TECHNICAL REPORT

CASUALTY EVACUATION BY FEMALE LITTER TEAMS UNDER HOT-DRY CONDITIONS

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June 1998

U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
JUNE 1998

3. REPORT TYPE AND DATES COVERED
Technical Report

4. TITLE AND SUBTITLE
Casualty Evacuation by Female Litter Teams Under Hot-Dry Conditions

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Institute of Environmental Medicine
Kansas Steet
Natick, MA 01760-5007

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick, MD 21702-5012

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
A Defense Women's Health Research Program sponsored protocol was conducted at Yuma Proving Ground (YPG), AZ, on 19-27 September 1995. Four female subjects participated in four activities in a hot, dry environment: walk-rest exercise in MOPP-0 and MOPP-4 at 3 mph for a maximum of 2 h 40 min and self-paced, two-person litter carriage with a 68 kg (150 lbs) "casualty" in the same uniforms. Metabolic rates for the walking and self-paced litter carriage tasks were also measured. The results are summarized in Table 1. For walking in MOPP-0, mean endurance time (ET) was 140±40 min and the increase in rectal temperature (Tre) was 0.93±0.27 C vs. an ET of 29±8 min and a Tre of 1.28±0.40 C in MOPP-4. For the litter carriage the ET values in MOPP-0 and MOPP-4 were 59±35 min vs. 43±19 min and for Tre the values were 0.69±0.51 C vs. 0.76±0.41. For walking, the increased physiological strain related to the chemical protective (CP) clothing worn in MOPP-4 was the apparent reason for the reduced activity time on the second day. During both days of litter carriage, the most common reason for termination was skeletal-muscular problems rather than heat stress, but the last subject in MOPP-4 stopped with indicators of thermal strain. This suggests that although muscular-skeletal problems were the proximate limiting factor for most subjects, thermal strain would have occurred within a short time. Mean results for Tre were compared with values predicted by two models: the Heat Strain Decision Aid (HSDA) and the SCENARIO model. Comparisons of predictive modeling results to subject responses show reasonable agreement with mean subject responses for both models.

14. SUBJECT TERMS
Chemical Protection; hot dry climate; heat or thermal stress; litter carriage

15. NUMBER OF PAGES
37

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	U

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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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ACKNOWLEDGMENTS

Protocols involving the use of human volunteers as test subjects require the involvement of a large staff. The authors would like to acknowledge the contributions of the following individuals who assisted in the protocol: Ms. L.A. Blanchard, SGT K.R. Schafer, SGT W.T. Allison and Mr. J.A. Gonzalez. We would like to thank Mr. T. Sargent for coordinating the study at Yuma Proving Ground and for assistance in the field. We would also like to thank Ms. D.M. Danielski for assistance with the manuscript and Ms. L.L. Lameka for assistance with the recruitment of test subjects. Finally, we would like to thank our volunteer test subjects, whose participation made this study possible.

EXECUTIVE SUMMARY

A Defense Women's Health Research Program sponsored protocol was conducted at Yuma Proving Ground (YPG), AZ, on 19-27 September 1995. Four female subjects participated in four activities in a hot, dry environment: walk-rest exercise in MOPP-0 and MOPP-4 at 3 mph for a maximum of 2 h 40 min and self-paced, two-person litter carriage with a 68 kg (150 lbs) "casualty" in the same uniforms. Metabolic rates for the walking and self-paced litter carriage tasks were also measured.

The results are summarized in Table 1. For walking, the increased physiological strain related to the chemical protective (CP) clothing worn in MOPP-4 was the apparent reason for the reduced activity time on the second day. During both days of litter carriage, the most common reason for termination was skeletal-muscular problems rather than heat stress, but the last subject in MOPP-4 stopped with symptoms of thermal strain. This suggests that although muscular-skeletal problems were the proximate limiting factor for most subjects, thermal strain would have occurred within a short time. Mean results for T_{re} were compared with values predicted by two models: the Heat Strain Decision Aid (HSDA) and the SCENARIO model. Comparisons of predictive modeling results to subject responses show reasonable agreement with mean subject responses for both models.

Table 1. Summary of subjects responses by activity

Activity	final T_{re} °C	ΔT_{re} °C	activity range minutes	average activity minutes
Walk in MOPP-0	38.33 (0.42)	0.93 (0.27)	80-160	140 (40)
Walk in MOPP-4	38.55 (0.26)	1.28 (0.40)	20-37	29 (8)
Litter carriage in MOPP-0	37.86 (0.50)	0.69 (0.51)	28-107	59 (35)
Litter carriage in MOPP-4*	38.00* (0.39)	0.76* (0.41)	22-57*	43* (19)

* Three subjects, otherwise n = 4

I. INTRODUCTION

A. PURPOSE

The purpose of this study was to evaluate the sustained performance of female soldiers simulating an existing combat support role, litter carriage, under hot-dry field conditions. The study provides data regarding the performance of sustained female soldier simulating an existing combat support role, litter carriage, under field condition, including meteorological data. At present, data for female soldiers are limited, and field data linked to environmental conditions are essentially nonexistent. The time series physiological measurements and comprehensive meteorological data are a valuable addition to the current USARIEM database. The data were also used to investigate the application of the Heat Strain Decision Aid (HSDA; 15) and SCENARIO (6) models to the physiological responses of female soldiers.

B. MILITARY RELEVANCE

Primarily because of the emphasis on male roles in combat, minimal data exist regarding the performance of female soldiers under field conditions. An absence of scientific data means that decisions will be made based on anecdotal information and speculation. Data provide a means to eliminate or reduce the impact of personal bias in the resolution of gender issues. The inclusion of female soldiers into performance databases and modeling databases is an important step in ensuring their full integration into the modern military.

The algorithms for the HSDA and SCENARIO models were derived from data for male soldiers with observed metabolic rates, work, and load carriage records. As noted previously, data on the performance of female soldiers, especially with various load carriage systems, are very limited and supporting meteorological data are inadequate. It is important to answer the question of whether or not there is a demonstrable difference in male-female thermoregulatory responses to heat stress under field conditions. Irrespective of any decision regarding the role of female soldiers in the battlearena, it is important to answer the question regarding the ability of the existing, male-based models to predict female responses to heat stress. This issue becomes particularly important as more emphasis is placed in the military on battle simulations. Elements that are not part of the database and/or existing models are not played. In the absence of any significant difference, one source of concern regarding the employment of female soldiers can be eliminated. If a significant difference exists, adjustments or compensation for the increased risk of heat strain will be necessary.

C. BACKGROUND

1. Prior Studies

In 1991, USARIEM personnel conducted a P^2NBC^2 sponsored field study of male soldier performance in MOPP-0, MOPP-1 and MOPP-4 clothing during day and night simulated approach marches while carrying a combat load (19). Soldier values measured were rectal temperature, heart rate, and surface skin temperatures. In addition, a test of simulated marksmanship was performed. Meteorological data were collected simultaneously. The data were used to evaluate the P^2NBC^2 HSDA and to expand the P^2NBC^2 Soldier Performance Database.

2. Heat Strain Modeling

a. Modeling. One study objective was to evaluate a heat strain model in respect to the data generated from the field study for women. Due to the greater availability of data on male populations exposed to extreme conditions, most thermal models are based on male performance. This study provided a unique database of time-series thermal physiological responses of women performing military tasks in a hot environment.

b. Models - General Background. The negative impact of heat casualties on military operations has been documented throughout history (20). One response to the health hazard represented by environmental heat exposure was the development of simple models or indices. The Wet Bulb Globe Temperature (WBGT) index (23) is the most widely recognized of many simple climatic indices (2). WBGT represents an empirical solution to quantifying thermal stress based on easily measured environmental variables and their relationship to the heat strain experienced by a selected human population. Although WBGT and related indices provide quick and simple metrics that address an important health concern, they do not consider variability in human parameters (height, weight, age), clothing thermal and vapor resistances, or activity level. Unfortunately, WBGT has become embedded in military and industrial application such that the environmental data required to support the development of alternative models are not being collected (18). The crucial interactions between climate, human physiology, hydration status, clothing and other factors are too complex to be wholly described by a simple relationship between temperature(s) and human responses.

c. Physiological Modeling. The alternative to simple indices like WBGT is the development of more comprehensive physiologically based mathematical models. These more sophisticated models evolved or developed concurrently with WBGT, but their use was generally restricted to academic circles. The long-term trend toward more complex mathematical models was greatly helped by the revolution in cost and accessibility of computing capabilities (3,22,4). At present refined mathematical heat strain models are available (11) which are applicable to field studies. Today, models can be run on a hand-held calculator (9), incorporated into a dedicated field instrument that can measure weather conditions, compute and display tailored guidance (8). The models are also the basis for decision aids developed for laptop or personal computers (12).

It is important to reiterate that the target groups for most thermal strain models have been young, healthy industrial or military male populations. Apart from scaling of physical values for adolescent children and women, these models make no adjustments for young, female, elderly or less healthy populations. If most heat strain models have been developed for young, male populations and are based on male values, an important question is whether or not a male-based model can be applied directly to a female population. If not, can the discrete algorithms in the model be adjusted, or is there a need to create new, female-based models?

d. Heat Strain Decision Aid. The Heat Strain Decision Aid (HSDA) model is an executable version developed by SAIC (15) from the USARIEM Heat Strain Model (9) that traces its roots to the Givoni-Goldman Model (4). As with most physiological models, the Heat Strain and HSDA models are frequently reviewed and upgraded in response to validation studies or new research that indicates possible product improvements. An executable version of a model, such as HSDA, represents what will be available to field users rather than research scientists. For a model intended for field use, inputs for some meteorological data, such as solar radiation, are broad and physiological values often selected from menus within the program. This makes the model accessible to a broad range of military users, but potentially attracts criticism for its conservative bias. The HSDA model has a limited capability for the entry of work-rest cycles, but makes no provision for meteorological upgrades.

e. SCENARIO. The SCENARIO model was developed by Kraning (6) for post hoc evaluation of physiological responses to heat stress. In contrast to the HSDA, the SCENARIO model was not developed by Kraning initially as a predictive model. The SCENARIO model may be characterized as a rational model because it incorporated both passive and controller characteristics from physiological and biophysical principles rather than derived primarily from empirical data. Compared with the HSDA, more input values are required -- such as $\dot{V}O_2max$ estimated body fat and water intake -- but the model also calculates a wide range of physiological values, including compartmentalized blood flow and temperature. In contrast to the USARIEM/HSDA models, there is no adjustment for heat acclimatization. Many calculated values, such as blood temperature or the distribution of blood volume into skin, muscle or core compartments, are difficult to measure with present technology under field conditions. In contrast to HSDA, the SCENARIO model is more amenable to short-term variations in work cycles and meteorology in intervals as short as 1 minute. Table 2 lists the input values required by the two models.

Table 2. Inputs for HSDA and SCENARIO models

	HSDA	SCENARIO
METEOROLOGY		
TEMPERATURE	AIR	AIR
HUMIDITY	RH	RH
WIND	SPEED	SPEED
RADIATION	LIMITED MENU	GLOBE OR MRT
SUBJECT		
HEIGHT	YES	YES
WEIGHT	YES	YES
BODY FAT	NO	YES
ACCLIMATIZATION	YES - MENU	NO
$\dot{V}O_2max$	NO	YES
AGE	NO	YES
ACTIVITY	VALUE OR MENU	VALUE OR MENU
HYDRATION	MENU	WATER CONSUMPTION
CLOTHING	MENU	MENU

II. METHODS AND MATERIALS

A. GENERAL

1. Measurement of Environmental Conditions

During the walking and litter carriage tests, black globe, ground and air temperatures, relative humidity (RH), wind speed and wind direction measurements were collected every minute with a portable weather station (Campbell Scientific Instruments, Logan, UT). A separate hs-371 WBGT monitor (Metrosonics, Rochester, NY) measured the WBGT index at 1 minute intervals during testing. Air temperature (T_a), globe temperatures (T_{bg}) and RH were measured at 1.5 m, wind speed was measured at 2 m and all WBGT related measurements were at 1.2 m above ground level.

2. Course

A 400-m course was laid out with markers every 50 m. The course was laid out on an east-west orientated, level gravel road on the desert driving course. For the paced walk, the time required to walk 400 m was slightly less than 5 min or 37.5 sec per every 50 m. At the end of each lap, the subjects reversed their direction. During litter carriage, for safety concerns, the course was restricted to 100 m so that all subjects remained close to the shelter, and the medical monitor was not required to cover a larger course.

B. PHYSIOLOGICAL TESTING WITH HUMAN SUBJECTS

1. Volunteer Population

Four healthy female volunteers (ages 19-25 years) were recruited for the study. Subjects participated in these studies after giving their free and informed voluntary consent. Investigators followed AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research. Before any experimental testing, all subjects were medically screened and familiarized with all test procedures.

2. Instrumentation and Safety Limits

a. Instrumentation. Physiological measurements of rectal temperature, three skin surface temperatures and heart rate were collected with Grant Squirrel (SQ-32; Grant Instruments, Cambridge, UK) individual dataloggers using the same procedures as the 1991 Ft. Bliss, TX (19) and 1994 YPG field tests. A chest band telemetric heart rate monitor (Polar Electro, Port Washington, NY) was used as a backup or substitute for the heart rate data. The datalogger automatically recorded data every 30 sec, but data was also read from the datalogger and hand-recorded every 5 min by test staff as a backup option. Water consumption and weight loss were measured to determine the gross water balance. Metabolic rates were collected with backpack mounted oxygen analyzers (Oxylog, P.K. Morgan Inst., Inc, Andover, MA). The Oxylog is a portable battery powered oxygen consumption monitor which contains a flowmeter and O_2 sensor unit.

b. Physiological Limits and Subject Safety. The safety procedures for this study conformed to the limits specified in the USARIEM Type Protocol for Human Research Studies in the Areas of Thermal, Hypoxic and Operational Stress, Exercise, Nutrition and Military Performance (21). For both acclimatization and garment testing, the physiological test limits were 39°C (102.2°F) or sustaining 90% of maximum heart rate for 5 minutes. Volunteers were also withdrawn from a test session on the basis of heat strain symptoms, or other non-heat related reasons at the direction of a medical monitor, test observer or the test volunteer's personal decision. Subjects were accompanied by staff and the medical monitor at all times. During litter carriage, staff were stationed on the sides of the litters to provide assistance if the subjects experienced difficulty in lifting or dropped the litters. A staffed ambulance was also present during all testing.

3. Test Methods

a. Metabolic Rate Measurements. Metabolic rates were collected between 07:30 and 09:00 hr on 19 and 20 SEP 95. A pair of subjects participated in either walking at a 1.34 $m \cdot s^{-1}$ (3 mph) pace or self-paced litter carriage. Two bags, each containing 34 kg (75 lbs) of sand and gravel, were placed on each litter to simulate a 68 kg (150 lbs) casualty. Metabolic data were recorded at 1 minute intervals by individual portable monitors carried on a backpack. Subject heart rates and rectal temperatures were recorded every 5 minutes.

b. Walking Tests. On 21 and 23 SEP 95, four subjects were tested while walking at a 1.34 $m \cdot s^{-1}$ (3 mph) pace in MOPP-0 (21 SEP) and MOPP-4 (23 SEP) levels of chemical protection. Subjects walked for an initial 40 minutes, rested for 10 minutes, then walked again, until the subjects either withdrew from testing, reached a physiological limit or completed 2 h 40 min of walk:rest. Water was provided ad libitum. Data included HR, T_{re}, total water consumption and weight losses.

c. Litter Carriage Tests. On 25 and 27 SEP 95, subjects participated in self-paced litter carriage in MOPP-0 (SEP 25) and MOPP-4 (SEP 27) clothing. Each litter team determined the duration and distance of each individual lift and carry interval. Start and stop times for each carry were recorded. To enhance subject safety and medical monitoring, all litter carriage was conducted within 100 m of the start-point, in proximity to the shelter and ambulance. On 27 SEP, one subject was unable to participate in litter carriage due to an unrelated illness. To extend the database, staff members carried one end of the litter after the first subject dropped out of each team. The same data were collected as for the walking tests.

4. Physiological Test Variables

The physiological measurements that were collected as test variables were core temperature, surface skin temperatures, and pre- and post-test body weights. Core temperature was measured as rectal temperature (T_{re}). As test statistics, the calculated change in rectal temperature ($\Delta T_{re} \cdot min^{-1}$) from the initial rise to subject termination for each day is better than T_{re} because of the combined intra- and intersubject variability in daily baseline T_{re}. Evaporative cooling was quantified by using subject weights to calculate a water balance. The difference between pre- and post-test nude weights provides a measure of the water lost as sweat (W_L). The evaporative water loss (E_{sw}) is simply the difference between pre- and post-test clothed weights. The rate of evaporative water loss ($\Delta E_{sw} \cdot h^{-1}$) was calculated by dividing the evaporative loss by time. The ratio of the sweat evaporated to the gross water loss from the body is the efficiency of sweating.

"Endurance" (also referred to as activity, exposure or tolerance time) refers to the length of participation in the test session by a subject. Heart rates were originally recorded for safety monitoring and were used as an indicator of subject strain during the data collection. For the purpose of discriminating between overgarments, changes in core temperature have generally been a more reliable physiological value.

5. Acclimatization

There was no procedure for pre-acclimation of the test subjects. The original assumption was that subjects would be recruited from a single training unit so that levels of acclimatization would be equivalent for all subjects. The actual acclimatization levels of the four subjects was assessed to vary from a high level of acclimatization for Subject 1 to a minimal level for Subject 3. However, because testing occurred at the end of the summer (September), all subjects could be considered partially heat acclimatized.

6. Clothing

During all testing, female test volunteers wore lycra shorts and sports bra under either the Battledress Uniform (BDU) or Battledress Overgarment (BDO) Chemical Protective (CP) uniform. The MOPP-4 ensemble consisted of the BDO over lycra shorts and sports bra with CP overboots and glove set, CP hood, and the M40 CP mask with filters. In MOPP-0, the BDU was worn in place of the BDO without the CP overboots, gloves, hood or mask. Each subject also wore leather combat boots, basic load bearing equipment (LBE) with two canteens. While walking, each subject carried a side pack with a 2.3 kg load to simulate a field medical pack. The BDU or MOPP-0 condition was worn during all metabolic testing. In the MOPP-4, subjects wore the BDO uniform, M-40 mask with filters, overboots and rubber gloves.

7. Pre-test

Subjects were encouraged to drink water prior to dressing. After being weighed nude, donning lycra underclothing and instrumentation, test volunteers dressed in either MOPP-0 or MOPP-4 level clothing as described above. The fully clothed and instrumented subjects were weighed just prior to the start of testing to obtain a pre-exercise clothed weight.

8. Testing

On test days, volunteers stood for 10 minutes to establish a data baseline, then they began walking at 1.34 $m \cdot s^{-1}$ (3 mph) or litter carriage. Volunteers followed the walking or litter carriage test scenarios for 160 minutes (Table 3), unless they reached the physiological limits selected for this study (39°C [102.2°F] or a sustained heart rate at 90% of the maximum rate), voluntarily ended their participation, or were removed by the test observers or the medical monitor for other medical or technical reasons.

Table 3. Testing schedule

Date	Activity
19 SEP 95	Metabolic rate measurements
20 SEP 95	Metabolic rate measurements
21 SEP 95	Walk in MOPP-0
23 SEP 95	Walk in MOPP-4
25 SEP 95	Litter carriage in MOPP-0
27 SEP 95	Litter carriage in MOPP-4

9. Post-Chamber Measurements

Upon completing the walk or carry, volunteers' post-exercise clothed weights were measured. After undressing and removal of instrumentation, they were weighed again to obtain the post-exercise nude weight.

10. Modeling

The HSDA and SCENARIO models were run with input for the meteorological conditions, subject values and clothing. Some model inputs were not directly derived from the field data. Percent body fat estimates and values for $\dot{V}O_2max$ were generated for input into SCENARIO. The HSDA model used estimates of acclimatization status, and full sun was selected for the solar radiation value.

III. RESULTS

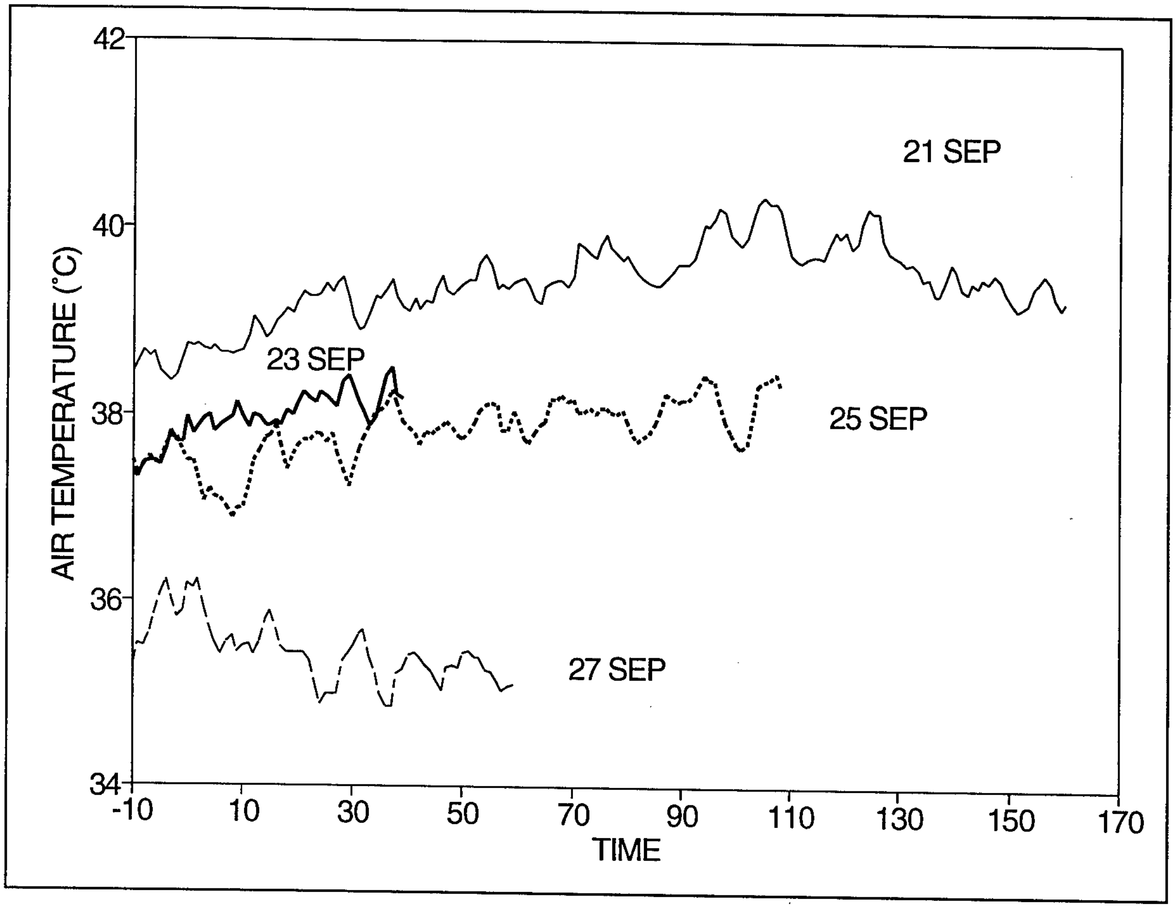
A. METEOROLOGY

Table 4 summarizes the meteorological data for the actual exposure intervals (including baseline) for each test day. Based on ANOVA (SYSTAT Inc, Evanston, IL) there were significant overall differences ($p<0.025$) between days for all meteorological variables. Except between SEP 23 and SEP 25, Tukey's paired t-tests found significant differences between test days for T_a, RH, and WBGT. For wind speed (u), there were no significant differences between SEP 23 and SEP 25 and between SEP 25 and SEP 27. For mean radiant temperature ($\bar{T}_r$) there were no significant differences between SEP 21 and SEP 23 or SEP 25. In all other cases, there were significant differences between test days for T_a, RH, WBGT, u and $\bar{T}_r$. There were also significant differences for T_{bg} between all test days. Figure 1 compares air temperatures (T_a) for all test days from the baseline to completion of testing.

Table 4. Summary of average environmental conditions during walking and litter carriage (exact interval data)

Test date	Meteorological values						
	T_a °C	T_g °C	wind $m \cdot s^{-1}$	RH %	WBGT °C	$\bar{T}_r$ °C	Tgrd °C
SEP 21 (walk, MOPP-0)	39.41 (0.43)	51.11 (0.96)	2.49 (0.98)	12.57 (1.00)	28.9 (0.5)	82.20 (6.87)	52.95 (1.30)
SEP 23 (walk, MOPP-4)	37.96 (0.27)	47.05 (0.44)	4.82 (1.25)	17.85 (0.52)	28.3 (0.3)	84.05 (4.72)	50.52 (0.21)
SEP 25 (litter, MOPP-0)	37.82 (0.34)	46.42 (0.65)	4.63 (1.13)	17.72 (1.57)	28.1 (0.4)	81.12 (4.86)	49.80 (1.17)
SEP 27 (litter, MOPP-4) (sd)	35.46 (0.33)	42.21 (1.98)	4.82 (1.10)	26.79 (1.10)	27.4 (0.8)	71.53 (7.30)	46.38 (1.60)

Figure 1. Comparison of air temperatures (T_a) from baseline to the end of test activity



B. RESULTS FROM HUMAN TESTING

1. Volunteer Subject Measurements

The study was initiated on 19 SEP 1995 with four subjects. Table 5 presents descriptive statistics for the test population.

Table 5. Subject data values

Subject	Height (cm)	Weight (kg)	Age (yr)
1	162.6	67.6 (0.8)	22
2	161.3	57.5 (0.7)	25
3	160.0	66.8 (0.2)	20
4	162.6	59.5 (0.4)	19
Mean	161.6 (1.2)	62.8 (5.1)	22 (3)

2. Metabolic Rates

On 19 and 20 SEP 95, subject metabolic rates were measured during walking and litter carriage (Table 6). Metabolic rates were collected with the backpack mounted oxygen analyzer described previously. All walking measurements were made at 3 mph (1.34 $m \cdot s^{-1}$). The BDU uniform (MOPP-0) was worn during all metabolic rate measurements. $\dot{V}O_2max$ values were obtained for 3 subjects from another study (Rice, unpublished) and one value was an estimate.

Table 6. Metabolic cost of activities

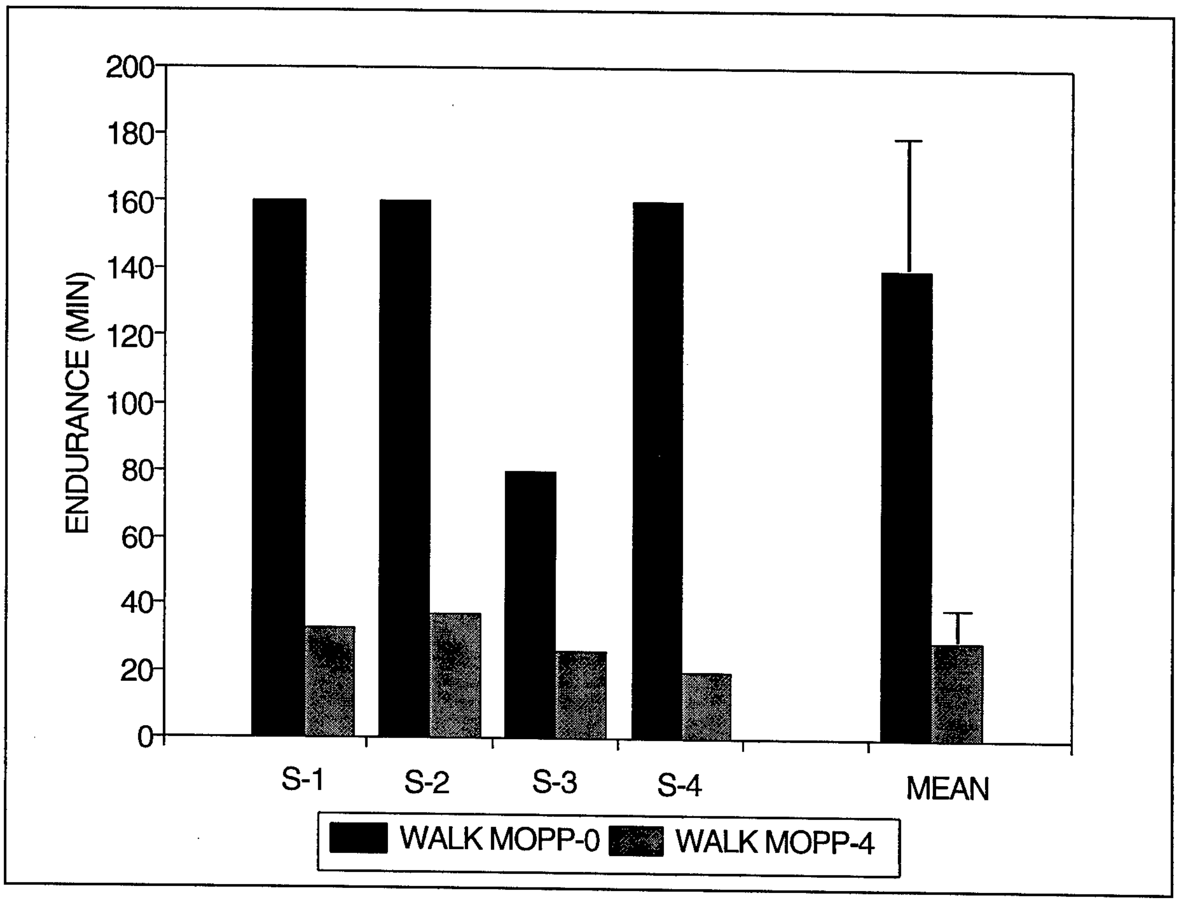
Subject	$\dot{V}O_2max$ (W)	stand $\dot{V}O_2$ (W)	walk $\dot{V}O_2$ (W)	carry $\dot{V}O_2$ (W)	carry/stand[3] (W)
1	964[1]	81	367	475	278[3]
2	967[2]	104	340	499	302[3]
3	1068[2]	94	407	563	328[3]
4	903[2]	88	334	425	257[3]
Mean (SD)	977 (68)	91 (10)	364 (33)	492 (57)	291[3] (31)

[1] estimated value [2] Rice (unpublished, 1995) [3] estimated from 1:1 ratio

3. Results by Variable Type

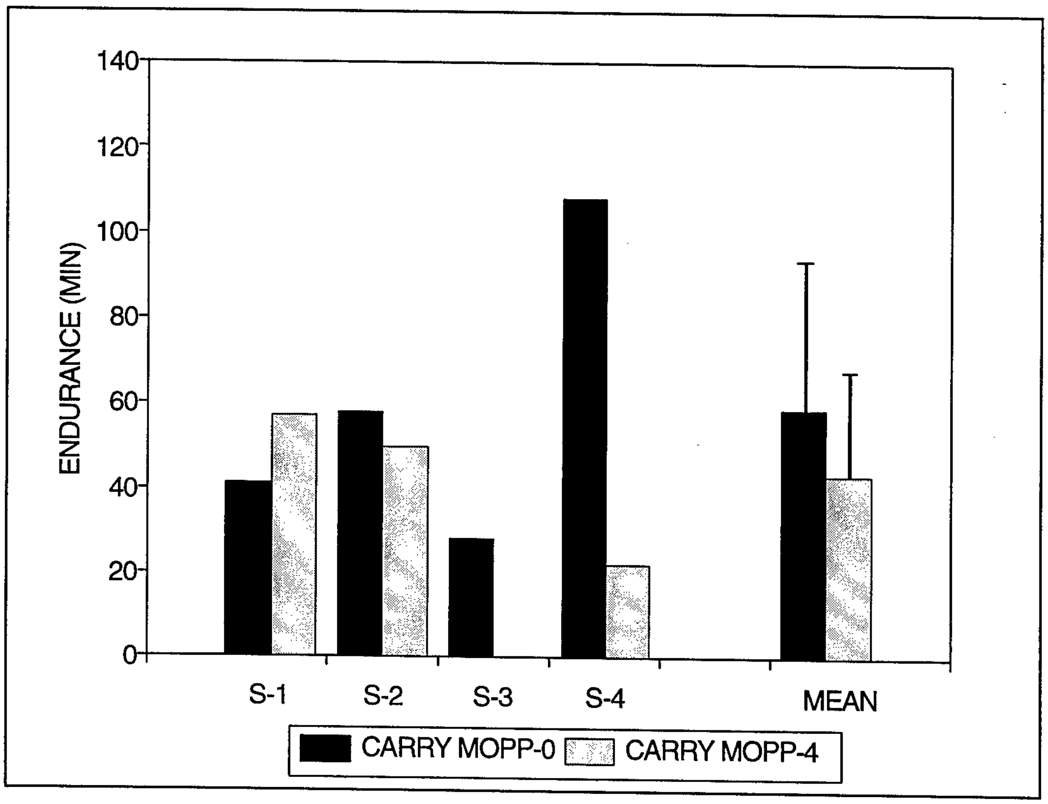
a. Walking Endurance Times. The maximum possible walk/rest time is 160 minutes (excluding the 10 min baseline). Figure 2 clearly illustrates the effect of CP clothing on walking time. The differences were statistically significant (p=0.011).

Figure 2. Comparison by subject of endurance time while walking in MOPP-0 and MOPP-4 levels of chemical protection.



b. Carry Endurance Times. The effect of CP clothing is not readily apparent (no significant difference) when the endurance times for litter carriage in MOPP-0 and MOPP-4 are compared in Figure 3. However, it should be recognized that environmental conditions were less stressful on 27 SEP 96, and the immediate limiting factor was hand and muscle fatigue for most subjects. All subjects indicated problems with the hands or forearms during litter carriage, but of three subjects on 27 SEP 95, the last remaining subject withdrew due to dizziness.

Figure 3. Comparison by subject of endurance time during litter carriage in MOPP-0 and MOPP-4 levels of chemical protection.



c. Litter Carriage Data. Data collected for litter carriage included the total endurance time for each subject, and the time and distance of each carry. If individual subjects withdrew from testing, the remaining subjects were either paired with another subject, or a staff member carried the other end of the litter. There is no significant difference between the mean carriage times in MOPP-0 versus MOPP-4, although speed, distance and percentage of total time of litter carriage all decreased for the MOPP-4 conditions (Table 7).

Table 7. Comparison of litter carriage in MOPP-0 vs. MOPP-4					
	ENDURANCE	REST/CARRY*	SPEED*	AVERAGE CARRY*	
UNITS	MIN	PERCENT	$m{\cdot}s^{-1}$	MIN	m
MOPP-0	59 (35)	34%	1.01	0.80	49
MOPP-4	43 (19)	25%	0.92	0.56	32
*VALUES BASED ON ALL TWO-PERSON DATA					

d. Rate of Increase in Rectal Temperature. When core temperature is at or near equilibrium, the highest value for T_{re} temperature may not occur at the exact end of the exercise period (Tables 8-11). Hence the value for the maximum ΔT_{re} (Table 8) may be greater than the difference between the initial and final values for T_{re}. In addition, when values for T_{re} are near or at equilibrium, a comparison between the rate of change in T_{re} is not a reliable means for comparing between days or clothing treatments. Mean values for T_{re} approached equilibrium for both walking and litter carriage in MOPP-0.

Table 8. Rectal temperature values for walking in MOPP-0 (21 SEP 95)					
Subject	ΔT_{re}	final T_{re}	ΔT_{re} 40 min	Activity time	change ΔT_{re}*
	°C*	°C	$°C{\cdot}min^{-1}$	min	$°C{\cdot}min^{-1}$
1	0.60	37.74	0.013	160	0.004
2	1.02	38.52	0.018	160	0.006
3	1.38	38.70	0.021	80	0.017
4	0.90	38.34	0.015	160	0.006
Mean (sd)	0.98 (0.32)	38.33 (0.42)	0.017 (0.003)	140 (40)	0.008 (0.006)

ΔT_{re} at 40 min is change in rectal temperature during first 40 minutes of walking
* Max difference is based on highest T_{re}, not final T_{re}

Table 9. Rectal temperatures for walking in MOPP-4 (23 SEP 95)				
Subject	ΔT_{re}*	final T_{re}	ΔT_{re} rate*	Activity time
	°C	°C	°C·min^{-1}	min
1	1.56	38.76	0.047	33
2	1.68	38.76	0.045	37
3	0.96	38.46	0.037	26
4	0.90	38.22	0.045	20
Mean	1.28 (0.40)	38.55 (0.26)	0.044 (0.005)	29 (8)

* Max difference is based on highest T_{re}, not final T_{re}

Table 10. Rectal temperatures for litter carriage in MOPP-0 (25 SEP 95)				
Subject	final T_{re}	ΔT_{re} (Max)	Time	change in T_{re}
	°C	°C	min	°C·min^{-1}
1	37.26*	0.36	41	0.009
2	38.46	1.44	58	0.025
3	37.98	0.54	29	0.019
4	37.74	0.42	108	0.004
Mean	37.86 (0.50)	0.69 (0.51)	59 (35)	0.014 (0.010)

* Max difference is based on highest T_{re}, not final T_{re}

Table 11. Rectal temperatures for litter carriage in MOPP-4 (27 SEP 95)				
Subject	final T_{re} (°C)	ΔT_{re} (°C)	Time (min)	rate ΔT_{re} (°C·min^{-1})
1	38.28	1.08	57	0.019
2	38.16	0.90	50	0.018
4	37.56	0.30	22	0.013
Mean	38.00 (0.39)	0.76 (0.41)	43 (19)	0.017 (0.003)

Maximum equals end-point range

e. Water Consumption. Water consumption (drinking) rates (Table 12) for the entire exposure time for all subjects in all tests (n=15) was 1.1 ± 0.7 l·h^{-1}. For all MOPP-1 (walk and litter, n=8), the consumption rate was 1.4 ± 0.7 l·h^{-1} and for all MOPP-4 (walk and litter, n=7) 0.8 ± 0.5 $l \cdot^{-1}$. For all walking (n=8) in either MOPP-1 or MOPP-4, water consumption was 0.9 ± 0.5 $l \cdot h^{-1}$ and for all litter carriage (n=7), 1.4 ± 0.8 $l \cdot h^{-1}$. The individual drinking pattern of each subject may impact the water consumption values. If a subject tends to drink large quantities at infrequent intervals, the timing of consumption relative to the termination of the test session may significantly alter the consumption rate. If subjects tend to drink small amounts frequently at short intervals, the length of the activity on water consumption will have less effect than if subjects drink large quantities infrequently. Another factor may be the frequency of breaks or stops, which varied with the type of exercise. During walking, subjects had to drink during movement, except for the 10 minute breaks at the end of each cycle. During litter carriage, there was an opportunity to drink every time the litter was put down. Subject 4 had difficulty with the drinking tube on her mask during the walk in MOPP-4.

Table 12. Water consumption rate ($l \cdot h^{-1}$)

Subject	21 SEP 95	23 SEP 95	25 SEP 95	27 SEP 95
1	1.9	1.3	2.5	1.7
2	0.9	0.8	0.9	0.7
3	0.7	0.6	1.7	...
4	0.7	0.1	1.4	0.4
Mean (sd)	1.1 (0.6)	0.7 (0.5)	1.7 (0.8)	0.9 (0.7)

f. Total and Net Evaporative Water Loss. There were difficulties in measuring small changes in weight -- for short duration exercises, this may be significant (Tables 13,14). In addition, other studies have indicated that the battery powered scales were affected by temperature and/or battery freshness. The times used to compute the rates of consumption and loss included the initial 10 minute baselines.

Table 13. Gross sweat or total water loss ($l \cdot h^{-1}$)

Subject	21 SEP 95	23 SEP 95	25 SEP 95
1	1.2	1.6	1.6
2	1.0	1.3	1.3
3	0.9	1.6	0.9
4	0.7	1.3	0.7
Mean (sd)	1.0 (0.2)	1.5 (0.2)	1.1 (0.4)

Table 14. Net or effective sweat rate ($l \cdot h^{-1}$)			
Subject	21 SEP 95	23 SEP 95	25 SEP 95
1	1.1	0.8	0.7
2	0.9	0.5	0.8
3	0.7	0.9	0.9
4	0.7	0.7	0.7
Mean (sd)	0.8 (0.2)	0.7 (0.1)	0.8 (0.1)

4. Comparison of Models

The Root Mean Squared Deviation (RMSD) statistic determines the average absolute value of the difference between the mean observed values and the value calculated by the model. The mean value for those differences is compared to the mean or average standard deviation ($\overline{SD}$). The model values for these test conditions fit the data well, usually falling within one SD of mean data. The RMSD for 84 min (n=4) was 0.26 versus a $\overline{SD}$ of 0.33. For 3 subjects (160 min) RMSD was 0.18 versus a $\overline{SD}$ of 0.41.

Table 15. Conservative $\overline{SD}$ versus RMSD for predicting T_{re}						
Activity	Date	$\overline{SD}$	HSDA RMSD	SCENARIO RMSD	N	TIME
WALK MOPP-0	21 SEP	0.33	0.11	0.26	4	84
WALK MOPP-4	23 SEP	0.17	0.02	NA	4	20
CARRY MOPP-0	25 SEP	0.21	0.06 (300 W*) 0.15 (229 W*)	0.13	4	29
CARRY MOPP-4	27 SEP	0.06	0.06 (216 W*) 0.11 (187 W*)	0.06	3	22
*METABOLIC RATES						

A comparison of the plots (Fig 4-7) and RMSD (Table 15) values for the HSDA and SCENARIO models lend support to a conclusion that the HSDA modeling results more closely fit the mean data for T_{re}. The primary strength of SCENARIO is the capability to handle short duration cycles of differing activities. An alternative method for estimating the net metabolic costs of mixed activities would perhaps mitigate this apparent advantage. Using a single metabolic rate based on the ratio of standing rest to carry, values from the HSDA model replicated the pattern of response, but clearly underestimated the mean values for T_{re}. In prior work with the SCENARIO model, we initially attempted to use a single combined value for load carriage, but found that the cumbersome process of entering alternate standing and resting values in 1 to 3 minute blocks yielded a much better fit of the data. As presented in the discussion, we thought that the metabolic cost of combined activities would be greater than a simple weighted value. We used an iterative method to determine that a single metabolic rate of 300 W (25 SEP data) provided approximately the same values as the method of entering alternative stand and carry inputs. A value of 300 W is equivalent to an equal weighting (1:1 ratio) of the standing and carrying metabolic rates, which is 291 W. As part of the same process, we determined that using the ratio of 2:1 ratio with the data for the three subjects on 27 SEP also provided a good fit with the data. As the HSDA model works best with a single metabolic rate, those alternative metabolic rates were used as input into the HSDA. Table 15 reports the RMSD values which are an indication of relative fit.

Figure 4. Comparison of observed mean T_{re} (±SD) to modeling results for walking in MOPP-0

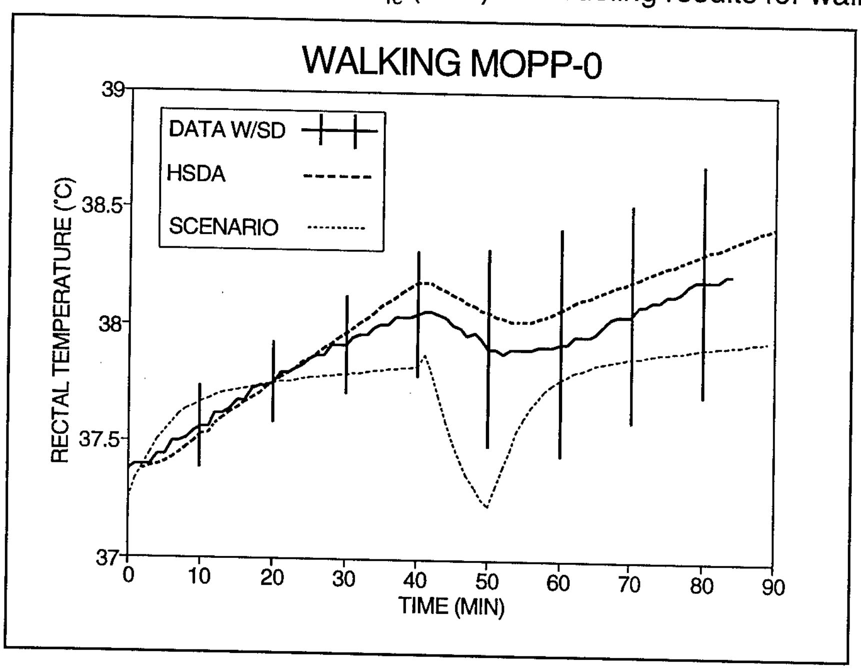


Figure 5. Comparison of observed mean T_{re} (±SD) to modeling results for walking in MOPP-4

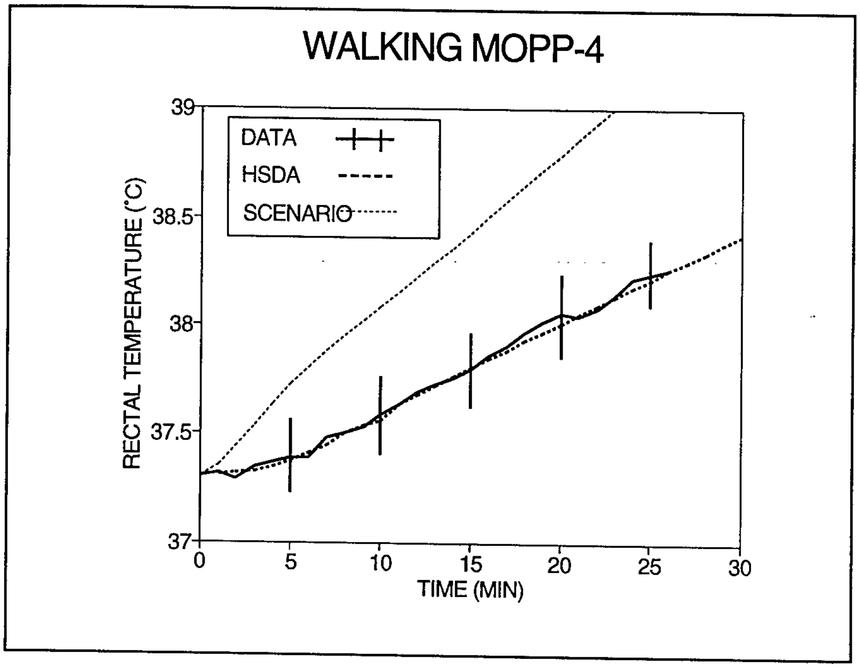


Figure 6. Comparison of observed mean T_{re} (±SD) to modeling results for litter carriage in MOPP-0

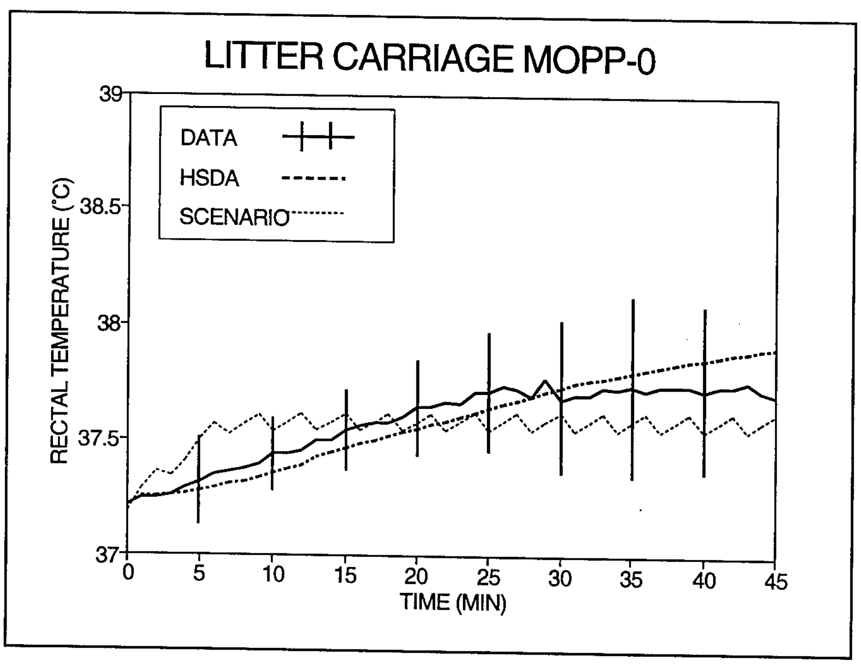
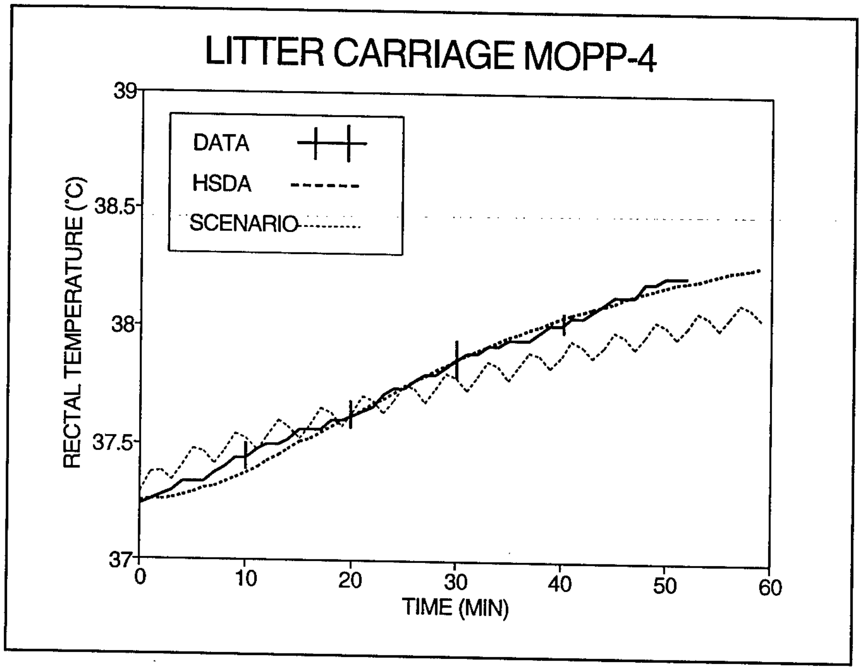


Figure 7. Comparison of observed mean T_{re} (±SD) to modeling results for litter carriage in MOPP-4



5. General Results

There were several general trends in the study results.

a. Importance of Experience with Chemical Protective Clothing. One subject had recently completed basic and advanced training as a military police. Her MOS required extensive training in CP equipment, including work with live riot control agents. Familiarity with CP clothing was a significant advantage. Other subjects, including one participant in a MOPP-2 (BDO without CP mask) outdoor test at YPG the previous month, were considerably less comfortable (more apprehensive) and less experienced during the MOPP-4 tests.

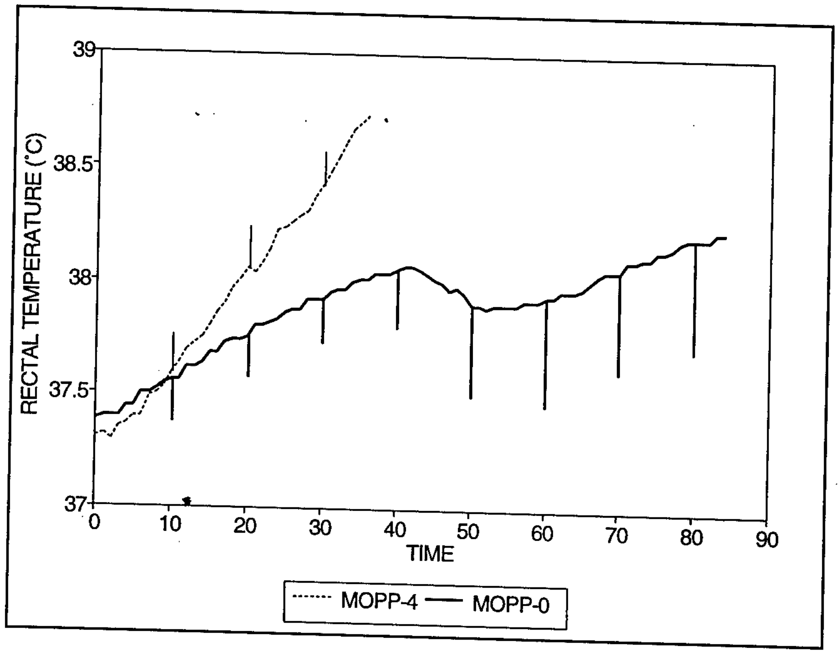
b. Litter Grips. All female subjects indicated that the diameter of the litter handles ("grips") were too large. Improvised handles of a smaller diameter with some padding were used during litter carriage after the first day. A complete description was recorded in the lab notebook, and photographs are available. The improvised handles provided an additional advantage by increasing the clearance between the litter bed and the bearer. During lifting with the normal clearance, the litter beds sometimes drag or catch against the bearer, thereby making a smooth lift more difficult. Some male staff indicated that while the padding was useful, the reduced diameter was too small for their hands. This suggests that grip diameter is an important factor regardless of gender.

Based on these experiences, several designs for modifying the litter were developed. We assumed that there is a large inventory of the current litters, so a complete redesign is not a practical solution. Some designs, but not all, would increase the overall length of the litters, and this was also not considered acceptable. What we propose is the production of a limited number of modification kits. During the development of procedures for this study, the staff practiced timing with an experimental litter which had a square grip cross-section and a nylon mesh litter bed.

In a previous study of litter bearing, Rice (13) found that an improved sling would reduce problems with muscle fatigue. A recommendation for the modified sling was rejected in part because there is already a sling in the inventory. We attempted to obtain these slings (straps, litter [stretcher] carrying: 6530 007844 335) from military inventories for the study, but were unsuccessful. The general impression is that although the litter slings exist in the inventory, they are often not well known or available.

c. Thermal Strain in MOPP-0 vs. MOPP-4. As would be expected from the general literature, exposure or endurance was more limited in CP clothing relative to the MOPP-0 level without CP clothing. For litter carriage, perhaps due to the more frequent rests and less stressful environmental conditions, there were no significant differences. A comparison (Figure 8) of the rate of increase in rectal temperature (T_{re}) during walking on 21 and 23 SEP 95 clearly indicates the impact of CP clothing on soldier performance ($p<0.01$). For walking, there were also statistically significant differences between MOPP-0 and MOPP-4 for ET ($p=0.011$), sweating rate ($p=0.010$) and sweating efficiency ($p<0.001$). This result is consistent with virtually all studies of CP clothing where combinations of environmental conditions and activity induce thermal strain. Meteorological co-factors are difficult to screen out with small subject populations. A comparison of air temperatures between the two walking days (Table 4 and Figure 1) clearly suggests that environmental conditions were a confounding factor.

Figure 8. Mean rectal temperatures (±SD) during walking in MOPP-0 and MOPP-4 levels of chemical protection



d. Muscular-Skeletal Fatigue. The second result suggests that in the majority of individuals, problems related to hand grips and other muscular-skeletal factors terminated litter carriage prior to the onset of thermal strain. Muscular-skeletal strain rather than thermal factors limited female soldier performance under hot-dry conditions. That conclusion should be tempered by the realization that in the absence of the more immediate impact of muscular-skeletal fatigue, and especially problems with the hands, thermal factors would have limited soldier performance. The difference in performance between 21 and 23 SEP may be attributed primarily to the difference between the MOPP-0 and MOPP-4 conditions which in turn is due to the increased heat strain experienced in MOPP-4 clothing. Despite the modified litter grips, all subjects indicated some difficulty with grip strength or fatigue during the sustained carry. This factor, rather than the overall exertion or thermal stress, was probably the proximate limiting factor for sustained carry. Despite the additional stress of CP clothing (see above), during litter carriage in MOPP-4, two (subjects 2,4) of three subjects quit because of problems with hand grips rather than heat factors. Hand problems may have been exacerbated by protective gloves in MOPP-4. During litter carriage in MOPP-0, three (subjects 1,2,3) of four subjects stopped because of hand problems. The use of slings to reduce stress on the hands and arms should be an improvement, although the muscular-skeletal fatigue will probably still be a limiting factor.

IV. DISCUSSION

A. GENERAL FINDINGS

1. Comparison Between Test Days and Treatments

For walking, despite more moderate weather, there were statistically significant differences between MOPP-0 and MOPP-4, which indicates degraded performance in CP clothing. Without CP clothing, thermal strain was not the immediate limiting factor even during prolonged heat exposure. A comparison between walking and litter carriage in MOPP-4 found a significantly higher gain in T_{re} for walking, which suggests that a combination of warmer conditions and longer periods of walking may be as stressful as self-paced litter carriage. Modeling results indicate that an activity that combines standing rest and litter carriage in a 1:2 ratio was equivalent to a continuous metabolic rate of 300 W, whereas the measured metabolic rate for walking was 364 W.

For litter carriage, there were no significant differences between MOPP-0 and MOPP-4. The changes in the ratio of carry to rest, and decreases in mean speed and distance of carry may be attributable to the encumbrance or hobbling effect of CP clothing. The thermal costs of CP clothing may be negated by lower metabolic costs, if changes in the ratio of work to rest ratio and T_a moderate the level of stress. Carry distances may be partially an artifact of the manner in which the course was laid out. This and other studies (13) indicate strength and equipment are limiting factors for litter carriage regardless of weather or gender.

2. Simulation of Litter Carriage vs. Actual Field Conditions

Litter carriage is a difficult task. Under non-tactical conditions, it is a relatively short-term task associated with overall casualty treatment. The frequency and distance of litter carriage for a field medic (MOS 91B) assigned to an aid station or ambulance is low under non-tactical conditions. Medical personnel would not participate in any activity involving patients or casualties while wearing CP clothing, except under tactical conditions or CP training exercises. During an actual tactical operation, when casualty numbers may be high and conditions and/or hostile fire may preclude the use of vehicle or aircraft close to forward areas, litter carriage may become a significant concern. Our test scenario assumed a tactical scenario.

Our two test activities were intended to simulate the forward movement of a medic to reach the casualty and the evacuation of a battle casualty by litter to either an aid station or transport transfer point. How realistic were the assumptions underlying the simulations? In the field, litter carriage may consist of a single linear evacuation off the battlefield, or repeated short carries at an aid station between treatment, holding and transfer areas. The primary difference between the two scenarios is that for self-paced linear carriage, the activity consists of only carriage and standing rest, whereas a series of short carries between treatment and evacuation would consist primarily of carry and walking return with the empty litter. The total duration of the activity would depend on the terrain, enemy actions and number of casualties.

In a true mass casualty, medical personnel with even limited training will devote their full attention to casualty treatment (14). It is highly unlikely under those circumstances that a field medic (MOS 91B) would be utilized as a litter bearer. Litter bearers will be drawn from whatever resources are available, regardless of MOS. It may be equally realistic for military police or other non-medical combat support personnel to practice litter evacuations as field medics. In an unexpected mass casualty situation, such as the Khobar Tower bombing, litters will be in short supply, and it is highly unlikely that litter carriage slings would be available or that the litter bearers, drawn from other, non-medical units, would be familiar with their use.

For a specific tactical environment, an estimate of casualties can be made. That estimate can be incorporated into logistical planning to ensure an adequate supply of litters, and possibly even litter slings. At field treatment and first aid stations, medics do move casualties to and from helipads or ambulances, but the distances will generally be short (40-50 m), and the activity will be sustained only in the event of heavy casualties. In the event of heavy battle field casualties, the medical staff may be able to utilize this prior experience with litter bearing to develop a better plan to larger scale or longer distance evacuations. In certain circumstances, such as the combination of rugged terrain and aggressive enemy fire encountered during the Korean conflict, it may be necessary to form discrete companies of litter bearers.

3. Subject Measurements

Of particular interest is that the physical measurements of the four subjects closely match mean values for several military female populations (n= 38 to 266) summarized by Hodgdon (5), despite the small population. Patton et al. (10) reported a mean height of 164.0 ± 6.2 cm and a mean weight of 61.1 ± 6.2 kg for his test population (n=26). Body fat (25%) was estimated. A slightly higher estimated value (28%) for body fat was derived using an equation presented by Hodgson (5). Patton et al. indicates a 27.4 ± 5.9% body fat for their female test population. Maximum oxygen uptake ($\dot{V}o_2max$) was obtained from other studies for three subjects (Rice, unpublished) and estimated for one subject. Our mean value, 977 ± 68 W whereas a value of 908 ± 101 W was obtained by Patton et al.

4. Metabolic Costs of Activities

When expressed as whole body values, metabolic rates for military tasks are lower for women (10). For modeling purposes, an accurate estimate of metabolic cost of activities is both important and difficult. Our measured metabolic costs were consistent with other studies for litter carriage, low for standing at rest and high for walking at 1.34 $m{\cdot}s^{-1}$. To place the values from this study into the context of other male-bases studies, it is more useful to express metabolic rates as a percentage of $\dot{V}o_2max$. Patton et al. (10) reported metabolic rates for male two-person litter carriage as 46.8% (MOPP-0) and 50.9% (MOPP-4) of $\dot{V}o_2max$. Our value for women in a MOPP-0 configuration was 50.3% of $\dot{V}o_2max$. The metabolic rate for walking was 364 W or 37% of $\dot{V}o_2max$. In a previous study (16), male subjects walking on a level treadmill at 1.34 $m{\cdot}s^{-1}$ averaged 25.2% of $\dot{V}o_2max$. However, Avellini et al. (1) reported that for treadmill walking at 1.34 $m{\cdot}s^{-1}$ in a hot-dry environment (49°C, 20% rh), male subjects worked at 29% of $\dot{V}o_2max$, whereas females worked at 36% of maximum. Other factors which may increase the observed metabolic costs for walking were clothing, load and the gravel road surface. If lower values for walking (290 W) are used as input into the models, the output T_{re} values are lower. For walking in MOPP-4, the output from the SCENARIO model will closely fit the observed data, but the values for MOPP-0 will now be an even lower underestimate of the observed values.

One of the strengths of the SCENARIO model is that it can simulate virtually any pattern of short-term events. At present, the process of hand-entering data is rather ponderous, but it is possible to enter both meteorology and metabolic rates on a minute-by-minute basis. The data for litter carriage for 23 SEP clearly illustrate the advantage of this method. On average during self-paced litter carriage in MOPP-0, the subjects carried the litter for 34% of the time. The whole-body metabolic rate for litter carriage was 492 W. The rest of the time consisted of standing rest at 91 W. One method to estimate the metabolic rate for self-paced litter carriage is to compute a weighted average for standing (66% at 91 W) and carriage (34% at 492 w) - or 227 W. That estimate works relatively well for estimating litter carriage in MOPP-4, but it would seriously underestimate the rectal temperature for litter carriage in MOPP-0. Kraning and Gonzalez (7) reported that for intermittent work, the total metabolic cost is higher than the cost predicted on the basis of individual tasks. There is apparently a metabolic cost for transitions. Instead, we exploited the capability of the SCENARIO model to utilize 1 minute data by entering the metabolic rate as a 1:2 ratio of litter carriage to rest (1 min at 492 W, 2 min at 91 W). For MOPP-4 (n=3), the ratio is 1:3 with slightly smaller values for metabolic rates. The actual mean carry times were less (48 s in MOPP-0 and 34 s in MOPP-4), but the calculated values closely fit the mean observed data.

There is no method currently available for determining the actual transitional costs. It was possible, however, to estimate that cost by using an iterative method of entering different values for continuous work into SCENARIO to find a value that closely replicated the observed values. For MOPP-0, that value is 300 W. In MOPP-4, the amount of resting increased, so there was a lower frequency of transitions per unit time. Thus, in addition to less activity at the higher metabolic rate, the cost for transitions would also be reduced if there were fewer transitions. Another way to arrive at approximately the same number is to change the ratio between standing and carrying. For 25 SEP, if the ratio is changed from 2:1 to 1:1, the combined metabolic cost is 291 W. For 27 SEP, if the ratio is changed from 3:1 to 2:1, for those three subjects, the estimated cost would be 216 W. It may be reasonable to use a common 2:1 ratio for both 25 and 27 SEP, but there is no underlying logic to changing the ratio of 2:1 to 1:1 for 25 SEP other than a general assumption that transitions increase overall metabolic costs. Empirical observations also indicate that the model with a 1:1 ratio fits the data on 27 SEP better.

Continuous walking at 364 W for 40 minutes is probably more stressful than self-paced litter carriage at an average cost of 300 W. Hence, despite the muscular-skeletal stresses, a combination of moderating weather conditions and a lower metabolic cost did allow subjects to perform litter carriage longer than they could walk at 1.34 $m \cdot s^{-1}$ in MOPP-4. Hence modeling confirms that the mean data for litter carriage is representative, despite the small sample population, and provides a possible explanation for the apparent contradiction between anticipated and actual subject responses.

5. Muscular-Skeletal Fatigue vs. Thermal Exhaustion

The results of this study demonstrate the potential errors in focusing on a narrow range of concerns in a complex scenario. Thermal strain, in conjunction with CP clothing, is a limiting factor. This was demonstrated on 23 SEP 95 for walking in MOPP-4. However, the apparent primary limiting factor for litter carriage was the muscular-skeletal strain. Thermal factors were less important, even in MOPP-4, due to moderation of environmental conditions and the indication that short bursts of high cost activities, even with the transitional costs of lifting a litter, mixed with longer rest in a 1:2 or 1:3 ratio, incurred less metabolic cost than continuous walking at a relatively moderate 1.34 $m \cdot s^{-1}$ (3 mph) pace. Another cautionary note was that although hand problems were cited as the primary limiting factor, other potential limiting factors were present (heart rate on 25 SEP, dizziness on 27 SEP 95).

6. Meteorology and Climate

By describing the climate at YPG as a hot-dry desert, there is an expectation that conditions will be extreme. One problem with subject recruitment was the almost universal presumption by prospective volunteers, and others, that the combination of litter carriage and the hot-dry desert environment would be brutal. The actual weather conditions varied considerably in terms of the thermal environment, but generally had a much less extreme impact than what might be expected for a hot-dry desert climate. In 7 days the mean T_a during the study decreased 4°C, RH increased 14.2 % and average wind speeds nearly doubled after the first day. Working with models affords an opportunity to see how altering one weather value can significantly alter the level of physiological strain experienced by soldiers. By observing the meteorological data and manipulating the models, one can develop a sense of both the variability and importance of meteorology data. The impact of weather cannot be predicted simply from generalities about the climate.

B. MODELING

1. Overall Modeling Results

The RMSD from the observed T_{re} values were compared to the $\bar{S}\bar{D}$ for both models and all days (2x4). In all but one case, RSMD$\leq\bar{S}\bar{D}$. The single exception is the calculated values from the SCENARIO model for walking in MOPP-4. Overall, HSDA fit the data better than the SCENARIO model. For litter carriage, identification of an appropriate metabolic cost for the mixture of standing and actual carry activities is important.

The HSDA model, which was derived of the USARIEM heat strain model for the specific purpose of field predictions, is better suited for that task. Most of the requisite inputs are readily available to local commanders or their staff. SCENARIO, which was originally developed for post-hoc analysis of experimental data, requires more specific data. The two advantages of SCENARIO are the capability to utilize minute-by-minute data to generate more accurate metabolic and/or meteorological inputs, and the more extensive physiological output.

2. Use of Models to Interpret Field Data

Modeling results supported the observed results. On 21 SEP 95 both models indicated that core temperatures would remain below 38.5°C, which would suggest that most individuals would not experience a significant level of thermal strain. Three of four subjects completed the full 170 min exposure (baseline included). On 23 SEP 95 in MOPP-4, both models indicated a steep climb in core temperature, although the SCENARIO results overpredicted the rate of increase. Due to physiological strain, none of the subjects were able to complete the first 40 min of walking on that day.

For litter carriage, the SCENARIO model predicted a dynamic equilibrium situation (maximum value 37.62°C) that closely fit the observed pattern of subject responses. The HSDA model predicted a slow rate of increase and an eventual equilibrium below 38.25°C. For the final day of litter carriage in MOPP-4, both models indicated a moderate increase in core temperature that suggests that if subjects had been able to overcome their muscular-skeletal problems and continue that activity, eventually thermal strain could have become a limiting factor with average core temperatures exceeding 38.5°C.

3. Application of Male-based Models to Female Populations

The HSDA in particular is "conservative" in that it overpredicts core temperature. Thus there is a safety margin for male soldiers. By simply changing the physical values (height and weight) of the model to be more representative of a female population, the model outputs were significantly altered. However, when metabolic rates, which reflected the lower metabolic (both models) and $\dot{V}O_2max$ values (SCENARIO only) for women, were also used (10), the model outputs were essentially identical. The general conclusion was that both male-based models are applicable to female military populations.

V. SUMMARY

The hot-dry environmental conditions experienced in the course of this study during the walking and litter carriage MOPP-0 tests were not sufficiently severe/extreme to limit the performance of the majority of female subjects. In MOPP-4, all female subjects experienced physiological strain while walking. For litter carriage in MOPP-4, although muscular-skeletal strain was the primary limiting factor, thermal stress was also present.

During self-paced litter carriage, the ratio of carry to rest varied between 1:2 and 1:3 in MOPP-0 and MOPP-4, respectively, and there were decreases in speed and distance of carriage, but there were no statistically significant differences. A combination of a small subject population, differing levels of CP protection, and decreasing or moderating weather conditions probably confounds any effort to identify significant differences. The data suggest that even for self-paced litter carriage, the limit for that activity, without a significant rest and recovery phase, is 30-45 min.

Without CP clothing, thermal strain was not as limiting as expected, even during prolonged heat exposure. The results indicate strength and equipment are limiting factors for litter carriage regardless of CP or weather condition. Both male-based models were applicable to our female subject population. Overall, values from HSDA fit the data better, if the question of metabolic costs for mixed or complex activity (litter carriage) can be resolved. The SCENARIO model had greater flexibility for inputing tasks that involved transitions between levels of metabolic intensity.

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