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EFFECT OF PROTECTIVE CLOTHING ENSEMBLES ON ARTILLERY BATTERY CREW PERFORMANCE

U S ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

Natick, Massachusetts

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NO. T8-92

Effect of Protective Clothing Ensembles on Artillery Battery Crew Performance

Patricia C. Szlyk[1], David M. Caretti[2], Ingrid V. Sils[1],
Orest Zubal[3], and Jim A. Faughn[3]

[1] Comparative Physiology Division, Environmental Pathophysiology Directorate, US Army Research Institute of Environmental Medicine, Natick, MA 01760-5007

[2] Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD 21010-5423

[3] Fire Support and Target Acquisition Division, US Army Human Engineering Laboratory, Aberdeen Proving Ground, MD 21005-5001

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Performance of three 9-man crews was evaluated while firing 90 rounds in a safe and expedient manner, with swabbing of the breech after each round. Each 9-man crew fired on three non-consecutive days; the independent variable among days was the MOPP level worn (BDU vs MOPP IV vs MOPP IV with cooling). All 90 rounds were fired by all three crews when wearing BDU. Despite similar climatic conditions, 2 of the 3 MOPP IV iterations were prematurely terminated due to high rectal temperatures and/or presyncopal symptoms. During the MOPP IV trials, average time to fire one round increased from the first to the second 45 rounds. In contrast, crews wearing BDU did not increase firing time. When cooling was added to the MOPP IV configuration (cool MOPP), all iterations were completed, and performance was enhanced despite warmer environmental conditions. As in the BDU trials, the time to fire a single round was unchanged over time, and was significantly less than that for MOPP IV. Significantly higher sweat losses in MOPP IV were reflected in the crew's enhanced perception of sweatiness, thirst, hyperthermia, and headache. Full encapsulation of crew members in chemical protective gear imposed a heat stress which reduced work tolerance and performance, but these decrements were lessened by microclimate cooling to the thorax and face.

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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FOREWORD

The Fire Support and Target Acquisition Division (FSTAD) of the Human Engineering Laboratory (HEL), Aberdeen Proving Ground, MD provides support to the "Physiological and Psychological Effects of the NBC Environment and Sustained Operations on Systems in Combat" (P^2NBC^2) research program. The basic tenet of the program is to develop a data base of soldier performance degradation as a function of the mission oriented protective posture (MOPP) chemical protective clothing worn during prolonged operations. The objective of this research effort was to evaluate physical work capacity and physiological performance of artillery crews during prolonged firing operations in which soldiers performed mission related tasks in MOPP IV configuration in a field environment. HEL requested the participation of the US Army Research Institute of Environmental Medicine (USARIEM) in monitoring soldiers' physiological responses.

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EXECUTIVE SUMMARY

The effect of auxiliary air cooling on the ability of artillery crews to perform firing operations in the heat while fully encapsulated in chemical protective gear was examined. Performance of three 9-man crews was evaluated while firing 90 rounds in a safe and expedient manner, with swabbing of the breech after each round. Six crew members (cannoneers) with the most labor intensive functions rotated positions every 15 rounds. Each 9-man crew fired on three non-consecutive days; the independent variable among days was the MOPP level worn (BDU vs MOPP IV vs MOPP IV with cooling).

All 90 rounds were fired by all three crews when wearing BDU, and average vehicle temperature ranged from 24.4° to 34.3°C. Despite similar climatic conditions, 2 of the 3 MOPP IV iterations were prematurely terminated due to high rectal temperatures and/or presyncopal symptoms. During the MOPP IV trials, average time to fire one round increased from 63±2 sec for the first 45 rounds to 227±107 sec for the second 45 rounds. In contrast, crews wearing BDU did not increase firing time, and averaged only 53±2 sec/round to fire the entire 90 rounds. When auxiliary cooling was added to the MOPP IV configuration (cool MOPP), all iterations were completed, and performance was enhanced despite warmer environmental conditions (27.2° to 39.7°C). As in the BDU trials, the time to fire a single round was unchanged over time (60±2 sec/round), and was significantly ($p<0.05$) less than that for MOPP IV.

Significantly ($p<0.05$) higher sweat losses in MOPP IV (0.40±0.04L/hr) compared to either BDU (0.29±0.03L/hr) or cool MOPP (0.29±0.03L/hr) were reflected in the crew's enhanced perception of sweatiness, thirst, hyperthermia, and headache. Irrespective of the clothing ensemble, sweat losses, fluid consumption, heart rate, and rectal temperature were consistently higher for the six cannoneers who transferred and loaded ammunition and fired the gun compared to the three commanders who prepared the gun settings. Neither presyncopal symptoms nor hypotension were seen in response to a change in posture from supine to standing in either the cannoneers or commanders in any of the three clothing ensembles.

Full encapsulation of crew members in chemical protective gear imposed a heat stress which reduced work tolerance and performance, but these decrements were lessened by microclimate cooling to the thorax and face.

INTRODUCTION

Under the threat of chemical, biological or nuclear contamination, a soldier must perform his mission while encapsulated in chemical protective clothing and hooded mask. Although the insulation and low permeability of chemical protective clothing provide protection against various agents, the ensemble limits heat dissipation by impeding sweat evaporation. The resultant compromised thermoregulation results in increased body temperature and sweat rates (8,16,17,20,21) and hypohydration (8,16,17,21), and adversely affects psychological well-being (13,18) and work performance (4,7,10,16,17,20,21) even in temperate environments.

Several earlier studies assessing the thermal strain imposed by wearing chemical protective gear demonstrated the reduced tolerance time for moderate to heavy physical work (7,10). Ordinarily, soldiers carrying the heaviest loads or performing the more intense work were the earliest casualties. More importantly, these authors found that endurance time of soldiers working in chemical protective gear was more affected by impaired heat dissipation than either the environmental thermal load or the subject's heat acclimatization (7,8,10).

More recently, Toner and colleagues (19) reported marked degradation of performance of routine tasks during prolonged simulated tank operations when crew members wore MOPP IV under harsh conditions (WBGT=35°C, unventilated compartment). However, auxiliary cooling (water-cooled vests under the chemical protective jacket) substantially reduced heat stress and sweat loss, and enabled the crews to complete their mission successfully (19). Numerous studies have confirmed that cooling the back, neck and thorax with microclimate cooling systems reduces the heat strain imposed by working in chemical protective gear, extends endurance time, and improves performance (2).

An air-cooled microclimate system was designed with the added capability of cooling the face by blowing air into the facepiece of the protective mask. Testing under laboratory conditions has shown that performance time in MOPP IV is significantly increased with this system (2,3,12). However, evaluation of this microclimate cooling system is limited when soldiers perform tasks specific to their primary mission under field conditions (2).

Thus, this study was designed to evaluate the impact of MOPP IV, with and without microclimate cooling of the back, thorax and face, on artillery crew performance during sustained firing operations of the 109A3 howitzer.

METHODOLOGY

Test Participants

Twenty-five (25) male reservists from the West Virginia Army National Guard (WVANG) participated in this study as their two week Annual Training. All subjects were experienced artillerymen with MOS 13B. Subjects were briefed on the nature and purpose of the study, and informed of the risks and safety precautions involved. Following medical screening, two soldiers were not cleared to participate in the testing and assisted in data collection. The other subjects provided informed consent to participate by signing a Volunteer Participation Agreement, and reserved the right to withdraw for any reason without retribution. Physical characteristics of these crew members (mean ± 1SE) are presented in Table 1.

Table 1: Physical Characteristics

	Group 1 (n=9)	Group 2 (n=8)	Group 3 (n=8)	ALL (n=25)
Age, years	28±3	33±3	33±5	31±2
Height, cm	183.9±2.8	173.9±2.3	175.4±2.7	178.0±1.7
Weight, kg	86.8±7.0	81.0±1.9	87.1±2.8	85.0±2.7
BSA, m^2	2.10±0.09	1.98±0.03	2.02±0.03	2.02±0.04

BSA, Body Surface Area.
Values are expressed as Mean ± 1SE.

Study Design

During the first week of the 2 week test interval, soldiers wore the chemical protective gear for 1-3 hrs per day, increasing the MOPP level, duration of wear, and level of physical activity daily. In addition, crew members practiced preparing and positioning the howitzer and ammunition vehicle (Field Artillery Support Vehicle, FAASV) and the crew rotation procedures for firing operations. Partial heat acclimation probably occurred during this first week because soldiers were physically active in some level of MOPP at ambient temperatures of 19.1-29.4°C in direct sunlight.

Data collection commenced during the second week. Each testing scenario required approximately 6 hrs and was conducted as follows: a crew of 9 men was instructed to fire 90 rounds as rapidly, accurately and safely as possible. Six crew men (cannoneers #1,2,3, and 4, howitzer driver, ammunition vehicle driver) performed the demanding tasks of preparing, transferring and loading the projectiles and charges, firing the howitzer, and then swabbing the breech after each round (Figure 1). During the second and third week of testing, only five cannoneers participated. The cannoneers rotated between positions after each 15 rounds fired as shown in Figure 1. Prior to firing and while the cannoneers rotated after 15 rounds, a 3-man command group (gunner, assistant gunner, chief of section) received instructions and set the deflection and elevation of the gun as specified by range control. On command, the cannoneers initiated firing of the howitzer. Upon completion of firing 90 rounds, crew members remained in position for a 1 hr sedentary recovery period.

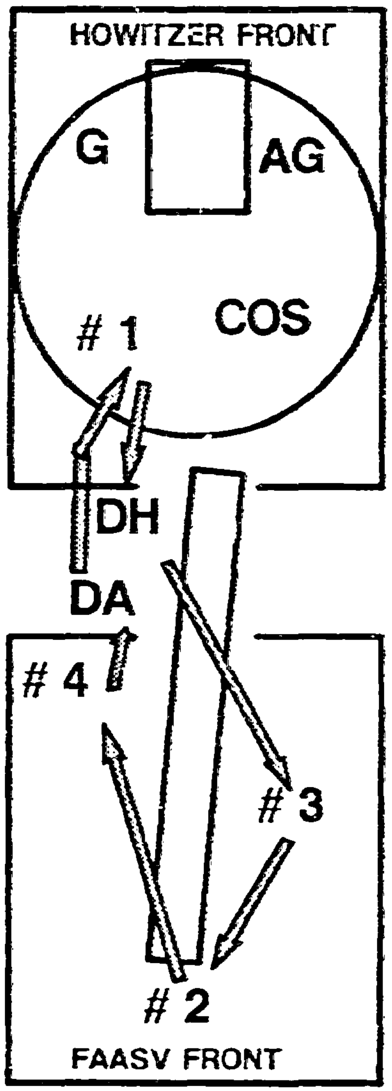
This test scenario was repeated 3 times on non-consecutive days during the second week, and differed in the clothing ensemble worn by the 9-man crew. The three ensembles were: Battle Dress Uniform (BDU), MOPP IV, and MOPP IV with auxiliary cooling (cool MOPP). Shorts, T-shirt, socks, and boots worn with the BDU trouser and shirt comprised the BDU ensemble. The MOPP IV ensemble consisted of the chemical protective trousers, jacket, new button and loop type boots, butyl rubber gloves with inserts, and hooded mask (M42 series) worn closed over the shorts, T-shirt, socks, and boots. A cooling vest (cool MOPP) worn under the chemical protective gear provided cool air (8.3-11.1°C below ambient temperature) to the upper body (15 ft^3/min) and face (3 ft^3/min). Each crewman also wore a Combat Vehicle Crewman (CVC) helmet which provided ear protection and enabled radio communication with crew members and range control.

On each test day, volunteers reported to the field site at 0800 h. Subjects were encouraged to drink plentiful fluids during the prior evening and to consume breakfast about 1 hr before arrival. As an index of hydration, a pre-test (pre-fire) urine sample was analyzed for specific gravity (refractometry, USG). Soldiers were provided water (0.25-1L) for consumption if USG was >1.025 or if thirsty.

An orthostatic tolerance test (OTT) which measures the circulatory responses to a change in position from supine to standing was performed prior to instrumentation and dressing, and again after the recovery period (study requirements imposed by P^2NBC^2 and FSTAD precluded OTT measurements immediately post-fire). After a minimum of 4 min in the supine position, blood pressure and heart rate were measured. Each subject then stood, and blood pressure and heart rate were again measured at 1, 2 and 4 min after standing.

Volunteers then proceeded to a trailer where body weight (shorts only) and height

NINE–MAN CREW ROTATION



G – **Gunner:** lays weapon in deflection

AG – **Assistant gunner:** lays weapon in quadrant

COS –**Chief of section:** safety officer and radio operator

#1 – **Cannoneer:** rams projectile, inserts powder, closes breech, inserts primer, attaches lanyard, fires, swabs breech

#2 – **Cannoneer:** projectile preparation

#3 – **Cannoneer:** powder preparation

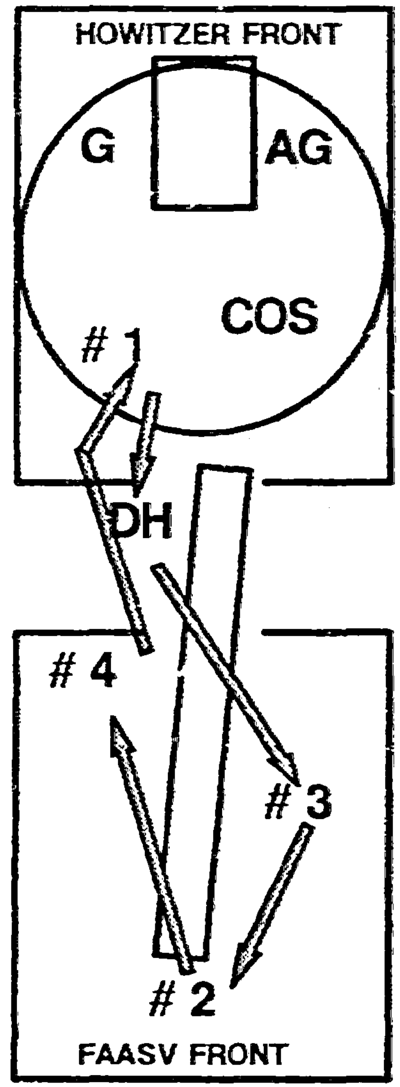
#4 – **Cannoneer:** safety officer, hands fuzes to #2 cannoneer

DH – **Howitzer driver**

DA – **FAASV driver**

The two drivers act as final checkers to insure proper preparation of ammunition

EIGHT–MAN CREW ROTATION



FAASV – Field Artillery Ammunition Supply Vehicle

Figure 1. Crew stations, duties, and rotation scheme

were measured. In compliance with the recommendation of the P^2NBC^2 Technical and Scientific Advisory Group, soldiers were then required to consume 300 ml of water. Although each soldier was fitted with a Heart Watch (Computer Instrument Corp) to monitor heart rate, heart rate was manually recorded only after each 15 rounds fired. Rectal probes were inserted (10 cm depth) to monitor rectal temperature using a YSI 49TA digital display at 10 min intervals during firing and recovery. Soldiers then proceeded to dress in the clothing ensemble scheduled for the test day, and all instrumentation was tested.

Soldiers then entered either the M109A3 howitzer (gunner, assistant gunner, chief of section, and #1 cannoneer), the Field Artillery Ammunition Supply Vehicle FAASV) (#2,#3 and #4 cannoneers), or stood between the two vehicles for transferring ammunition (howitzer and ammunition vehicle drivers) (Figure 1). All personnel side doors of the vehicles remained open during firing and recovery, and vehicle and ambient conditions were monitored. After the command group (gunner, assistant gunner and chief of section) received and set the deflection and quadrant for firing, the remaining five (2nd and 3rd weeks) or six (1st week) cannoneers initiated firing upon command. Endurance time and time to fire each 15 rounds were recorded.

In BDU, soldiers drank directly from a 2 qt canteen, whereas soldiers dressed in either MOPP IV or MOPP IV with auxillary cooling (cool MOPP) consumed water using the fluid intake suction tubing (FIST) unit. This FIST unit incorporates a collapsible canteen, squeeze bulb and tube which requires a one time only connection to the M42 mask. To drink, the soldier inserted the drinking spigot into his mouth and squeezed the FIST bulb to force water hydraulically from canteen to mouth, thereby interfering minimally with his task. Soldiers carried the 2 qt canteens by suspending them with shoulder and waist straps which held the canteen securely against the body. Tap water (25°C) was provided ad libitum in the 2 qt canteens. Fluid intake was measured for three intervals: after firing 45 rounds, firing 90 rounds, and recovery, or sooner if necessary, by weighing each canteen on an electronic balance (Sartorius, ±10g).

After all 90 rounds (six rotations) were discharged, soldiers remained in position for a 1 hr sedentary recovery period during which they remained in the day's clothing ensemble in either the howitzer or FAASV. During this recovery, soldiers were encouraged to relax, consume water ad libitum and complete the symptomatology questionnaire.

After recovery, test clothing ensembles were removed and a final body weight (shorts only) was obtained. During the firing and recovery periods, urine was collected and weighed, and subjects provided a post-recovery urine sample for analysis of specific gravity. It is important to note that study requirements precluded removal of clothing ensembles immediately post-fire; thus, body weight changes could not be separately obtained for the firing and recovery periods, but are reported as total loss or gain for the entire firing and recovery scenarios. Total sweat production was calculated as the difference between the post-recovery and pre-firing 'nude' (shorts only) body weights, adjusted for total fluid intake and total urine loss. Likewise, % rehydration was calculated as the ratio of total fluid consumed during firing and recovery to total sweat lost.

Removal of a subject from a day's trial occurred if rectal temperature exceeded the safety criterion (T_{re}≈39.2°C). In addition, subjects were removed if they either reported or displayed symptoms of hyperthermia, dehydration or exhaustion. Removal of subjects from the day's trial was supervised by the attending medical monitor. No study-related measurements were acquired following subject removal unless requested by the attending physician.

Data were analyzed using analysis of variance for between group comparisons and paired t-tests for within group comparisons using the CSS Statistical Software Package. Results are presented as mean ± 1 standard error (SE) with significance accepted at $p<0.05$ unless otherwise noted.

RESULTS

Although environmental temperature showed daily variation, the average air temperature was not different between clothing ensembles (Table 2). The significantly higher relative humidity during the MOPP IV trials contributed to the slightly higher ($p<0.05$) ambient WBGT on these days compared to the BDU trials.

Table 2: Ambient Conditions

Ensemble	$T_{ambient}$ (°C)	T_{FAASV} (°C)	$T_{howitzer}$ (°C)	WBGT (°C)	% R.H.
BDU	23.9±0.6	29.7±1.0‡	26.5±1.1	22.9±0.6*	64.0±1.0*
MOPP IV	23.9±0.6	30.5±0.8	27.9±0.6	24.7±0.3	77.2±0.8
Cool MOPP	24.4±0.6	34.3±1.0*	29.0±0.5	24.1±0.5	64.8±1.0*

* Significantly different ($p<0.05$) from MOPP IV.

‡ Significantly different ($p<0.05$) from Cool MOPP.

Although the 2 side doors of the FAASV were open, the vehicle was cramped with equipment and soldiers transferring and loading ammunition. In addition, the FAASV's auxiliary power unit ran continuously throughout the testing and may have contributed additional heat to the inside of the FAASV. These conditions probably contributed to the higher internal temperatures of the FAASV compared to the howitzer, which had 2 side and 1 rear door open and housed the commanders. The only statistical difference in compartment temperature was the higher ($p<0.007$) average temperature measured in the FAASV during the cool MOPP trial compared to both BDU and MOPP IV trials.

TABLE 3. Time (seconds) to Fire a Single Round

	BDU	MOPP IV	Cool MOPP
First 45 rounds	51±2*	63±2	61±3
Second 45 rounds	58±8*	272±107§	60±6*
All 90 rounds	55±5*	81±4	60±3*

* Significantly different ($p<0.05$) from MOPP IV.

§ Two of three missions terminated after firing 46 and 49 rounds.

When crew members wore the BDU, all three iterations were completed with 90 rounds fired in 96, 75, and 75 min. Endurance was reduced in MOPP IV; two of the three MOPP IV iterations were prematurely terminated for medical reasons with only 46 and 49 rounds fired. The only MOPP IV session completed required 140 min to fire 90 rounds. When auxiliary cooling was used with MOPP IV (cool MOPP), crew members successfully completed all missions in time periods (101, 92, and 78 min) similar to those observed for BDU (96, 75, and 75 min). Performance was also impaired when soldiers worked in MOPP IV; time taken to fire a single round quadrupled from the first 45 to the second 45 rounds (Table 3). In contrast, when wearing either BDU or using auxiliary cooling with the protective gear, average time to fire a round remained unchanged with time as the firing progressed and was significantly less than that for MOPP IV.

While in BDU, total sweat rate for all crew members (commanders and cannoneers) varied from 0.04-0.61L/hr for the entire trial (firing and recovery periods). Likewise, total fluid intake varied from 0.07-0.74L/hr with percent rehydration ranging from 21-741%. Thus, in the BDU ensemble (Table 4), the moderate sweat rate (0.29L/hr) and average percent rehydration (154%) did not significantly affect body weight. When the soldiers wore MOPP IV, similar variability in sweat rate and percent rehydration was noted. Nonetheless, average total sweat rate (0.40L/hr) was significantly increased ($p \leq 0.02$) and average % rehydration was lower (100%, $p \leq 0.04$) in MOPP IV compared to BDU. Although average body weight losses for all crew members were greater in MOPP IV (0.36%) than BDU, these differences were not statistically different ($p \leq 0.1$). The smaller body weight deficits (0.26%) observed when the cooling vest was worn under MOPP IV for all crew members were probably due to attenuated sweat loss (0.29L/hr, $p \leq 0.008$) since fluid replacement was similar. Average post-recovery urine specific gravity was significantly ($p<.025$) greater in the two MOPP IV ensembles relative to BDU.

Table 4: Fluid Balance: All Crew Members[1]

	BDU	MOPP IV	Cool MOPP
Sweat loss, L/hr	0.29±0.03*	0.40±0.04	0.29±0.03*
Fluid intake, L/hr	0.35±0.04‡	0.35±0.04‡	0.27±0.03
Rehydration, %	154±28*	100±11	108±12*
Body weight loss, kg/hr	0.01±0.03	0.09±0.03	0.06±0.02
Body weight loss, %	0.07±0.17	0.36±0.13	0.27±0.12
USG, post-recovery	1.012±0.002‡*	1.017±0.002	1.017±0.002

1 Values reported for combined firing and recovery periods.
* Significantly different ($p<0.05$) from MOPP IV.
‡ Significantly different ($p<0.05$) from Cool MOPP.
USG, urine specific gravity.

Crew members (n=25) perceived significantly greater degrees of sweatiness ($p<0.003$), thirst ($p<0.007$), hyperthermia ($p<0.003$), and headache ($p<0.006$) when working in MOPP IV compared to either the BDU or cool MOPP ensemble (Table 5). Perceptions of tiredness, boredom, hunger, and comfort were similar for the three clothing configurations.

Because work intensity for the five or six cannoneers in the FAASV who prepared, loaded and fired the rounds was greater than that for the three commanders in the howitzer who prepared the gun settings for each firing mission (Figure 1), we expected and observed differences in responses in all three clothing ensembles. Total sweat losses for the commanders were similar for the BDU, MOPP IV and cool MOPP ensembles, averaging 0.21±0.02L/hr (Figure 2). Total fluid intake either matched or exceeded losses (rehydration≥100%); therefore, the total body weight lost was negligible (0.13% of initial body weight). In contrast, total sweat losses were significantly ($p<0.01$) greater when the cannoneers wore MOPP IV compared to either the BDU or cool MOPP while working in the FAASV (Figure 2). Body weight losses were minimal irrespective of clothing ensemble because fluid consumption replaced sweat losses.

Table 5. Response to Comfort Questionnaire: All Crew Members

FACTOR	BDU	MOPP	Cool MOPP
Tired	1.8±0.2	2.4±0.2	2.3±0.2
Sweaty	2.7±0.3*	4.2±0.2	2.9±0.3*
Thirsty	1.6±0.1*	2.4±0.2	1.6±0.2*
Bored	2.1±0.3	2.2±0.3	2.3±0.2
Hungry	2.9±0.3	2.8±0.3	3.0±0.3
Hot	2.5±0.3*	3.5±0.3	2.1±0.2*
Comfortable	3.2±0.2	2.7±0.3	3.1±0.2
Short of Breath	1.1±0.1*	1.6±0.2	1.2±0.1
Headache	1.4±0.2*	2.3±0.3	1.4±0.1*

Scale: 1-not at all; 3-neutral; 5-very.

* Significantly ($p<0.05$) different from MOPP IV.

Total sweat losses for the six cannoneers assigned to the labor intensive positions were 60, 90 and 110% higher ($p<0.02$) than for the commanders who occupied less physically demanding positions during the BDU, MOPP IV and cool MOPP iterations, respectively (Figure 2). Likewise, more fluid was consumed by the cannoneers in all three clothing ensembles. Although fluid replacement was nearly complete for both groups for each iteration, the ratio of fluid replacement to fluid loss (rehydration) calculated for the commanders, was consistently above 100% and higher than that for the cannoneers. In fact, the commanders actually had a small gain in body weight during the BDU trial, as shown by the negative body weight loss. However, the greater change in body weight in the cannoneers was not significantly different from that of the commanders.

Average rectal temperatures during the 90 round firing missions were similar for BDU, MOPP IV, and cool MOPP ensembles for both the cannoneers and commanders (Figure 3), although the cannoneers had consistently higher rectal temperatures. The only significant difference ($p<0.04$) was the higher rectal temperature (0.2°C) measured during the cool MOPP iteration in the cannoneers relative to commanders. Heart rate varied in each cannoneer depending on the work intensity of the position occupied during each 15 rounds fired. However, average heart rate during the firing misson was always higher for the cannoneers than the commanders for all clothing ensembles (Figure 3). Moreover, heart rate was higher ($p<0.05$) when the cannoneers wore MOPP IV compared to both BDU and cool MOPP.

Ratings of comfort (Figure 4) suggest that cooling the chest, back and face is beneficial to the soldier working in MOPP IV. Of particular importance is the finding that the perceived level of sweatiness during the firing scenario in the BDU and cool MOPP trials was significantly less than when MOPP IV was worn by either the cannoneers or commanders. In both of these groups, a significantly smaller degree of headache, perceived hyperthermia and thirst were observed when the cooling vests and ventilated face piece were employed.

Assignment to positions was done using age and training experience with the older and more 'seasoned' soldiers designated as commanders, and likewise, the younger, less-experienced designated as cannoneers. Age (commanders, 43±3 yrs; cannoneers, 25±5 yrs; $p<0.0001$) may have contributed to the consistently higher supine heart rate (p=ns), diastolic and mean blood pressures ($p<0.001$), and significantly ($p<0.001$) lower pulse pressure observed in the commanders during the pre-fire orthostatic tolerance test (OTT) (Table 6).

The OTT responses to a change in position from supine to standing were normalized for differences in the supine position by subtracting the value measured while supine from those measure at each min of standing. A typical response included increases in heart rate, and diastolic and mean blood pressures, and minimal change in systolic pressure. During the pre-fire OTT, the blood pressure and heart rate changes were similar between the commanders and cannoneers for all clothing ensembles, and between the three clothing ensembles for the commanders (Table 7). For the cannoneers, we observed a smaller

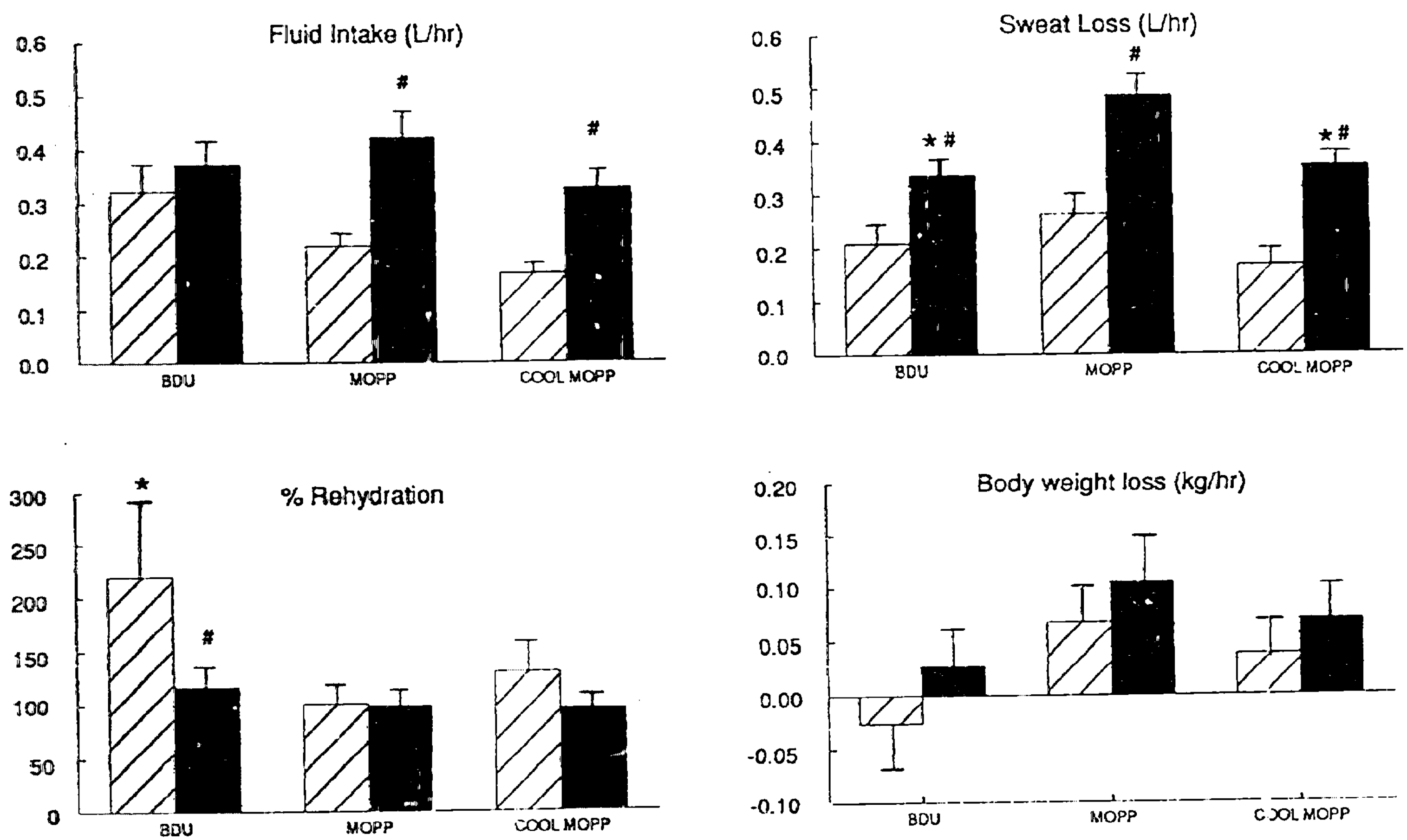


Figure 2. Commanders ▨ vs Cannoneers ■ : Comparison of Fluid Balance
* Significant difference ($p<0.05$) from MOPP
# Significant difference ($p<0.05$) between Commanders and Cannoneers

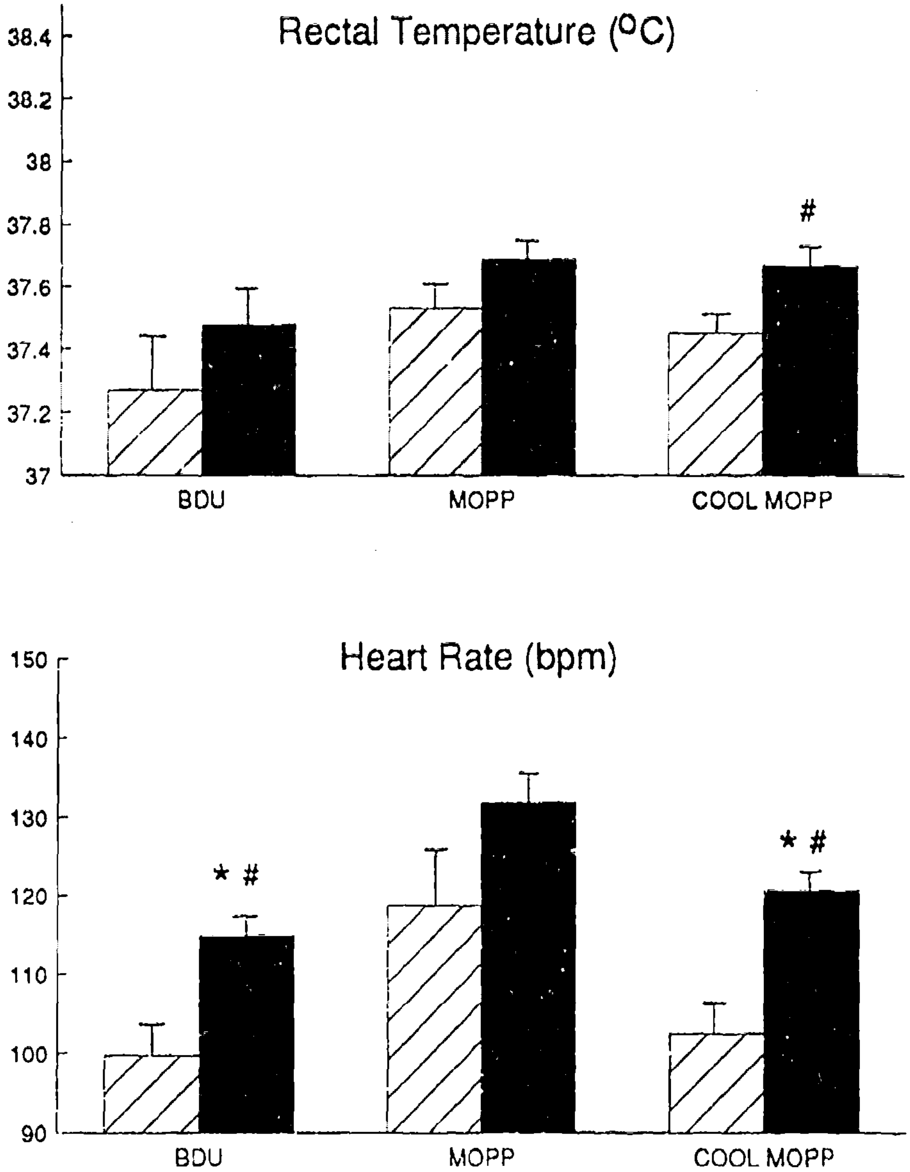


Figure 3. Commanders ▨ vs Cannoneers ■ : Comparison of Heat Strain Indices
* Significant difference ($p<0.05$) from MOPP
\# Significant difference ($p<0.05$) between Commanders and Cannoneers

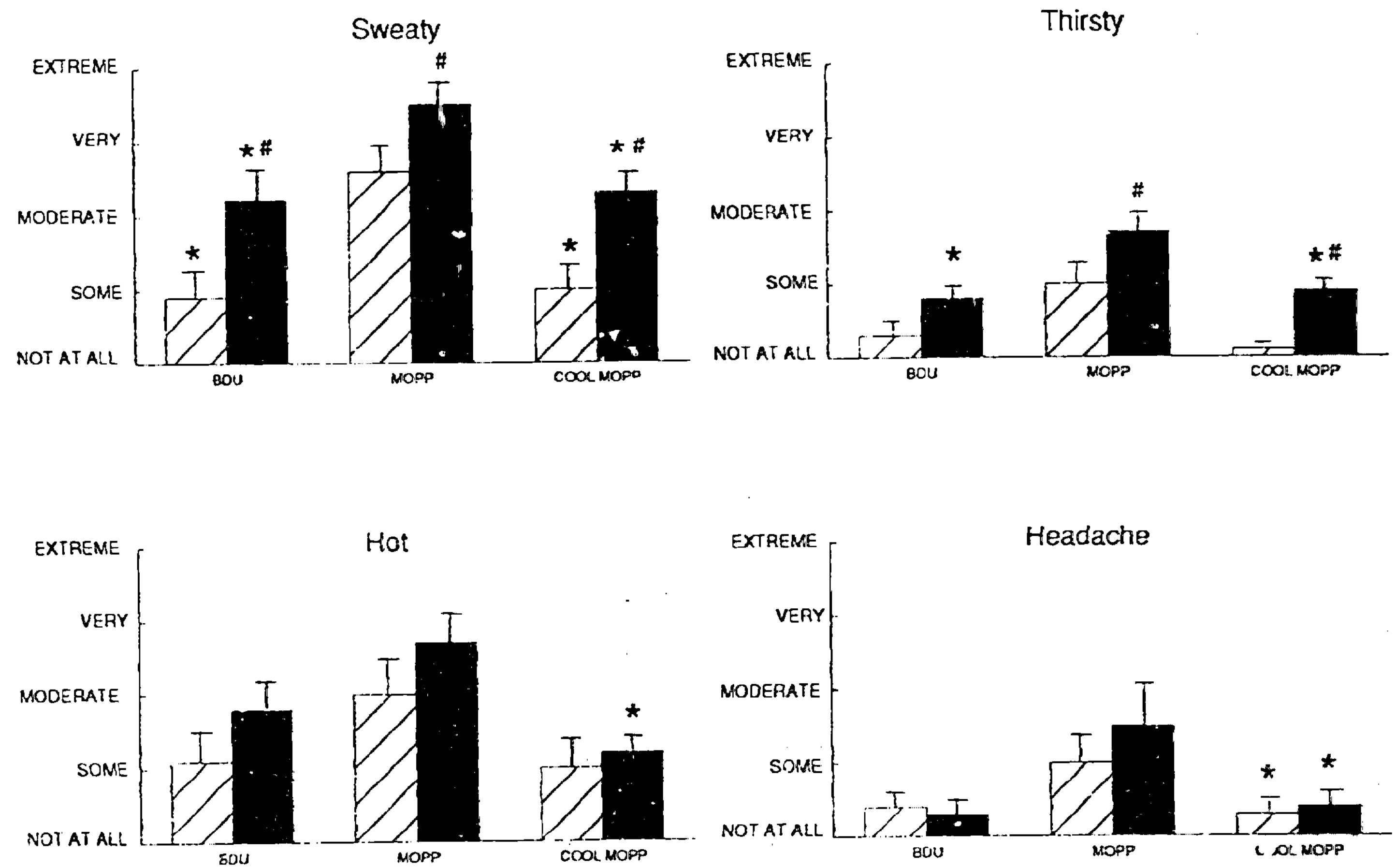


Figure 4. Commanders ▨ vs Cannoneers ■ : Comparison of Perceived Comfort
* Significant difference ($p<0.05$) from MOPP
# Significant difference ($p<0.05$) between Commanders and Cannoneers

Table 6. Supine Circulatory Values: Pre-Fire and Post-Recovery

	Commanders						Cannoneers					
	BDU		MOPP IV		Cool MOPP		BDU		MOPP IV		Cool MOPP	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
HR	78±3	69±3♦	80±6	75±4	76±3	71±3	74±3	69±2*	73±2	78±3	69±2	69±1*
P_{SYS}	123±4	120±3	124±3	126±5	122±2	122±4	126±3	117±3◊	123±3	118±3	126±3	121±2♦
P_{DIAS}	71±3	71±2	69±2	72±3	70±3	70±3	58±2#	50±1#	57±2#	64±2#◊	63±3	59±2#
BP	88±3	87±2	87±2	90±3	87±3	87±3	81±2#	79±1#	79±1#	82±2#	83±2	80±2#
PP	53±4	49±4	55±4	54±4	52±3	52±3	67±4#	57±2◊	65±4#	54±2◊	63±3#	62±2#

Values denote mean ± SE.

* Significant difference ($p<0.05$) from MOPP IV.

\# Significant difference ($p<0.05$) between Commanders and Cannoneers.

\## Significant difference ($p<0.07$) between Commanders and Cannoneers.

◊ Significant difference ($p<0.05$) from pre-fire.

♦ Significant difference ($p<0.07$) from pre-fire.

Table 7. Change in Circulatory Values in Response to Standing: Pre-Fire and Post-Recovery

	time standing	Commanders						Cannoneers					
		BDU		MOPP IV		Cool MOPP		BDU		MOPP IV		Cool MOPP	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
ΔHR	1 min	10±3	20±3♦	13±7	15±4	13±4	12±4	13±4	21±3◊	19±2	18±3	18±3	14±4
	2 min	11±2	17±4	10±6	19±2	7±3	15±2◊	15±4	19±3	15±2	17±3	17±2#	14±3
	4 min	13±2	16±3	8±7	11±3	13±3	14±2	14±4	17±3	16±3	16±2	17±2	13±2
ΔP_{SYS}	1 min	7±3	1±4	10±3	2±2◊	5±2	1±3♦	8±3	11±2#	11±2	7±2	10±1	7±2
	2 min	6±2	4±1	5±3	-4±3◊	8±3	3±3	7±4	5±2	10±3	7±3#	8±2	6±2
	4 min	8±4	3±2	8±2	5±2	7±4	1±4	2±3	8±2◊	8±2	6±2	6±2	5±2
ΔP_{DIAS}	1 min	10±3	13±3	14±3	14±2	10±2	13±2♦	17±2‡	17±3	17±2‡	13±2	9±2•	15±2◊
	2 min	11±3	15±3	14±3	14±4	10±3	15±2◊	17±4	16±3	18±2	15±2	12±2	15±3
	4 min	10±3	15±3♦	13±3	15±2	10±2	16±2◊	19±3	18±2	17±2	15±3	13±2	17±2
ΔBP	1 min	9±3	9±3	13±3	10±2	8±1	9±2	14±2	15±2	15±2	11±2	9±1⊗	12±2
	2 min	10±3	11±2	11±3	8±3	9±3	11±2	14±2	12±2	15±2	12±2	11±2	12±2
	4 min	9±3	11±2	12±2	12±2	9±2	11±2	13±2	14±2	14±2	12±2	11±2	1[illegible]2
ΔPP	1 min	-3±3	-12±3	-4±2	-12±3◊	-5±2	-12±3◊	-3±2‡	-6±3	-6±2	-6±3	1±2	-8±2◊
	2 min	-5±3	-11±3	-9±3	-18±2◊	-2±2	-12±3◊	-10±6	-11±3	-8±3	-8±3#	-5±3	-9±3
	4 min	-2±4	-12±3	-6±3	-10±3	-3±4	-15±4◊	-17±5##	-9±2	-8±2	-8±3	-7±2	-13±2◊

Values denote mean ± SE.

- • Significant difference ($p \leq 0.05$) from MOPP IV.
- ⊗ Significant difference ($p<0.07$) from MOPP IV.
- ‡ Significant difference ($p<0.05$) from Cool MOPP.
- # Significant difference ($p<0.05$) between Commanders and Cannoneers.
- ## Significant difference ($p<0.07$) between Commanders and Cannoneers.
- ◊ Significant difference ($p<0.05$) from pre-fire.
- ♦ Significant difference ($p<0.07$) from pre-fire.

increase in diastolic and mean blood pressures ($p<0.05$) and no change rather than a fall in pulse pressure ($p<0.03$) 1 min standing which disappeared by 4 min.

The significantly higher diastolic and mean blood pressures and smaller pulse pressure observed in the commanders compared to the cannoneers in the supine during the pre-fire OTT were also observed post-recovery (Table 6). In addition, the circulatory changes accompanying the change from supine to standing during the post-recovery OTT were similar between the commanders and cannoneers, and between all clothing ensembles for both groups (Table 7).

Significant differences in the supine circulatory measures (Table 6) were observed between pre-fire and post-recovery, with the number of variables differing and the magnitude of difference being dependent on the severity of the conditions. For example, the only significant difference for the commanders was a higher supine heart rate (9 bpm) during the pre-fire compared to post-recovery OTT for the BDU trial. Not surprisingly, numerous supine circulatory values were different pre-fire to post-recovery for the cannoneers during the MOPP IV trial. The higher diastolic pressure (7 mmHg, $p<0.02$) and lower systolic pressure (5 mmHg, p=ns) probably contributed to the smaller pulse pressure (11 mmHg, $p<0.005$) and higher heart rate (5 bpm, $p<0.09$) measured in the supine position in the cannoneers after the MOPP IV trial.

Compared to the pre-fire OTT, when changing from supine to standing post-recovery, the commanders displayed a smaller increase in systolic pressure for the MOPP IV trial and a larger increase in diastolic pressure for the cool MOPP trial, both of which contributed to significantly smaller pulse pressures (Table 7). Significantly smaller pressures were also observed in the cannoneers during the post-recovery OTT, but no consistent differences in either systolic or diastolic pressure occurred concurrently.

DISCUSSION

The results of the present study demonstrate that full encapsulation of crew members in chemical protective clothing and hooded mask imposed a heat stress which reduced their tolerance time and work performance. It is important to note that our study utilized well trained soldiers who performed tasks specific to their Military Occupation Specialties (MOS) in a realistic military scenario. Furthermore, our results extend previous reports indicating that microclimate cooling systems lessen heat stress, increase tolerance and enhance performance of soldiers in MOPP IV (2,3,12,19), and demonstrate that these effects occur under simulated battle conditions. These differences were most striking for the cannoneers who performed the physically demanding tasks of preparing, loading and firing the 90 rounds of ammunition.

When crew members wore BDU, all 90 rounds were fired by each of the three 9-man groups although the average temperature inside the FAASV varied for the groups (24.4°, 28.9° and 34.4°C). Under similar vehicle conditions (24.4°, 32.2° and 34.4°C), two of the three MOPP IV iterations were terminated after firing only 46 and 49 rounds, and work performance was dramatically reduced. Performance worsened with increasing time spent in MOPP IV, such that firing times markedly increased from the first to the second set of 45 rounds (Table 3). Furthermore, the mean time required to fire a round for all 90 rounds was significantly greater when the battery crews were in MOPP IV (81±4 sec/round) compared to when dressed in BDU (55±5 sec/round). Moreover, when crew members wore the BDU ensemble, they fired the 90th round about as rapidly as they had fired the first shot.

To alleviate the problems of dehydration and hyperthermia associated with MOPP IV, microclimate cooling systems designed to cool the micro-environment adjacent to the skin, lessen heat stress and increase tolerance time, have been developed. When air cooled vests with facial cooling were employed with MOPP IV (cool MOPP), all iterations were completed and work performance was enhanced despite harsher conditions (34.4°, 39.4°, and 27.2°C) inside of the FAASV. Like the BDU ensemble trials (Table 3), the time to fire a single round during the cool MOPP trials was unchanged with time, averaging 60±3 sec/round. Thus, a significant advantage of the microclimate cooling system with MOPP IV was the average reduction of 21 sec/round for firing all 90 rounds.

The air-cooled microclimate cooling system was compatible with either an air conditioning unit organic to the howitzer and FAASV or to an external unit. However, irrespective of the cooled air source, soldiers were tethered to the unit by long bulky air supply hoses which reduced and interfered with soldier motion. Crew members occasionally got tangled in or tripped over connections, but they perceived cooling of the thorax and face to be beneficial while working in MOPP IV (Table 5, Figure 4). It is important to note that all perceptions of comfort were similar for BDU and cool MOPP trials, and this was observed for both the cannoneers and the commanders. Moreover, crew members felt sweatier and hotter, and experienced greater thirst and headaches when MOPP IV was worn compared to either BDU or cool MOPP. This perceived discomfort reflected differences in heat strain indices. Total sweat losses for the firing and recovery periods were 38% higher in MOPP IV compared to either the BDU or cool MOPP trials, although work and environmental loads were roughly equivalent. The low permeability and high insulative characteristics of chemical protective gear probably increased the metabolic load and limited dissipation of this increased metabolic heat in the current as well as other studies (4,7). The higher heart rates and rectal temperatures observed during the firing scenario in MOPP IV compared to either the BDU or cool MOPP trial probably reflected these higher metabolic costs and heat storage, and poorer heat dissipation. Skin temperature, although not measured in the present study, most likely was reduced in the cool MOPP ensemble by the microclimate cooling (2,3,12), and probably contributed to the enhanced thermal comfort of cool MOPP compared to MOPP IV despite similar rectal temperatures.

When working in MOPP IV configuration, the risk of dehydration is increased due to the difficulty of obtaining sufficient fluid through the protective mask without contamination. Crew members wearing both the MOPP IV and cool MOPP ensembles used a prototype through-mask drinking system designed to facilitate drinking by reducing some of the risks and difficulties associated with the current drinking system (16,17). This modified drinking system required a one time connection of drinking tube and canteen, and employed single-handed operation of a squeeze bulb to move water from the canteen to the soldier's mouth. Although fluid requirements were 38% greater in MOPP IV compared to BDU, total intakes were similar (Table 4). Total fluid intake was 24% less ($p<0.08$) in cool MOPP compared to BDU despite similar sweat losses. While these results show that crew members consumed sufficient fluids to match and in some cases, overcompensate for sweat losses, other studies report that soldiers marching under simulated desert conditions for 2-6 hrs rehydrate only 70-85% and 50-65% when wearing BDU and MOPP IV, respectively (16,17,21). These differences in rehydration most likely are due to the higher sweat losses (1.3- and 2.1-fold higher for BDU and chemical protective ensembles, respectively) observed in the latter studies, and suggest that soldiers have difficulty consuming enough fluids to prevent dehydration as the rate of sweat loss increases. Adolph observed this same phenomenon in soldiers performing desert maneuvers, and remarked that soldiers generally failed to replace more than 50% of losses as sweat rates approached 1L/hr (14).

Urine specific gravity (USG), an index of impending hypohydration or a renal adaptation to prevent hypohydration (6), paralleled the changes in rehydration. Although average USG post-firing was significantly ($p<.025$) greater in either the MOPP IV or cool MOPP ensemble (1.017±0.002) relative to BDU (1.012±0.002), no significant hypohydration was noted during any of the three trials using this criterion. The overall weight losses measured following the recovery period in the MOPP IV and cool MOPP ensembles, although 10- and 6-fold greater than that of BDU, were small (<1% of original body weight) and should have had minimal impact on the crew's performance.

The mission for each of the three 8- or 9-man crews was to fire 90 rounds quickly and safely. The cannoneers occupying the five or six rotating positions in the FAASV and howitzer (cannoneer #1) prepared, transferred, loaded, and fired the 90 rounds at a high rate of sustained firing, and swabbed the breech after each round was fired. While these crew members changed stations after every 15 rounds, the commanders occupying the three nonrotating positions in the howitzer set the gun deflection and elevation for each firing mission. Thus, it is not surprising that based on total sweat losses, the overall fluid requirements for the commanders were similar for all three clothing ensembles (~ 0.21±0.02L/hr, Figure 2). Fluid replacement typically exceeded losses (rehydration=220%, 101% and 130% for BDU, MOPP IV and cool MOPP, respectively); thus, body weight losses were negligible. In contrast, average total sweat rates for the cannoneers were different for the clothing ensembles. While similar in the cool MOPP and BDU trials, total sweat rates averaged 35% higher when the cannoneers wore MOPP IV. Nearly complete rehydration resulted in minimal body weight losses in all three trials (Figure 2).

The cumulative sweat losses following the recovery period for the cannoneers were 1.6-, 1.9- and 2.1-fold greater ($p<0.02$) than those measured for the commanders during the BDU, MOPP IV and cool MOPP trials, respectively (Figure 2). These differences in sweat rates are important because they represent fluid requirements that must be replaced to prevent hypohydration and its consequences on behavior and performance. Due to the higher intensity of work which required use of both hands and resulted in higher body water losses, total fluid intake was significantly higher in cannoneers irrespective of clothing ensemble. For comparison, the total fluid consumed by the cannonneers was 15%, 93% ($p\leq0.003$) and 95% ($p\leq0.02$) greater than that consumed by the commanders during the BDU, MOPP IV and cool MOPP trials, respectively. In addition, crew members using the modified through-mask drinking system consumed the majority of water when firing rather than waiting to replace losses during the recovery period as typically seen with the current water delivery system (16,17).

Sohar and associates (15) reported that even mild dehydration causes drowsiness, irritability, headache, and reduced work efficiency. During two of the MOPP IV iterations, four cannoneers ('casualties') displayed symptoms of mild dehydration and hyperthermia, were prematurely removed from the day's trial, and were designated as casualties to differentiate them from the asymptomatic cannoneers. None of the soldiers occupying command positions was removed for medical reasons. Moreover, when cooling was provided to MOPP IV, all iterations were completed, no crew members were removed for medical reasons, signs and symptoms of hyperthermia and dehydration were minimal, and work performance was enhanced although average body weight losses and ambient conditions were similar to the MOPP IV trials.

Only one of the four cannoneer casualties was prematurely removed with a rectal temperature (39.2°C) exceeding limits set in the protocol. In association with the elevated body temperature, this soldier displayed signs of mild hyperthermia including irritability, agitation, dizziness, headache, and leg cramps. Average rectal temperature while firing for the 12 noncasualty cannoneers during the MOPP IV trial was 37.6°C (Table 8). The other 3 cannoneer casualties removed from the MOPP IV trials complained of lightheadedness, dizziness and headache. Although rectal temperatures at the time of removal of these three casualties had not exceeded the safety criterion, they were significantly greater (0.9°C, $p<0.001$) than those of the noncasualty cannoneers. All four of the casualties were stripped of their chemical protective gear, transferred to a cool trailer and provided oral fluids. None of these soldiers displayed signs or symptoms of orthostatic hypotension after this treatment.

The four cannoneer casualties indicated that they felt very sweaty, while only 73% of the noncasualties answered likewise. These perceptions were reflected in the higher ($p<0.07$) sweat rates in the casualties (Table 8). Some of the more notable differences were the higher % body weight loss and post-fire urine specific gravity ($p<0.04$), higher heart rate

Table 8. Comparison of Casualties and Non-Casualties.

	Subj 1	Subj 2	Subj 3	Subj 4	Casualties (n=4)	Non-Casualties (n=11)
Rectal temperature[1], °C	39.2	38.2	38.2	38.3	38.5† ±0.2	37.6 ±0.1
Heart rate[1], bpm	151	156	152	144	151† ±2	128 ±5
Total body weight loss, %	1.23	1.08	0.46	0	0.69 ±0.28	0.28 ±0.25
Total sweat loss, L/hr	0.619	0.750	0.677	0.412	0.615†† ±0.072	0.438 ±0.048
Work fluid intake[2], L/hr	0.358	0.305	0.571	0.563	0.449 ±0.069	0.644 ±0.123
Rehydration, %	61	44	75	100	70 ±12	110 ±19
USG, post-fire	1.024	1.028	1.028	1.020	1.025† ±0.002	1.014 ±0.003

1 Rectal temperature and Heart rate at time of removal from days' trial.

2 Two of 3 MOPP IV trials were prematurely terminated and recovery intakes were not obtained.

† Significantly different from Non-casualties at $p<0.05$.

†† Significantly different from Non-casualties at $p<0.07$.

($p<0.03$) and rectal temperature ($p<0.05$) during the firing, and the lower percent rehydration in the four casualties compared to the other cannoneers. In addition, these casualties indicated more shortness of breath ($p<0.01$), more headache ($p<0.002$), greater thirst ($p<0.006$), and less boredom ($p<0.06$) than the other cannoneers.

The orthostatic tolerance test (OTT) is used clinically to measure the ability of the circulatory system to respond to a change in posture (from supine to standing). It is well accepted that the presence of presyncopal symptoms (lightheadedness, dizziness, nausea, or pallor) constitutes orthostatic intolerance. In addition, measurements of heart rate and blood pressure responses in going from the supine to the upright position are often used to confirm hypotension (11). Orthostatic hypotension appears to be related to peripheral vascular pooling of blood (1,5,9) and is often observed following hypohydration, physical exertion, and heat exposure (1,5,9,11). Although we anticipated that hypohydration in combination with increased skin temperature during the MOPP IV trials would increase skin perfusion and reduce the effective circulating blood volume, neither presyncopal symptoms nor hypotension were observed during the post-recovery OTT for either the cannoneers or the commanders in any of the three clothing ensembles. In fact, the circulatory responses to a change from supine to standing measured both pre-fire and post-recovery were typical of those reported in the literature. However, the lack of consistent significant differences, particularly in the four subjects prematurely removed from the MOPP IV trials, may be attributed to the treatment of symptoms and signs prior to performing the OTT.

CONCLUSIONS

Under similar ambient conditions, when soldiers were fully encapsulated in chemical protective gear, they required significantly more time to fire a single round compared to when dressed in the BDU. Moreover, only one of three iterations in MOPP IV was completed when soldiers attempted a high rate of sustained firing for 90 rounds. However, when a microclimate cooling vest and face piece were used with the MOPP IV, work performance was increased as all iterations were completed and the average time required to fire one round was reduced significantly. Hypohydration was minimal during all iterations for all three clothing ensembles indicating that the modified through-mask drinking system did not compromise rehydration even during periods of sustained firing under hot, cramped conditions in the FAASV and howitzer.

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