion 60°s-1	Unloaded	14	97.6 (33.0)	7.2 (6.7)	4.1 (7.9)	13.3 (7.5)	11.3 (7.9)	0.260		
	Loaded	12	118.4 (39.5)	8.3 (12.7)	4.0 (9.3)	11.5 (12.6)	8.2 (16.9)			
Knee Flexion 0°s-1	Unloaded	14	91.8 (32.9)	−2.4 (4.6)	−4.4 (13.5)	−4.3 (17.3)	−5.3 (11.1)	0.442		
	Loaded	12	102.0 (31.7)	−4.4 (14.2)	−0.2 (12.4)	−10.0 (19.5)	−7.2 (20.0)			

[a] Denotes statistical interaction effect($p < 0.05$).

[b] Represents statistical significance from D2 pre. Results are presented as means with standard deviations in brackets.

4. Discussion

The aim of the current study was to evaluate whether multiple days of load carriage increases fatigue as measured by VO_2 and reduces knee extensor strength compared to an unloaded control. This study observed significant increases in VO_2 and reductions in the torque producing capacity of the knee extensors in the loaded group compared to no change in the unloaded control. Associations were observed between all knee extensor torque variables and VO_2. These findings suggest a second day of load carriage significantly increases VO_2 compared to a single day of load carriage and supports the postulation that reductions to knee extensor strength increases VO_2. Secondary analysis highlighted associations that suggest magnitude of change for D1 VO_2 could be used as a predictor of subsequent day performance.

In agreement with previous work, the loaded group presented VO_2 38% greater than the unloaded group (Bennett et al., 2013; Coombes and Kingswell, 2005; Grenier et al., 2012; Lyons et al., 2003). The D1 drift in VO_2 for the load group observed in this study (9%) was comparable to previous work, which observed increases between 13% and 18% from baseline (Epstein et al., 1988; Mullins et al., 2015; Patton et al., 1991). As VO_2 is a commonly accepted marker of fatigue, these findings show that participants experience significant fatigue during a bout of load carriage which could reduce task specific performance such as marksmanship (Taylor et al., 2016) and cognitive performance (Eddy et al., 2015).

The loaded group VO_2 was significantly increased at D2pre compared to baseline (4%). Loaded participants experienced VO_2 drift of 13% on the second day of load carriage which resulted in statistically increased D2post score compared to D1post (D1post 24.2(3.5) v D2post 26.9(3.9)). These findings suggest that the increase in VO_2 is due to insufficient recovery between load carriage sessions, as opposed to a change during the load carriage task. This indicates 24 h is insufficient recovery time between bouts of load carriage activity to ensure homeostasis of VO_2 during load carriage and places participants at increased fatigue, which may reduce task specific performance during subsequent activities, such as setting up military camp (Orr, 2010), tactical operations and marksmanship (Ojanen et al., 2018), Secondary analysis highlighted strong associations between D1pre to D2 VO_2 change score. This suggests that acute load carriage VO_2 could be used as a predictor for subsequent performance. Future applied work could focus on developing cost effective acute screening protocols that may predict performance over longer load carriage period, potentially identifying characteristics that predispose a participant to significant VO_2 drift during load carriage tasks.

An interaction effect was observed for VCO_2, characterised by a main effect for load and a reduction in loaded group VCO_2 at D2post compared to D2pre. The small differences makes interpreting this finding difficult. Moreover, respiratory exchange ratio followed a similar profile for both groups resulting in an observed main effect difference in RER for time but not interaction effect in line with previous work (Blacker et al., 2009). Suggesting load carriage had no effect on whole body substrate oxidation across the two exercise bouts compared to unloaded walking.

Reductions in the loaded group knee extensors were observed between D1pre and D1post (between 11 and 23%) compared to the unloaded group that presented no loss in torque. This corroborates previous work demonstrating that torque during knee extension is significantly reduced following 2 h of load carriage compared to unloaded walking (Clarke et al., 1955; Blackeret al., 2013). Reduced knee extension function may account for increased injury rates observed during load carriage, as participants are less able to mitigate the external impact of the load (Rice et al., 2016).

Large variation was observed in knee extensor scores, this variance is again comparable to previous research (Blackeret al., 2013; Fallowfield et al., 2012; O'Leary et al., 2018). Current consensus suggests that this variance in performance is due to the absolute weight of the external packs compared to the relative mass of the participants (Blackeret al., 2013). However, the present study found no associations to support this assertion.

Loaded group knee extension torque at 0°s^{-1} remained reduced compared to baseline after 24 h recovery and was accompanied by a non-significant reduction for 60°s^{-1} and 180°s^{-1} in agreement with previous work (Blackeret al., 2013). Such findings suggest the load carriage group exhibited reduced knee extensor torque following a single bout of prolonged walking, that was still prevalent at D2pre, 24 h later. No differences were observed between D1post and D2post suggesting that while 24 h of recovery period was not sufficient to mitigate the effects of load carriage between days, the percentage was relatively stable at approximately 20% reduction in force after both days of load carriage. Therefore, while being inexperienced load carriers, the participants were able to complete the load carriage task without statistically reduced torque output compared to the previous day. As a result, the participants and military recruits for which these participants are representative, are reasonably capable of undergoing load carriage on two consecutive days and still being able to limit the reduction of knee extensor torque output over at least two days.

No significant interaction effects were observed for knee flexor torque at any speed. The mean reductions in knee flexors appeared to be roughly comparable to the knee extensors, which would not be expected during normal locomotion (Millet et al., 2003). This may be due to the need of the knee flexors to activate to maintain pelvis position to resist against the forward lean, which is widely accepted to occur as an acute effect of load carriage (Lloyd and Cooke, 2011) or as a result of a central reduction in physiological function.

Knee extensor torque at all three speeds demonstrated significant, moderate associations with VO_2, building on previous work, which has observed acute associations (Lloyd and Cooke, 2011). Observed significant association in extensors but not flexors could be due to the increased role the knee extensors play in the early phase of gait. It is commonly accepted increased knee flexion following heel contact and to mid-stance occurs in order to mitigate the effect of the load (Birrell et al., 2007). Load carriage may increase the load on the knee extensors, subsequently increasing strength loss during load carriage and reducing the body's capacity to maintain normal gait and result in an increase in VO_2. Improved recovery between load carriage tasks may mitigate against reduction in knee extensor torque, help the load carrier to maintain normal gait, reducing risk of injury, and reducing VO_2 increase. As such, physical training programmes designed to limit strength loss of the knee extensors during load carriage will both reduce injury risk and mitigate fatigue. Previous work has suggested dietary supplementation may provide a mechanism to limit fatigue during load carriage and knee extensor torque loss (Blacker et al., 2010a). However, a placebo-controlled study should be completed to confirm any impact over multiple days.

Some limitations should be considered; this study used non-military inexperienced load carriers which could limit the transferability of these findings to experienced load carriers. Inexperienced participants were intentionally recruited to this study to be directly comparable to early stage military recruits. This has become a commonly used protocol due to the comparable physical characteristics between the cohorts (Blacker et al., 2009) and the very high injury rates experienced by novice recruits. To reduce skin sore injury participants wore their own shoes and not military issue boots, reducing the replicability of these findings to a military cohort.

5. Conclusion

This work profiles lower limb fatigue and metabolic variables during multiple days of load carriage. We present that VO_2 is significantly increased following multiple days of load carriage compared to a single day of load carriage. These findings highlight that training programmes need to consider participant recovery between load carriage bouts to reduce fatigue and to ensure load carriers can perform follow on tasks optimally. There was some support that Day 1 performance could be used as a predictor of subsequent performance. Correlation analysis highlights a relationship between knee extensor torque output and VO_2, which could be attributed to a change of gait because of the knee extensors reduced capacity to mitigate the effect of the load. This may partially provide a mechanistic account for the increased VO_2 due to less economical gait. The cohort in this study are comparable to early stage military recruits, the findings suggest limiting strength loss in the knee extensors will enhance ability to maintain load carriage performance, prior research suggests nutritional supplementation or adapting physical training (Blacker et al., 2010a) could be considered.

Ethics approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by Canterbury Christ Church University research ethics committee (SAS/460).

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Authors' contributions

J Scales: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing - original draft, Writing - review & editing. M Brown: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing - review & editing, Supervision.

D Coleman: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing - review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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