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Physiological, Perceptual, and Biomechanical Responses to Load Carriage While Walking at Military-Relevant Speeds and Loads—Are There Differences between Males and Females?

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Abstract: This study aimed to investigate the physiological, perceptual, and biomechanical differences between male and female soldiers across several military-relevant load and walking speed combinations. Eleven female and twelve male soldiers completed twelve 12 min walking trials at varying speeds (3.5 km·h^{-1}, 5.5 km·h^{-1}, 6.5 km·h^{-1}) and with varying external loads (7.2 kg, 23.2 kg, 35.2 kg). Physiological (indirect calorimetry, heart rate), perceptual (perceived exertion), and biomechanical (spatiotemporal, kinematic, kinetic) outcomes were measured throughout each trial. Females had a lower aerobic capacity and lower body strength than males, which resulted in them working at a greater exercise intensity (%VO_{2peak} and heart rate) but with a lower oxygen pulse. Females demonstrated higher breathing frequency and perceived exertion with specific loads. At selected loads and speeds, frontal and sagittal pelvis, hip, and knee motions and forces were greater for females. Females consistently displayed greater relative stride length and step width. In conclusion, this study demonstrates the importance of tailored interventions, periodisation, and nutritional strategies for female military personnel, given their higher relative work rate and increased injury risk during load carriage tasks. Understanding these differences is crucial for preparing female soldiers for the physical demands of military service.

Keywords: gait; kinematics; spatiotemporal; force; military ergonomics

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1. Introduction

Load carriage is a compulsory requirement within physically demanding occupations such as the military and firefighting [1–3]. Within military settings, a standard load carriage ensemble distributes load via material positioned on the head (e.g., helmet, goggles), trunk (e.g., body armour, webbing, pack), hips (e.g., webbing, hip belt), hands (e.g., weapon, monitoring devices), and feet (boots). However, load requirements vary depending on military trade, role, and training or operational requirements. Load carriage can be described in echelons: Patrol Order is a requirement for all personnel that consist of a mass of between 15 and 30 kg, including all essential operating equipment, to be distributed in a vest-type carry system, and; Marching Order requires additional mission-specific loads to be placed in a pack and can exceed 60 kg [1]. In addition to these loads, soldiers may undertake load carriage across a range of speeds (2.5 to 6.5 km·h^{-1}) dependent on the specific task [4,5]. These load- and speed-related task constraints are determined by the specific training and mission requirements, irrespective of an individual's physical characteristics, physical fitness, or biological sex.

Many Western military forces require their workforce to meet a minimum physical employment standard (PES) [6]. For the Australian Army, a key component of their PES is a 5 km march carrying 23 kg at a speed of 5.5 km·h^{-1} [7]. Furthermore, long-standing gender exemptions for certain roles (e.g., direct combat roles) in many Western military organisations have now been removed [6]. In Australia, gender exemptions were removed in 2011 [8], likely contributing to the increased representation of females in the Australian Defence Force, which reached 20.1% in June 2022 [9]. However, despite these exemptions being removed, it is acknowledged that females are generally lighter in body mass, shorter in height, and possess a lower functional capacity than males [10]. Even when height-matched, physiological differences persist, with females having smaller lungs, airways, and hearts and lower muscle mass, resulting in lower strength and cardiorespiratory capacity [11–13]. Despite this, PES is applied universally to both males and females as they are based on objective occupation task demands [6]. Within military roles, females serving in the military have demonstrated higher injury rates than males [14–16], particularly in the pelvis and foot regions, likely due to exposure to load carriage tasks [16–19]. Such findings have previously been attributed to the reported between-sex anthropometric differences as well as the lower levels of aerobic fitness and muscular strength [16]. Therefore, acknowledging and addressing the physiological and biomechanical differences between males and females who are serving in the military, particularly during load carriage, is imperative for enhancing overall occupational performance and reducing injury occurrence.

Physiological differences between males and females during load carriage have been recently summarised in a systematic review by Hudson et al. [20]. Females commonly exhibit lower absolute ventilation ($\dot{V}_E$), oxygen consumption ($\dot{V}O_2$), and carbon dioxide production ($\dot{V}CO_2$) than males when carrying torso-borne loads [21–23]. Females also work at a greater relative intensity (percentage of maximal oxygen uptake [%$\dot{V}O_{2max}$]) when compared with males during load carriage, for both absolute loads as well as loads relative to body mass [21,22,24]. Previous studies examining sex differences have investigated the physiological responses to load carriage across a limited number of speed and load combinations, often with a lack of participant characterisation (body composition, strength, aerobic capacity) [20]. Understanding sex-specific physiological responses to load carriage is crucial for designing effective training programs and tailoring load management strategies that could be used to support occupational task performance and sustain the health of the workforce.

A recent systematic review reported that males and females display similar biomechanics during load carriage for spatiotemporal (five of seven studies) and lower limb kinematic (seven of ten studies) responses [20]. Where differences were reported, females were shown to have a shorter stride length and higher cadence for a given walking speed [22,25]. Additionally, females demonstrated greater trunk lean as well as differing pelvis and hip kinematics during load carriage compared to males [26–28]. To date, biomechanical assessments during load carriage have been predominantly assessed on loads relative to body mass and across a limited number of walking speeds [20]. Quantifying the biomechanics of load carriage across a range of speeds can reveal specific loading conditions that might be associated with an increased risk of injury. This information allows for the development of targeted injury prevention strategies and training programs that reduce the risk of overuse injuries or joint-related issues.

Previous research has tended to assess load carriage responses at set speeds or loads in isolation [20], with few incorporating a *range* of military-relevant load and walking speed combinations with the aim of comparing males and females. Such data may contribute to customising fatigue and injury risk management processes through improved training programming, ultimately promoting better outcomes for both males and females engaging in load carriage activities. Therefore, the primary aim of this study was to determine if the physiological, perceptual, and biomechanical responses to load carriage in females and males are dependent on the interaction between military-relevant loads and speeds. The secondary aim was to determine if there are differences between or within sexes across various military-relevant loads and speeds.

2. Materials and Methods

2.1. Participant Information

Twenty-three qualified soldiers (11 F, 12 M) from the Australian Defence Force School of Signals and the Combined Arms Training Centre were recruited to participate in this study. All participants had completed basic military training and reported no known neuromuscular injuries in the six months prior to data collection. All procedures were approved by the Departments of Defence and Veterans' Affairs Human Research Ethics Committee (DDVA HREC; Ethics #302-20), and reciprocal approval was granted by the La Trobe University Human Ethics Committee (Ethics #302-20 DDVA HREC). Written informed consent was obtained from the participants prior to commencement.

2.2. Protocol Overview

Pre-experimental testing was conducted across the first two (of four) data collection sessions to familiarise participants with the laboratory environment and equipment, as well as to collect demographic and anthropometric information. First, a dual-energy X-ray absorptiometry scan was conducted, with participants exposed to an effective dose of ~0.01 mSv (Hologic Inc., Marlborough, MA, USA) to determine whole-body fat mass and lean body mass. Secondly, participants were familiarised with the AMTI dual-belt (front and back) instrumented treadmill (AMTI, Watertown, MA, USA) for a minimum of six minutes of walking at different speeds (ranging from 4 to 6 km·h^{-1}) with different load conditions (7.2 kg, 23.2 kg, and 35.2 kg) [29]. Following this, participants underwent a dynamic warmup and then completed three maximal isometric mid-thigh pull (IMTP) efforts, as described by Guppy [30]. Lastly, a graded exercise test to determine peak oxygen consumption ($\dot{V}O_{2peak}$) was performed using a loaded vest (23 kg), as previously described by Hingley [31]. The test included five minutes of seated and standing rest, which was followed by five minutes of walking at 5 km·h^{-1} on a 1% inclined gradient. The test then continued at 9 km·h^{-1}, with speed increased by 1 km·h^{-1} each minute until a rating of perceived exertion (RPE) of ≥16/20 was reached; thereafter, the gradient was also increased by 1% each minute until volitional exhaustion.

The experimental protocol was then conducted across the third and fourth data collection sessions, which took place seven days after the pre-experimental testing and were spaced seven days apart. The full protocol consisted of twelve 12 min walking trials on the instrumented dual-belt treadmill (AMTI, Watertown, MA, USA), with 12 min of passive rest in between each trial. The trials included a range of military-relevant speeds (Patrol March: 3.5 km·h^{-1}; Administrative March: 5.5 km·h^{-1}; Movement to Contact: 6.5 km·h^{-1}) and loads (Control: 7.2 kg; Patrol Order: 23.2 kg; Marching Order: 35.2 kg; Figure 1). For each trial, the control condition was performed first before the load carried was incrementally increased to allow safe task completion. Speeds were counterbalanced among the participants for each session. Specifically, the third data collection session included the 5.5 km·h^{-1} speed, while the fourth data collection session included speeds of 3.5 and 6.5 km·h^{-1}.

During each load carriage trial, participants wore standard physical training uniforms (shorts, t-shirt) with approved Australian Army combat boots (2 kg). The Control condition also included the mass of measurement devices, primarily on the torso (2 kg), and a replica F88 Austeyr (3.2 kg), held in both hands. The Patrol Order condition consisted of the Control condition, with the addition of a weighted vest, representative of a Patrol Order front (10 kg) and back (6 kg) distribution. The Marching Order condition consisted of the Patrol Order condition, with an additional mass placed in the back of the vest (4 kg), plus a standard military issue backpack (weighted evenly throughout the pack (PLATATAC medium assault pack Mk II; 14 kg)).

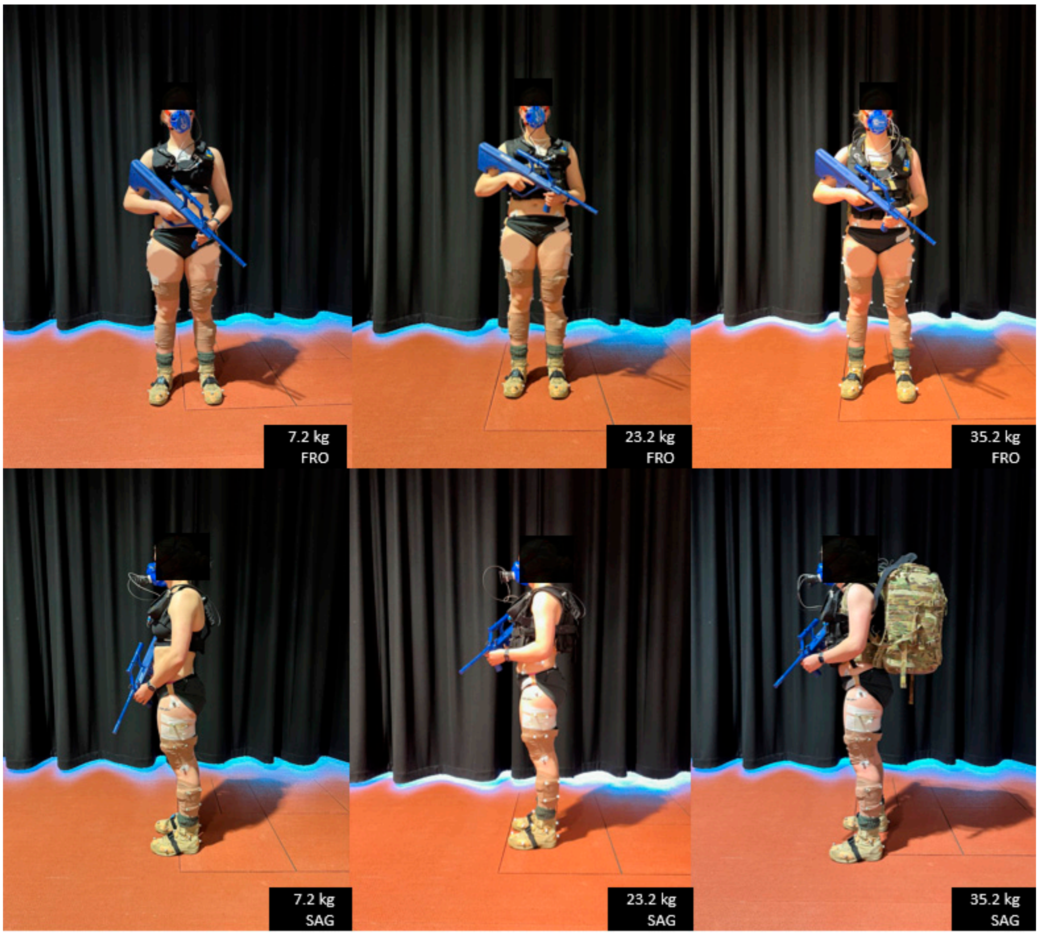

Figure 1. Representation of the three load carriage conditions (7.2 kg (**left**), 23.2 kg (**middle**), 35.2 kg (**right**)). FRO: Frontal; SAG: Sagittal.

2.3. Biomechanical Variables

Forty retroreflective markers were attached bilaterally to the anterior and posterior superior iliac spines, iliac crests, the most lateral point in line with the anterior superior iliac spines, medial and lateral femoral epicondyles, medial and lateral malleoli, calcaneus, middle of foot, first metatarsal head, and fifth metatarsal head. Leg and thigh segment motion were recorded with markers attached to custom-designed thermoplastic plates. Marker trajectories were collected using an 18-camera Vantage motion capture system (8 × V5 cameras and 10 × V16 cameras; Vicon Motion Systems Ltd., Oxford, UK; 120 Hz). Raw marker trajectories were reconstructed and gaps were filled within Vicon Nexus (v. 2.14.0, Vicon Motion Systems Ltd., Oxford, UK). Marker trajectories were filtered using a dual-pass second-order low-pass Butterworth filter with a 12 Hz cut-off frequency (determined by a residual analysis and visual inspection). Hip joint centres were calculated using the Symmetrical Centre of Rotation Estimation function in Vicon Nexus during a hip full range of motion trial, which included hip flexion/extension, abduction/adduction, and circumduction, while the knee and ankle joint centres were calculated using the Symmetrical Axis of Rotation Analysis function in Vicon Nexus during three squats. Where this was not possible due to data quality, hip joint centres were calculated using the regression equation of Harrington et al. [32], while the knee and ankle joint centres were identified as the midpoint between the femoral epicondyles and malleoli, respectively. Segment-embedded anatomical coordinate systems were defined following the International Society of Biomechanics recommendations [33], while non-orthogonal joint coordinate systems were used to calculate sagittal plane hip, knee, and ankle flexion–extension joint angles.

The timing of foot contact events was determined using foot marker kinematics [34]. Specifically, heel strike was determined using the point of negative anterior/posterior velocity of the calcaneus marker and toe-off was determined at the point of positive anterior/posterior velocity of the first metatarsal head marker. Calculations of spatiotemporal variables were based on foot marker trajectories from heel strike to heel strike [35]. Stride length was calculated as the total anterior–posterior distance traversed by the right calcaneus marker from right heel strike to sequential right heel strike. Step width was determined as the medial–lateral displacement between the calcaneus markers of sequential right and left heel strikes. Stride length and step width were also normalised to body height. Stride time was calculated as the time between two sequential right heel strikes. Stance time was determined as the time between the right heel strike and toe-off, and relative stance time was calculated as the percentage of time spent in the stance of the total stride. Cadence was calculated as the total steps taken divided by the total step time in minutes. The kinematics of the pelvis and lower limb were calculated using the right leg during a stride from peaks and troughs during regions of interest of the gait cycle for ten sequential strides and averaged per condition (see Figure 2 for each variable definition). Ground reaction forces (GRFs) were measured using the inbuilt force plates of the treadmill (AMTI, Watertown, MA, USA; 1000 Hz), filtered using the same methods as per marker trajectories (dual-pass second-order low-pass Butterworth filter with a 12 Hz cut-off frequency), and normalised to body weight (in Newtons). Peaks and troughs for braking and propulsive forces were determined for three strides and averaged for each condition. Data were analysed between the first 30 s and the third minute of each trial to avoid start-up effects and ensure the best data quality.

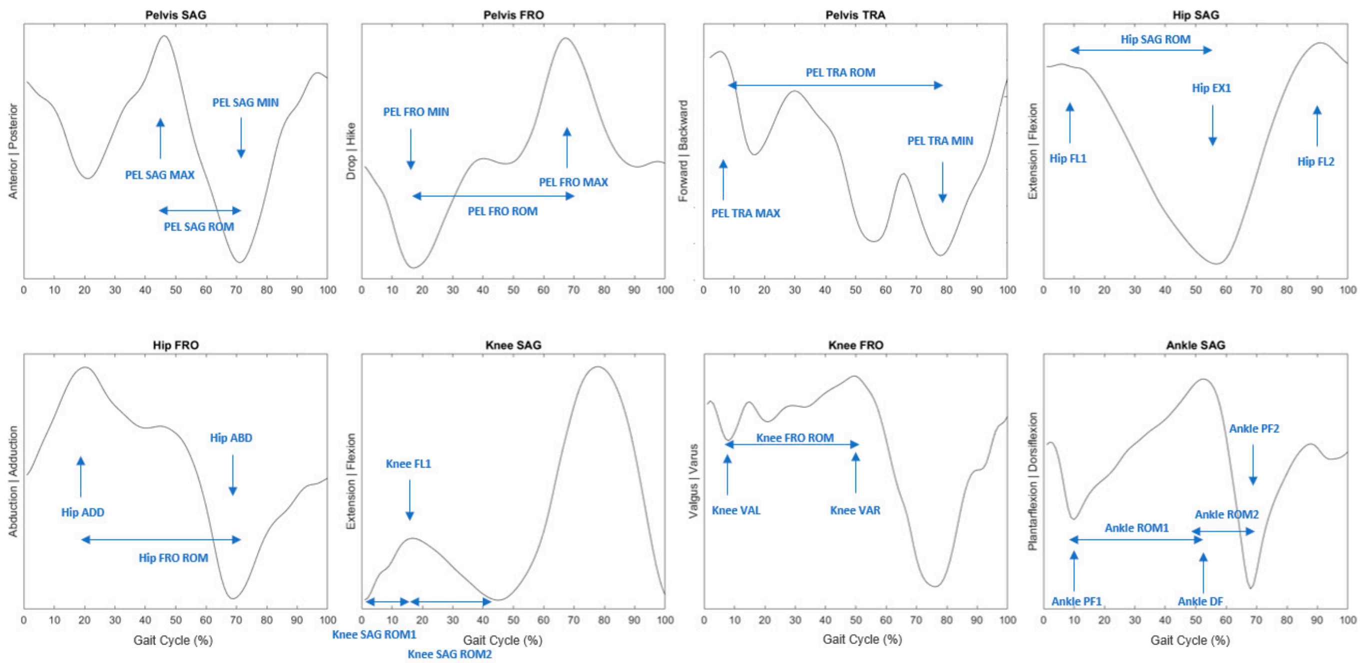

Figure 2. A single gait cycle from 0% (heel strike) to 100% (prior to subsequent heel strike) for pelvis, hip, knee, and ankle kinematics. Specific discrete points of interest per cycle were identified for analysis. ABD: Abduction; ADD: Adduction; DF: Dorsiflexion; EXT: Extension; FL: Flexion; FRO: Frontal; MAX: Maximum; MIN: Minimum; PEL: Pelvis; PF: Plantarflexion; ROM: Range of Motion; SAG: Sagittal; TRA: Transverse; VAL: Valgus; VAR: Varus.

2.4. Physiological and Perceptual Variables

During all experimental trials, expired gases were collected through a Hans Rudolf face mask connected to a MetaMax 3B portable metabolic system (Metamax3B, Cortex Inc., Germany), which has been reported to be reliable for load carriage activities [36]. Prior to each testing session, the metabolic system was calibrated as per the manufacturer's instructions using a standardised reference gas (15% O_2, 5% CO_2, BAL. N_2; Cortex Inc., Leipzig, Germany) and for a volume and flow rate of ±2 and 4 L·s^{-1}. Variables included breathing frequency (BF [breaths·min^{-1}]), tidal volume (V_T [L]), ventilation ($\dot{V}_E$ [L·min^{-1}]), oxygen consumption ($\dot{V}O_2$; absolute [L·min^{-1}], relative to body mass [mL·kg^{-1}·min^{-1}], relative to lean body mass [mL·kgLBM^{-1}·min^{-1}], and relative to $\dot{V}O_{2peak}$ [%]), carbon dioxide production ($\dot{V}CO_2$ [L·min^{-1}]), respiratory exchange ratio (RER), and oxygen pulse (O_2 pulse [mL·b^{-1}·min^{-1}]). Heart rate (HR [beats·min^{-1}]) was measured using a transmitter (T31-coded or Polar Team 2, Polar Electro, Finland) fitted to the chest and recorded through the MetaMax 3B. For each trial, the final three minutes of data were averaged for each variable for analysis. The RPE (6–20 scale) [37] and an Omnibus-Resistance Exercise Scale (OMNI-RES) to measure perceived physical impact of load [38] were obtained at the end of each 12 min trial.

2.5. Statistical Analysis

Descriptive statistics (mean ± standard deviation) were calculated for each variable across the three speed and load conditions for both males and females. Independent-sample *t* tests were used to determine any differences in demographics between the male and female participants. All residuals approximated a normal distribution (as assessed by Q-Q plots and Shapiro–Wilk tests), except for age, $\dot{V}O_{2peak}$, and load carriage experience. When data were not normally distributed, a Mann–Whitney U *t* test was used, and data were also presented as median ± interquartile range. Experimental data were analysed using linear mixed-effects models to examine the interaction and main effects of sex, load, and speed, with random slopes for speed and load and a random intercept for participant. The mixed models included fixed effects of sex (male, female), load (7.2 kg, 23.2 kg, 35.2 kg), and speed (3.5 km·h^{-1}, 5.5 km·h^{-1}, 6.5 km·h^{-1}). All residuals approximated a normal distribution (as assessed by *Q-Q* plots and Kolmogorov–Smirnov tests). Statistical significance was set at $p < 0.05$. If there were no interaction effects, the model was then refitted without that level of interaction term. Significant three-way interactions underwent simple main effects analysis, and *post*-hoc comparisons were conducted for two-way interactions and main effects, with a Holm correction to reduce the probability of type I errors. Partial-eta squared (η_p^2) effect sizes were calculated for interaction and main effects as per Lakens [39] and interpreted using the following qualitative descriptors: trivial (<0.01), small (0.01–0.05), medium (0.06–0.13), and large (>0.14) [40]. All statistical analyses were conducted using the jamovi statistical package (v. 2.2.5, the jamovi project, 2022).

3. Results

Female participants were shorter and lighter; had lower lean body mass, VO_{2peak}, maximal IMTP strength; and had less load carriage experience when compared with the male participants ($p < 0.05$, Table 1). Further, female participants possessed a greater body fat percentage and carried heavier relative loads when compared with males ($p < 0.05$). Age ($p = 0.441$) and total fat mass ($p = 0.229$) were not different between males and females.

Some participants faced challenges in successfully completing experimental trials (Table 2). These factors included dropout, time limitations, equipment malfunctions, or failed attempts resulting in premature trial termination. Descriptive and linear mixed-effects model statistics are presented below for the physiological and perceptual variables (Tables 3 and 4), spatiotemporal variables (Tables 5 and 6), kinematic variables (Tables 7 and 8), and kinetic variables (Tables 9 and 10).

Table 1. Demographic differences between the female and male participants.

	n		Mean ± SD (Median ± IQR)		Mean Diff	*t* Statistic	*p* Value	Effect Size (Cohen's *d*)
	F	M	F	M				
Age (y)	11	14	23.3 ± 2.9 (24.0 ± 4.5)	25.7 ± 5.7 (24.0 ± 4.8)	−1.00	62.50	0.441	0.19 #
Height (m)	11	14	1.68 ± 0.05	1.83 ± 0.08	−0.14	−5.48	**<0.001**	−2.21
Body mass (kg)	11	14	68.6 ± 10.9	84.9 ± 14.0	−16.3	−3.17	**0.004**	−1.28
Lean mass (kg)	9	14	49.5 ± 10.6	60.0 ± 9.3	−10.5	−2.49	**0.021**	−1.07
Fat mass (kg)	9	14	22.2 ± 4.5	18.9 ± 7.0	3.3	1.24	0.229	0.53
Total fat (%)	9	14	31.1 ± 4.1	23.5 ± 6.0	7.6	3.32	**0.003**	1.42
VO_2 peak ($mL \cdot kg^{-1} \cdot min^{-1}$)	9	12	45.9 ± 7.7 (47.2 ± 5.8)	61.4 ± 7.4 (60.7 ± 13.5)	8	4.00	**<0.001**	0.93 #
IMTP peak ($N \cdot kg^{-1}$)	9	13	25.8 ± 3.5	30.6 ± 1.4	−4.8	−4.46	**<0.001**	−1.94
7.2 kg load (% BM)	11	14	10.7 ± 1.5	8.7 ± 1.4	2.0	3.39	**0.003**	1.36
23.2 kg load (% BM)	11	14	34.5 ± 4.9	28.0 ± 4.6	6.5	3.39	**0.003**	1.36
35.2 kg load (% BM)	11	14	52.3 ± 7.4	42.5 ± 7.0	9.8	3.39	**0.003**	1.36
7.2 kg load (% LBM)	9	14	15.1 ± 2.9	12.3 ± 1.9	2.8	2.84	**0.010**	1.21
23.2 kg load (% LBM)	9	14	48.6 ± 9.3	39.6 ± 6.1	9.1	2.84	**0.010**	1.21
35.2 kg load (% LBM)	9	14	73.8 ± 14.2	60.0 ± 9.2	13.8	2.84	**0.010**	1.21
Load carriage experience (months)	11	14	17.8 ± 23.7 (6.0 ± 8.5)	25.1 ± 22.6 (12.0 ± 15.8)	−6.0	40.00	**0.045**	0.48 #

BM: Body Mass; F: Female; IMTP: Isometric Mid-thigh Pull; IQR: Interquartile Range; LBM: Lean Body Mass; M: Male; n: Number; VO_2: Oxygen Consumption. Effect sizes are reported as Cohen's *d*, except where rank biserial correlation is used and indicated by #. *p* values < 0.05 are denoted in bold.

Table 2. Number of participants that completed each condition.

	Control (7.2 kg)			Patrol Order (23.2 kg)			Marching Order (35.2 kg)		
	3.5 $km \cdot h^{-1}$	5.5 $km \cdot h^{-1}$	6.5 $km \cdot h^{-1}$	3.5 $km \cdot h^{-1}$	5.5 $km \cdot h^{-1}$	6.5 $km \cdot h^{-1}$	3.5 $km \cdot h^{-1}$	5.5 $km \cdot h^{-1}$	6.5 $km \cdot h^{-1}$
Female (total n = 11)	8 ǀ 8	11 ǀ 11	8 ǀ 8	8 ǀ 8	11 ǀ 11	4 ǀ 8	7 ǀ 8	10 ǀ 10	3 ǀ 8
Male (total n = 12)	10 ǀ 10	10 ǀ 10	10 ǀ 10	12 ǀ 12	12 ǀ 12	10 ǀ 12	10 ǀ 10	8 ǀ 8	5 ǀ 10

The following is the number of participants who completed each condition: trials successfully completed ǀ trials attempted.

Table 3. Physiological and perceptual variables (mean ± standard deviation) for each load and speed split by sex.

		Control (7.2 kg)			Patrol Order (23.2 kg)			Marching Order (35.2 kg)		
		3.5 km·h^{-1}	**5.5 km·h^{-1}**	**6.5 km·h^{-1}**	**3.5 km·h^{-1}**	**5.5 km·h^{-1}**	**6.5 km·h^{-1}**	**3.5 km·h^{-1}**	**5.5 km·h^{-1}**	**6.5 km·h^{-1}**
BF (breaths·min^{-1})	Female	26.5 ± 8.0	31.0 ± 9.4	35.0 ± 11.5	31.9 ± 7.4	39.2 ± 9.6	47.1 ± 7.8	35.9 ± 7.2	49.9 ± 7.4	56.4 ± 12.2
	Male	27.5 ± 5.6	31.5 ± 6.6	33.0 ± 7.3	29.9 ± 4.8	34.3 ± 7.6	36.7 ± 7.9	33.6 ± 5.4	40.7 ± 7.6	40.3 ± 5.3
V_T (L)	Female	0.95 ± 0.17	1.27 ± 0.30	1.36 ± 0.28	0.89 ± 0.13	1.23 ± 0.22	1.35 ± 0.23	0.86 ± 0.16	1.21 ± 0.19	1.39 ± 0.28
	Male	1.10 ± 0.15	1.39 ± 0.21	1.69 ± 0.25	1.17 ± 0.23	1.51 ± 0.26	1.82 ± 0.28	1.11 ± 0.17	1.44 ± 0.23	1.84 ± 0.13
$\dot{V}_E$ (L·min^{-1})	Female	24.1 ± 4.2	37.4 ± 8.7	44.8 ± 6.9	27.7 ± 3.7	47.3 ± 11.7	62.2 ± 2.8	30.0 ± 3.4	59.6 ± 10.0	76.1 ± 5.2
	Male	29.6 ± 3.2	42.8 ± 6.2	54.8 ± 10.8	34.1 ± 4.6	50.2 ± 6.3	65.3 ± 8.1	36.4 ± 3.3	57.1 ± 7.3	73.8 ± 7.5
$\dot{V}O_2$ (L·min^{-1})	Female	0.88 ± 0.10	1.40 ± 0.28	1.71 ± 0.18	0.99 ± 0.09	1.69 ± 0.32	2.24 ± 0.18	1.09 ± 0.13	2.03 ± 0.27	2.61 ± 0.24
	Male	1.06 ± 0.13	1.58 ± 0.23	2.07 ± 0.32	1.20 ± 0.18	1.85 ± 0.24	2.50 ± 0.27	1.29 ± 0.11	2.09 ± 0.20	2.83 ± 0.20
$\dot{V}O_2$ (body mass) (mL·kg^{-1}·min^{-1})	Female	13.4 ± 1.1	20.4 ± 1.8	26.3 ± 2.2	15.2 ± 1.4	24.7 ± 2.1	34.8 ± 2.9	17.3 ± 2.2	28.8 ± 4.0	39.2 ± 2.0
	Male	12.8 ± 2.0	18.7 ± 2.5	24.8 ± 3.0	14.1 ± 1.6	21.6 ± 2.3	29.8 ± 3.9	15.5 ± 1.9	24.5 ± 3.7	31.6 ± 2.8
$\dot{V}O_2$ (lean mass) (mL·kg^{-1}·min^{-1})	Female	18.1 ± 4.4	27.3 ± 6.1	35.4 ± 8.5	20.4 ± 4.8	33.0 ± 6.8	49.2 ± 13.3	23.4 ± 6.8	40.0 ± 7.9	54.7 ± 18.0
	Male	17.7 ± 4.2	26.8 ± 5.7	34.3 ± 6.7	20.1 ± 4.2	31.6 ± 5.8	43.1 ± 7.4	21.4 ± 4.3	36.4 ± 5.7	46.2 ± 7.7
VO_2 (%VO_{2peak})	Female	30.6 ± 8.0	45.6 ± 12.6	59.8 ± 15.4	34.5 ± 9.4	55.3 ± 15.4	69.3 ± 9.1	40.1 ± 11.4	69.7 ± 26.5	76.2 ± 6.1
	Male	21.3 ± 4.4	31.3 ± 5.9	41.3 ± 7.2	23.1 ± 3.3	35.6 ± 5.7	48.6 ± 7.9	25.8 ± 3.8	40.3 ± 6.1	53.1 ± 6.4
$\dot{V}CO_2$ (L·min^{-1})	Female	0.81 ± 0.13	1.31 ± 0.24	1.66 ± 0.20	0.91 ± 0.10	1.62 ± 0.31	2.24 ± 0.19	1.02 ± 0.15	1.99 ± 0.26	2.74 ± 0.28
	Male	0.95 ± 0.13	1.48 ± 0.23	2.00 ± 0.33	1.11 ± 0.19	1.77 ± 0.23	2.42 ± 0.25	1.18 ± 0.11	1.98 ± 0.24	2.78 ± 0.15
RER (au)	Female	0.92 ± 0.05	0.93 ± 0.06	0.97 ± 0.05	0.93 ± 0.04	0.96 ± 0.05	1.00 ± 0.04	0.93 ± 0.03	0.98 ± 0.03	1.05 ± 0.04
	Male	0.90 ± 0.04	0.94 ± 0.04	0.96 ± 0.03	0.92 ± 0.04	0.96 ± 0.04	0.97 ± 0.04	0.92 ± 0.04	0.95 ± 0.04	0.98 ± 0.04
HR (beats·min^{-1})	Female	97 ± 9	121 ± 12	137 ± 9	104 ± 8	137 ± 15	161 ± 12	114 ± 11	158 ± 16	169 ± 5
	Male	94 ± 9	113 ± 9	128 ± 10	100 ± 9	123 ± 9	144 ± 11	109 ± 9	132 ± 7	159 ± 5
O_2 pulse (mL·beat^{-1})	Female	9.11 ± 1.65	11.57 ± 1.82	12.63 ± 1.80	9.57 ± 1.37	12.39 ± 1.72	13.96 ± 1.12	9.71 ± 1.77	12.89 ± 1.46	15.42 ± 1.11
	Male	11.28 ± 0.94	14.00 ± 1.70	16.17 ± 1.83	12.04 ± 1.64	15.09 ± 1.67	17.41 ± 1.75	11.89 ± 1.17	15.76 ± 1.20	17.78 ± 1.30
RPE (au)	Female	7 ± 0	9 ± 2	11 ± 2	10 ± 2	13 ± 2	14 ± 2	13 ± 3	16 ± 2	18 ± 2
	Male	7 ± 1	7 ± 1	9 ± 2	8 ± 2	10 ± 2	12 ± 2	10 ± 2	11 ± 4	13 ± 2
OMNI-RES (au)	Female	1 ± 1	2 ± 1	2 ± 2	5 ± 2	6 ± 2	7 ± 2	7 ± 2	8 ± 1	9 ± 1
	Male	0 ± 1	1 ± 1	2 ± 2	2 ± 1	3 ± 1	4 ± 2	4 ± 2	5 ± 2	6 ± 2

BF: Breathing Frequency; $\dot{V}CO_2$: Carbon Dioxide Production; HR: Heart Rate; $\dot{V}O_2$: Oxygen Consumption; OMNI-RES: OMNI-Resistance Exercise Scale; O_2 pulse: Oxygen Pulse; RER: Respiratory Exchange Ratio; RPE: Rating of Perceived Exertion; V_T: Tidal Volume; $\dot{V}_E$: Ventilation.

Table 4. Linear mixed-effects model results (*p* values) for physiological and perceptual variables.

	Sex × Load × Speed	Sex × Load	Sex × Speed	Load × Speed	Sex	Load	Speed
BF (breaths·min^{-1})	0.062	**0.004**	**0.006**	**<0.001**	0.112	<0.001	<0.001
V_T (L)	0.405	0.053	**0.008**	0.268	0.003	0.932	<0.001
$\dot{V}_E$ (L·min^{-1})	**0.030**	0.026	0.443	<0.001	0.337	<0.001	<0.001
$\dot{V}O_2$ (L·min^{-1})	0.830	0.061	0.520	**<0.001**	0.264	<0.001	<0.001
$\dot{V}O_2$ (body mass) (mL·kg^{-1}·min^{-1})	0.087	0.068	0.060	**<0.001**	**0.011**	<0.001	<0.001
$\dot{V}O_2$ (lean mass) (mL·kg^{-1}·min^{-1})	0.101	0.077	0.375	**<0.001**	0.657	<0.001	<0.001
VO_2 (%VO_{2peak})	**<0.001**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
$\dot{V}CO_2$ (L·min^{-1})	0.364	0.233	0.824	**<0.001**	0.077	<0.001	<0.001
RER (au)	**0.025**	0.124	0.350	<0.001	0.342	<0.001	<0.001
HR (beats·min^{-1})	**<0.001**	0.013	0.009	<0.001	0.002	<0.001	<0.001
O_2 pulse (mL·beat^{-1})	**0.017**	0.887	0.008	0.011	<0.001	<0.001	<0.001
RPE (au)	0.666	**<0.001**	0.072	0.108	<0.001	<0.001	**<0.001**
OMNI-RES (au)	0.956	**<0.001**	0.707	0.162	<0.001	<0.001	**<0.001**

BF: Breathing Frequency; $\dot{V}CO_2$: Carbon Dioxide Production; HR: Heart Rate; $\dot{V}O_2$: Oxygen Consumption; OMNI-RES: OMNI-Resistance Exercise Scale; O_2 pulse: Oxygen Pulse; RER: Respiratory Exchange Ratio; RPE: Rating of Perceived Exertion; V_T: Tidal Volume; $\dot{V}_E$: Ventilation. Mixed model results were interpreted in a hierarchical system, with bolded values representing this from three-way interactions, followed by two-way interactions, and then main effects.

Table 5. Spatiotemporal variables (mean ± standard deviation) for each load and speed, split by sex.

		Control (7.2 kg)			**Patrol Order (23.2 kg)**			**Marching Order (35.2 kg)**		
		3.5 km·h^{-1}	**5.5 km·h^{-1}**	**6.5 km·h^{-1}**	**3.5 km·h^{-1}**	**5.5 km·h^{-1}**	**6.5 km·h^{-1}**	**3.5 km·h^{-1}**	**5.5 km·h^{-1}**	**6.5 km·h^{-1}**
Cadence (steps·min^{-1})	Female	89.9 ± 6.5	117.3 ± 4.8	129.1 ± 5.6	92.8 ± 6.3	119.1 ± 5.3	130.2 ± 5.3	94.1 ± 7.1	120.6 ± 7.1	132.5 ± 5.3
	Male	90.6 ± 6.8	112.7 ± 5.2	125.4 ± 7.4	92.2 ± 6.9	114.6 ± 5.9	126.6 ± 8.1	90.5 ± 7.5	117.3 ± 7.1	128.5 ± 7.5
Stride time (s)	Female	1.31 ± 0.08	1.01 ± 0.05	0.92 ± 0.05	1.27 ± 0.07	0.99 ± 0.05	0.91 ± 0.04	1.25 ± 0.08	0.99 ± 0.05	0.90 ± 0.04
	Male	1.32 ± 0.09	1.05 ± 0.05	0.96 ± 0.05	1.31 ± 0.08	1.04 ± 0.05	0.94 ± 0.06	1.32 ± 0.08	1.02 ± 0.06	0.93 ± 0.06
Stance time (s)	Female	0.88 ± 0.06	0.65 ± 0.03	0.58 ± 0.03	0.86 ± 0.05	0.65 ± 0.03	0.59 ± 0.02	0.85 ± 0.06	0.65 ± 0.03	0.58 ± 0.03
	Male	0.89 ± 0.06	0.68 ± 0.04	0.61 ± 0.04	0.89 ± 0.05	0.68 ± 0.04	0.61 ± 0.04	0.90 ± 0.06	0.67 ± 0.04	0.60 ± 0.04
Stance time (% stride)	Female	67.2 ± 0.9	64.7 ± 0.7	63.4 ± 0.5	67.8 ± 0.8	65.1 ± 0.5	64.2 ± 0.4	68.1 ± 0.9	65.8 ± 0.5	64.8 ± 0.4
	Male	67.1 ± 1.2	64.6 ± 0.9	63.8 ± 0.7	67.7 ± 1.2	65.1 ± 0.8	64.4 ± 0.9	68.1 ± 1.3	65.5 ± 0.9	65.1 ± 0.9
Stride length (m)	Female	1.39 ± 0.09	1.59 ± 0.06	1.64 ± 0.10	1.37 ± 0.07	1.58 ± 0.06	1.67 ± 0.07	1.37 ± 0.09	1.60 ± 0.07	1.67 ± 0.06
	Male	1.39 ± 0.11	1.63 ± 0.10	1.73 ± 0.10	1.39 ± 0.09	1.63 ± 0.10	1.71 ± 0.12	1.43 ± 0.10	1.61 ± 0.09	1.70 ± 0.13
Step width (m)	Female	0.13 ± 0.04	0.12 ± 0.02	0.14 ± 0.03	0.13 ± 0.03	0.13 ± 0.04	0.14 ± 0.03	0.14 ± 0.03	0.14 ± 0.03	0.14 ± 0.02
	Male	0.11 ± 0.03	0.10 ± 0.03	0.11 ± 0.03	0.11 ± 0.03	0.11 ± 0.03	0.12 ± 0.03	0.11 ± 0.04	0.12 ± 0.04	0.12 ± 0.04
Stride length (% height)	Female	82.8 ± 4.2	94.6 ± 3.3	98.5 ± 5.1	81.9 ± 2.9	94.0 ± 4.2	99.8 ± 3.3	82.2 ± 3.5	94.8 ± 5.4	99.3 ± 2.5
	Male	76.9 ± 4.4	90.1 ± 3.4	95.5 ± 3.2	76.6 ± 4.3	89.8 ± 3.2	94.3 ± 4.1	79.1 ± 3.6	89.7 ± 1.5	94.3 ± 4.5
Step width (% height)	Female	7.54 ± 2.23	7.22 ± 1.44	8.20 ± 1.64	7.55 ± 1.81	7.56 ± 2.09	8.24 ± 1.50	8.30 ± 1.81	8.47 ± 1.41	8.11 ± 1.35
	Male	6.02 ± 1.56	5.67 ± 1.42	6.09 ± 1.37	5.87 ± 1.65	5.81 ± 1.55	6.31 ± 1.58	6.06 ± 1.95	6.45 ± 2.37	6.43 ± 1.79

Table 6. Linear mixed-effects model results (*p* values) for spatiotemporal variables.

	Sex × Load × Speed	**Sex × Load**	**Sex × Speed**	**Load × Speed**	**Sex**	**Load**	**Speed**
Cadence (steps·min^{-1})	0.783	0.136	0.309	0.349	0.169	**0.001**	**<0.001**
Stride time (s)	0.238	0.161	0.989	0.373	0.075	**0.003**	**<0.001**
Stance time (s)	0.185	0.245	0.912	0.478	0.087	0.706	**<0.001**
Stance time (% stride)	0.311	0.945	0.247	0.060	0.887	**<0.001**	**<0.001**
Stride length (m)	0.178	0.424	0.232	0.125	0.178	0.511	**<0.001**
Step width (m)	0.172	0.845	0.890	**0.033**	0.078	0.026	0.050
Stride length (% height)	0.191	0.447	0.326	0.148	**0.006**	0.496	**<0.001**
Step width (% height)	0.165	0.750	0.820	**0.035**	**0.011**	0.023	0.047

Mixed model results were interpreted in a hierarchical system, with bolded values representing this from three-way interactions, followed by two-way interactions, and then main effects.

Table 7. Kinematic variables (mean ± standard deviation) for each load and speed, split by sex.

		Control (7.2 kg)			**Patrol Order (23.2 kg)**			**Marching Order (35.2 kg)**		
		3.5 km·h^{-1}	**5.5 km·h^{-1}**	**6.5 km·h^{-1}**	**3.5 km·h^{-1}**	**5.5 km·h^{-1}**	**6.5 km·h^{-1}**	**3.5 km·h^{-1}**	**5.5 km·h^{-1}**	**6.5 km·h^{-1}**
Pelvis SAG Max (°)	Female	9.34 ± 3.84	11.18 ± 3.97	13.35 ± 4.78	8.62 ± 3.53	10.89 ± 3.86	14.08 ± 4.52	17.29 ± 2.77	21.56 ± 5.54	23.15 ± 4.38
	Male	10.09 ± 4.24	11.66 ± 3.37	12.95 ± 4.13	9.46 ± 4.18	12.20 ± 3.16	13.80 ± 4.10	14.01 ± 6.36	18.86 ± 6.81	19.35 ± 7.70
Pelvis SAG Min (°)	Female	5.36 ± 4.01	6.62 ± 4.32	8.48 ± 5.69	4.07 ± 4.29	5.48 ± 3.41	7.91 ± 5.01	9.41 ± 3.60	10.49 ± 5.61	11.25 ± 5.18
	Male	5.42 ± 3.62	7.10 ± 3.32	7.99 ± 3.99	4.47 ± 3.66	7.21 ± 3.26	8.40 ± 4.05	7.94 ± 5.29	10.77 ± 4.49	11.89 ± 5.98
Pelvis SAG ROM (°)	Female	3.98 ± 1.04	4.56 ± 0.93	4.87 ± 1.69	4.55 ± 1.79	5.41 ± 1.70	6.17 ± 2.73	7.88 ± 2.11	9.81 ± 3.94	10.52 ± 4.52
	Male	4.67 ± 1.60	4.57 ± 0.90	4.96 ± 0.95	4.99 ± 1.23	5.00 ± 1.06	5.40 ± 1.10	6.07 ± 2.25	8.09 ± 2.72	7.46 ± 3.05
Pelvis FRO Max (°)	Female	4.28 ± 1.45	5.20 ± 2.85	7.02 ± 2.90	4.29 ± 1.05	5.47 ± 1.12	8.46 ± 2.08	4.50 ± 2.53	4.04 ± 2.26	6.58 ± 2.38
	Male	3.30 ± 2.21	4.25 ± 2.60	5.30 ± 2.59	3.76 ± 1.67	3.91 ± 1.96	6.00 ± 2.88	3.36 ± 1.30	4.38 ± 2.51	5.31 ± 2.20
Pelvis FRO Min (°)	Female	−4.16 ± 1.00	−5.85 ± 2.32	−7.34 ± 1.91	−4.64 ± 1.24	−6.38 ± 2.19	−7.92 ± 1.70	−2.32 ± 1.99	−3.66 ± 2.69	−6.25 ± 2.63
	Male	−3.02 ± 2.84	−5.13 ± 1.98	−5.37 ± 2.50	−2.91 ± 2.76	−5.22 ± 2.29	−5.34 ± 2.50	−3.09 ± 2.15	−4.44 ± 3.31	−5.29 ± 3.10
Pelvis FRO ROM (°)	Female	8.44 ± 1.64	11.05 ± 2.63	14.35 ± 4.07	8.93 ± 1.31	11.85 ± 1.99	16.38 ± 1.83	6.82 ± 0.81	7.70 ± 3.28	12.82 ± 1.89
	Male	6.32 ± 1.95	9.39 ± 3.43	10.67 ± 3.67	6.67 ± 2.49	9.12 ± 3.07	11.34 ± 3.57	6.46 ± 2.25	8.82 ± 4.13	10.60 ± 4.16
Pelvis TRA Max (°)	Female	4.91 ± 2.19	6.72 ± 2.97	6.42 ± 1.70	4.38 ± 2.38	5.95 ± 2.84	7.17 ± 2.12	2.35 ± 1.98	4.09 ± 3.13	6.63 ± 3.00
	Male	4.26 ± 1.84	4.76 ± 1.94	5.27 ± 2.66	4.57 ± 2.04	3.99 ± 2.22	5.29 ± 2.31	2.43 ± 1.63	3.15 ± 3.00	4.05 ± 2.13
Pelvis TRA Min (°)	Female	−3.38 ± 1.55	−3.09 ± 3.01	−4.68 ± 2.01	−2.07 ± 2.41	−3.01 ± 2.32	−5.62 ± 3.22	−2.12 ± 1.86	−0.96 ± 2.26	−3.25 ± 2.05
	Male	−3.87 ± 1.42	−2.74 ± 2.11	−4.25 ± 1.87	−3.61 ± 1.67	−2.74 ± 2.43	−4.41 ± 1.67	−3.22 ± 1.51	−2.06 ± 2.91	−3.69 ± 1.95
Pelvis TRA ROM (°)	Female	8.29 ± 1.19	9.80 ± 2.82	11.10 ± 2.57	6.45 ± 1.49	8.96 ± 2.27	12.8 ± 4.56	4.47 ± 1.7	5.05 ± 1.82	9.87 ± 3.76
	Male	8.13 ± 1.90	7.50 ± 2.26	9.52 ± 4.22	8.18 ± 2.31	6.73 ± 2.25	9.69 ± 3.44	5.65 ± 2.14	5.21 ± 1.94	7.74 ± 2.95
Hip FL1 (°)	Female	32.5 ± 5.9	36.9 ± 4.6	40.2 ± 8.4	32.3 ± 4.2	37.4 ± 4.5	41.5 ± 5.3	41.8 ± 6.5	49.1 ± 6.2	50.2 ± 9.6
	Male	29.4 ± 4.3	34.0 ± 3.9	37.2 ± 4.3	29.7 ± 4.4	36.1 ± 4.4	38.7 ± 4.5	35.4 ± 5.8	43.3 ± 5.2	45.1 ± 7.2
Hip EX1 (°)	Female	−10.85 ± 7.75	−12.72 ± 5.39	−14.05 ± 5.86	−12.28 ± 6.02	−14.50 ± 5.40	−15.34 ± 6.08	−5.49 ± 4.71	−5.09 ± 6.38	−7.67 ± 6.63
	Male	−8.12 ± 6.07	−11.43 ± 5.24	−12.20 ± 5.56	−9.34 ± 5.21	−10.68 ± 5.70	−11.59 ± 6.32	−8.07 ± 6.95	−7.71 ± 9.41	−8.52 ± 9.88
Hip FL2 (°)	Female	35.6 ± 5.0	40.3 ± 4.1	44.0 ± 5.4	36.3 ± 3.9	39.8 ± 4.0	45.3 ± 4.5	47.1 ± 5.1	48.8 ± 5.7	54.4 ± 5.5
	Male	33.0 ± 4.8	37.8 ± 4.8	40.5 ± 4.1	34.1 ± 4.6	38.4 ± 4.8	41.3 ± 4.1	40.1 ± 5.0	45.8 ± 5.5	48.1 ± 6.5
Hip SAG ROM (°)	Female	43.7 ± 3.5	49.8 ± 4.5	55.0 ± 4.4	45.1 ± 4.3	52.1 ± 5.5	56.9 ± 5.2	48.2 ± 7.9	54.5 ± 6.3	58.2 ± 13.3
	Male	37.6 ± 3.1	45.5 ± 3.2	49.6 ± 3.8	39.1 ± 4.2	46.9 ± 4.0	50.5 ± 4.6	43.9 ± 5.7	51.1 ± 9.2	53.7 ± 7.9
Hip ADD (°)	Female	9.36 ± 2.23	10.46 ± 2.26	12.30 ± 1.78	9.43 ± 2.13	10.65 ± 2.89	12.35 ± 2.48	7.79 ± 2.34	8.38 ± 2.97	11.72 ± 2.60
	Male	5.92 ± 3.18	8.45 ± 2.58	8.24 ± 2.77	6.28 ± 3.07	8.02 ± 2.70	7.83 ± 2.56	6.56 ± 2.81	7.61 ± 3.90	8.21 ± 3.44

Table 7. *Cont.*

		Control (7.2 kg)			Patrol Order (23.2 kg)			Marching Order (35.2 kg)		
		3.5 km·h^{-1}	5.5 km·h^{-1}	6.5 km·h^{-1}	3.5 km·h^{-1}	5.5 km·h^{-1}	6.5 km·h^{-1}	3.5 km·h^{-1}	5.5 km·h^{-1}	6.5 km·h^{-1}
Hip ABD (°)	Female	−4.87 ± 2.99	−5.48 ± 2.89	−6.88 ± 4.52	−5.19 ± 2.37	−6.06 ± 1.74	−8.79 ± 3.04	−5.25 ± 2.08	−5.93 ± 2.11	−6.28 ± 3.42
	Male	−5.14 ± 3.81	−6.14 ± 3.90	−6.68 ± 3.77	−6.64 ± 3.41	−6.20 ± 4.23	−7.54 ± 3.98	−5.89 ± 3.38	−7.32 ± 4.00	−6.77 ± 3.53
Hip FRO ROM (°)	Female	14.2 ± 2.1	15.9 ± 1.9	19.2 ± 4.0	14.6 ± 1.9	16.7 ± 2.2	21.1 ± 2.6	13.0 ± 2.0	14.3 ± 3.5	18.0 ± 3.5
	Male	11.1 ± 2.7	14.6 ± 3.7	14.9 ± 3.6	12.9 ± 2.4	14.2 ± 3.5	15.4 ± 3.3	12.5 ± 2.5	14.9 ± 3.2	15.0 ± 3.7
Knee FL1 (°)	Female	19.4 ± 4.9	23.7 ± 4.3	25.9 ± 4.5	20.2 ± 7.1	25.0 ± 5.4	28.2 ± 4.0	25.2 ± 7.0	29.5 ± 4.8	31.3 ± 6.2
	Male	14.5 ± 4.7	19.8 ± 4.0	23.4 ± 3.4	15.8 ± 3.5	21.6 ± 4.6	24.5 ± 3.4	17.4 ± 3.9	25.0 ± 4.1	25.4 ± 4.1
Knee SAG ROM1 (°)	Female	19.4 ± 4.9	22.4 ± 5.5	22.0 ± 4.1	17.0 ± 5.9	21.3 ± 5.1	21.6 ± 4.4	18.3 ± 6.9	18.5 ± 6.2	18.8 ± 3.4
	Male	15.0 ± 3.5	21.2 ± 2.5	23.5 ± 3.3	15.0 ± 3.1	21.7 ± 3.0	23.3 ± 3.3	15.1 ± 3.9	21.4 ± 2.9	20.4 ± 4.8
Knee SAG ROM2 (°)	Female	14.16 ± 3.57	19.20 ± 5.97	24.63 ± 4.04	15.97 ± 6.67	20.87 ± 7.73	28.89 ± 3.83	17.12 ± 7.54	22.74 ± 9.90	26.55 ± 7.90
	Male	9.49 ± 3.03	17.47 ± 3.57	20.15 ± 3.66	11.60 ± 4.31	18.96 ± 5.38	20.40 ± 4.57	12.31 ± 5.09	22.00 ± 4.48	21.03 ± 6.17
Knee VAL (°)	Female	5.95 ± 3.30	6.16 ± 3.10	6.43 ± 3.47	5.84 ± 3.37	6.42 ± 3.22	6.79 ± 3.73	6.46 ± 3.50	7.59 ± 3.77	7.42 ± 3.00
	Male	3.16 ± 3.14	4.08 ± 3.03	3.38 ± 3.13	3.45 ± 3.08	3.88 ± 2.83	4.07 ± 2.91	3.07 ± 3.03	3.27 ± 3.32	3.89 ± 2.90
Knee VAR (°)	Female	−0.25 ± 3.21	0.02 ± 2.35	−0.75 ± 3.19	−0.21 ± 3.29	−0.45 ± 2.48	−0.37 ± 3.54	−0.56 ± 3.79	−0.97 ± 2.26	−1.23 ± 3.45
	Male	1.68 ± 2.58	1.38 ± 2.52	1.52 ± 2.30	1.81 ± 2.41	1.37 ± 2.44	1.26 ± 2.29	1.82 ± 2.78	1.94 ± 3.60	1.34 ± 2.70
Knee FRO ROM (°)	Female	6.73 ± 5.73	6.29 ± 4.93	7.56 ± 5.99	6.80 ± 5.73	7.13 ± 5.03	7.63 ± 6.47	7.67 ± 6.46	8.73 ± 5.60	8.67 ± 6.27
	Male	4.97 ± 2.30	4.81 ± 2.97	4.56 ± 2.84	4.64 ± 2.63	4.55 ± 2.81	4.85 ± 2.58	4.74 ± 2.64	5.70 ± 3.27	4.81 ± 3.02
Ankle PF1 (°)	Female	−9.81 ± 3.58	−5.84 ± 3.20	−9.15 ± 3.11	−9.76 ± 3.10	−6.28 ± 2.75	−9.48 ± 3.48	−9.34 ± 3.62	−6.69 ± 3.46	−8.09 ± 3.46
	Male	−6.38 ± 2.38	−7.47 ± 2.88	−6.80 ± 3.29	−6.30 ± 3.13	−6.84 ± 4.69	−6.76 ± 3.24	−7.36 ± 2.81	−7.89 ± 4.05	−6.72 ± 3.36
Ankle DF1 (°)	Female	15.2 ± 4.5	17.0 ± 2.7	12.3 ± 4.9	15.9 ± 4.6	16.6 ± 3.0	12.1 ± 3.7	16.5 ± 3.6	17.0 ± 2.8	13.1 ± 1.7
	Male	16.3 ± 1.9	15.2 ± 2.8	14.6 ± 3.0	17.2 ± 2.4	15.9 ± 2.8	14.1 ± 2.5	16.6 ± 2.4	14.9 ± 3.0	14.2 ± 3.0
Ankle PF2 (°)	Female	−14.7 ± 3.1	−15.3 ± 5.0	−19.2 ± 3.8	−14.9 ± 3.4	−16.5 ± 5.1	−19.0 ± 3.3	−13.9 ± 2.9	−16.3 ± 3.7	−18.1 ± 1.8
	Male	−11.8 ± 2.5	−17.9 ± 3.4	−17.7 ± 3.8	−12.9 ± 3.2	−17.7 ± 3.0	−18.3 ± 3.5	−13.4 ± 3.8	−17.8 ± 3.8	−17.7 ± 4.2
Ankle SAG ROM1 (°)	Female	25.0 ± 2.3	22.8 ± 4.2	21.4 ± 4.4	25.6 ± 2.8	22.9 ± 4.6	21.6 ± 3.7	25.9 ± 2.6	23.7 ± 5.5	21.2 ± 4.0
	Male	22.6 ± 3.1	22.7 ± 2.9	21.4 ± 3.6	23.5 ± 4.0	22.8 ± 4.4	20.9 ± 3.4	24.0 ± 3.6	22.8 ± 2.3	20.9 ± 3.9
Ankle SAG ROM2 (°)	Female	29.9 ± 4.2	32.2 ± 4.4	31.5 ± 3.6	30.8 ± 4.1	33.1 ± 3.7	31.1 ± 2.4	30.4 ± 3.1	33.3 ± 3.7	31.2 ± 2.7
	Male	28.1 ± 3.3	33.1 ± 3.4	32.3 ± 3.6	30.1 ± 3.9	33.6 ± 3.1	32.4 ± 3.9	30.0 ± 4.3	32.7 ± 4.6	31.8 ± 4.1

ABD: Abduction; ADD: Adduction; DF: Dorsiflexion; EX: Extension; FL: Flexion; FRO: Frontal; Max: Maximum; Min: Minimum; PF: Plantarflexion; ROM: Range of Motion; SAG: Sagittal; TRA: Transverse; VAL: Valgus; VAR: Varus. Note: All variables are defined and visually represented in Figure 1.

Table 8. Linear mixed-effects model results (p values) for kinematic variables.

	Sex × Load × Speed	**Sex × Load**	**Sex × Speed**	**Load × Speed**	**Sex**	**Load**	**Speed**
Pelvis SAG Max (°)	0.622	0.069	0.473	0.003	0.479	**<0.001**	**<0.001**
Pelvis SAG Min (°)	0.628	0.500	0.367	0.703	0.919	**<0.001**	**<0.001**
Pelvis SAG ROM (°)	0.523	0.086	**0.033**	**0.008**	0.129	<0.001	<0.001
Pelvis FRO Max (°)	0.031	0.050	0.366	0.101	0.321	0.145	<0.001
Pelvis FRO Min (°)	0.684	**0.011**	0.170	0.931	0.138	<0.001	**<0.001**
Pelvis FRO ROM (°)	0.348	**<0.001**	0.085	0.412	0.036	<0.001	**<0.001**
Pelvis TRA Max (°)	0.447	0.874	0.209	0.050	**0.042**	**<0.001**	**0.012**
Pelvis TRA Min (°)	0.200	0.510	0.432	0.075	0.157	**0.003**	**0.003**
Pelvis TRA ROM (°)	0.085	0.414	**0.027**	0.147	0.140	**<0.001**	<0.001
Hip FL1 (°)	0.527	0.298	0.880	0.202	0.139	**<0.001**	**<0.001**
Hip EX1 (°)	0.338	0.064	0.885	**0.048**	0.720	<0.001	0.003
Hip FL2 (°)	0.545	0.158	0.388	0.656	**0.042**	**<0.001**	**<0.001**
Hip SAG ROM (°)	0.808	0.710	0.828	0.243	**0.003**	**<0.001**	**<0.001**
Hip ADD (°)	0.500	0.059	0.065	0.607	**<0.001**	0.094	**<0.001**
Hip ABD (°)	**0.044**	0.395	0.316	0.093	0.580	0.055	<0.001
Hip FRO ROM (°)	0.087	**0.003**	**0.041**	0.386	0.016	<0.001	<0.001
Knee FL1 (°)	0.187	0.054	0.551	0.306	0.061	**<0.001**	**<0.001**
Knee SAG ROM1 (°)	0.091	0.130	0.087	**<0.001**	0.821	0.005	<0.001
Knee SAG ROM2 (°)	0.531	0.412	0.225	0.436	**0.017**	**0.010**	**<0.001**
Knee VAL (°)	0.130	0.087	0.715	0.356	0.099	**0.009**	**0.005**
Knee VAR (°)	**0.019**	0.785	0.984	0.624	0.148	0.806	0.308
Knee FRO ROM (°)	0.062	0.206	0.345	**0.003**	0.326	0.008	0.327
Ankle PF1 (°)	0.378	0.449	0.086	0.214	0.289	0.176	0.354
Ankle DF1 (°)	0.410	0.411	0.058	0.072	0.882	0.575	**<0.001**
Ankle PF2 (°)	**0.007**	0.784	0.090	0.477	0.559	0.256	<0.001
Ankle SAG ROM1 (°)	0.964	0.798	0.089	0.097	0.441	0.312	**<0.001**
Ankle SAG ROM2 (°)	0.173	0.995	0.142	**<0.001**	0.990	0.175	<0.001

ABD: Abduction; ADD: Adduction; DF: Dorsiflexion; EX: Extension; FL: Flexion; FRO: Frontal; Max: Maximum; Min: Minimum; PF: Plantarflexion; ROM: Range of Motion; SAG: Sagittal; TRA: Transverse; VAL: Valgus; VAR: Varus. Mixed model results were interpreted in a hierarchical system, with bolded values representing this from three-way interactions, followed by two-way interactions, and then main effects. Note: All variables are defined and visually represented in Figure 1.

Table 9. Kinetic variables (mean ± standard deviation) for each load and speed, split by sex.

		Control (7.2 kg)			**Patrol Order (23.2 kg)**			**Marching Order (35.2 kg)**		
		3.5 km·h^{-1}	**5.5 km·h^{-1}**	**6.5 km·h^{-1}**	**3.5 km·h^{-1}**	**5.5 km·h^{-1}**	**6.5 km·h^{-1}**	**3.5 km·h^{-1}**	**5.5 km·h^{-1}**	**6.5 km·h^{-1}**
Min A-P GRF (BW)	Female	−0.19 ± 0.03	−0.27 ± 0.04	−0.31 ± 0.05	−0.22 ± 0.04	−0.31 ± 0.06	−0.38 ± 0.04	−0.26 ± 0.03	−0.37 ± 0.08	−0.42 ± 0.03
	Male	−0.16 ± 0.03	−0.26 ± 0.01	−0.30 ± 0.03	−0.18 ± 0.04	−0.31 ± 0.03	−0.34 ± 0.05	−0.21 ± 0.04	−0.33 ± 0.04	−0.37 ± 0.05
Max A-P GRF (BW)	Female	0.20 ± 0.01	0.30 ± 0.02	0.33 ± 0.04	0.23 ± 0.02	0.36 ± 0.04	0.40 ± 0.03	0.28 ± 0.02	0.39 ± 0.05	0.43 ± 0.03
	Male	0.19 ± 0.03	0.27 ± 0.03	0.32 ± 0.02	0.20 ± 0.03	0.33 ± 0.03	0.36 ± 0.03	0.24 ± 0.04	0.35 ± 0.03	0.40 ± 0.04
Braking VGRF (BW)	Female	1.12 ± 0.08	1.33 ± 0.07	1.47 ± 0.08	1.37 ± 0.10	1.61 ± 0.16	1.82 ± 0.11	1.55 ± 0.13	1.83 ± 0.19	2.16 ± 0.11
	Male	1.10 ± 0.03	1.30 ± 0.05	1.36 ± 0.08	1.29 ± 0.05	1.53 ± 0.10	1.68 ± 0.18	1.41 ± 0.08	1.69 ± 0.14	1.88 ± 0.22
Prop VGRF (BW)	Female	1.19 ± 0.03	1.33 ± 0.06	1.35 ± 0.08	1.41 ± 0.05	1.52 ± 0.15	1.58 ± 0.11	1.59 ± 0.04	1.70 ± 0.23	1.71 ± 0.13
	Male	1.15 ± 0.02	1.28 ± 0.05	1.31 ± 0.06	1.32 ± 0.06	1.46 ± 0.08	1.43 ± 0.10	1.47 ± 0.08	1.60 ± 0.08	1.61 ± 0.10
M-L Impulse (BW·s)	Female	0.025 ± 0.013	0.020 ± 0.004	0.018 ± 0.009	0.034 ± 0.006	0.024 ± 0.006	0.021 ± 0.007	0.048 ± 0.013	0.034 ± 0.007	0.025 ± 0.008
	Male	0.025 ± 0.006	0.020 ± 0.006	0.017 ± 0.003	0.037 ± 0.011	0.024 ± 0.009	0.021 ± 0.008	0.040 ± 0.009	0.030 ± 0.012	0.026 ± 0.007

A-P: Anterior–Posterior; BW: Body Weight; GRF: Ground Reaction Force; Max: Maximum; Min: Minimum; M-L: Medio-Lateral; VGRF: Vertical Ground Reaction Force.

Table 10. Linear mixed-effects model results (p values) for kinetic variables.

	Sex × Load × Speed	**Sex × Load**	**Sex × Speed**	**Load × Speed**	**Sex**	**Load**	**Speed**
Min A-P GRF (BW)	0.279	0.758	0.116	**0.012**	0.352	<0.001	<0.001
Max A-P GRF (BW)	0.476	0.613	**0.014**	**<0.001**	0.037	<0.001	<0.001
Braking VGRF (BW)	0.061	**0.013**	0.233	**<0.001**	0.032	<0.001	<0.001
Prop VGRF (BW)	0.434	0.476	0.560	**0.027**	0.142	<0.001	<0.001
M-L Impulse (BW)	0.224	0.608	0.925	**0.015**	0.834	<0.001	<0.001

A-P: Anterior–Posterior; BW: Body Weight; GRF: Ground Reaction Force; Max: Maximum; Min: Minimum; M-L: Medio-Lateral; VGRF: Vertical Ground Reaction Force. Mixed model results were interpreted in a hierarchical system, with bolded values representing this from three-way interactions, followed by two-way interactions, and then main effects.

3.1. Sex-by-Load-by-Speed

There were sex-by-load-by-speed interactions for $\dot{V}_E$ ($F_{(4, 72.99)}$ = 2.85, p = 0.030, η_p^2 = 0.135), VO_2 (%VO_{2peak}; $F_{(4, 60.87)}$ = 5.74, p < 0.001, η_p^2 = 0.274), RER ($F_{(4, 67.79)}$ = 2.97, p = 0.025, η_p^2 = 0.149), HR ($F_{(4, 66.60)}$ = 6.52, p < 0.001, η_p^2 = 0.281), O_2 pulse ($F_{(4, 63.45)}$ = 3.27, p = 0.017, η_p^2 = 0.171), Pelvis FRO Max ($F_{(4, 82.35)}$ = 2.80, p = 0.031, η_p^2 = 0.120), Hip ABD ($F_{(4, 80.00)}$ = 2.57, p = 0.044, η_p^2 = 0.114), Knee VAR ($F_{(4, 64.42)}$ = 3.18, p = 0.019, η_p^2 = 0.165), and Ankle PF2 ($F_{(4, 81.45)}$ = 3.78, p = 0.007, η_p^2 = 0.157). No other variables demonstrated a significant three-way interaction. Parameter estimates of the observed interactions for simple effects of sex are presented in Table 11. $\dot{V}_E$ was lower for females than males at 3.5 km·h^{-1} across all loads; however, $\dot{V}_E$ was similar between males and females for all other loads and speeds. Relative exercise intensity (%VO_{2peak}) increased with heavier loads and faster speeds for both males and females, but the increase was greater for females. HR was higher for females than males for all loads at the 5.5 and 6.5 km·h^{-1} speeds, despite HR being similar between females and males at 3.5 km·h^{-1} for all loads. O_2 pulse was lower for females than males for all loads and speeds. RER, Pelvis FRO Max, Hip ABD, Knee VAR, and Ankle PF2 were similar between males and females for each load and speed comparison.

Table 11. Simple effects of sex parameter estimates for sex-by-load-by-speed interactions.

	Load	Speed (km·h^{-1})	Estimate (F-M)	SE	df	t	p
V_E (L·min^{-1})	Control (7.2 kg)	3.5	−8.15	2.15	16.06	−3.80	**0.002**
		5.5	−4.86	3.42	20.84	−1.42	0.169
		6.5	−4.56	4.90	12.82	−0.93	0.369
	Patrol Order (23.2 kg)	3.5	−5.75	2.14	13.99	−2.69	**0.018**
		5.5	−2.46	3.63	20.53	−0.68	0.506
		6.5	−2.15	5.63	12.66	−0.38	0.709
	Marching Order (35.2 kg)	3.5	−3.55	1.49	15.11	−2.38	**0.031**
		5.5	−0.27	3.31	20.67	−0.08	0.937
		6.5	0.04	5.25	12.86	0.01	0.994
VO_2 (%$\dot{V}O_2$peak)	Control (7.2 kg)	3.5	9.10	2.36	23.06	3.86	**<0.001**
		5.5	14.89	4.46	19.77	3.34	**0.003**
		6.5	18.76	4.87	19.49	3.85	**0.001**
	Patrol Order (23.2 kg)	3.5	11.13	2.81	21.06	3.97	**<0.001**
		5.5	19.66	5.04	19.45	3.90	**<0.001**
		6.5	27.34	5.62	19.75	4.86	**<0.001**
	Marching Order (35.2 kg)	3.5	12.95	3.97	20.29	3.26	**0.004**
		5.5	25.98	6.29	20.15	4.13	**<0.001**
		6.5	33.49	6.98	20.88	4.80	**<0.001**
RER (au)	Control (7.2 kg)	3.5	0.01	0.02	20.76	0.36	0.722
		5.5	−0.01	0.02	22.97	−0.44	0.661
		6.5	−0.00	0.02	20.74	0.21	0.838
	Patrol Order (23.2 kg)	3.5	−0.00	0.02	20.31	0.03	0.978
		5.5	−0.00	0.02	22.64	−0.00	0.998
		6.5	0.04	0.02	26.31	1.79	0.085
	Marching Order (35.2 kg)	3.5	−0.00	0.02	20.50	0.04	0.966
		5.5	0.03	0.02	24.08	1.65	0.112
		6.5	0.05	0.03	29.62	1.86	0.072

Table 11. *Cont.*

	Load	Speed (km·h^{-1})	Estimate (F-M)	SE	df	*t*	*p*
HR (beats·min^{-1})	Control (7.2 kg)	3.5	6	4	18.38	1.41	0.176
		5.5	11	5	21.78	2.19	**0.040**
		6.5	15	5	18.89	2.99	**0.008**
	Patrol Order (23.2 kg)	3.5	7	4	17.78	1.60	0.127
		5.5	14	5	21.99	2.71	**0.013**
		6.5	24	6	21.04	4.18	**<0.001**
	Marching Order (35.2 kg)	3.5	6	5	21.36	1.35	0.190
		5.5	28	5	24.18	5.29	**<0.001**
		6.5	23	6	27.26	3.66	**0.001**
O_2 pulse (mL·beat^{-1})	Control (7.2 kg)	3.5	−2.40	0.71	21.84	−3.39	**0.003**
		5.5	−2.84	0.77	21.58	−3.69	**0.001**
		6.5	−3.80	0.78	21.57	−4.86	**<0.001**
	Patrol Order (23.2 kg)	3.5	−2.32	0.64	22.52	−3.61	**0.002**
		5.5	−2.70	0.70	22.24	−3.89	**<0.001**
		6.5	−3.83	0.78	23.24	−4.93	**<0.001**
	Marching Order (35.2 kg)	3.5	−2.22	0.61	21.89	−3.62	**0.002**
		5.5	−3.90	0.69	23.71	−5.63	**<0.001**
		6.5	−3.11	0.74	25.04	−4.19	**<0.001**
Pelvis FRO Max (°)	Control (7.2 kg)	3.5	0.23	0.92	24.80	0.25	0.804
		5.5	0.92	1.07	24.75	0.85	0.402
		6.5	0.92	1.26	21.65	0.73	0.475
	Patrol Order (23.2 kg)	3.5	0.43	0.77	26.12	0.56	0.583
		5.5	1.56	0.77	27.20	2.04	0.051
		6.5	2.23	1.10	22.39	2.03	0.055
	Marching Order (35.2 kg)	3.5	0.77	0.81	23.80	0.95	0.353
		5.5	−1.05	0.93	29.59	−1.13	0.268
		6.5	0.77	1.15	22.39	0.67	0.508
Hip ABD (°)	Control (7.2 kg)	3.5	1.05	1.48	25.17	0.71	0.485
		5.5	0.65	1.39	23.36	0.47	0.645
		6.5	0.52	1.80	23.28	0.29	0.776
	Patrol Order (23.2 kg)	3.5	1.67	1.32	24.84	1.27	0.217
		5.5	0.14	1.33	23.15	0.10	0.918
		6.5	−1.09	1.54	23.45	−0.71	0.485
	Marching Order (35.2 kg)	3.5	0.75	1.14	26.13	0.66	0.516
		5.5	1.96	1.40	25.77	1.40	0.174
		6.5	0.48	1.48	23.65	0.32	0.750
Knee VAR (°)	Control (7.2 kg)	3.5	−1.16	1.20	20.26	−0.97	0.346
		5.5	−1.27	0.97	21.86	−1.31	0.205
		6.5	−1.86	1.16	19.88	−1.60	0.126
	Patrol Order (23.2 kg)	3.5	−1.53	1.24	20.02	−1.24	0.229
		5.5	−1.82	1.03	21.51	−1.77	0.091
		6.5	−1.16	1.23	19.92	−0.95	0.355
	Marching Order (35.2 kg)	3.5	−1.81	1.37	20.82	−1.32	0.201
		5.5	−1.98	1.18	22.07	−1.67	0.108
		6.5	−1.52	1.33	20.87	−1.14	0.267

Table 11. *Cont.*

	Load	Speed (km·h^{-1})	Estimate (F-M)	SE	df	*t*	*p*
Ankle PF2 (°)	Control (7.2 kg)	3.5	−2.87	1.49	20.26	−1.93	0.067
		5.5	2.32	1.74	22.29	1.33	0.196
		6.5	−1.82	1.58	18.61	−1.15	0.266
	Patrol Order (23.2 kg)	3.5	−2.66	1.45	18.78	−1.83	0.083
		5.5	1.20	1.74	21.87	0.69	0.498
		6.5	−1.52	1.73	18.47	−0.88	0.391
	Marching Order (35.2 kg)	3.5	−0.91	1.50	19.32	−0.61	0.551
		5.5	0.42	1.85	22.36	0.23	0.821
		6.5	−1.55	1.74	18.97	−0.89	0.384

ABD: Abduction; F: Female; FRO: Frontal; HR: Heart Rate; M: Male; Max: Maximum; $\dot{V}O_2$: Oxygen Consumption; $\dot{V}$O2/HR: Oxygen Pulse; PF: Plantarflexion; RER: Respiratory Exchange Ratio; SE: Standard Error; VAR: Varus; V_E: Ventilation. *p* values < 0.05 are denoted in bold.

3.2. Sex-by-Load

There were sex-by-load interactions for BF ($F_{(2, 23.29)}$ = 6.90, p = 0.004, η_p^2 = 0.372), RPE ($F_{(2, 32.70)}$ = 10.72, p < 0.001, η_p^2 = 0.396), OMNI-RES ($F_{(2, 20.12)}$ = 10.80, p < 0.001, η_p^2 = 0.518), Pelvis FRO Min ($F_{(2, 27.86)}$ = 5.30, p = 0.011, η_p^2 = 0.276), Pelvis FRO ROM ($F_{(2, 17.51)}$ = 11.20, p < 0.001, η_p^2 = 0.561), Hip FRO ROM ($F_{(2, 27.30)}$ = 7.28, p = 0.003, η_p^2 = 0.348), and Braking VGRF ($F_{(2, 25.17)}$ = 5.16, p = 0.013, η_p^2 = 0.291). No other variables demonstrated a significant two-way interaction between sex and load. *Post-hoc* effects of the observed interactions for sex-by-load are presented in Table 12. BF was similar between males and females for the 7.2 kg and 23.2 kg loads; however, females had a higher BF when walking with 35.2 kg when compared with males. Within sex, males and females had increased BF with load. RPE and OMNI-RES ratings were similar between males and females for loads of 7.2 kg; however, females had higher ratings for both the 23.2 kg and 35.2 kg loads when compared with males. Within sex, males and females had increased RPE and OMNI with load, except for males where RPE did not change between the 35.2 kg and 23.2 kg loads. Pelvis FRO ROM and Hip FRO ROM were greater for females for the 7.2 kg and 23.2 kg loads when compared with males; however, they were similar for males and females for the 35.2 kg load. Within sex, males and females had increased Pelvis FRO ROM with load; however, they had similar Hip FRO ROM between loads. Pelvis FRO Min was similar between males and females for the 7.2 kg and 35.2 kg loads; however, females had a lower angle for 23.2 kg when compared with males. Within sex, males and females had similar Pelvis FRO Min between loads, except for females where Pelvis FRO Min increased between the 35.2 kg and 23.2 kg and the 35.2 kg and 7.2 kg loads. Braking VGRF was similar between males and females for the 7.2 kg and 23.2 kg loads; however, females had greater VGRF for 35.2 kg when compared with males. Within sex, males and females had increased VGRF with load.

Table 12. *Post-hoc* effects of sex-by-load interactions.

	Variable	Comparison	Difference	SE	df	*t*	*p*
BF (breaths·min^{-1})	7.2 kg	F-M	−0.39	3.42	19.23	0.11	0.911
	23.2 kg	F-M	4.37	3.03	19.81	−1.45	0.164
	35.2 kg	F-M	8.11	3.11	2.61	15.65	**0.019**
	Female	35.2–23.2	6.72	2.43	2.76	−7.93	**0.025**
		23.2–7.2	7.00	2.16	3.24	−8.69	**0.021**
		35.2–7.2	13.72	2.41	5.70	−8.16	**0.001**
	Male	35.2–23.2	3.24	1.39	2.33	−9.11	**0.044**
		23.2–7.2	3.90	1.20	3.25	−8.75	**0.021**
		35.2–7.2	7.14	1.37	5.20	−8.60	**0.002**

Table 12. *Cont.*

	Variable	Comparison	Difference	SE	df	*t*	*p*
RPE (au)	7.2 kg	F-M	1	1	56.00	−1.89	0.060
	23.2 kg	F-M	2	1	3.18	20.23	**0.005**
	35.2 kg	F-M	4	1	4.14	17.14	**<0.001**
	Female	35.2–23.2	3	1	4.87	−8.19	**0.002**
		23.2–7.2	3	1	4.96	−8.72	**0.002**
		35.2–7.2	7	1	9.70	−8.27	**<0.001**
	Male	35.2–23.2	1	1	2.09	−9.00	0.066
		23.2–7.2	2	1	4.01	−10.21	**0.005**
		35.2–7.2	4	1	4.96	−9.30	**0.002**
OMNI-RES (au)	7.2 kg	F-M	1	0	17.87	−1.82	0.086
	23.2 kg	F-M	3	1	4.79	20.84	**<0.001**
	35.2 kg	F-M	3	1	3.61	17.78	**0.002**
	Female	35.2–23.2	2	0	5.71	−8.10	**<0.001**
		23.2–7.2	4	0	9.65	−9.25	**<0.001**
		35.2–7.2	6	0	14.00	−8.84	**<0.001**
	Male	35.2–23.2	2	0	4.91	−8.92	**0.001**
		23.2–7.2	2	0	4.89	−10.39	**0.001**
		35.2–7.2	4	1	7.43	−9.68	**<0.001**
Pelvis FRO Min (°)	7.2 kg	F-M	−1.50	0.80	17.86	1.87	0.078
	23.2 kg	F-M	−1.93	0.83	−2.33	20.79	**0.030**
	35.2 kg	F-M	0.12	1.04	17.48	−0.12	0.910
	Female	35.2–23.2	2.18	0.65	3.37	−8.29	**0.028**
		23.2–7.2	−0.39	0.59	−0.65	−8.61	0.534
		35.2–7.2	1.79	0.65	2.75	−8.24	**0.049**
	Male	35.2–23.2	0.51	0.50	1.02	−8.91	1.00
		23.2–7.2	−0.18	0.47	−0.38	−9.43	1.00
		35.2–7.2	0.33	0.52	0.65	−9.15	1.00
Pelvis FRO ROM (°)	7.2 kg	F-M	2.60	1.16	2.25	18.29	**0.037**
	23.2 kg	F-M	3.28	0.95	3.43	20.24	**0.003**
	35.2 kg	F-M	0.24	1.16	17.53	−0.21	0.839
	Female	35.2–23.2	2.39	0.80	2.98	−9.05	**0.015**
		23.2–7.2	6.51	0.93	7.04	−7.10	**<0.001**
		35.2–7.2	4.12	1.12	3.67	−8.81	**0.0110**
	Male	35.2–23.2	2.70	0.79	3.43	−10.90	**0.0110**
		23.2–7.2	4.44	0.61	7.27	−10.86	**<0.001**
		35.2–7.2	1.73	0.73	2.37	−10.87	**0.0380**
Hip FRO ROM (°)	7.2 kg	F-M	2.95	1.16	2.54	18.36	**0.020**
	23.2 kg	F-M	3.18	1.01	3.16	20.59	**0.005**
	35.2 kg	F-M	−0.88	1.19	18.17	−0.74	0.467
	Female	35.2–23.2	−2.53	0.97	−2.62	−8.26	0.090
		23.2–7.2	0.94	0.93	1.01	−8.66	0.340
		35.2–7.2	−1.59	1.03	−1.55	−8.35	0.318
	Male	35.2–23.2	−0.23	0.60	−0.38	−9.28	0.713
		23.2–7.2	0.85	0.58	1.46	−9.17	0.532
		35.2–7.2	0.62	0.61	1.02	−8.95	0.671

Table 12. *Cont.*

	Variable	Comparison	Difference	SE	df	t	p
Braking VGRF (BW)	7.2 kg	F-M	0.06	0.04	46.00	−1.45	0.153
	23.2 kg	F-M	0.11	0.06	2.01	19.03	0.059
	35.2 kg	F-M	0.20	0.09	2.35	16.43	**0.032**
	Female	35.2–23.2	0.27	0.07	3.90	−8.25	**0.004**
		23.2–7.2	0.28	0.06	4.63	−8.36	**0.003**
		35.2–7.2	0.55	0.08	7.36	−8.34	**<0.001**
	Male	35.2–23.2	0.18	0.06	3.28	−8.66	**0.010**
		23.2–7.2	0.23	0.05	4.33	−9.86	**0.003**
		35.2–7.2	0.41	0.06	6.42	−8.75	**<0.001**

BF: Breathing Frequency; F: Female; FRO: Frontal; M: Male; Min: Minimum; OMNI-RES: OMNI-Resistance Exercise Scale; RPE: Rating of Perceived Exertion; ROM: Range of Motion; SE: Standard Error; VGRF: Vertical Ground Reaction Force. p values < 0.05 are denoted in bold.

3.3. Sex-by-Speed

There were sex-by-speed interactions for BF ($F_{(2, 19.13)}$ = 6.75, p = 0.006, η_p^2 = 0.414), V_T ($F_{(2, 18.65)}$ = 6.38, p = 0.008, η_p^2 = 0.406), Pelvis SAG ROM ($F_{(2, 26.96)}$ = 3.90, p = 0.033, η_p^2 = 0.224), Pelvis TRA ROM ($F_{(2, 19.29)}$ = 4.40, p = 0.027, η_p^2 = 0.313), Hip FRO ROM ($F_{(2, 19.63)}$ = 3.78, p = 0.041, η_p^2 = 0.278), and Max A-P GRF ($F_{(2, 18.76)}$ = 5.42, p = 0.014, η_p^2 = 0.366). No other variables demonstrated a significant two-way interaction between sex and speed. *Post-hoc* effects of the observed interactions for sex-by-speed are presented in Table 13. BF was similar between males and females across all speed comparisons. Within sex, males and females had increased BF with speed, except for females where BF did not change between 6.5 km·h^{-1} and 5.5 km·h^{-1}. Females had lower V_T when compared with males for each speed comparison. Within sex, males and females had increased V_T with speed. Pelvis SAG ROM was similar between males and females across all speed comparisons. Within sex, males and females had similar ROM between speeds. Pelvis TRA ROM was similar between males and females across all speed comparisons. Within sex, males and females had increased ROM with speed between 6.5 km·h^{-1} and 5.5 km·h^{-1} and females had increased ROM between 6.5 km·h^{-1} and 3.5 km·h^{-1}; however, males and females had similar results for remaining between-speed comparisons. Hip FRO ROM was similar between males and females for the 3.5 and 5.5 km·h^{-1} speeds; however, females had greater ROM at 6.5 km·h^{-1} when compared with males. Within sex, males and females had increased ROM with speed, except for males where ROM did not change between the 6.5 km·h^{-1} and 5.5 km·h^{-1} speeds. Max A-P GRF was similar between males and females for the 3.5 and 6.5 km·h^{-1} speeds; however, females had greater GRF for 5.5 km·h^{-1} than males. Within sex, males and females had increased GRF with speed, except for females where GRF did not change between the 6.5 km·h^{-1} and 5.5 km·h^{-1} speeds.

Table 13. *Post-hoc* effects of sex-by-speed interactions.

	Variable	Comparison	Difference	SE	df	t	p
BF (breaths·min^{-1})	3.5 km·h^{-1}	F-M	1.05	2.80	17.25	−0.37	0.714
	5.5 km·h^{-1}	F-M	4.52	3.50	20.87	−1.29	0.211
	6.5 km·h^{-1}	F-M	5.33	3.95	17.67	−1.35	0.194
	Female	5.5–3.5	7.06	2.53	2.79	−8.00	**0.047**
		6.5–3.5	10.99	3.15	3.49	−6.32	**0.036**
		6.5–5.5	3.93	3.12	1.26	−6.37	0.252
	Male	5.5–3.5	3.21	1.35	2.38	−9.97	**0.046**
		6.5–3.5	6.88	1.32	5.21	−8.94	**0.002**
		6.5–5.5	3.66	1.35	2.73	−9.16	**0.046**

Table 13. *Cont.*

	Variable	Comparison	Difference	SE	df	t	p
$\mathbf{V_T}$ (L)	3.5 km·h^{-1}	F-M	−0.26	0.09	−2.97	16.94	**0.009**
	5.5 km·h^{-1}	F-M	−0.26	0.10	−2.60	20.96	**0.017**
	6.5 km·h^{-1}	F-M	−0.45	0.12	−3.76	17.02	**0.002**
	Female	5.5–3.5	0.31	0.04	7.16	−9.13	**<0.001**
		6.5–3.5	0.46	0.05	9.62	−8.15	**<0.001**
		6.5–5.5	0.15	0.03	4.94	−6.26	**0.002**
	Male	5.5–3.5	0.34	0.04	9.41	−10.09	**<0.001**
		6.5–3.5	0.62	0.05	13.74	−10.18	**<0.001**
		6.5–5.5	0.27	0.03	9.18	−9.50	**<0.001**
Pelvis SAG ROM (°)	3.5 km·h^{-1}	F-M	0.31	0.58	18.11	−0.54	0.599
	5.5 km·h^{-1}	F-M	0.68	0.70	57.00	−0.97	0.336
	6.5 km·h^{-1}	F-M	0.98	0.80	52.00	−1.23	0.226
	Female	5.5–3.5	0.74	0.89	0.83	−8.44	0.863
		6.5–3.5	1.35	0.98	1.38	−6.91	0.631
		6.5–5.5	0.612	0.908	0.674	−8.43	0.863
	Male	5.5–3.5	0.30	0.45	0.66	−10.02	0.831
		6.5–3.5	0.68	0.43	1.57	−10.07	0.443
		6.5–5.5	0.38	0.45	0.85	−10.02	0.831
Pelvis TRA ROM (°)	3.5 km·h^{-1}	F-M	−1.11	0.75	17.88	1.48	0.156
	5.5 km·h^{-1}	F-M	1.58	0.80	20.12	−1.98	0.062
	6.5 km·h^{-1}	F-M	1.90	1.48	17.43	−1.28	0.216
	Female	5.5–3.5	1.89	0.85	2.22	−8.83	0.055
		6.5–3.5	5.25	1.38	3.81	−7.47	**0.018**
		6.5–5.5	3.36	1.06	3.18	−7.03	**0.031**
	Male	5.5–3.5	−0.72	0.61	−1.17	−10.51	0.266
		6.5–3.5	1.95	1.09	1.79	−10.89	0.202
		6.5–5.5	2.67	0.80	3.34	−10.76	**0.020**
Hip FRO ROM (°)	3.5 km·h^{-1}	F-M	1.84	0.94	18.32	−1.95	0.066
	5.5 km·h^{-1}	F-M	1.28	1.13	20.99	−1.14	0.269
	6.5 km·h^{-1}	F-M	4.35	1.41	3.09	17.73	**0.006**
	Female	5.5–3.5	1.71	0.69	2.47	−7.88	**0.039**
		6.5–3.5	5.55	0.97	5.72	−7.10	**0.002**
		6.5–5.5	3.84	1.11	3.45	−7.84	**0.018**
	Male	5.5–3.5	2.37	0.55	4.27	−10.74	**0.004**
		6.5–3.5	3.11	0.73	4.25	−10.88	**0.004**
		6.5–5.5	0.75	0.79	0.95	−10.90	0.364
Max A-P GRF (BW)	3.5 km·h^{-1}	F-M	0.02	0.01	37.00	−1.70	0.098
	5.5 km·h^{-1}	F-M	0.04	0.01	2.99	18.81	**0.008**
	6.5 km·h^{-1}	F-M	0.02	0.01	49.00	−1.58	0.120
	Female	5.5–3.5	0.12	0.02	7.03	−7.51	**<0.001**
		6.5–3.5	0.14	0.02	7.88	−6.66	**<0.001**
		6.5–5.5	0.02	0.01	1.62	−7.94	0.145
	Male	5.5–3.5	0.10	0.01	8.92	−9.05	**<0.001**
		6.5–3.5	0.15	0.01	13.14	−9.37	**<0.001**
		6.5–5.5	0.04	0.01	4.14	−9.60	**0.002**

A-P: Anterior–Posterior; BF: Breathing Frequency; F: Female; FRO: Frontal; GRF: Ground Reaction Force; M: Male; Max: Maximum; ROM: Range of Motion; SAG: Sagittal; SE: Standard Error; V_T: Tidal Volume; TRA: Transverse. p values < 0.05 are denoted in bold.

3.4. Sex Main Effects

There were main effects of sex for $\dot{V}O_2$ relative to body mass (mL·kg^{-1}·min^{-1}) ($F_{(1, 21.51)}$ = 7.78, p = 0.011, η_p^2 = 0.265), stride length (% height) ($F_{(1, 19.38)}$ = 9.68, p = 0.006,

η_p^2 = 0.333), step width (% height) ($F_{(1, 21.45)}$ = 7.85, p = 0.011, η_p^2 = 0.268), Pelvis TRA Max ($F_{(1, 16.62)}$ = 4.85, p = 0.042, η_p^2 = 0.226), Hip FL2 ($F_{(1, 21.87)}$ = 4.67, p = 0.042, η_p^2 = 0.176), Hip SAG ROM ($F_{(1, 18.57)}$ = 12.01, p = 0.003, η_p^2 = 0.393), Hip ADD ($F_{(1, 21.04)}$ = 16.09, p < 0.001, η_p^2 = 0.433), and Knee SAG ROM2 ($F_{(1, 21.69)}$ = 6.75, p = 0.017, η_p^2 = 0.237). No other variables demonstrated a significant main effect of sex. *Post-hoc* effects of the observed main effects for sex are presented in Table 14. $\dot{V}O_2$ relative to body mass was greater for females when compared with males. Relative stride length and step width (% height) were also greater for females when compared with males. Hip SAG ROM, Hip ADD, and Knee SAG ROM2 were greater for females when compared with males. Pelvis TRA Max and Hip FL2 were similar between females and males.

Table 14. *Post-hoc* main effects of sex.

Variable	Comparison	Difference	SE	*df*	*t*	*p*
$\dot{V}O_2$ (body mass) (mL·kg^{-1}·min^{-1})	F-M	2.76	0.91	3.03	21.18	**0.006**
Stride length (% height)	F-M	3.83	1.47	2.61	20.59	**0.017**
Step width (% height)	F-M	1.72	0.62	2.80	21.01	**0.011**
Pelvis TRA Max (°)	F-M	1.64	0.89	1.84	20.47	0.080
Hip FL2 (°)	F-M	3.28	1.80	1.83	20.90	0.082
Hip SAG ROM (°)	F-M	5.01	1.72	2.91	20.73	**0.008**
Hip ADD (°)	F-M	3.70	1.10	3.37	20.68	**0.003**
Knee SAG ROM2 (°)	F-M	3.76	1.75	2.15	18.98	**0.045**

ADD: Adduction; F: Female; FL: Flexion; M: Male; Max: Maximum; $\dot{V}O_2$: Oxygen Consumption; ROM: Range of Motion; SE: Standard Error; TRA: Transverse. p values < 0.05 are denoted in bold.

4. Discussion

The primary aim of this study was to investigate the differences in physiology, perception, and biomechanics during load carriage between sexes and determine whether the responses were dependent on military-relevant loads and speeds. Collectively, the results showed that the relative exercise intensity for males and females during load carriage tasks is influenced by load and speed, as demonstrated by $\dot{V}_E$, VO_2 ($\%VO_{2peak}$), O_2 pulse, and HR results. Specifically, O_2 pulse was lower and relative exercise intensity ($\%VO_{2peak}$) was greater for females than for males across all conditions, with differences getting larger as speed and load increased. However, HR was only higher for females at the 5.5 and 6.5 km·h^{-1} speeds. $\dot{V}_E$ was lower for females at the 3.5 km·h^{-1} speed across all loads. There were further differences in exercise intensity and biomechanics between sexes that were dependent on either load or speed. Females reported higher perceived exertion when walking with the 23.2 and 35.2 kg loads, as well as greater BF and Braking VGRF for the 35.2 kg load when compared with males. Further, the addition of load increased Pelvis and Hip ROM for females. Across all speeds, females demonstrated a smaller V_T than males. Maximum A-P GRFs were greater for females at the 5.5 km·h^{-1} speed and Hip FRO ROM was greater at the 6.5 km·h^{-1} speed compared with males. Across all loads and speeds, females demonstrated greater $\dot{V}O_2$ (relative to body mass), relative stride length and width (% height), Hip SAG ROM and ADD, and Knee SAG ROM2.

The observed differences in the kinematics suggest that variation in spatiotemporal patterns could be associated with an attempt for females to increase stability [41,42]. Females exhibited a greater relative step width (1.7% of height) than males across all speed and load combinations in the current study. This contrasts with the results of previous research whereby step width was similar between sexes while walking at both relative (up to 40% BM) [22] and absolute (up to 55 kg) loads [43] when assessed at a single speed (4.6–4.8 km·h^{-1}). Importantly, Bode et al. [43] matched participants for height and body mass, which differs to the current study, which employed a representative military sample [44]. Females may require greater stability during such load carriage tasks as they are carrying a higher relative load compared with males, and a wider step width would increase the base of support and improve lateral stability [41]. Greater step width was further demonstrated through joint and segment kinematics, with females exhibiting greater Hip and Pelvis FRO ROM (occurring during loading response) compared with males. Hip ADD in the current study was also four degrees greater for females during the loading response. This is likely to reflect the differences in pelvis anatomy between the sexes, with females adducting to a greater degree due to having a wider pelvis, despite having a wider stride width [45,46]. Greater hip adduction has previously been reported for females in studies that employed similar loading to the current study, i.e., using a vest of up to 22 kg at 4.86 km·h^{-1} [27] and 23 kg at 5 km·h^{-1} [26]. In addition to load, there was also an effect of speed in the current study, with Hip FRO ROM being four degrees greater for females at the 6.5 km·h^{-1} speed. It is proposed that this is an attempt to increase stability due to the carrying of load and maintaining a faster walking speed. This research demonstrates that in representative military load carriage tasks, females are required to adapt hip and pelvis kinematics and increase step width (relative to height) to respond to the addition of load and maintain stability.

Males and females completed the load carriage tasks with comparable absolute stride lengths; however, when made relative to height, stride length was 3.8% greater in females. As such, the magnitude of strain may be higher for females per stride as the foot is traversing a greater relative distance from the centre of mass [47], with the current investigation finding higher braking VGRF for the load of 35.2 kg in females but not in males. The increase in relative stride length in part explains the requirement to have a four-degrees-larger knee SAG ROM2 to assist in forward propulsion at toe-off and a five-degrees-greater hip SAG ROM due to over-striding. This opposes the findings of Bode et al. [43], who recruited male and female participants that were matched for height and mass, where males had larger knee ROM during walking with loads of up to 55 kg. Previously, when loads relative to body mass have been investigated, there have been no lower limb biomechanical differences reported between males and females [22,28,48–50]. Females who overstride during absolute load carriage are likely to increase lower limb muscular demands [47] and place additional shearing stress on the pelvis [51], which could provide a potential mechanism for the higher incidence of pelvis and lower limb stress fractures reported in females [18,52]. Individuals who experience such stress fractures have been reported to have smaller thigh muscles and bone cross-sectional geometries, as well as being generally less physically fit compared to the non-fracture cases [18]. Therefore, the lower fitness levels and lean mass reported for females in the current study suggest that such differences could increase the risk of stress fractures arising from the repetitive microtraumas sustained during demanding occupational tasks such as load carriage [53,54]. Importantly, the current study demonstrates that when meeting the demands imposed by the same absolute loads and speeds during load carriage, the biomechanical responses (when relative to height) differ between males and females, which likely reflects the observed differences in their physical capacities. Whether these differences are inherently related to sex or are partially a result of gendered experiences in sport and health is yet to be determined.

In the current study, relative exercise intensity differed between males and females, appearing highly dependent on military-relevant loads and speeds. Females worked at a ~33% greater relative intensity (%VO_{2peak}) when compared with males, which is consistent with prior studies [22–24]. The higher task intensity demonstrated by females will likely lead to greater fatigue and may result in an inability to sustain a load carriage task or compromise the ability to perform a subsequent task/s [3]. When assessing the intensity of the military-relevant load carriage tasks, females worked at 70% VO_{2peak} for the more challenging speed and load conditions that are beyond the Australian Army baseline PES of 23 kg and 5.5 km·h^{-1} [7]. In contrast, male participants only elicited a relative intensity of ~53% VO_{2peak} for trials undertaken with loads of 35 kg and speeds of 6.5 km·h^{-1}. Further, this study did not demonstrate any differences in absolute exercise intensity, contrary to previous research that has reported greater absolute $\dot{V}O_2$ [22,23,55,56] and $\dot{V}CO_2$ [22] for males compared with females. Hudson et al. [20] hypothesised that males, being larger, would require a higher level of aerobic metabolism due to the greater lean body mass, but this outcome was not observed in the current study. In the current study, females demonstrated greater $\dot{V}O_2$ relative to body mass when compared with males across all loads and speeds (mean: 2.7 mL·kg^{-1}·min^{-1}), despite there being no difference in $\dot{V}O_2$ relative to lean mass. The differences observed in $\dot{V}O_2$ relative to body mass and relative to lean body mass are due to the similar absolute $\dot{V}O_2$ values observed between the sexes, despite women being lighter and possessing less lean body mass than males. Furthermore, males demonstrated an ~22% greater O_2 pulse than females, which, as absolute VO_2 was similar between sexes, reflects their lower heart rate and higher capacity for oxygen utilisation in the additional ~10 kg (~20%) of lean mass. As a result of their higher relative exercise intensity, females demonstrated a higher RER, indicating an increased reliance upon carbohydrates during these occupational tasks [57]. These differences in relative intensity and macronutrient utilisation between males and females need to be taken into consideration during both training and operations that impose load carriage tasks beyond that reflective of the PES.

In the current study, males and females demonstrated differing cardiovascular and perceptual responses during the walking tasks across loads and speeds. While the Control condition was perceived to be the same intensity between males and females, females perceived the Patrol and Marching Order conditions to be harder (~17% for RPE and ~33% for OMNI-RES), irrespective of speed. This supports previous research where females reported higher RPE values during walking whilst carrying absolute loads of up to 40 kg [24,58,59]. Past data have also reported no differences in RPE when carrying relative loads of up to 40% of body mass [22]. Importantly, RPE ratings are significantly correlated with cardiovascular responses [60,61], so it is not surprising that they exhibited a similar pattern in the current study. Females demonstrated greater HR responses than males, particularly as the magnitudes of speed and load increased. However, HR was only significantly different between sexes when walking at the 5.5 km·h^{-1} and 6.5 km·h^{-1} speeds across all loads, which supports past studies that employed absolute external loads at speeds above 4 km·h^{-1} [24,58,59]. Therefore, it is suggested that the 3.5 km·h^{-1} speed evoked a work intensity that was too low to elicit any differences in cardiovascular demands between sexes. It is evident that with the addition of external loads at or above moderate walking speeds, females demonstrated greater perceptual and cardiovascular demands than males. These findings are likely reflective of their lower physiological capacities and the reported changes in their biomechanical responses to the task demands.

Females employed a different respiratory strategy than males during the load carriage trials, where they typically decreased V_T and $\dot{V}_E$ and increased BF as work intensity increased. In the current study, females increased their BF by 7–14 breaths·min^{-1} across loads and by 4–11 breaths·min^{-1} across speeds, which was greater than the male responses (3–7 breaths·min^{-1} for both load and speed). This reflects the disproportionate increase in relative exercise intensity that females demonstrated with the heavier loads and faster speeds employed in the current study when compared to males. Past research has observed that the typical respiratory strategy in response to added external load is to increase $\dot{V}_E$, BF, and V_T due to the mechanical compression of the chest and lungs [62,63]. Further, the incommensurate responses in respiratory mechanics between sexes are also a result of females being shorter, which would translate to smaller lung volumes and would therefore require greater increases in B_F to meet the increased ventilatory demands. Moreover, during the faster walking speeds and heavier loads, females would also have a greater need to clear additional $\dot{V}CO_2$ because of the higher exercise intensity they must meet, which would require additional carbohydrate utilisation and evoke some level of bicarbonate buffering within the blood because of increased anaerobic metabolism. Importantly, the resultant increase in BF and workload on inspiratory muscles during prolonged high-intensity exercise can lead to diaphragmatic [64] and respiratory muscle fatigue [65]. Past studies demonstrated that when males and females were height-matched and completed an incremental exercise test whilst wearing a 20.4 kg backpack, there were no differences present between males and females for $\dot{V}_E$, despite males having greater lung volumes [56]. However, the current research applied the load with a backpack rather than a vest, where the compression of the chest can be a greater perturbation. Through identifying sex-specific respiratory differences during load carriage, additional training needs (e.g., inspiratory muscle training [66]) can be identified with the aim of enhancing the overall performance, health, and well-being of military personnel.

The results of this study identified many between-sex differences in the biomechanical, physiological, and perceptual responses to load carriage across various combinations of military-relevant speeds and loads. This highlights that there is a strong need to tailor training and personnel management approaches to address individual needs, particularly in sex-integrated scenarios. Firstly, the individualisation of training programs will further increase physical and physiological capacities, which are associated with increased physical performance and lower injury risk. Physical training programs that incorporate load carriage and that are targeted towards females have demonstrated reductions in RER and $\dot{V}O_2$ requirements, as well as increases in upper and lower body strength capacities [67]. Secondly, implementing periodised training approaches will promote training adaptation and ensure sufficient recovery. While group training has its advantages, it does not effectively address the unique relative workload challenges faced by females across all combinations of military-relevant speeds and loads. The adoption of customised periodisation strategies could be instrumental in overcoming this challenge. Further to this point, this study revealed that females are required to work at higher relative exercise intensities (%VO_{2peak}) than males when walking at speeds or loads that exceed the Australian Army PES requirements of 23 kg and 5.5 km·h^{-1} [7]. In turn, this increased physiological intensity demonstrated by female soldiers may impact the quality of subsequent activities if sustained over long periods. Thirdly, nutritional strategies could be developed to support training and occupational task performance. The metabolic data in the current study demonstrated that with heavier loads and faster walking speeds, females have a greater reliance on carbohydrate oxidation as a result of the greater exercise intensity [57]. Considering that load carriage tasks are typically prolonged, these data suggest that a greater emphasis should be placed on maintaining carbohydrate stores in female personnel to ensure that they are able to complete any high-intensity, mission-critical tasks following the more challenging load carriage marches. In summary, adopting an approach that emphasises individualisation in training programs, incorporates effective periodisation, and addresses specific nutritional needs will give better outcomes for both male and female soldiers.

From a biomechanical perspective, the higher risk of injuries among female military personnel (~2-fold increase) further highlights the need to tailor separate strategies for males and females [17,19]. Prior to entry, females tend to have lower physical fitness levels than males [58], and, as such, they may require more initial training and time to adapt to the required levels of strength and endurance. Addressing this disparity in fitness prior to recruit training could help overcome some of the specific challenges faced by less physically fit individuals, regardless of whether they are male or female [68]. Another critical aspect involves improving the physical fitness of serving soldiers in conjunction with gait education and retraining to overcome females' higher incidence of pelvis and foot injuries [19,52]. These injuries may be attributed to a potential lack of adaptation in the absolute biomechanical responses to heavier relative load carriage, considering that females are shorter, lighter in total and lean body mass, and possess lower aerobic and strength capacities [10]. Reduced injury incidence and positive gait adaptations have been shown for gait retraining using real-time biofeedback to monitor knee kinematics [69] and plantar pressures [70]. In terms of physical training, most between-sex kinematic differences in the current study were identified within the pelvis and hip region, where there are known anatomical and morphological differences [45]. Therefore, the between-sex anatomical differences and how they affect gait mechanics should be taken into consideration when prescribing training specific to military personnel that includes females to reduce injury risk. Further, in terms of education and gait retraining, the implementation of strategies aimed at reducing over-striding to mitigate augmented musculoskeletal stress may help to lessen the incidence of overuse injuries. Although outside the scope of this study, it is possible that shorter males may experience similar risks to females due to the need to over-stride, as previous research has indicated that height is a primary contributor to the biomechanical differences observed between sexes when carrying relative loads [50]. Importantly, through reducing injury occurrence and improving physical fitness, the risk of subsequent injuries [71], the number of working days lost [72], and the financial burden [73] will be decreased. This multifaceted approach addresses the concerns related to physical fitness and gait but also contributes to the overall well-being and performance of military personnel.

While our study provides valuable insights, it is important to acknowledge limitations that may influence its interpretation. Firstly, the utilisation of a treadmill within a controlled laboratory environment was necessary for the study to apply the various loads and speeds and undertake the wide array of biomechanical, physiological, and perceptual measurements. This may limit the real-world translation of the results, as treadmill and overground load carriage are not perfectly comparable for some physiological, perceptual, and biomechanical measures [74,75]. Separately, this study recruited a convenience sample that was anthropometrically representative of the Australian Army personnel [44], rather than a sample matched for body mass and height, and, as such, physical size could not be removed as a confounder. The variation in physical size, together with the differing levels of physical fitness, may explain the higher number of females who failed to complete all trials, particularly at the fastest walking speed and with the heaviest load. Another limitation was the inability to control for and standardise the participants prior to exposure to load carriage and training history, which may also have introduced potential confounders related to familiarisation with imposed loads and speeds within the study. Additionally, any fatigue manifesting from concurrent training within their job could have influenced the outcomes. These limitations highlight the need for future research to be conducted in the field over an extended duration. Additionally, to determine whether differences are due to biological sex, physical size, or fitness, it is essential to conduct studies involving both male and female soldiers who are matched for height and body mass. This approach would enhance understanding of the demands placed on individuals of different sexes during load carriage tasks reflective of military occupational demands.

5. Conclusions

In conclusion, this study revealed differences in relative exercise intensity between males and females during military-relevant load carriage tasks, with the variations observed in the physiological, perceptual, and biomechanical responses dependent on both speed and load. Females exhibited distinct differences in their gait mechanics, including increased relative stride length and step width (% height), as well as altered pelvic and hip biomechanics, which, together, aim to maintain stability in response to increased system perturbations and demands. Further, the observed differences in relative exercise intensity and respiratory mechanics between sexes highlight the importance of tailoring training and nutritional approaches, especially in sex-integrated scenarios. This will be particularly crucial in combat-centric roles such as infantry. The heightened injury risk among female military personnel, coupled with the challenges they face in sustaining a greater relative exercise intensity, emphasises the need for targeted interventions, specific periodisation, and nutritional strategies. Future research that investigates the modification of training load, load carriage exposure, and specific nutritional interventions will lead to better outcomes for female soldiers.

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