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The Effects of Walking with a Load in the Heat on Physiological Responses among Military Reserve Female Cadets

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ABSTRACT

International Journal of Exercise Science 13(2): 900-911, 2020. This study aimed to investigate the effects of walking in a hot and humid environment while wearing a combat suit with a load on physiological responses among the Malaysian Military Reserve Officer Training Unit (ROTU) female cadets. Eight healthy female ROTU cadets (age: 21.3 ± 1.0 years old; height: 156.3 ± 4.9 cm; weight: 55.6 ± 7.5 kg) participated in this randomised, crossover trial. They walked for 1 h on a treadmill at 3 km.h^{-1} while carrying either 8.2 kg load (WL) or without load (WOL) in a room maintained at 30°C and 70% relative humidity. Heart rate, rate of perceived exertion (RPE), and tympanic temperature were recorded at regular intervals during the trials. Nude body weight was recorded before and after the walk to determine body weight loss and sweat rate. Urine samples were also collected before and after the walk to determine urine specific gravity of the participants. There was a significant main effect of time and interaction for heart rate ($p < 0.001$) during the experimental trials. Tympanic temperature was significantly higher at 60th min in WL trial ($p < 0.05$) compared to the WOL trial. Similarly, RPE was found to be significantly higher in WL trial ($p < 0.01$) compared to the WOL trial. However, the percentage of body weight loss and sweat rate was significantly different between trials ($p < 0.05$). Wearing a combat suit with a load showed significantly increased metabolic demands compared to wearing combat suit alone during prolonged walking in a hot and humid environment.

KEY WORDS: Exertional heat stress, load-bearing, walking, military reserve unit

INTRODUCTION

Reserve Officer Training Unit (ROTU), or in the Malay language "Pasukan Latihan Pegawai Simpanan" (PALAPES) is established in Malaysian public universities to train undergraduate students as volunteer reserve officers for the armed forces in Malaysia. It was founded in 1979 by Brigadier General Dato 'Abul 'As bin Ismail, who was then the director of the Malaysian Territorial Army. However, the existence of ROTU in university reportedly began after the establishment of the Universiti Malaya's First Battalion Voluntary Infantry Soldier or in the Malay language "Batalion Pertama Infantri Askar Wataniah" on 3 April 1965 with 30 students (1). The main goal of ROTU is to train students with military skills and knowledge while contributing to national defence (19). The ROTU training mostly involves tough physical

training such as marching, walking, assault courses among others in the hot and humid conditions of Malaysian dense, tropical rainforests (37).

Heat illness, a condition when a person experiences symptom such as headache, nausea, fatigue and muscle cramp after prolonged exposure to the heat (9), often causes difficulty to the ROTU's physical training. While exercising, the human body will cool itself by sweating and heat will dissipate from the body (20). Heat illness usually happens when the body temperature increases, and sweating is insufficient to cool the body during hot and high humidity weather conditions. Increases in body temperature can also result in premature fatigue, possibly due to the effect of increased temperature upon brain function particularly during the planning of military tactical defence (33). Besides the army, heat illness often occurs in endurance athletes, labourers and those exposed to extremely hot temperatures (18). It was previously reported that training located in the hot and dry climate of South Texas has caused three heat strokes and 30 heat exhaustion cases due to dehydration and overheating in basic military trainees of the U.S. Air Force (13). A study conducted based on the marching activity found that most of the participants withdrew from the activity due to high body core temperature (>39^{o}C temperature) and heat exhaustion (22). Conversely, a mild weather condition also has the potential to cause heat illness. It has been reported that more than 9000 high school athletes were treated for exertional heat illness at the beginning of the autumn sports season and between 1995 - 2010, 35 football players died from exertional heat stress (25). In the military, a cadet from the Royal Military Academy in the United Kingdom had collapsed in environmental conditions of 18^{o}C and 72% relative humidity at the end of a marching training (39).

Heat stress, a condition when the body is under stress from uncompensated overheating, when prolonged, can progress to a more serious condition known as heat stroke (42). Heatstroke is described as a condition with an elevated core body temperature of more than 40°C which may cause central nervous system dysfunction, subsequent delirium, convulsion or coma (21, 48). In Malaysia, several clinical cases related to heat illness with one death in the armed and police forces were reported. According to the Malaysian Ministry of Health (30), a newly recruited trainee of Police Training Centre (PULAPOL) had died due to heatstroke on 16th March 2016 due to the global heatwave or Equinox phenomenon which occurred in Malaysia in March and April 2016. Moreover, the Health Ministry recorded 14 cases of heat-related illness during that period which comprised of 11 heat exhaustion and 3 heatstroke cases (43). In the Malaysian public universities, the numbers of female ROTU outnumbered their male counterparts. Based on the data from the year 2015 to 2017, the number of female ROTU has increased considerably from 870 to 1076 compared to male ROTU, which has shown a small increase from 750 to 755 (16, 50). It is not immediately clear why female students are interested to participate in ROTU. However, females have been found to cope better than males in a thermally stressed condition across varying humidity, with core temperature remaining at safe level up to 70% RH (31, 32). Furthermore, there is also an independent influence of gender on thermoregulation. The physiological gender-related differences in body temperature regulation between females and

males is due to a lower sudomotor activity, thermosensitivity and body surface area in females during exercise performed at a fixed rate of metabolic heat production (8, 14).

The Malaysian ROTU cadets field training activities remain a challenge in the humid and hot Malaysian climate particularly for the young recruits. In humid conditions, wearing the combat suit in the heat with a load can result in heat illness where the body is unable to maintain the thermal steady state (22). Military soldiers are required to wear their protective clothing as protection from any occupational hazards such as heat or chemicals during warfare, including carrying some weight which could hamper their mobility due to the garment stiffness, bulk and fit (10). According to Taylor (46), operation or any combat activities performed in the heat involving load carriage and armored protection with almost total body clothing coverage will overwhelm the physiological regulation and thermal impediment. In addition, distribution of clothing weight and additional layering of clothing can also be important factors which affect soldiers' work efficiency. Wearing a range of personal protective clothing garments while performing an obstacle course consisted of continuous walking and stepping can increase perceived exertion and metabolic rate by 2.4–20.9% when compared to a control condition, with increases above 10% being significant (10).

To our knowledge, to date, there is no data on thermoregulatory responses of the female ROTU cadets following prolonged walking with load in a hot and humid environment. A study on heat stress responses in walking among female ROTU cadets is essential to understand the physiological progression to heatstroke during marching in full gear. We hypothesised that walking with load in the hot and humid environment will significantly increase thermoregulatory demands. Therefore, the present study was to investigate the effects of combat suit with a load on heart rate, core (tympanic) body temperature, sweat rate and hydration status of the female ROTU cadets.

METHODS

Participants

Eight healthy female ROTU cadets from Universiti Sains Malaysia (USM) volunteered for this study. The physiological characteristics of the participants are presented in Table 1. To be included in this study, the participants had to be healthy with body mass index (BMI) of below 25, aged between 18 to 25 years old and actively training with at least three times per week of physical activity for a year. Participants who had any lower extremity or back pain and acute injuries were excluded from this study. In addition, the participants who were pregnant or consumed any supplements and medication were excluded. All the participants were briefed on the associated risk and discomfort of the procedure and they signed informed consent before the experiment. A randomised, crossover study design was adopted, with participants randomly assigned using a coin toss to start with either load-bearing (WL) or without load-bearing (WOL) trial, separated by one week. The schematic study design is presented in Figure 1. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (35). The study protocol conformed to the Declaration of Helsinki for human research and approved by the USM Human Research Ethics Committee

(USM/JEPeM/17020123). The sample size was calculated using G*Power version 3.1.9.2 (12). Based on a previous study, a sample size of eight participants was sufficient to detect a significant mean change in sweat loss between trials when given a relative effect size of 2.63, alpha of 0.05 and statistical power set at 80% with 95% confidence interval (5).

Table 1. Physical and Physiological status of the participants.

Parameters	Mean ± SD (*n* = 8)
Age (years)	21.3 ± 1.0
Height (cm)	156.3 ± 4.9
Weight (kg)	55.6 ± 7.5
BMI (kg.m^{-2})	22.8 ± 2.3
Fat (%)	28.5 ± 3.9
Fat Mass (kg)	16.1 ± 4.2
Fat-Free Mass (kg)	39.6 ± 3.5
Predicted VO_2max (L.min^{-1})	3.2 ± 0.1

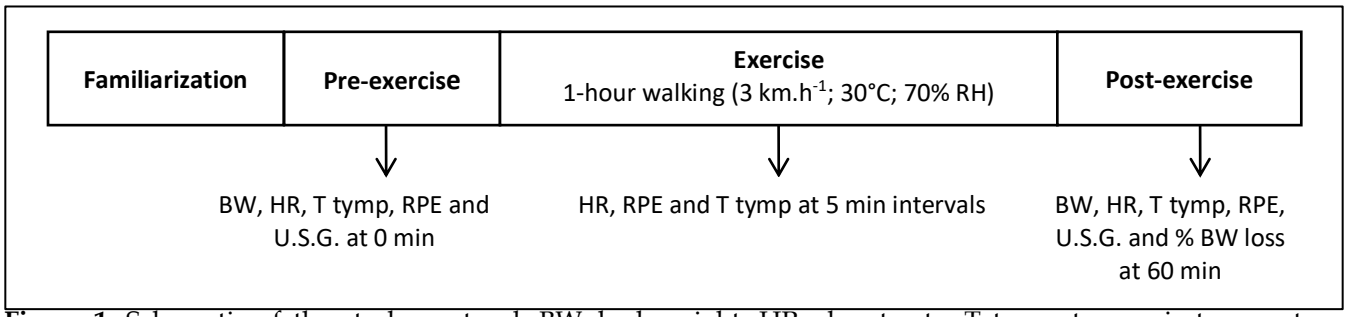

Figure 1. Schematic of the study protocol. BW=bodyweight, HR= heart rate, T tymp=tympanic temperature, RPE=ratings of perceived exertion, U.S.G.= urine specific gravity, RH= relative humidity

Protocol

All trials were conducted in a temperature-controlled exercise laboratory. Room temperature and relative humidity (whirling thermo-hygrometer, Brannan, England) were measured every 10 min throughout the trials. The participants were first familiarised by walking and wearing full combat suit on a motorized treadmill (Track Master TMX425CP, United States) at 3 km.h^{-1} for 15 min in 30°C environmental temperature and 70% relative humidity. Caffeinated food and drinks, including strenuous exercises 24 hours were avoided by the participants before the trials. Trials were scheduled during the follicular phase to avoid menstrual cycle influence by tracking their basal body temperature and no oral contraceptive pills were administered to minimise possible small endogenous rhythm of menstrual cycle (27). Standardisation of hydration was attained by instructing participants to eat similar breakfast 1-2 hours and drink at least 350 ml of water before reporting to the laboratory. The participants emptied their bladder, and nude weight was measured before changing into combat suits. They were euhydrated according to previously published urine specific gravity (U.S.G.) reference values of ≤ 1.020 (38). Predicted maximal oxygen consumption (VO_{2max}) was determined based on previous methods (40).

A 5-min warm-up on a treadmill at 3 km.h^{-1} was performed before each trial. In the WL trial, participants wore the full combat suit, carrying a rucksack over their shoulders, which was filled

with sandbags weighing 8.2 kg whereas, in the WOL trial, a full combat suit was worn without a load-bearing rucksack. The combat suit comprised of a t-shirt, long-sleeved camouflage shirt and trousers, a pair of calf-length socks and a pair of ankle-high boots. Both trials consist of walking on the treadmill at 3 $km.h^{-1}$ for one hour in 30°C environmental temperature and 70% RH, based on a modified procedure (5) with oral encouragements given throughout. No fluid was given during the trials. Immediately after the trials, participants were towel-dried and nude body weight was measured. Heart rate (S710, Polar, Finland), tympanic temperature (AG 9435, Microlife, Switzerland) and ratings of perceived exertion (RPE) (3) were measured at rest and during trials at 5 min intervals. Majority of our participants did not prefer an invasive method. Hence, to comply to human ethical guideline and to avoid losing valuable primary data, we have chosen to use tympanic temperature as a non-invasive surrogate measurement of core temperature. The validity and reliability of tympanic temperature during indoor exercise in the heat have been previously described (15). A cotton ball was inserted into the aural canal to insulate the probe from the environment to reduce the influence of environmental air on aural temperature environment. Urine was sampled before and after trials and analysed for U.S.G. using an in-house benchtop refractometer (Sports Science Lab, USM, Malaysia). Sweat rate and per cent body weight loss were calculated according to Aragón-Vargas (2) and Cheung and McLellan (6) respectively.

Statistical Analysis

All data were analysed using a statistical software package (IBM SPSS for Windows, Version 22.0., IBM Corp, Armonk, NY). The normality of data was verified using the Shapiro-Wilk test. Normally distributed data were presented as means ± SD (standard deviation). Repeated measures analysis of variance (ANOVA) used to compare differences over time between the trials and a Tukey's post hoc test was used in the event of a significant F value. Non-normally distributed data (tympanic temperatures, RPE and U.S.G.) were presented as median and interquartile range (IQR) with Mann-Whitney U test used to compare differences over time between the trials. Comparison of percentage body weight loss and sweat rate between the two trials was conducted using independent sample t-test. Significance difference was set at $p < 0.05$.

RESULTS

Heart rate: A significant main effect for time (Greenhouse-Geisser; $F = 121.8$; $df = 3.303$; $p < 0.001$; $\eta^2 = 0.897$) and a significant time x trial interaction effect (Greenhouse-Geisser, $F = 3.601$; df = 3.303; $p = 0.017$; $\eta^2 = 0.205$) were found. In the WL trial, the heart rate of the participants was significantly higher from the 10th to 35th and at the 50th min ($p < 0.05$) and at 40th to 45th and 55th to 60th min ($p < 0.01$) (Figure 2).

Tympanic Temperature: At 60th min, there was a significantly higher tympanic temperature in the WL (Median: 37.0, IQR: 0.4) compared to WOL trial (Median: 36.7, IQR: 0.5), $U = 11.5$, $p = 0.03$, $r = 0.54$. However, no significant differences between trials were found from 5th to 55th min (Figure 3).

Ratings of Perceived Exertion (RPE): The RPE was significantly higher in the WL trial [5th min (Median: 7.00, IQR = 2); 60th min (Median = 12.00 , IQR = 2)] compared to the WOL trial [5th min (Median: 6.00, IQR = 0); 60th min (Median = 8.00, IQR = 2)], from 5th min (U = 6.5, p = 0.004, r = 0.73) to 60th min (U = 0.5, p = 0.001, r = 0.84) (Figure 4).

Urine Specific Gravity (U.S.G.): The U.S.G. before trial [WL (Median: 1.023, IQR: 0.010); WOL (Median:1.019, IQR: 0.013)] and after trial [WL (median: 1.025, IQR: 0.012); WOL (median: 1.020, IQR: 0.014)] were not significantly different, Z = 1.01 , p= 0.314, r = 1.05).

Percentage of Body Weight Loss and Sweat Rate: There was a significant increase in percentage of body weight loss in WL (1.0 ± 0.2%) compared with WOL trial (0.8 ± 0.3%), $t(14)$ =2.26, p = 0.04, d = 1.13. Sweat rate was significantly higher between WL (0.6 ± 0. 13 $L.h^{-1}$) and WOL (0.4 ± 0.14 $L.h^{-1}$) trials, $t(14)$ =2.47, p = 0.027, d = 1.23.

Environmental conditions: Mean room temperature and relative humidity (RH) during WL and WOL trials were 33.2 ± 0.4°C, 71.6 ± 0.7% RH and 33.0 ± 0.7°C, 72.5 ± 1.2% RH respectively.

Figure 2

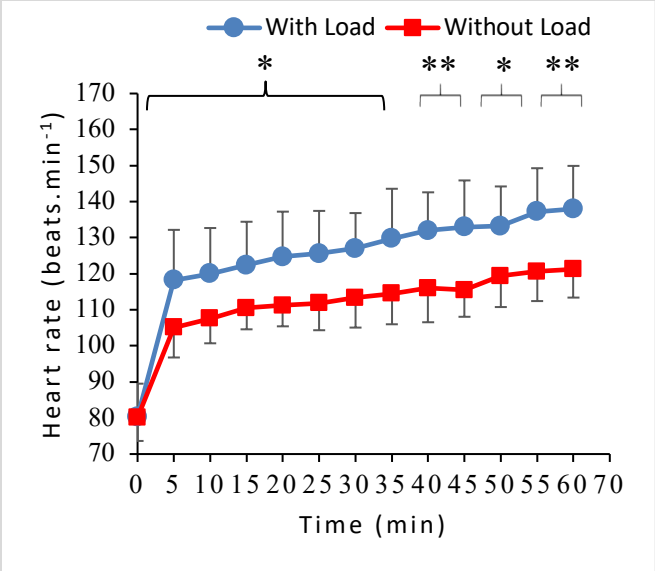

Figure 3

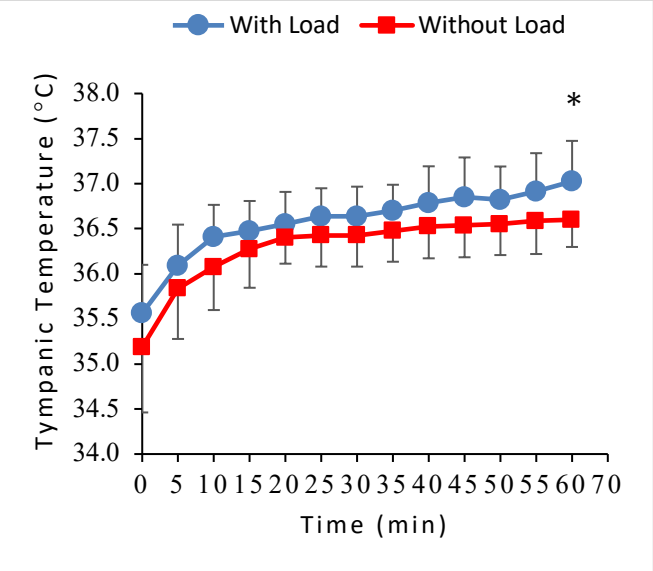

Figure 2. Heart rate and **Figure 3**. Tympanic temperature during the walking trials with load and without load. *p < 0.05 significantly different between trials; ** p < 0.01 significantly different between trials.

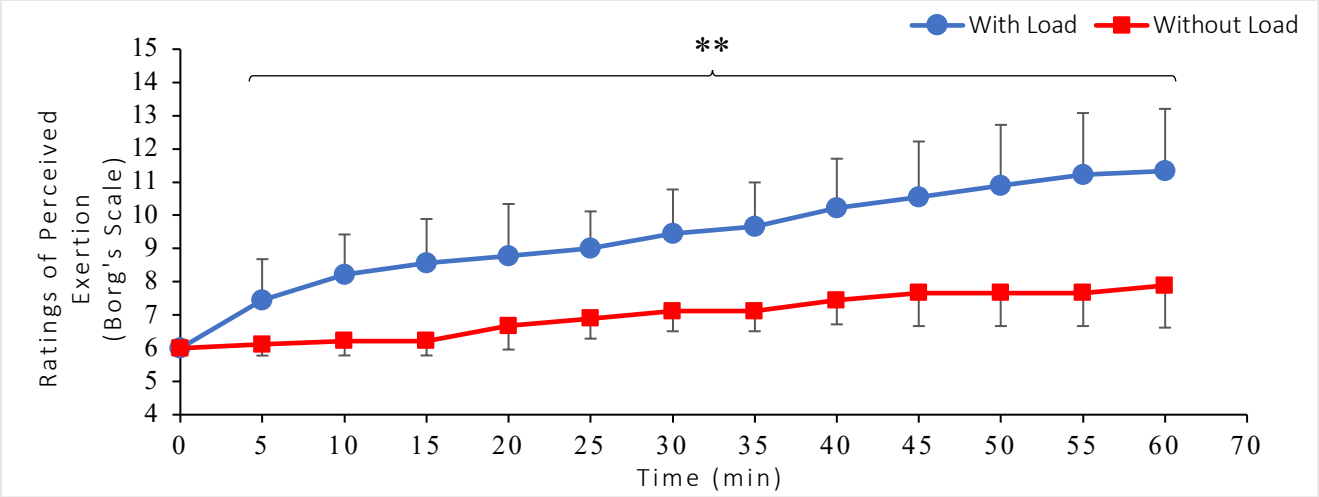

Figure 4. Ratings of perceived exertion (RPE) during walking trials with load and without load.
** $p < 0.01$ significantly different between trials.

DISCUSSION

The present study examined the effect of walking with a load in the heat on heart rate, tympanic temperature, RPE, sweat rate and per cent bodyweight loss of Malaysian ROTU female cadets. The main findings were that walking with a load in the heat significantly increased physiological and perceptual strain in young military female cadets. Ten minutes into walking while carrying 8.2 kg load, heart rates increased significantly, suggesting a small decline in stroke volume similarly observed in hyperthermic individual in the absence of dehydration (17).

The highest mean heart rate attained at the completion of the walk in the current study was 138 beats.min^{-1} which was much lower compared to a more physically demanding previous protocol (22) in which 37 full-time male soldiers marched 10 km at 5.5 km.h^{-1} while carrying over 40 kg of equipment in 23°C wet-bulb globe temperature (WBGT). Although the main requirement of military soldiers is to perform a march while carrying military essentials and equipment, Malaysian ROTU cadets were not assessed for this aspect. Only the march-past technique and form are assessed primarily in the ROTU cadets. Unlike their Australian counterparts (22) who must be able to complete a 10 km forced-march carrying 40 kg in less than 1 h 50 min to pass their minimum performance standard, Malaysian ROTU cadets are only required to pass the 2.4 km run by completing it under 13 min whereas full time Malaysian armed forces are required to run under 11 min (34). Although there was no previous written report, one of the Malaysian ROTU cadets from the current study revealed that they regularly marched 20-30 km in the jungle carrying 8.2 kg of essentials and occasionally carrying weaponry which is an additional 3 kg or more.

The Malaysian ROTU cadets generally clock up a minimum of 240 hours of training each year of their three years of undergraduate study (47). The compulsory physical endurance aspects of training in ROTU includes marching in parades, war exercises, cross obstacles, cross-country and hiking (19). The Malaysian weather, with a monthly highest recorded average temperature of 28.3°C (49), can considerably challenge the ROTU's thermoregulatory processes. Our present

study demonstrated that walking with a load in the heat did not differ significantly in tympanic temperature compared to the non-load bearing. However, the tympanic temperature was significantly increased at the completion of the walk with a load. The use of heavy equipment or clothing such as personal protection equipment or combat armor will have a direct impact on the ability to lose heat from the body (23). During prolonged walking with load, the highest attained tympanic temperature at the end of the trial was 38°C. This value has been indicated as the initial point of heat illness termed as heat exhaustion (21). Heat exhaustion is defined as mild-to-moderate illness due to water depletion that occurs between 37°C to 40°C whereas heatstroke, which is more severe, occurs at a much higher body core temperature of above 40°C (4, 6).

There were no signs or symptoms of heat exhaustion observed in the female ROTU cadets during the experimental trials in the heat. The lower walking intensity compared to other studies (10, 48) and the possible acclimation to heat may have prevented the rise of tympanic temperature to critical levels at the initial phase of load-bearing. We could only postulate as our study design could have been improved with the addition of heat-tolerance and maximal oxygen consumption protocol. Well-trained and heat acclimatized individuals typically present lower tympanic temperature which can be heat-protective. Two weeks of short-term 60 min endurance and sprint-interval exercise in the heating chamber has been shown to improve aerobic fitness, resulting in blunted body core temperature increase (29). Similarly, our colleagues reported that exercising on a bicycle ergometer for 60 min each day at 60% VO_2max in a hot and humid environment for 14 days caused significantly lower rectal temperature, heart rate, RPE and thermal sensation (41). Heat acclimatization stimulated the sweat gland sensitivity and improved sweating response at a lower core temperature threshold which promotes body cooling (23). However, we presume that if the exercise is prolonged or becoming more strenuous, tympanic temperatures may be higher in load-bearing ROTU cadets (11, 40).

The present results indicated a significant difference in sweat rate and percentage of body weight loss following walking in the heat wearing combat suit with a load. Wearing combat suit with load produced a higher percentage of body weight loss of 1.1% compared to wearing the combat suit without load which yielded 0.8% body weight loss. The current study's walking protocol with a load showed minimal dehydration in ROTU. A loss of > 2% body weight is considered excessive dehydration, impairing performance (44). Exercising in hot condition can cause sweating rate up to 1-1.5 $L.h^{-1}$ and may even reach 2 $L.h^{-1}$ under extreme efforts, providing a potential loss of excess heat by evaporation in the amount of 4500 kJ (24).

Limited water vapor permeability through the clothing, possibly increased the sweat production in trained or heat-acclimated subjects and caused physiological strain by promoting a faster rate of dehydration rather than increasing evaporative heat loss (6, 24, 36). Less permeable garments can increase the oxygen consumption between 13% to 18%, which could place an increased load to the metabolic system (10). In our study, the inner of the suit is made of natural fabric while the core material is made of natural fibers, which facilitates evaporation (45). However, some outer layer of the suit made of synthetic fibers that impaired sweat evaporation could be improved (6). Suitable material of military cloth such as active charcoal may be recommended

to increase the air permeability and induce lower strain (11). However, the main influence affecting the thermoregulatory changes to physiological strain in our study was neither the garment nor the hot and humid environment conditions as both variables were constant. Although one study found that protective vests alone can increase physiological strain independent of added load, we believe that the additional 8.2 kg load in our study were significantly higher to cause an effect compared to the previous study which used only a 1.3 kg load (7). Thus, we postulate that the load-bearing weight in our study may have caused an increased metabolic demand to the ROTU cadets, similar to a previous study (5).

We have chosen not to administer OCP during trials because regular OCP users have also been found to experience a slight endogenous rhythm of the menstrual cycle. Lei and colleagues found a significantly consistent but small quasi-phase increase of 0.15°C in resting core temperature during cycling in humid heat (26). Although we assume that all our participants experienced at least 16 days of follicular phase on average, we acknowledged the limitation may be in the length of the follicular phase which may vary between participants according to the timing of the luteinizing hormone surge (28). Ideally, future exercise heat research should control for early and late follicular phases in female participants menstrual phases.

In conclusion, the present data showed that load-bearing among female ROTU cadets significantly increased cardiovascular and psychological strain during one-hour walking in the heat, including increased thermal state at the final minutes of walking. Walking with load also significantly reduced hydration and increased sweat rate response in female ROTU cadets. The combat garment and the hot and humid environment were constant variables in both trials which did not affect the thermoregulatory changes.

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