Loaded March and FORCE Combat™ Performance: Effects of Heat Exposure and Previous Experience

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Abstract

Purpose: This study investigated the effects of heat exposure and previous experience on thermoregulatory and cardiovascular responses to performing a loaded march in the HEAT and on FORCE Combat™ circuit performance.

Methods: Ten civilians (inexperienced) and 10 infantry reservists (experienced) performed a 60 min loaded march (~35kg), in NORMAL (21±0.2°C) and HEAT (30±0.2°C) conditions and the FORCE Combat™ military physical performance evaluation. Participant groups were matched for morphology and physiological capacity.

Results: Out of the 10 experienced participants that participated in the loaded march in HEAT, 9 completed the full 60 min but only 5 of 10 inexperienced participants were able to do the same. Performing a loaded march in the HEAT caused a state of uncompensable heat stress (continuous increase in core temperature) for both the inexperienced and experienced participants. Heart rate (134±12vs143±9bpm,$p=0.027$), rate of perceived exertion (13±1vs10±1,$p\leq0.001$) and thermal comfort (1.9±0.5vs2.4±0.4,$p=0.011$) were lower in the experienced compared to the inexperienced group during the loaded march in HEAT. The FORCE Combat™ completion times were higher in HEAT compared to NORMAL, but lower in experienced participants in both conditions ($p\geq0.05$).

Conclusion: Both heat exposure and previous experience had an effect on cardiovascular, thermal and subjective measures during the loaded march and on completion time of the FORCE Combat™ circuit.

Introduction

It is well established that exercise in hot and humid environments has detrimental effects on performance due to the impact of hyperthermia, elevated cardiovascular stress and dehydration.[1,2] While these effects can impact the outcome in sports and athletic events, consequences during military operations may result in injury and possible loss of life. In this context, modern infantry soldiers are required to operate in any climate; carrying food, water and equipment, while wearing military personal protective equipment (PPE), in the form of helmet and ballistic plating. While wearing PPE is crucial to prevent life-threatening injuries, it remains energy costly,[3] reduces evaporative cooling and thus, increases the risk of hyperthermia by increased metabolic heat production and reduced heat loss.[4,5] This uncompensable heat stress, where maximal evaporative capacity is lower than required evaporative capacity, progressively increases core temperature and cardiovascular strain.[6, 7]

In 2017, the Canadian Army implemented a loaded march (5 km, wearing military PPE and carrying critical combat supplies weighing 35 kg) followed by a military-specific physical performance check (FORCE Combat™ circuit) for all of its members training for a land-based deployment. FORCE Combat™ is an evaluation designed to simulate the demands of dismounted or urban operations.[8] A large part of military training and performance testing is required to take place outside and an increasing number of military operations are taking place in extreme environmental conditions.[9] Although several studies have shown that performing moderate to high-intensity exercise in the heat while wearing PPE can induce uncompensable heat stress,[10,11] no previous studies have examined the cardiovascular and thermoregulatory response to performing a 5 km loaded march in a warm and humid environment while wearing military PPE.

Furthermore, several studies have suggested that previous task experience can have a beneficial effect on performance outcome and improve task solving tactics.[12,13] FORCE Combat™ is required to be performed by all members of the Canadian Army training for land-based deployment, ranging from soldiers in the field to truck drivers and desk clerks. However, the effects of heat exposure and previous experience on a loaded march and the FORCE Combat™ circuit performance has yet to be determined.

Consequently, the purpose of this study was to investigate the effects of heat exposure and previous experience on thermoregulatory and cardiovascular responses to performing a 60 min loaded march in the HEAT and on FORCE Combat™ circuit performance. More specifically, 10 inexperienced and 10 experienced men performed a loaded march at NORMAL temperature and in HEAT, where the effects of heat exposure and previous experience on thermoregulatory and cardiovascular responses and loaded march performance were assessed. Following the loaded march, an assessment of performance on the FORCE Combat™ circuit was performed, where the effects of heat exposure and previous experience on performance outcome were investigated. Based on results from previous studies,[12-15] it was hypothesised that performing a loaded march in the heat would have a greater negative effect on thermoregulatory and cardiovascular responses, thermal comfort and rate of perceived exertion (RPE), and FORCE Combat™ circuit performance in inexperienced participants compared to experienced participants.

Methods

Participants

A total of 20, 19–35 year-old healthy male participants were recruited. Ten participants were recruited from the civilian population with limited to no previous experience with a loaded march (INEXP), and 10 were reservist Canadian Armed Forces (CAF) members with extensive previous experience with loaded marching (EXP). Efforts were made to select participants in both groups to match for morphology (height, weight, body composition) and physiological capacity (VO^2max). Ethics approval for this study was received from the University of Ottawa Research Ethics Board, and the study was conducted following the guidelines of the Helsinki Declaration.

Preliminary session

Participants recruited for this study were asked to undertake a preliminary session before any experimental data was collected. During the preliminary session, written consent was obtained from each participant and they also filled out the Par-Q & You health questionnaire[16] and the AHA/ACSM Health/Fitness Pre-participation Screening Questionnaire.[17] Height (Seca 217 Stadiometer, Seca, Hamburg, Germany) and weight (Sartorius Combics 2, Sartorius AG, Goettingen, Germany) were recorded, as well as an estimate of body composition using bioelectrical impedance analysis (InBody 520, InBody USA). The InBody 520 has previously been validated against the gold standard for body composition measurements, Dual Energy X-ray Absorptiometry.[18] Body surface area was estimated using the following equation developed by Dubois and Dubois.[19]

$$\text{BSA } (kg/m^2) = (height^{0.425} \times weight^{0.725}) \times 0.007184$$

Measurement of maximal oxygen consumption (VO2max) was also performed, using a metabolic cart system (FMS Field Metabolic System, Sable Systems International, Las Vegas, NV) during an incremental stepwise treadmill protocol (i.e., 1 min incremental stages until exhaustion).[20]

Experimental procedures

Participants recruited for this study were asked to participate in three experimental sessions; an unloaded march at NORMAL temperature (21±0.7°C, 47±4% RH), a loaded march at NORMAL temperature (21.0±0.2°C, 49±3% RH) and a loaded march in the HEAT (30±0.2°C, 46±2% RH). Acclimation status of the participants was not assessed; however, all data collection was conducted between November and March where any heat acclimatisation due to weather should be negligible and none of the participants had occupations requiring them to work outside. For the loaded march, the participants wore military gear (including PPE) (25.1±0.5 kg) and a day pack, equal to a total external load of 35.1±0.5 kg. The unloaded march was used to familiarise participants with the equipment and procedures of the trial and to rule out any difference in thermal and cardiovascular responses between the participant groups. The unloaded march was performed on the initial experimental visit to the lab, whereas the order of the loaded march at NORMAL temperature and HEAT was randomised. All experimental sessions were separated by a minimum of four days to avoid any effects of fatigue. Participants were asked not to perform strenuous physical activity 24 hours prior to an experimental session, and abstain from alcohol and caffeine consumption for a minimum of 6 hours before testing. Participants were also encouraged to drink a minimum of 500 ml of water the night before and arrive in a fasted state. All experimental sessions took place in the morning between 7.00 and 11.00 am. Upon arrival, participants ingested a telemetric pill (Jonah™ Ingestible Core Temperature Capsule, Philips, NV, USA), used to measure core temperature (T_{core}). Nude weight and equipment weight were then recorded (Sartorius Combics 2, Sartorius AG, Goettingen, Germany) before participants were equipped with a heart rate (HR) monitor (Garmin Forerunner 310xt, Canton of Schaffhausen, Switzerland) and iButtons (Thermocron iBUTTONS® model DS1922H, Maxim Integrated, CA, USA) on 12 skin sites to measure skin temperature (Tskin). Following the equipment placement, participants donned the standardised military uniform with PPE and the day pack (total 35.1±0.5 kg). Participants then entered a climate-controlled chamber (3.3 m length x 2.3 m width x 2.3 m height), containing a precalibrated treadmill (True 850, True Fitness Technology, St. Louis, MO, USA). A facemask connected to a Field Metabolic System (FMS Field Metabolic System, Sable Systems International, Las Vegas, NV) was fitted on the participants, for the measurement of energy expenditure. Next, participants stood on the treadmill for a 10 min period of baseline data collection. Participants were then asked to walk on the treadmill at a speed of 5.17 km/h with a grade of 1%. Energy expenditure, HR and T_{skin} were measured continuously, T_{core} was recorded every 5 min, while thermal comfort (ASHRAE scale) and RPE was recorded every 10 min. The trial lasted 60 min or until participants' voluntary termination. Following the completion of the march, the participant exited the climate chamber, removed the day pack and within 5 min the FORCE Combat™ circuit was initiated. The FORCE Combat™ circuit is an evaluation designed to simulate the demands of urban operations.[8] The circuit consisted of four military physical performance tasks (20-meter rushes, sandbag lifts, loaded shuttle and a sandbag drag) performed continuously. The FORCE Combat™ circuit was performed outside the environmental chamber at room temperature (~22°C). Following the completion of the FORCE Combat™ circuit, a post-measurement of nude body and equipment weight was performed.

Loaded march clothing and equipment

For the loaded march (NORMAL and HEAT0), in addition to cotton socks, cotton t-shirt, walking boots and uniform (approximately 3 kg), participants wore a fragmentation vest (7 kg), a tactical vest (10 kg), C7 Colt replica rubber rifle (3.7 kg), a helmet (1.6 kg) and a day pack (10 kg), for a total external load of ~35.3 kg.

Skin, core and body temperature measurement

Wireless temperature sensors (Thermocron iBUTTONS® model DS1922H, Maxim Integrated, CA, USA) located on 12 sites: forehead, upper back, lower back, abdominal area, quadriceps, hamstrings, front calf, back calf, chest, biceps, forearm and hand were used to measure $T_{skin.}$ They were affixed to the skin using 3M Transpore tape (3M Canada, ON, Canada). The response time of the iButtons is 0:28±0:01 sec. Weighted mean skin temperature (Tskin) was calculated using the following skin site weightings: head 7%, hand 4%, upper back 9.5%, chest 9.5%, lower back 9.5%, biceps 9%, forearm 7%, abdominals 9.5%, quadriceps 9.5%, hamstring 9.5%, front calf 8.5% and back calf 7.5%.[21] Tcore was measured using a telemetric pill (Jonah™ Ingestible Core Temperature Capsule, Philips, NV, USA), and the signal from the telemetric pill was received, monitored and recorded on a Vital Sense Integrated Physiological Monitor (VitalSense, Philips, NV, USA). The thermal gradient between the core and periphery was calculated using the following equation.

$$\text{Thermal gradient} = T_{core} - T_{skin}$$

Physiological strain index

The Physiological Strain Index was calculated using the equation developed by Moran et al.[22]

$$PSI = 5(T_{core}t - T_{core}0)x(39.5 - T_{core}0)-1 + 5(HRt - HR0)\ x(180 - HR0)-1$$

where $T_{core}0$ is resting core temperature, and $T_{core}t$ is the final core temperature. HR0 is resting heart rate and HRt is final heart rate.

Heart rate, RPE and thermal comfort

Heart rate (HR) was measured using a Garmin Forerunner 310x (Garmin Ltd., Canton of Schaffhausen, Switzerland). The Garmin Forerunner 310x collected multiple samples per min, which were averaged and presented as the mean of a five min segment. The Borg Scale[23] was used to assess participants RPE and the 7-point ASHRAE scale[24] was used to determine the participants' perceived thermal comfort. Participants were asked to rate their RPE and thermal comfort level at the end of the baseline period and every 10 min during the march.

FORCE Combat™ circuit

To measure the participants' military physical performance following the loaded march, total time to complete the FORCE Combat™ circuit was recorded. The FORCE Combat™ circuit consists of four military physical performance tasks: 20 m rushes with a drop to prone position every 10 m (4x), sandbag lifts (30x 20 kg sandbags lifted to a height of 1 m), an intermittent loaded shuttle carrying a 20 kg sandbag (participants perform 5x 40 m loaded shuttles, intermitted by a 40 m unloaded shuttle) and a 20 m sandbag drag (pull load equivalent to 330 N) performed continuously. A detailed description of the procedures of the FORCE Combat™ circuit are found elsewhere (www.forcecombat.ca). Total time (sec) to complete all four tasks were used as the performance measure. None of the participants in either group had previously been exposed to the specific evaluation used in this study.

Statistical analysis

Due to previous pilot work on the FORCE Combat™ circuit showing an approximate 10% improvement from the first to second attempt, and no significant improvement from the second to third attempt[8], results recorded following the unloaded march were used only to confirm the absence of a difference in baseline marching data between experienced and inexperienced participants. Before performing any statistical analysis, all samples were tested for normal distribution. To compare changes over time and the effect of condition (NORMAL and HEAT), a two-way repeated measures ANOVA was used with an LSD post-hoc test to determine where significant differences occurred. An independent sample t-test was used to determine the effects of experience level. Differences in mean values for the total duration of the trial were compared for the effect of condition and experience level using a two-way ANOVA, with paired and independent sample t-test post-hoc tests to determine where significant differences occurred. A Bonferroni alpha correction was made for multiple t-test comparisons. Results were presented as mean±SD, and effect size was determined using Cohen's d and partial eta squared ($p\eta^2$). All statistical analyses were performed using SPSS 17.0 (IBM SPSS Statistics, Armonk, NY, USA).

Results

Participant characteristics and loaded march results for INEXP and EXP are found in Table 1. Apart from the difference in previous loaded march

Table 1: Participant characteristics for the INEXP and EXP group. BMI (Body Mass Index); BSA (Body Surface Area).

	INEXP	EXP	T-statistic
Demographics			
n	10	10	
Age	26±3	23±5	t(18)=1.378, p=0.185
Height (cm)	183.4±8.4	178.3±4.1	t(18)=1.729, p=0.101
Body mass (kg)	80.9±9.4	78.6±13.2	t(18)=0.495, p=0.651
BMI ($kg*m^2$)	24.2±3.2	24.7±3.4	t(18)=-0.345, p=0.734
BSA (m^2)	2.03±0.13	1.96±0.16	t(18)=0.720, p=0.481
Lean body mass (kg)	70.5±7.5	66.8±7.4	t(18)=1.095, p=0.288
Body fat %	12.1±7.3	14.1±6.2	t(18)=-0.649, p=0.525
VO2max ($ml*min^{-1}*kg^{-1}$)	49.1±4.3	49.2±4.9	t(18)=-0.053, p=0.958
Loaded March			
Energy expenditure ($kJ*min^{-1}*kg^{-1}$)			
NORMAL	0.44±0.03	0.42±0.04	t(18)=0.624, p=0.540
HEAT	0.45±0.04	0.45±0.04	t(18)=0.240, p=0.813
Water loss (l)			
NORMAL	1.2±0.2	1.3±0.2	t(18)=1.146, p=0.268
HEAT	1.4±0.3	1.6±0.3	t(18)=1.523, p=0.146
%VO_2max			
NORMAL	42.2±4.9	40.4±1.7	t(18)=1.102, p=0.285
HEAT	43.7±5.0	42.3±3.7	t(18)=0.720, p=0.482
Load-to-body mass ratio (%)			
NORMAL	43.9±4.4	45.3±6.5	t(18)=-0.549, p=0.590
HEAT	43.9±4.8	45.4±6.2	t(18)=-0.554, p=0.587
Total work performed (kJ)			
NORMAL	58.7±4.9	57.8±6.9	t(18)=0.324, p=0.750
HEAT	58.8±0.5	57.5±6.5	t(18)=0.481, p=0.637

experience, there were no differences in participant characteristics between the two groups. There were also no differences in energy expenditure, water loss, loaded march intensity (%VO_2max), load-to-body mass ratio and total work performed (kJ) between INEXP and EXP in either of the experimental conditions.

Loaded march completion rates

All participants in both groups completed the unloaded march at NORMAL temperature. All 10 participants completed the loaded march at NORMAL temperature in EXP, and 9 of the 10 participants completed the loaded march in HEAT. The one EXP participant unable to complete the loaded march in HEAT asked to terminate the trial after 40 min due to gastric distress. In INEXP, 8 of the 10 participants were able to complete the loaded march at NORMAL temperature, and only 5 participants were able to complete the full 60 min of loaded march in the HEAT. One participant asked to stop the trial after 25 min in the NORMAL condition due to neck pain and migraine symptoms from the external load and he did not attempt the loaded march in the HEAT. The data from this participant was not included in the data analysis. Four other participants in INEXP requested to stop the trial before 60 min in the HEAT condition, due to exhaustion and intolerable discomfort.

Given the inability of several participants to continue the trial beyond 30 min in INEXP and 40 min in EXP, a statistical analysis comparing the effect of time and condition was performed only up until 30 min in INEXP and 40 min in EXP.

Cardiovascular and thermoregulatory responses

The HR responses to a loaded march in a NORMAL and HEAT condition are found in Figure 1A and B, for INEXP and EXP respectively. A main effect of time ($F(8)=168.681$, $p<0.01$, $p\eta^2=0.960$) and condition ($F(1)=6.947$, $p=0.034$, $p\eta^2=0.498$) was observed in EXP for HR, as well as an interaction ($F(8)=6.204$, $p<0.01$, $p\eta^2=0.470$) between time and condition. In this group, a continuously steeper increase in HR over time was observed in the HEAT condition compared to NORMAL, from 20 to 40 min. A main effect of time ($F(6)=64.397$, $P<0.01$, $p\eta^2=0.902$) and condition ($F(1)=7.029$, $p=0.033$, $p\eta^2=0.501$) for HR was also observed in INEXP, with HR increasing over time and being higher in the HEAT compared to NORMAL. However, there was no interaction ($F(6)=3.631$, $p=0.072$, $p\eta^2=0.342$) between the two. Mean HR for the total duration of the trial (Figure 1C) was significantly higher in HEAT compared to NORMAL, in both the INEXP (8%) ($t(7)=-3.485$, $p=0.01$, $d=1.18$) and the EXP group (7%) ($t(7)=-4.964$, $p<0.01$, $d=1.13$).

Although there was no difference in HR between INEXP and EXP at any specific time point, mean HR was 4.4% ($t(14)=2.642$, $p=0.019$ $d=1.32$), and 5.6% ($t(14)=2.486$, $p=0.026$, $d=1.25$) higher in INEXP compared to EXP, in the NORMAL and HEAT conditions respectively (Figure 1C).

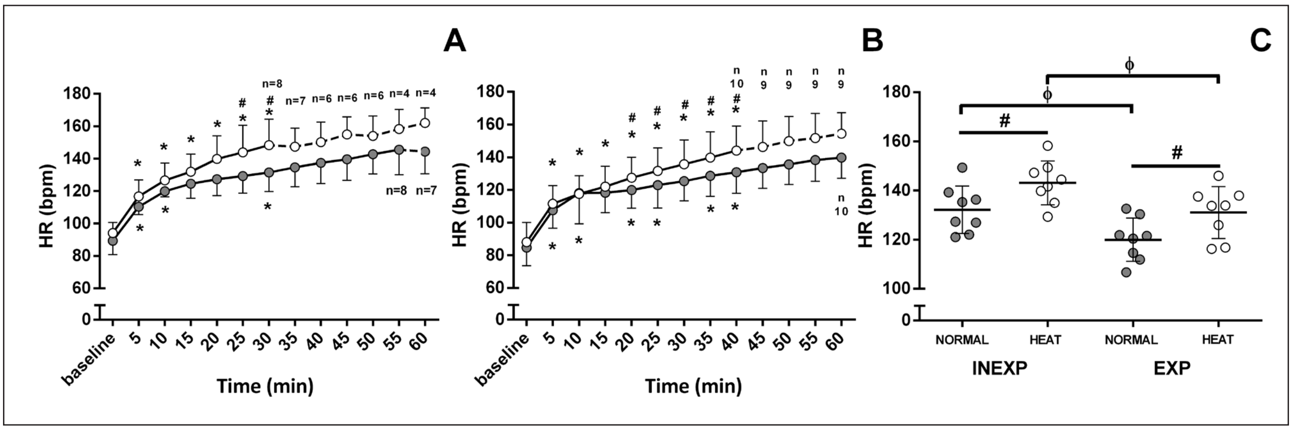

*Figure 1: Cardiovascular responses to performing a loaded march in NORMAL and HEAT condition for inexperienced (A) and experienced (B) participants and mean values (C). *significantly different from previous time point, # significant difference between NORMAL and HEAT, Φ significant difference between inexperienced and experienced. p≤0.05.*

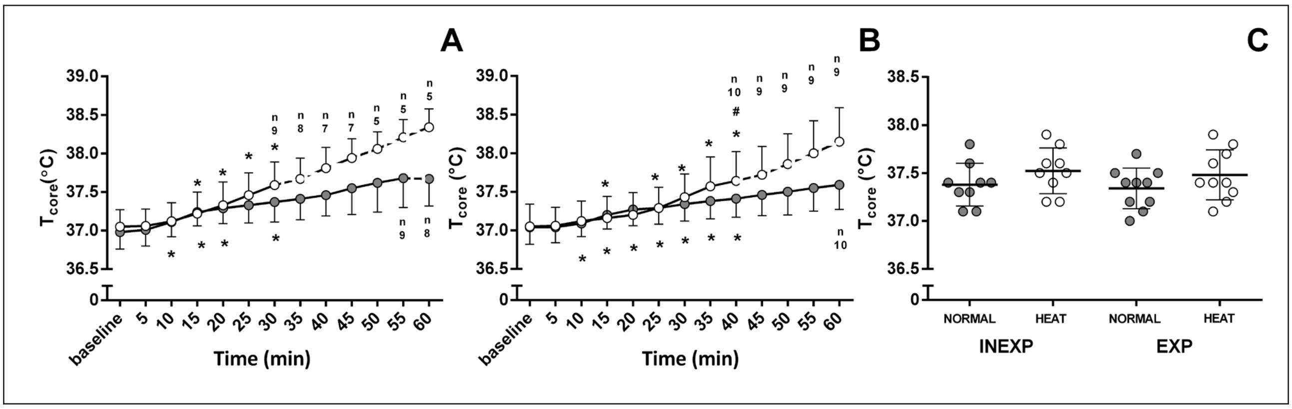

*Figure 2: Core temperature responses to performing a loaded march in NORMAL and HEAT condition for inexperienced (A) and experienced (B) participants and mean values (C). *significantly different from previous time point, # significant difference between NORMAL and HEAT, Φ significant difference between inexperienced and experienced. p≤0.05.*

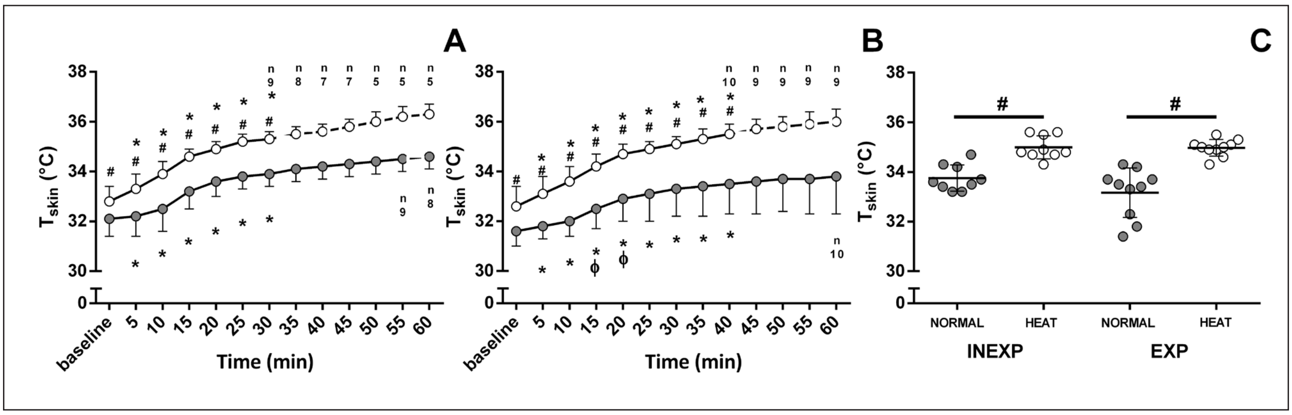

*Figure 3: Skin temperature responses to performing a loaded march in NORMAL and HEAT condition for inexperienced (A) and experienced (B) participants and mean values (C). *significantly different from previous time point, # significant difference between NORMAL and HEAT, Φ significant difference between inexperienced and experienced. p≤0.05.*

Change in T_{core} over time is seen in Figure 2A and B, for INEXP and EXP respectively. A main effect of time ($F(6)=30.304$, $p<0.01$, $p\eta^2=0.791$ and $F(8)=45.012$, $p<0.01$, $p\eta2=0.833$ for INEXP and EXP respectively) and an interaction ($F(6)=4.763$, $p=0.042$, $p\eta^2=0.371$, and $F(8)=6.451$, $p<0.01$, $p\eta^2=0.418$ for INEXP and EXP respectively) between time and condition was observed in both INEXP and EXP but there was no main effect of condition. Increase in T_{core} was significantly steeper in HEAT compared to NORMAL in both INEXP and EXP. Mean T_{core} for the duration of the loaded march was not different between conditions (NORMAL and HEAT) in either INEXP ($t(8)=-1.886, p=0.096$), or EXP ($t(9)=-1.709$, $p=0.122$), and there was no effect of experience level on T_{core} ($t(17)=0.379$, $p=0.709$ and $t(17)=0.366$, $p=0.719$, NORMAL and HEAT respectively) (Figure 2C).

A main effect of time ($F(6)=144.602$, $p<0.01$, $p\eta^2=0.948$ and $F(8)=61.494$, $p<0.01$, $p\eta^2=0.872$ for INEXP and EXP respectively) and condition ($F(1)=76.533$, $p<0.01$, $p\eta^2=0.905$ and $F(1)=46.998$, $p<0.01$, $p\eta^2=0.839$ for INEXP and EXP respectively) was observed for T_{skin}, in both INEXP and EXP (Figure 3A and B). There was also a significant interaction ($F(6)=15.387$, $p<0.01$, $p\eta^2=0.658$ and $F(8)=9.193$, $p<0.01$, $p\eta^2=0.505$) for INEXP and EXP respectively) between time and condition for T_{skin}, where a steeper increase in T_{skin} was observed over time in the HEAT condition compared to NORMAL, for both INEXP and EXP.

T_{skin} for the total duration of the loaded march was 3.7% (t(8)=-12.508, $p<0.01$, d=2.45) and 5.5% (t(8)=-6.434, $p<0.01$, d=2.47) higher in HEAT compared to NORMAL in INEXP and EXP respectively (Figure 3C). There was no effect of experience level on T_{skin} in either the NORMAL (t(17)=1.607, p=0.127) or HEAT condition (t(17)=0.102, p=0.920).

The mean thermal gradient between periphery and core was significantly reduced during the loaded march in the HEAT compared to NORMAL (3.8±0.4 vs 2.8±0.5°C (t(8)=8.601, $p<0.01$, d=1.98) in INEXP and 4.3±0.9 vs 2.7±0.3°C in EXP (t(9)=5.220, $p<0.01$, d=2.18). At the end of the loaded march in HEAT the thermal gradient between core and periphery was reduced to 2.2±0.2°C and 2.2±0.3°C in INEXP and EXP respectively.

Rate of perceived exertion and thermal comfort

Rate of perceived exertion (RPE) was not different between the NORMAL and HEAT condition in either INEXP (t(8)=-2.116, p=0.067), nor EXP (t(9)=-1.853, p=0.097) (Figure 4A). However, EXP reported a 26% lower RPE in the NORMAL condition (t(17)=2.785, p=0.013, d=1.24) and a 25% lower RPE in the HEAT condition (t(17)=4.371, $p<0.01$, d=2.), compared to INEXP.

Thermal comfort scores were significantly higher in the HEAT compared to the NORMAL condition, in both INEXP and EXP (34% (t(8)=-5.315, $p<0.01$,d=1.85) and 47% (t(9)=-5.459, $p<0.01$,d=1.54) respectively) (Figure 4B), meaning participants were less comfortable performing the loaded march in the HEAT compared to the NORMAL condition. Participants in EXP group also reported lower thermal comfort scores in both the NORMAL and HEAT condition, compared to INEXP (38% and 56% lower in NORMAL (t(17)=2.724, p=0.014, d=1.34) and HEAT (t(17)=2.849, p=0.011, d=1.34) respectively).

Physiological Strain Index

Performing a loaded march in the NORMAL condition caused a moderate physiological strain for participants in both the INEXP and EXP group and when performing the loaded march in the HEAT, both groups reached the high physiological strain zone (Figure 5). Experience level had no effect on Physiological Strain Index, and there was no difference between INEXP and EXP in either condition (NORMAL t(16)=1.251, p=0.123; and HEAT t(16)=1.082, p=0.519).

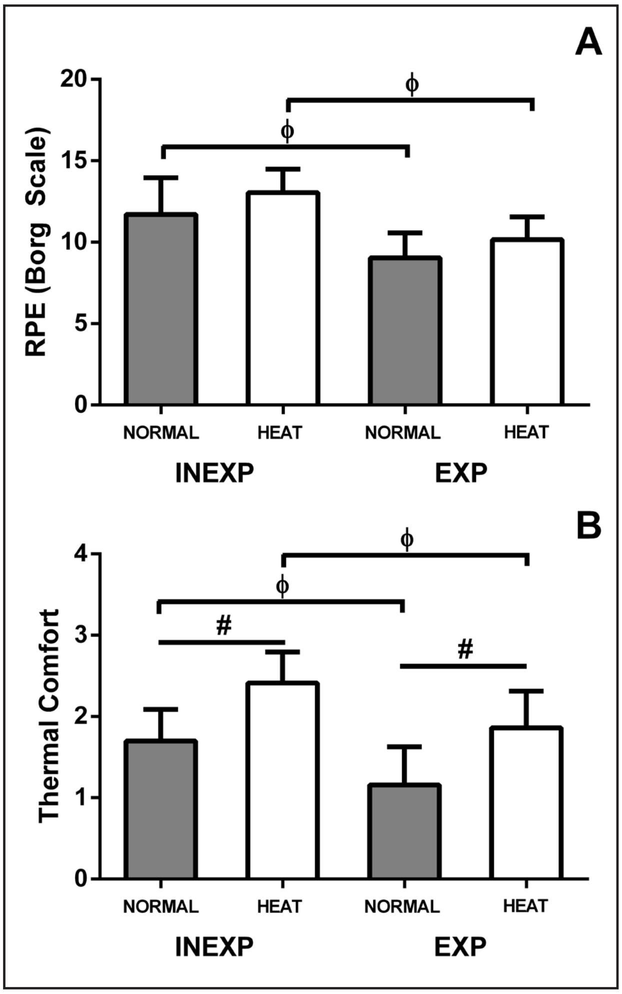

Figure 4: Mean rate of perceived exertion (RPE) (A) and mean thermal comfort scores (B) for the inexperienced and experienced group during a loaded march in a NORMAL and HEAT condition. # significant difference between NORMAL and HEAT, Φ significant difference between INEXP and experienced group. p≤0.05.

FORCE Combat™ circuit performance

During the loaded march in the NORMAL condition, one of the EXP participants injured his shoulder, which severely affected his performance time on the FORCE Combat™ circuit. Therefore, his results were excluded from the analysis. Completion time on the FORCE Combat™ circuit was significantly affected by both condition and experience level (Figure 5). Completion time was significantly higher in the HEAT compared to the NORMAL condition, where INEXP increased completion time by 15% (88 sec) (t(8)=-3.816, $p<0.01$, d=0.73) and EXP increased completion time by 9% (43 sec) (t(8)=-3.670, $p<0.01$, d=0.73). There was also a difference in FORCE Combat™ circuit completion time between

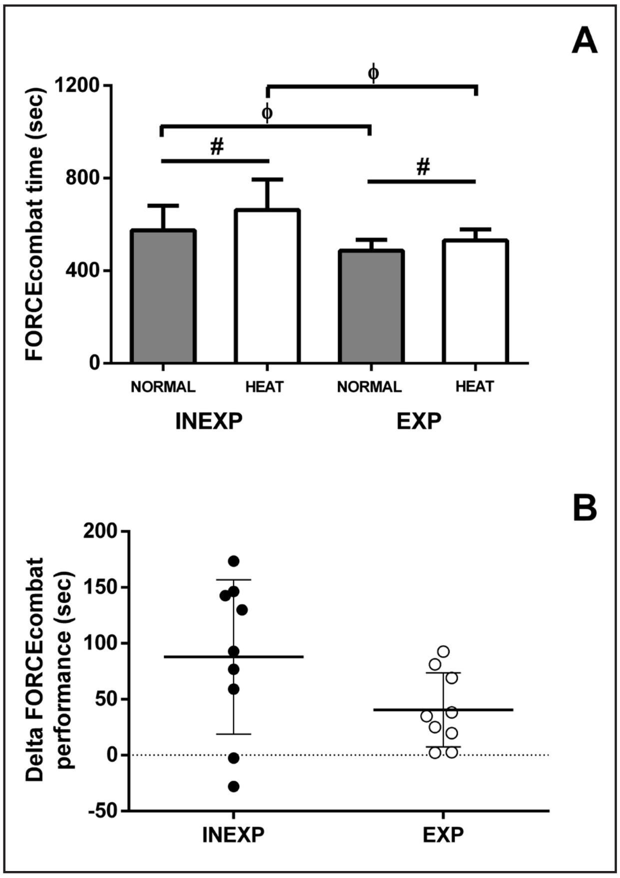

Figure 5: Calculated Physiological Strain Index at the end of an unloaded march and loaded march in NORMAL and HEAT for inexperienced and experienced participants. # significant difference between NORMAL and HEAT, Φ significant difference between INEXP and experienced group. p≤0.05."

EXP and INEXP, where EXP completed the FORCE Combat™ circuit significantly faster than INEXP, in both conditions (88 sec, or 10.7% faster in NORMAL ($t(16)=2.262$, $p=0.038$, $d=0.73$) and 132 sec, or 14.3% faster in the HEAT condition ($t(17)=2.946$, $p<0.01$, $d=1.27$) (Figure 6A). The difference in completion time between the NORMAL and HEAT condition is seen in Figure 6B. There was a trend towards a larger difference in completion time between the NORMAL and HEAT condition in the INEXP compared to EXP group; however, the difference was not significant ($t(16)=1.851$, $p=0.08$).

Discussion

The purpose of this study was to investigate the effects of heat exposure and previous experience on thermoregulatory and cardiovascular responses to performing a 60 min loaded march and on FORCE Combat™ circuit performance. Results showed that heat exposure had a negative effect on completion

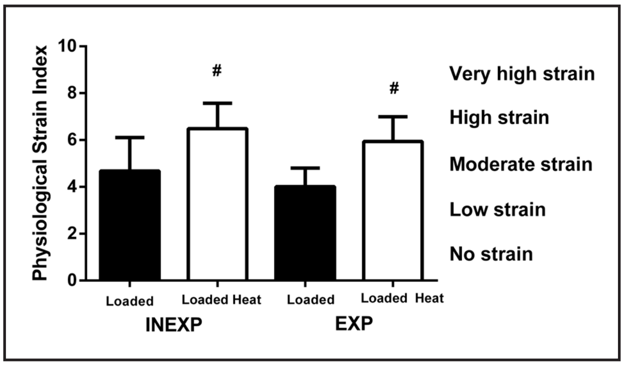

Figure 6: FORCE Combat™ completion times following a loaded march in a NORMAL and HEAT condition for inexperienced and experienced participants (A) and difference in completion time between NORMAL and HEAT condition (B). # significant difference between NORMAL and HEAT, Φ significant difference between inexperienced and experienced. p≤0.05.

rate, thermoregulatory, cardiovascular responses and FORCE Combat™ circuit performance. Performing a loaded march in HEAT (30±0.2°C, 46±2% RH) while wearing military PPE led to a state of uncompensable heat stress for participants in both the EXP and INEXP group. The two groups were matched for anthropometrics and VO^{2}max; however, the group with previous task experience (EXP) had a higher completion rate and lower HR, RPE and thermal comfort scores in the HEAT condition compared to the INEXP group. T_{skin} and T_{core} were not affected by experience level.

Thermoregulatory and cardiovascular responses to loaded march in heat

PPE is designed to shield humans from external bodily harm. The properties of PPE cause a reduction in heat loss ability, due to the impermeable nature with which the equipment is constructed. Studies have reported a reduced heat loss ability in participants wearing different types of PPE, such as in soldiers wearing nuclear, biological and chemical protective ensembles,[7] firefighters,[25] and football players wearing pads and helmets.[11] The reduced heat loss can cause a state of uncompensable heat stress, depending on the intensity of the activity and environmental temperature.[6] Based on the continuous increase in HR, T_{skin} and T_{core} observed in this study, the results suggest that performing a loaded march in HEAT (30±0.2°C, 46±2%RH) while wearing military PPE exposes an individual to uncompensable heat stress. Uncompensable heat stress is also likely to be one of the main causes for several of the INEXP participants being unable to complete the loaded march in the

HEAT. The reduced ability for evaporative heat loss caused by the PPE would lead to an upregulation in skin blood flow to facilitate dry heat loss from the skin, which further exacerbates the cardiovascular strain of performing the loaded march. The increase in cardiovascular strain is believed to be the cause of participants inability to continue exercise, rather than a high T_{core}.[26, 27]

Core temperature did not reach critical levels in this trial (39–40°C threshold for increased risk of exertional heat stroke[28]). However, the PSI scores suggest that performing a loaded march in HEAT exposes participants to a severe physiological strain. When performing the loaded march at NORMAL temperature, participants only reached a moderate physiological strain (Figure 5). The 9°C increase in environmental temperature between the NORMAL and HEAT conditions, pushed participants in both the INEXP and the EXP group into the high physiological strain category. The thermal gradient between periphery and core was also significantly reduced during the loaded march in the heat causing a decline in the heat transfer ability from the core to the periphery. Based on these results it seems evident that performing a loaded march in the heat while wearing military PPE exposed participants to an uncompensable heat stress and a high physiological strain, which could have a significant effect on CAF members continued physiological capacity and operational readiness.

The effect of previous experience

The effect of previous experience on performance outcome is a topic that has been given limited attention throughout the years, but a few studies have been conducted suggesting a beneficial effect of previous experience on performance and task solving ability.[12, 13] The results from this study support this idea. Even though the two participant groups were matched for morphology and physiological capacity, only five participants completed the loaded march in the HEAT in the INEXP group, compared to nine in the EXP group. The one participant unable to complete the loaded march in the HEAT in the EXP group was suffering from gastric distress, which is a common incident during high-intensity exercise in the heat.[29,30] Thermoregulatory responses (T_{skin}, and T_{core}) were not affected by experience level. However, participants in the EXP group had a significantly lower mean HR during the loaded march, in both the NORMAL and HEAT conditions, compared to the INEXP group. With no notable difference in anthropometry, and with participants working at a fixed workload, it is possible that the INEXP group had a higher sympathetic stimulation (stress response due to the stress of performing the loaded march task) leading to an increase in HR.[31] This response was reduced or absent in the EXP group due to their extensive experience with loaded marches. However, more research is required to confirm the mechanism behind the difference in HR between the INEXP and EXP groups.

Participants in the EXP group also reported significantly lower RPE and thermal comfort scores in both the NORMAL and HEAT conditions. However, there was no difference in aerobic capacity, body mass or body composition between the two groups. Based on these results, it seems that having previous loaded march experience led to a lower mean HR, RPE and thermal comfort scores during the loaded march, both in a NORMAL and HEAT condition. Although a limited number of studies have reported a beneficial effect of previous experience on task performance,[12,13] the cause of the positive effect on performance remains unclear. Micklewright and colleagues[12] suggest that previous task experience could have a beneficial effect on RPE, which was also observed in this study. However, more research is required to determine the specific mechanism causing the difference in performance between inexperienced and experienced participants.

FORCE Combat™ circuit

For a large number of Canadian Army members, loaded marching is a common task and mode of transportation. Following the loaded march to the objective, soldiers need to maintain operational readiness and still be able to perform combat duties. Therefore, this study sought to determine how performing a loaded march in the HEAT compared to NORMAL temperature affects performance on the FORCE Combat™ circuit, performed immediately after the loaded march. The results showed that heat exposure led to an increase in completion times in both the INEXP and EXP group (Figure 6A). These findings are in accordance with previous publications showing that heat exposure can have a negative effect on exercise performance.[32, 33] It was also shown that participants in the EXP group had significantly lower completion times compared to participants in the INEXP group (Figure 6A). There was also a trend towards a larger increase in FORCE Combat™ completion between the NORMAL and HEAT condition in the INEXP group compared to the EXP group. There were no physiological or anthropometric differences that could explain the differences in completion time between the INEXP and EXP group; however, the participants in the EXP group had, apart from previous loaded march experience, also previous experience with urban operation exercises. None of the participants in either group had previously been exposed to this specific evaluation used in this study, yet the previous experience with similar tasks could potentially explain some of the difference in completion time. The results from this study confirmed the negative effect of heat exposure on physical performance and showed that previous experience had a positive effect on FORCE Combat™ circuit performance.

Performing a loaded march while wearing PPE is an essential task for soldiers serving in the armed forces, and since the march parameters and equipment cannot always be changed (shorter duration or lighter load), the results from this study suggest the requirement for an increased awareness of the negative effects of heat exposure on loaded march completion rates, cardiovascular and thermal responses, and military operational readiness. The conditions in which the loaded march and FORCE Combat™ circuit testing are performed (temperature and humidity) need to be monitored and measures like heat acclimation and hyper-hydration protocols could be required to maintain operational readiness. The outcomes of this research could also potentially be transferable to other military tasks and could have an implication on the focus on experience level and heat exposure when planning military exercises and operations. The results from this study clearly indicate the effects of both experience level and heat exposure on performance outcome. Future research should focus on expanding the participant pool and the demographics of the population (including females, older individuals and a wider range of body composition) to obtain more generalisable results.

Conclusion

After assessing the effects of heat exposure and previous experience on a loaded march and FORCE Combat™ circuit performance, the results from this study showed that high environmental temperature and humidity had a negative effect on thermoregulatory and cardiovascular responses during a loaded march. The high environmental temperature also caused a state of uncompensable heat stress and reduced performance on the FORCE Combat™ circuit. On the other hand, previous experience had a beneficial effect on the ability to complete a loaded march in the HEAT and on FORCE Combat™ circuit performance.

Acknowledgements

The authors acknowledge the PSP Human Performance Research and Development team for lending the military equipment used in this study. The authors declare that the results of this study are presented clearly, honestly and without fabrication, falsification or inappropriate data manipulation.

Conflict of Interest

The authors declare they have no competing interest and declare that they have no conflicts of interest to disclose. The results of the present study do not constitute endorsement by the America College of Sports Medicine.

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