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# Physiological and subjective responses to a novel military specific load carriage treadmill protocol

Christopher A. J. Vine[1], Sarah L. Coakley [1, 2], Sam D. Blacker [1], Oliver R. Runswick [1, 3], Stephen D. Myers [1 *]

[1]*Occupational Performance Research Group, Institute of Sport, Nursing and Allied Health, University of Chichester, Chichester, UK*
[2]*Faculty of Sport, Allied Health and Performance Science, St Mary's University, London, UK*
[3]*Institute of Psychiatry, Psychology & Neuroscience, Kings College London, London, UK*

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A B S T R A C T

*Treadmill-based load carriage protocols typically use a single fixed speed; however, these are not representative of occupational load carriage tasks. This study aimed to quantify the metabolic, cardiovascular, thermal, neuromuscular, and perceptual responses to a treadmill-based, military-specific, fast load carriage protocol (FLCP). This protocol comprised of carrying 25 kg, for 20 minutes at 5.1 km·h$^{-1}$; 40 minutes, at 6.5 km·h$^{-1}$; and 8 x 9 s shuttles, at 11 km·h$^{-1}$ with 11 s recovery. Twelve men (age, 27 ± 6 y; stature, 1.83 ± 0.05 m; body mass, 80.6 ± 8.0 kg; maximal oxygen uptake, 52.7 ± 5.5 mL·kg$^{-1}$·min$^{-1}$), completed a FLCP during which oxygen consumption ($\dot{V}O_2$), heart rate, core body temperature, and perceptual ratings were recorded. Performance assessments (weighted counter-movement jump [wCMJ], maximal isometric voluntary contraction [MIVC] of the quadriceps, seated medicine ball throw [SMBT]) were completed pre-FLCP, immediately-post and, 30, 60, 120 minutes' post. $\dot{V}O_2$ was similar for 5.1 km·h$^{-1}$, but increased by 7.4% during the 40 minutes at 6.5 km·h$^{-1}$ ($p$ = 0.013). Core temperature increased by 0.92 ± 0.22 ºC in response to the FLCP. Post-FLCP, SMBT was not dissimilar across measurement points, ($p$ = 0.315), however, MIVC peak force reduced by 12.6 ± 10.9% 60 minutes post-FLCP ($p$ = 0.031), and wCMJ height decreased by 8.7 ± 5.9% 120 minutes post-FLCP ($p$ = 0.011). The completion of the FLCP does not affect upper body power (SMBT), but appears to modestly decrease lower body explosiveness (wCMJ and MIVC) up to two hours' post. Future investigations can use the FLCP protocol to investigate occupationally relevant scenarios, such as the interaction between physical and cognitive performance during load carriage, or the implications of multiple repeated load carriage bouts.*

## 1. Introduction

Load carriage is a strategically important facet of military training and operations; which can often be mission-critical (Knapik et al., 2004). Specifically, load carriage refers to the action of moving from one location to another, by way of walking or running, whilst carrying an external load of mission-specific equipment. As a consequence of its criticality, factors influencing load carriage performance have generally been well researched (see review by Knapik et al., 2012). In particular, the influence of external load mass has received considerable attention; with studies detailing an upward trend over time in loads carried during military operations (Knapik et al., 2004, 2012; Orr, 2010). However, scenarios exist, where the combination of faster load carriage speeds (> 4.8 km·h$^{-1}$) and lighter load masses (< 30 kg), to facilitate these movement speeds, are undertaken; termed herein a 'fast march'. For example, soldiers will be required to move at speed with lighter loads as when coming under fire or whilst assaulting an enemy position. This necessity to complete load carriage tasks at different speeds and with different loads is reflected in the new British Army annual fitness tests (British Army, 2020). Despite its relevance to military populations, the implications of this alternative speed-load combination have received considerably little attention. Notably, those studies investigating this combination have typically utilized purely rucksack borne loads at fixed speeds (e.g., Blacker et al., 2009, 2010), which does not reflect the external load distribution of soldiers during these aforementioned scenarios. Instead, the

*Corresponding Author: Stephen D. Myers, Institute of Sport, Nursing and Allied Health, University of Chichester, UK, S.Myers@chi.ac.uk

lighter load mass carried during a fast march would typically consists of a belt webbing system, body armor, a personal weapon, and in some instances a small rucksack; totaling ~25 kg. This ensemble is carried in situations where enemy contact is anticipated (Knapik et al., 2004), and represents a typical minimum load carried by dismounted infantry soldiers whilst patrolling. It is important to assess this load distribution given the known metabolic cost implications of different load mass carrying locations (e.g., Soule & Goldman, 1969; Browning et al., 2007; Taylor et al., 2012).

Military load carriage and other arduous military tasks are rarely completed in isolation. As such, it is important to consider the impact of load carriage on subsequent military and physical performance (Knapik et al., 2012; van Dijk, 2007). For example, following a fast march, soldiers may be likely to undertake a fire and maneuver task in response to enemy contact. In turn, this may be followed by other tasks such as a casualty evacuation, replenishment of stores or even subsequent assaults on enemy positions. However, due to factors such as high task complexity, the multitude of sequential task permutations, and the difficulty in accurately replicating military scenarios, investigating subsequent military task performance can be problematic. As a result, field-expedient tests are frequently used to assess changes in key physical competencies (Hauschild et al., 2017). These physical performance assessments can therefore act as an indicator of task-induced fatigue as well as indicators of role-specific physical readiness. Broadly, these physical assessments can be categorized into those assessing cardiorespiratory endurance (e.g., multi-stage fitness test), muscular strength (e.g., back squat), muscular endurance (e.g., repeated shuttles), and flexibility (e.g., sit-and-reach) (Hauschild et al., 2017). Of these assessment domains, cardiorespiratory endurance, lower body strength and upper body muscular endurance are among the most effective predictors of occupational performance (Hauschild et al., 2017; Knapik et al., 2006). These assessments, therefore, provide a time and space-efficient method for quantifying soldier physical readiness.

A number of studies have utilized physical performance assessments as indicators of fatigue following load carriage tasks. For example, Fallowfield et al., (2012) demonstrated a reduction in vertical jump height (8 ± 9%) following a 19.3 km march at 4.3 $km \cdot h^{-1}$ (including breaks), carrying 31 kg. Conversely, Knapik et al. (1991) reported no decrement in soldiers vertical jump height following a 20 km march (mean completion speed 3.82 $km \cdot h^{-1}$), carrying 46 kg; however, grenade throw distance decreased by 9%. It was noted that this latter observation was likely due to nerve entrapment or pain in the shoulder region caused by the strenuous march (Knapik et al., 1991). Critically, these studies investigated load carriage tasks conducted at relatively modest paces (<4.8 $km \cdot h^{-1}$), using moderate to heavy loads (>30 kg), carried predominantly in a rucksack. As such, the implications of a fast march with load distributed on the torso and waist on indicators of soldier physical readiness are not well known.

The current study designed and employed a novel treadmill protocol to replicate the physical demands of a military specific fast march, and fire and maneuver task. Physical performance assessments were included to evaluate the effect of load carriage on subsequent indicators of soldier physical readiness in the 2 hours' post-task. Therefore, this study aimed to; 1) quantify the metabolic, cardiovascular, thermal, neuromuscular, and perceptual responses to a treadmill-based, military-specific, fast load carriage protocol (FLCP); and 2) identify the effects of the FLCP on subsequent indicators of soldier physical readiness.

## 2. Methods

### *2.1. Experimental Overview*

Participants completed a familiarization session followed by an experimental session, separated by a minimum of five days. For the familiarization session participants had baseline measures of body composition recorded, after which they completed an unloaded treadmill walking assessment, followed by a maximal rate of oxygen consumption ($\dot{V}O_{2max}$) test. Participants were also familiarized with the physical performance assessments (4 kg seated medicine ball throw [SMBT], weighted countermovement jump [wCMJ], quadriceps maximal isometric voluntary contraction [MIVC]), and an abridged version of the FLCP. For the experimental session, participants completed these performance assessments before completing the FLCP, immediately afterwards and at 30-, 60-, and 120-minutes' post. During the FLCP, oxygen consumption ($\dot{V}O_2$), heart rate (HR), core temperature, and perceptual ratings were recorded. All testing was conducted in an air-conditioned laboratory.

### *2.2. Fast Load Carriage Protocol Design*

This occupationally relevant load carriage task was developed from prior literature and current military load carriage assessments. The FLCP (Figure 1), consisted of walking at 5.1 $km \cdot h^{-1}$ and 6.5 $km \cdot h^{-1}$ for 20 and 40 minutes respectively (1% gradient). At 60 minutes, participants walked for one minute at 2.5 $km \cdot h^{-1}$ (1% gradient) before completing eight, nine-second shuttles at 11 $km \cdot h^{-1}$ and 3% gradient. Shuttles were interspersed by an 11 second recovery period at 2.5 $km \cdot h^{-1}$ and 3% gradient. The first part of the FLCP mimicked the load carriage speeds typical of fast marches undertaken by the British Army, and are speeds and distances that have been utilized effectively in both prior load carriage literature (Blacker et al., 2010; Blacker, Fallowfield, Bilzon, et al., 2013; Vine et al., 2020), and the new British Army physical employment standards (British Army, 2020). The subsequent shuttle speed, distance, and work-to-rest ratio are in line with offence or defensive fire and maneuver based tasks, undertaken by militaries worldwide (Myers et al., 2016; Silk & Billing, 2013; Treloar & Billing, 2011), and again are in line with the new British Army physical employment standards (British Army, 2020).

### *2.3. Participants*

Twelve recreationally active men, with no military experience volunteered to participate (age, 27 ± 6 years; stature, 1.83 ± 0.05 m; body mass 80.6 ± 8.0 kg; body fat percentage, 13.3 ± 2.8%; $\dot{V}O_{2max}$, 52.7 ± 5.5 $mL \cdot kg^{-1} \cdot min^{-1}$). Ethical approval was granted by the Institutional Research Ethics Committee and data collection was conducted in accordance with the Declaration of Helsinki. Participants provided full written consent, having received both a written and verbal brief.

For both sessions, participants were instructed to attend the laboratory in a hydrated state, having avoided caffeine and

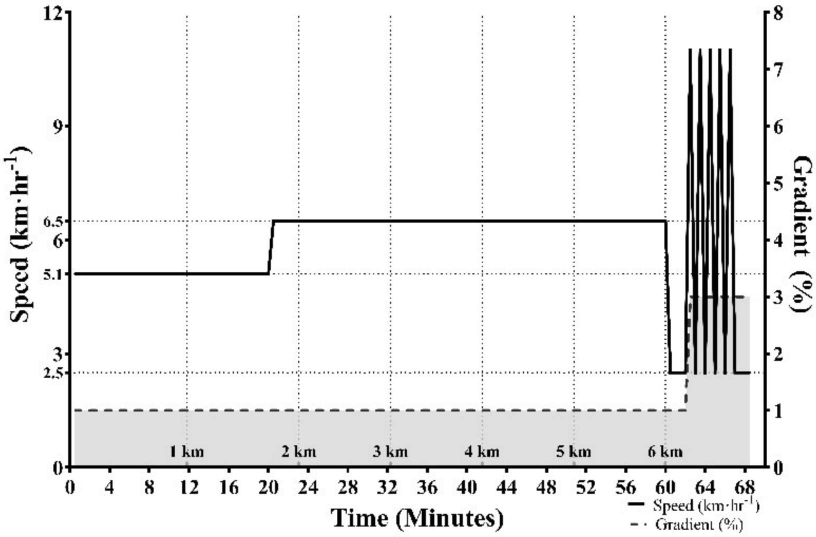


Figure 1: The fast load carriage protocol, detailing the changes in treadmill speed (solid black line) and gradient (dashed grey line and light grey fill). *Note:* Number of shuttles are for diagrammatic clarity, as per the manuscript there are a total of eight, the time duration of the shuttle period is however correct. Vertical dashed lines denote cumulative distance covered.

strenuous exercise for a minimum of three hours and 24 hours preceding respectively. In addition, participants were instructed to maintain a habitual diet in the lead up to, and between sessions, along with abstaining from nutritional supplements for the entirety of the data collection period, and two weeks preceding. For both sessions, participants wore a sports t-shirt, shorts, and training shoes.

## *2.4. Familiarization Session*

Upon arrival at the laboratory, participants provided a urine sample to determine hydration status (urine specific gravity [ATAGO Uricon-Ne 2722, Fisher Scientific, UK]) (Sawka et al., 2007). Stature and body mass (Seca 837 digital scales & 213 portable stadiometer, Seca Ltd, UK) were then recorded to the nearest 0.01 m and 0.01 kg respectively, prior to body composition being assessed using the bioelectrical impedance method (Tanita BC-418MA, Tanita EU, Netherlands). Participants then rested for 10 minutes before undertaking two six-minute periods of unloaded walking on a motorized treadmill (HP Cosmos Saturn, HP Cosmos, Germany) at 5.1 and 6.5 km·h$^{-1}$ with gradient fixed at 1% (replicating speeds and gradient of the full FLCP, described subsequently). In the final two minutes of each six-minute period $\dot{V}O_2$ was assessed using the Douglas bag technique; allowing the calculation of load carriage economy utilizing the external load index (described subsequently).

Upon completion of the unloaded walking periods, participants were familiarized with the three performance assessments (SMBT, wCMJ, MIVC). These were selected due to either their known correlations to military performance (Pihlainen et al., 2018; Spiering et al., 2019) or demonstrated sensitivity to load carriage tasks (Blacker et al., 2010; Blacker, Fallowfield, Bilzon, et al., 2013; Fallowfield et al., 2012; Knapik et al., 1991). For all performance assessments, three maximal attempts were conducted at each assessment interval, with peak performance reported.

*Seated Medicine Ball Throw.* Performance was assessed by measuring the maximum distance (to the nearest 0.01 m) an individual could throw a 4 kg medicine ball, using a chest pass technique. Participants conducted the SMBT whilst in a seated position, on the floor, with legs extended out in front of them and back upright against a wall (Cronin & Owen, 2004).

*Weighted Counter Movement Jump.* Force data were collected using two force plates with a sampling rate of 1000 Hz, calibrated prior to use, in accordance with the manufacturer's guidelines (Pasport Force Platform, PASCO, USA). During the wCMJ, participants wore military webbing and a weighted vest (20 kg). To negate the influence of the upper body, participants were instructed to place their arms across their chest and maintain this position throughout the jump (Lake & McMahon, 2018). Prior to jumping, a three-second quiet standing period was enforced, before the command "jump", where participants were instructed to jump as high and as fast as possible (Lake & McMahon, 2018).

*Quadricep Maximal Isometric Voluntary Contraction.* Force data were collected using an adjustable custom-built chair (University of Chichester, UK) and an s-beam load cell (250kg Tedea-Huntleigh, RS Components, UK). Data were recorded at 1000 Hz, using a PowerLab data acquisition device (AD Instruments, UK), and a computer running Chart 4 software (V4.1.2, AD Instruments, UK). Using the adjustable backrest, participants were positioned so that hip and knee angles were at 90$^{o}$ of flexion, whilst their right leg was attached to the base of the chair via the load cell and ankle cuff (Blacker et al., 2010). Chest and waist Velcro straps were used to restrict participant's upper body movement. Before the maximal contraction, participants were instructed to 'take up the slack' and remain still (three seconds), before the command 'go' at which time participants were instructed to contract as hard and fast as possible.

*Maximal Aerobic Capacity Assessment.* Following familiarization to the physical performance assessment, participants completed a $\dot{V}O_{2max}$ assessment (Part 1) and subsequent verification (Part 2) (Draper et al., 2006; Midgley et al., 2009). For Part 1 participants commenced running at 9 km·h$^{-1}$, with a gradient increase of 1 %·min$^{-1}$ until minute five, thereafter speed only was increased by 0.4 km·h$^{-1}$ every 20 s (1.2 km·h$^{-1}$·min$^{-1}$), until they reached volitional exhaustion. Participants were given verbal encouragement throughout. On completion, they rested for five minutes, before commencing Part 2. Here, participants initially ran for three minutes at 9 km·h$^{-1}$, 5% gradient, after which the speed increased to 1 km·h$^{-1}$ above their peak treadmill speed from Part 1. Again, participants were instructed to run to volitional exhaustion.

Heart rate was recorded continuously throughout the assessment using short-range telemetry (RS800, Polar Electro, Finland), with HR averaged across 5 s epochs. Expired gas samples were collected via a mouthpiece, Salford type valve, and low resistance tubing into 150 L Douglas bags (Cranlea Human Performance Limited, UK). Collections of ~60 seconds were taken with a minimum final sample of 75 L. Gas fractions were quantified using an offline gas analyzer (Servomex 5200, Servomex, UK), volumes using a dry gas meter (Harvard Apparatus, USA), and temperature measured using a digital thermometer (Fisher Scientific, UK). The gas analyzer was calibrated using a two-point calibration, following the manufacturer's instructions.

After the participant was sufficiently rested, they were familiarized with an abridged version of the FLCP comprising two, eight-minute bouts of walking at 5.1 and 6.5 km·h$^{-1}$ (1% gradient), followed by three, nine-second shuttles at 11 km·h$^{-1}$ (shuttles were separated by 11 seconds at 2.5 km·h$^{-1}$). Throughout this protocol, participants wore a military-specific load mass ensemble (25.0 ± 0.3 kg) consisting of a belt webbing system (10 kg), a weighted vest mimicking body armor (10 kg), and a replica assault rifle with sling (5 kg). Participants were instructed to carry the replica rifle in the 'ready position' with the weapon slung across their chest and supported by both hands.

### *2.5. Experimental Session*

Participants arrived at the laboratory, between 07:30-08:00, in a euhydrated and fed state. A standardized breakfast was provided (carbohydrate - 34 g; fat - 5.8 g; protein - 9.6, 0.95 MJ) 1.5 hours before the start of the trial with participants having fasted for the preceding 11 hours. Hydration status was assessed in the manner previously described.

Before commencing the baseline performance assessments, participants completed a standardized cycle ergometer (Wattbike Pro, Wattbike, UK) warm-up comprising of five minutes at ~100 W at a rating of perceived exertion (RPE) (Borg, 1970) ~10 (Lake et al., 2014). This warm-up was then repeated prior to all post-performance assessments, apart from immediately post-FLCP. Participants completed the three performance assessments to best effort, to obtain baseline performance data. Subsequently, nude, and clothed (base layer minus shoes) body masses were collected. Participants then inserted a rectal thermistor (Grant Instruments, UK), for the measurement of core body temperature, fitted their HR monitor and donned the load ensemble. Participants then commenced the FLCP (Figure 1).

During the FLCP, participants RPE, load discomfort (Comfort Affective Labelled Magnitude, CALM) (Cardello et al., 2003), thermal comfort (Bedford, 1936), and thermal sensation (ASHRAE Standard, 1992) were collected at five-minute intervals (Table 1). A 90 second expired gas collection was taken at the end of the first 5 minutes, and then every 10 minutes subsequently, to assess $\dot{V}O_2$. Environmental conditions (QT-34 WBGT Monitor, 3M, USA), HR, and core temperature were recorded continuously (Squirrel 1000 series, Eltek, UK). To ensure euhydration, 150 mL of water was provided to participants every 15 minutes (Sawka et al., 2007). All measures taken throughout the protocol are detailed in Table 1. After completion of the treadmill protocol, clothed, and nude body mass were measured to determine sweat loss, euhydration was deemed to have been maintained if <1% reduction in nude body mass had occurred (Sawka et al., 2007). Additionally, a post-exercise urine sample was collected and assessed for urine specific gravity. Following completion of load carriage protocol, removal of the rectal thermistor, and assessment of body mass (seven minutes' post), participants then completed the three physical performance assessments (SMBT, wCMJ, MIVC). Participants then rested in a seated position until they repeated the performance assessments at 30-, 60-, and 120-minutes' post.

### *2.6. Data Analysis*

*Physiological Variables* Measured $\dot{V}O_2$, HR, environmental data, and perceptual scales were time aligned; with HR data averaged over the final minute of each five-minute block. The highest $\dot{V}O_2$ and HR values obtained during both assessments were taken as $\dot{V}O_{2max}$ and HR maximum ($HR_{max}$) respectively. For secondary analysis purposes, $\dot{V}O_2$ and HR data were expressed relative to $\dot{V}O_{2max}$, $HR_{max}$, and HR reserve (HRR; calculated using $HR_{max}$ and lowest resting value from the familiarization session). Furthermore, using unloaded $\dot{V}O_2$ (familiarization session) and loaded $\dot{V}O_2$ (experimental session), External Load Index was calculated to describe load carriage economy (Lloyd et al., 2010). It has been suggested that this approach has a distinct advantage over other economy metrics (such as %$\dot{V}O_{2max}$), as it factors in individual walking gait (Lloyd et al., 2010).

*Performance Assessments* For the wCMJ, the performance variable of jump height was calculated using the flight time method described by Moir (2008). Take-off and landing were the first instances where resultant vertical force fell below and increased above 10 N, respectively. Flight time was the time between these instances. In addition, Reactive Strength Index Modified ($RSI_{Mod}$) was calculated for each jump (McMahon et al., 2018). The onset of the wCMJ was identified as the instance where resultant force fell below the threshold of body mass minus five standard deviations of the 'quiet standing' period. These variables were identified using visual inspection in combination with Dplot Jr software (version, 2.3.5.7; HydeSoft Computing, USA).

For the MIVC, contractions lasted approximately five seconds and were separated by 45 seconds (Blacker et al., 2009). The onset of the contraction was identified as the instance where force exceeded mean 'slack' force plus three times standard deviations

Table 1: Overview of experimental measures and their timings during the fast load carriage protocol.

| | Time (minutes) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65* |
| Speed ($km \cdot h^{-1}$) | 0 | 5.1 | 5.1 | 5.1 | 5.1 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | FM |
| Gradient (%) | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 |
| Perceptual Scales | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| $\dot{V}O_2$ | | ✓ | | ✓ | | ✓ | | ✓ | | ✓ | | ✓ | | |
| HR | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Environmental | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Water Provision | | | | ✓ | | | ✓ | | | ✓ | | | ✓ | |

*Note:* Speeds – see methodology for detailed description of the treadmill speed in this section of the protocol. *Note this block is not 5 minutes in duration – see methodology for detailed description of duration of this section of the protocol.

of this period. The variables of peak force, peak 250 ms, and 500 ms force epochs were calculated as these have been identified as reliable performance outcomes (Blacker, Fallowfield, & Willems, 2013).

*2.7. Statistical Approach*

Data are presented as mean ± standard deviation unless otherwise stated. Statistical analysis was conducted using JASP (version 0.11.1, University Amsterdam, Netherlands). The *P*-values were converted to base-2 log-transformed S-values (S) (Shannon, 1948) to aid interpretation and clarity of statistical estimation (Cole et al., 2021). Data were assessed for normality, using skewness and kurtosis ratios, and sphericity; with the Greenhouse-Geisser correction applied if assumptions of sphericity were violated. For normally distributed data a one-way repeated measures Analysis of Variance (ANOVA) was conducted to identify whether a main effect of time was present for both the physiological measures across the FLCP task and for the performance measures. Effect sizes are presented as Omega squared ($\omega^2$) (Levine & Hullett, 2002), where 0.01, 0.06, 0.14 are classed as small, medium and large effect sizes, respectively (Field, 2013). Where the combination of F-statistics, *p*-values / S-values, and effect sizes, indicate a likely incompatibility with the null model, *post-hoc* pairwise comparisons were made with a Holm-Bonferroni adjustment (denoted by subscript H). Mean differences and 95% compatibility (confidence) intervals, with Bonferroni adjustment, were calculated for pairwise comparisons. In addition, effect sizes were calculated as Cohen's standardized means and converted to Hedges $g_z$ (Lakens, 2013), to account for the overestimation of effect sizes from small sample sizes. From these *post-hoc* effect sizes, common language effect sizes (CLES) were also calculated (Lakens, 2013). In some instances, where many differences are observed ranges of *p*-values / S-values, and effect sizes are presented. For non-parametric data, a Friedman's test was employed with effect sizes presented using Kendall's W. Where the combination of $\chi^2$-statistics, *p*-values / S-values, and effect sizes, indicate a likely incompatibility with the null model, *post hoc* pairwise comparisons were made using Conover's test.

## 3. Results

The environmental conditions in the laboratory were 12.3 ± 1.5 ºC Wet Bulb Globe Temperature indoors, 64.9 ± 9.9 % relative humidity with a mean change across the trials of 0.9 ± 0. 5 ºC and 6.3 ± 4.3% respectively. Pre- and post-FLCP urine specific gravity values were 1.010 ± 0.006 and 1.007 ± 0.003 respectively.

*3.1. Physiological and Subjective Responses*

Relative $\dot{V}O_2$ increased throughout the FLCP ($F_{(1.207, 12.07)}$ = 189.423, $p < 0.001$, S > 9.97, $\omega^2 = 0.743$) (Figure 2a). *Post-hoc* comparisons did not provide evidence that $\dot{V}O_2$ values differed between both measurement points at 5.1 $km \cdot h^{-1}$ ($t_{(11)} = -0.696$, $p_H = 0.503$, $S_H = 0.99$, $g_z = -0.187$, 95% $CI_H$ [0.396, -0.572]). However, compared with the first measurement point, at 6.5 $km \cdot h^{-1}$ (25 minutes) mean $\dot{V}O_2$ increased by 2.5%, 5.9%, and 7.4% at 35, 45 and 55 minutes respectively (35 minutes: $t_{(11)} = -2.473$, $p_H = 0.105$, $S_H = 3.25$, $g_z = -0.654$, 95% $CI_H$ [0.423, -1.905]; 45 minutes: $t_{(11)} = 3.608$, $p_H = 0.024$, $S_H = 5.38$, $g_z = -0.969$, 95% $CI_H$ [0.078, -2.655]; 55 minutes: $t_{(11)} = 4.177$, $p_H = 0.013$, $S_H = 6.27$, $g_z = -1.122$, 95% $CI_H$ [-0.139, -3.174]). As such, controlling for individual differences, the likelihood that an individual had a greater relative $\dot{V}O_2$ at 35, 45, and 55 minutes, compared with 25 minutes was 76%, 85%, and 89% respectively, as indicated by the CLES. External Load Index also increased across measurement points ($F_{(1.186, 11.859)} = 24.581$, $p_H < 0.001$, $S_H > 9.97$, $\omega^2 = 0.435$). Compared with External Load Index values at 25 minutes there was an increase of 3.6%, 5.9%, and 7.4% at measurement points 35, 45 and 55 minutes respectively (35 minutes: $t_{(11)} = -2.322$, $p_H = 0.128$, $S_H = 2.97$, $g_z = -0.624$, 95% $CI_H$ [0.02, -0.081]; 45 minutes $t_{(11)} = -3.521$, $p_H = 0.028$, $S_H = 5.16$, $g_z = -1.100$, 95% $CI_H$ [0.005, -1.111]; 55 minutes: $t_{(11)} = -4.097$, $p_H = 0.015$, $S_H = 6.06$, $g_z = -1.122$, 95% $CI_H$ [-0.005, -0.133]). Thus, the likelihood that an individual had a greater External Load Index at 35, 45, and 55, compared with 25 minutes, when controlling for individual differences was 75%, 85%, and 88% respectively, as indicated by the CLES. Conversely, External Load Index values at 5.1 $km \cdot h^{-1}$ did not appear to differ according to *post-hoc* comparisons ($t_{(11)} = -0.611$, $p_H = 0.555$, $S_H = 0.85$, $g_z = -0.164$, 95% $CI_H$ [0.023, -0.032]).

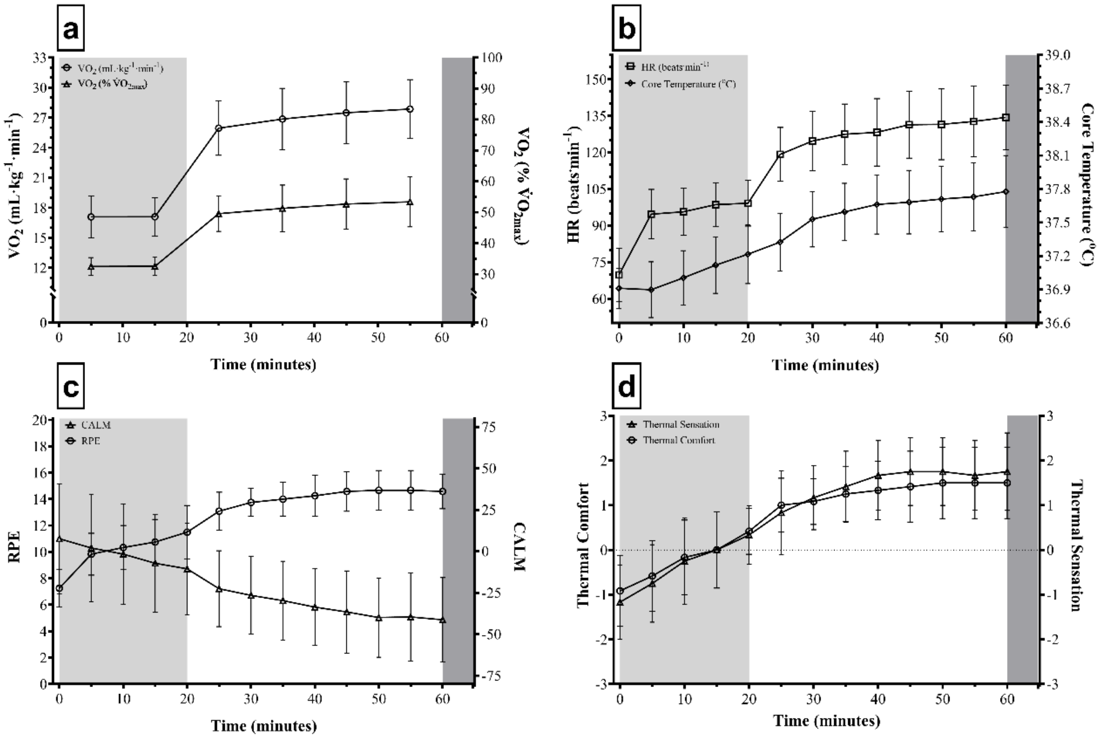


Figure 2: The relative $\dot{V}O_2$ (a), heart rate and core temperature (b), comfort affective labelled magnitude (CALM) and ratings of perceived exertion (RPE) (c), and thermal sensation and thermal comfort (d) during the fast load carriage protocol. *Note:* Data are presented as mean ± SD. The light grey, white, and dark grey areas denote the 5.1 km·h$^{-1}$, 6.5 km·h$^{-1}$, and simulated fire and maneuver portions of the protocol respectively. Note core temperature values were only obtained for 10 participants.

A large effect for measurement point was also evident in HR responses ($F_{(1.599, 17.594)} = 116.344$, $p < 0.001$, S > 9.97, $\omega^2 = 0.616$) (Figure 2b). At 5.1 km·h$^{-1}$, measurements at 5 and 10 minutes, did not appear to be different according to *post-hoc* comparisons ($t_{(11)} = 1.168$, $p_H = 1.000$, $S_H = 0.00$, $g_z = 0.314$, 95% $CI_H$ [4.808, -2.863]); however, mean HR increased from minutes 5 to 15 ($t_{(11)} = 3.963$, $p_H = 0.033$, $S_H = 4.92$, $g_z = 1.064$, 95% $CI_H$ [8.499, -0.638]). When compared with the first measurement point at 6.5 km·h$^{-1}$ (25 minutes), there was an increase in HR across all subsequent measurement points ($p_H$ = 0.033 - <0.001, $S_H$ = 4.92 - >9.97, $g_z$ = -1.056 - -1.941). During the shuttles phase of the FLCP, peak HR corresponded to 81.9 ± 5.9% and 73.5 ± 8.7% $HR_{max}$ and HRR, respectively.

Core body temperature also displayed a large effect for measurement point ($F_{(12, 108)} = 50.153$, $p < 0.001$, S > 9.97, $\omega^2 = 0.584$); with a mean increase of 0.92 ± 0.22 ºC in response to the FLCP (Figure 2b; *n*=10 participants only). *Post-hoc* comparisons did not provide an indication that core body temperature differed from baseline to measurements at 5 and 10 minutes but did at all following measurement points ($p_H$ = 0.031 - <0.001, $S_H$ = 5.01 - >9.97, $g_z$ = -1.383 - -3.748). Pre- to post-FLCP nude body mass remained similar, with a change in body mass of 0.0 ± 0.4% (n=11; one participant's data was removed due to a transcriptional error leading to an implausible post-FLCP body mass).

Perceived exertion increased across the protocol ($F_{(12, 132)} = 85.153$, $p < 0.001$, S > 9.97, $\omega^2 = 0.693$) with a mean change of 7 ± 1 points (Figure 2c). This change reflected a transition from a median response of 'extremely light' to a median response of 'hard' at 60 minutes. Conversely, CALM, had a mean reduction of 49 ± 32 points ($\chi^2_{(12)} = 132.427$, $p < 0.001$, S >9.97, Kendall's W = 0.637); indicating participants were finding the load carried during the protocol progressively more uncomfortable (Figure 2c). Median ratings decline from around 'neither comfortable nor uncomfortable' pre-FLCP to around 'moderately uncomfortable'. Ratings of thermal comfort ($F_{(12, 132)} = 31.771$, $p < 0.001$, S > 9.97, $\omega^2 = 0.556$) and thermal sensation ($F_{(12, 132)} = 35.195$, $p < 0.001$, S > 9.97, $\omega^2 = 0.593$) both increased across measurement points, with a mean change of 2 ± 1, and 3 ± 1 for thermal comfort and sensation respectively. Thus, indicating participants perceived they were getting hotter and becoming less comfortable throughout the FLCP, transitioning from 'comfortably cool' and 'slightly cool' to 'too warm' and 'warm'.

### *3.2. Performance and Neuromuscular Responses*

Table 2 lists physical performance assessments outcomes, whilst Figure 3 displays the percentage change in performance compared with pre-FLCP values. Statistical analysis did not provide evidence that SMBT distance differed across measurement points ($F_{(4, 44)} = 1.223$, $p = 0.315$, S = 1.67 $\omega^2 = 0.001$). Conversely, for wCMJ, both jump height and $RSI_{Mod}$ displayed a moderate main

Table 2: Change in performance for each performance metric across assessment time points post-fast load carriage protocol (Mean ± SD).

| Performance Measure | | Pre-FLCP Performance | Effect Size for Assessment Time Point ($\omega^2$) | Post-Load Carriage Protocol Mean Difference [95% Compatibility Intervals] | | | |
|---|---|---|---|---|---|---|---|
| | | | | Post | 30 min post | 60 min post | 120 min post |
| SMBT | Distance (m) | 4.48 ± 0.40 | 0.001 | -0.03<br>[-0.10, 0.05] | 0.00<br>[-0.08, 0.07] | -0.03<br>[-0.11, 0.05] | -0.06<br>[-0.15, 0.03] |
| wCMJ | Jump Height (m) | 0.26 ± 0.06 | 0.013 | -0.01<br>[0.03, 0.02] | -0.01<br>[-0.04, 0.01] | -0.02<br>[-0.04, 0.01] | -0.02<br>[-0.04, -0.01]* |
| | $RSI_{Mod}$ (ratio) | 0.27 ± 0.08 | 0.024 | -0.02<br>[-0.06, 0.02] | -0.03<br>[-0.05, 0.00] | -0.03<br>[-0.07, 0.00] | -0.04<br>[-0.06, -0.01]* |
| MIVC | Peak Force (N) | 816.0 ± 108.6 | 0.092 | -72.1<br>[-150.4, 6.2] | -85.6<br>[-198.8, 27.7] | -105.7<br>[-203.5, -7.8]* | -99.0<br>[-229.2, 31.3] |
| | 250 s Force Epoch (N) | 808.4 ± 108.4 | 0.097 | -78.5<br>[-165.3, 8.4] | -91.6<br>[-217.3, 34.1] | -109.3<br>[-209.2, -9.5]* | -102.4<br>[-234.7, 30.0] |
| | 500 s Force Epoch (N) | 570 ± 149.6 | 0.071 | -67.0<br>[-163.2, 29.2] | -86.7<br>[-201.9, 28.4] | -90.9<br>[-184.1, 2.3] | -86.2<br>[-207.7, 35.3] |

*Note:* SMBT, seated medicine ball throw; wCMJ, weighted counter movement jump; MIVC, maximal isometric voluntary contraction of the quadriceps; $RSI_{Mod}$, reactive strength index modified. * $p < 0.05$ compared to pre-fast load carriage protocol performance. Note, where post hoc comparisons have occurred (wCMJ & MIVC) compatibility intervals are Bonferroni adjusted.

effect for measurement point (jump height: $F_{(4,44)} = 3.441$, $p = 0.016$, S = 5.97, $\omega^2 = 0.013$, $RSI_{Mod}$: $F_{(4,44)} = 5.145$, $p = 0.002$, S = 8.97, $\omega^2 = 0.024$). *Post-hoc* comparisons identified a mean reduction in jump height of 13.6 ± 7.2% at 120 minutes post-FLCP ($t_{(11)} = -4.386$, $p_H = 0.011$, $S_H = 6.51$, $g_z = -1.178$, 95% $CI_H$ [-0.005, -0.041]). Thus, as indicated by the CLES, the likelihood that an individual had a reduced jump height at 120 minutes post-FLCP compared with pre-FLCP was 90%, when controlling for individual differences. Compared with pre-FLCP values, a reduction in $RSI_{Mod}$ were observed for 30, 60, and 120 minutes post-FLCP (30 minutes: $t_{(11)} = -3.44$, $p_H = 0.05$, $S_H = 4.32$, $g_z = -0.924$, 95% $CI_H$ [0.000, -0.053]; 60 minutes: $t_{(11)} = -3.154$, $p_H = 0.073$, $S_H = 3.78$, $g_z = -0.847$, 95% $CI_H$ [0.003, -0.066]; 120 minutes: $t_{(11)} = -5.154$, $p_H = 0.003$, $S_H = 6.51$, $g_z = -1.178$, 95% $CI_H$ [-0.005, -0.041]). Correspondingly, CLES indicated that the likelihood that an individual had a reduction in $RSI_{Mod}$ at 30, 60, and 120-minutes post-FLCP was 84%, 82%, and 93% respectively, when controlling for individual differences.

For all MIVC variables a moderate main effect of measurement point was evident (peak force: $F_{(1.480,16.281)} = 7.192$, $p = 0.009$, S = 6.80, $\omega^2 = 0.092$; peak 250 ms epoch: $F_{(1.510,16.607)} = 7.061$, $p = 0.010$, S = 6.64, $\omega^2 = 0.097$; and peak 500 ms epoch: $F_{(1.860,20.461)} = 5.539$, $p = 0.013$, S = 6.27, $\omega^2 = 0.071$). Compared with pre-FLCP values, peak force reduced by 8.4 ± 8.2% immediately post-FLCP ($t_{(11)} = -3.219$, $p_H = 0.074$, $S_H = 3.76$, $g_z = -0.864$, 95% $CI_H$ [6.208, -150.36], and by 12.6 ± 10.9% 60 minutes' post FLCP ($t_{(11)} = -3.776$, $p_H = 0.031$, $S_H = 5.01$, $g_z = -1.014$, 95% $CI_H$ [-7.83, -203.49]). Similarly, 250 ms peak force epochs reduced at these two measurement points by 9.1 ± 9.1% and 13.2 ± 11.2% respectively (post: $t_{(11)} = -3.16$, $p_H = 0.082$, $S_H = 3.61$, $g_z = -0.849$, 95% $CI_H$ [-8.361, -165.305]; 60 minutes: $t_{(11)} = -3.828$, $p_H = 0.028$, $S_H = 5.16$, $g_z = -1.024$, 95% $CI_H$ [-9.464, -209.209]). 500 ms peak force epochs also reduced at 60 minutes post-FLCP by 14.0 ± 13.9% ($t_{(11)} = -3.412$, $p_H = 0.058$, $S_H = 4.11$, $g_z = -0.916$, 95% $CI_H$ [2.265, -184.061]). According to all other *post-hoc* comparisons for the MIVC variables post-FLCP performance did not differ compared with pre-FLCP values.

## 4. Discussion

This is the first study to collectively measure the metabolic cardiovascular, thermoregulatory, neuromuscular, and perceptual responses to a military-specific and occupationally relevant treadmill-based load carriage protocol. The $\dot{V}O_2$ remained similar during the 5.1 km·h$^{-1}$ portion of the protocol and an upwards drift was apparent during the 6.5 km·h$^{-1}$ portion. A similar observation was apparent for HR; collectively indicating an increased metabolic cost as the protocol ensued. With respect to the FLCP's effect on subsequent physical performance, it appeared not to affect the upper body, as indicated by no change in SMBT performance but did affect the lower body, demonstrated by reduced wCMJ peak height, $RSI_{Mod}$, MIVC peak force, peak 250 ms force epoch, and peak 500 ms force epoch at measurement points up to two hours' post.

The slowest portion of the FLCP (5.1 km·h$^{-1}$) resulted in no discernible difference between $\dot{V}O_2$ values from 5 to 15 minutes (~32% $\dot{V}O_{2max}$) indicative of individuals achieving a steady-state. Conversely, when the treadmill speed was increased to 6.5 km·h$^{-1}$, there was a notable increase in $\dot{V}O_2$ at the final two assessment points (45 and 55 minutes; 50-53%$\dot{V}O_{2max}$) compared to the first assessment point (25 minutes); indicative of $\dot{V}O_2$ drift. Previously

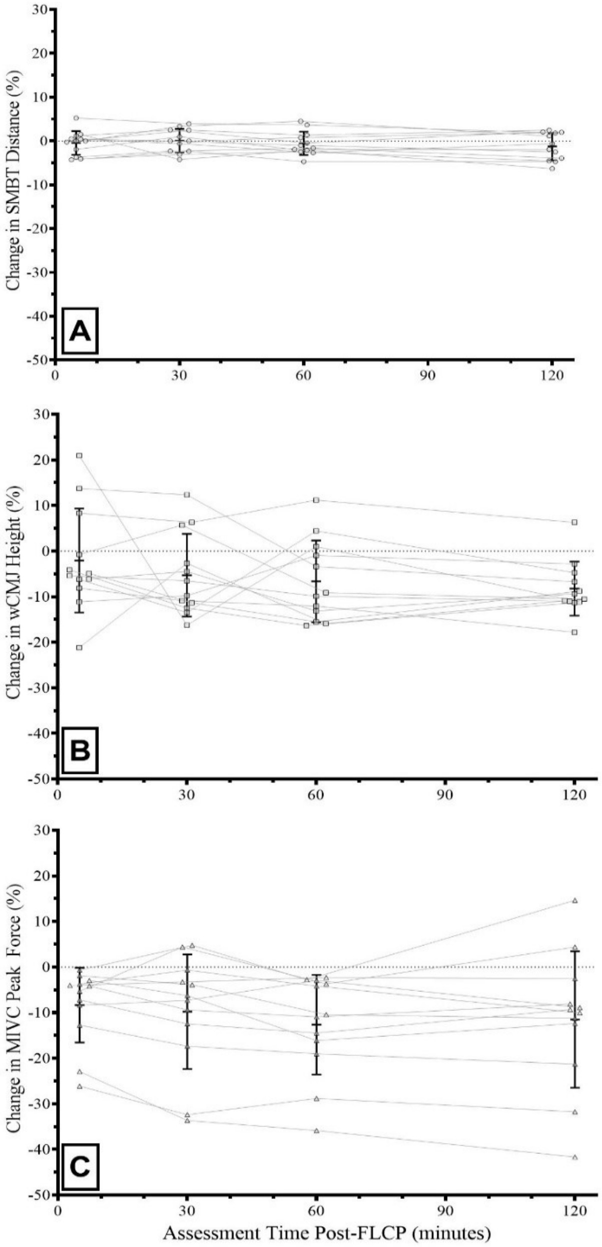


Figure 3: Percentage change in seated medicine ball throw (SMBT) distance (a), weighted countermovement jump (wCMJ) height (b), and maximal isometric voluntary contraction of the quadriceps (MIVC) force (c) post-fast load carriage protocol. *Note:* Data are presented as mean ± SD.

a $\dot{V}O_2$ drift has been demonstrated in prolonged load carriage exercise, at intensities generally above 50% $\dot{V}O_{2max}$ (Blacker et al., 2009; Epstein et al., 1988; Patton et al., 1991).

The observed 7.4% increase in $\dot{V}O_2$ over the faster portion of the FLCP, is broadly in line with the magnitudes of change observed in other investigations. For example, an 8.8% increase was observed for a 2-hour march at 4.5 km·h$^{-1}$, 5% gradient, carrying 40 kg (Epstein et al., 1988). With $\dot{V}O_2$ drift evident, participant's movement efficiency worsened throughout the FLCP; evidenced by the rising External Load Index values. Specifically, the rising External Load Index scores suggest a reduction in efficiency compared with unloaded walking at the same speed, when corrected for the additional load mass carried. External Load Index values are, broadly comparable to those previously published in non-military personnel (6 km·h$^{-1}$ and 20 kg) (Hudson et al., 2017). However, the progressive inefficiency, resulting from a $\dot{V}O_2$ drift, has not previously been demonstrated using External Load Index.

Similar to $\dot{V}O_2$, a HR drift was evident across the 6.5 km·h$^{-1}$ element of the protocol, with a ~15 beat mean change between minutes 25 and 60. This cardiovascular drift, the magnitude of change in HR, and average HR values are comparable to previously reported data during similar load carriage conditions, despite the difference in load mass distributions walking at a fixed pace (Blacker et al., 2009; Quesada et al., 2000). Moreover, mean changes in RPE across the time course of the current study are similar to those reported previously (+5 vs +4) (Blacker et al., 2009); when calculated in the same manner. However, the task duration in the current study was half that of Blacker and colleagues (2009). This difference could therefore be attributed to the way the load mass was distributed in the current study (belt webbing, weighted vest, and weapon vs. rucksack), and the perceived additional effort associated with the increased thermal discomfort of the weighted vest.

The thermal implications of the load carriage protocol in the present study resulted in an average core temperature increase of approximately 1ºC. This response is similar to that observed during a field-based load carriage study, where 60 soldiers undertook the load carriage element of the British Army's new physical employment standards (Waldock et al., 2021). Moreover, the thermal load of the current study resulted in thermal comfort and sensation increases of approximately 2.5 and 3 points respectively; indicating participants perceived they were getting hotter and becoming less comfortable across the time course of the FLCP. As well as participants perceiving they were getting hotter their ratings of comfort associated with the load also reduced with a mean change of -50 points; indicating participants were finding the load carried progressively more uncomfortable. Initial CALM values were similar to those reported previously for heavier load masses (44.45 kg) in combatants (Kobus et al., 2010); which is likely a result of the participant's familiarity with the load. A decline in comfort ratings has also been reported by Mullins et al. (2015), who reported progressive increases in shoulder/upper-back pain and discomfort scores over 2 hours of walking at 5.5 km·h$^{-1}$, carrying 22 kg. The current study demonstrated no discernible effect of the FLCP on upper body neuromuscular performance, as measured through the SMBT. Previously grenade throw distance has reduced following a load carriage task (Knapik et al., 1991), however, the authors suggested this decrement may be the result of brachial plexus nerve entrapment in the shoulder region. Plausibly, this difference between studies is a result of the differences in load (20 versus 46 kg), load distribution (hands, hips, torso, vs. back, hands, and head), and task duration (~65 minutes vs. 314 ± 70 minutes). Load carriage has also previously been shown to reduce shoulder peak torque at slow velocities immediately post a load carriage task (Blacker et al., 2010). Whilst a similar additional load mass was carried in this investigation, a duration two-fold greater, and a load purely supported by the shoulders is likely to contribute to the differences in findings. Moreover, with load carriage increasing trapezius activity (Holewijn, 1990), and subsequently reducing muscle function, it is likely that the overhead shoulder flexion and extension protocol employed by Blacker et al. (2010) to assess shoulder function would be attenuated to a greater extent than the SMBT by a reduction in trapezius function. The current results, therefore, suggest operationally relevant upper body 'push' capabilities, for tasks such climbing through a window or overhead lifts are unlikely to be impacted. Moreover, with upper body strength, which contributes to power, being demonstrated to correlate well with load carriage performance (e.g., Orr et al., 2021; Robinson et al., 2018), it is unlikely that subsequent load carriage tasks are going to be influenced by changes in upper body performance.

In contrast, lower body neuromuscular performance was likely affected by the FLCP. A decrease in wCMJ performance was apparent at 120 minutes' post-FLCP, with an approximately 9% reduction in jump height evident. This modest decrement in performance corresponds to a mean jump height reduction of 2.2 cm. There was a large degree of variation in performance change from the pre-performance scores, particularly across the first two assessment points as evidenced by a standard deviation of 11.4 and 9.6% respectively. This variability in performance immediately post-task perhaps, partially explains the opposing outcomes of Knapik et al. (1991) and Fallowfield et al. (2012); where following their respective load carriage tasks no change (0.46 ± 0.07 m vs 0.45 ± 0.07 m) and a reduction (0.37 ± 0.05 m vs. 0.34 ± 0.06 m) in jump height was observed. Differences between studies could be attributed to the study populations employed and their load carriage experience (e.g., serving soldiers (Knapik et al., 1991); Royal Marines recruits (Fallowfield et al., 2012); vs. a civilian population, in the current study. A progressive decline in $RSI_{Mod}$ values was also observed. The $RSI_{Mod}$ has been suggested to be indicative of an individual's slow stretch-shortening capabilities (Suchomel et al., 2015), with data indicating that individuals are prolonging their impulse generation period; a change considered to be less desirable for performance (McMahon et al., 2018). However, to date, the $RSI_{Mod}$ literature is limited to sporting contexts, with no data linking decrements to occupational or military tasks. With a lower $RSI_{Mod}$ being suggestive of a reduced force and power capacity, it could be purported that explosive and/or anaerobic-based military tasks such as a fire and maneuver or casualty drag task could be negatively impacted post-load carriage task. Further research within this area is therefore warranted to ascertain whether this is a meaningful metric for occupational and military testing.

The MIVC values in the present study are similar to those previously reported (Blacker, Fallowfield, Bilzon, et al., 2013), although differences in magnitudes of change do exist. As with the SMBT performance, differences could be principally attributed to the longer load carriage duration (~65 min vs 120 min for Blacker et al. 2013a). However, the inclusion of the repeated shuttles, in the current study, may somewhat attenuate these differences observed, due to the rapid accelerations and decelerations of the fire and maneuver aspect of the FLCP. Previously a similar magnitude (~5%) of knee flexor strength reduction has been observed following a 12.1 km march (4.8 $km \cdot h^{-1}$) carrying between 13.2-18.6 kg (Clarke et al., 1955), although as noted by Blacker et al. (2010) caution should be used when interpreting these data due to the rudimentary data collection techniques. Collectively, these investigations support those data presented in the current study. In addition, the current study demonstrates this neuromuscular impairment and performance reduction may last upwards of two hours. This is despite carrying a relatively 'light' load compared with load masses commonly carried during operations (Dean, 2003; Knapik et al., 2012). Previously, neuromuscular function has been investigated over successive days post load carriage task (Blacker et al., 2010), but not within the hours proceeding the task. The study by Blacker et al. (2010) demonstrated that peak torque values remained suppressed for up to 48 hours post a load carriage task. From an applied perspective, a decrement in muscle function may increase musculoskeletal injury risk whilst also degrading military physical and skilled task performance (Blacker et al., 2010); an outcome likely compounded by the frequent operational requirement for multiple military tasks to be completed successively.

A key focus of the present study was to maximize the external validity of the load carriage task, the external load mass, and how it was distributed. The protocol was designed to replicate the demands of a fast approach march or an advance to contact, and the subsequent fire and maneuver task, a highly probable pairing during military operations. As such, all parameters of the load carriage protocol were derived from the literature (Myers et al., 2016; Silk & Billing, 2013; Treloar & Billing, 2011). Critically, due to the protocol being undertaken on a motorized treadmill, participants were unable to safely undergo the prone to standing and standing to prone transitions typical in a fire and maneuver task. To mitigate this limitation, shuttle speed was increased along with shuttle duration. These alterations resulted in the attainment of work rates corresponding to 81.9 ± 5.9% and 73.5 ± 8.7% of $HR_{max}$ and HRR respectively, which match well to previous data [~80% $HR_{max}$ (Myers et al., 2016); ~80% HRR, (Silk & Billing, 2013)]. The external validity of the FLCP's design therefore makes it suitable for future intervention studies which wish to use a laboratory-based treadmill protocol. An additional limitation of the present study was the use of non-military male participants. However, markers of both aerobic fitness ($\dot{V}O_{2max}$) and strength (wCMJ) match those previously reported for military populations (Pihlainen et al., 2018; Vine et al., 2020). However, differences pertaining to load carriage efficiency between trained and untrained populations may exist. As such, changes in performance measures may be different for populations more accustomed to load carriage. Moreover, differences in load carriage kinematics between sexes have also been reported, with females working at a higher relative intensity for a fixed load carried, and having a higher cadence and shorter stance time; although this may in fact be a repercussion of differences in body mass and stature (Vickery-Howe et al., 2020).To extend this applied focus, future investigations should look beyond discrete bouts of load carriage and characterize the physiological responses and military performance repercussions of repeated bouts. Despite the high relevance of sequential military taskings, only two studies have investigated this previously, with both having alternative primary focuses (Giles et al., 2019; Scales et al., 2021).

In conclusion, the present study has developed a treadmill-based FLCP that combines the individual aspects of an approach march and a fire and maneuver task. The demands of this protocol resulted in an increased metabolic and cardiovascular requirement when moving at a faster pace. These data also demonstrate that the completion of a single FLCP does not affect neuromuscular performance in the upper body power (SMBT) but appears to modestly decrease neuromuscular performance in the lower body (wCMJ and MIVC) up to two hours' post. Moreover, those $RSI_{Mod}$ data demonstrate that individuals may be prolonging their impulse generation period, which is suggested to be less favorable, although a greater understanding of these implications within the military context is required. Future investigations can use the FLCP protocol to investigate externally relevant scenarios, such as the interaction between physical and cognitive performance during load carriage, or the implications of multiple repeated load carriage bouts.

**Conflict of Interest**

The authors declare no conflict of interests.

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