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**SOLDIER PHYSIOLOGICAL MONITORING -
RESULTS OF DISMOUNTED BATTLESPACE BATTLE LAB
CONCEPT EXPERIMENTATION PROGRAM FIELD STUDY**

**U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts**

NOVEMBER 1997



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13. ABSTRACT (Maximum 200 words) Soldier volunteers were studied over four days of training at Ft. Benning, Georgia, using new ambulatory monitors. This report focuses on the 20 km road march performed on the first day. Study objectives: (a) define baseline requirements for physiological monitoring of individual soldiers for force management, (b) use prototype ambulatory monitoring systems to record the physiological responses of soldiers during field training, and (c) address operational issues and criteria raised in the original Dismounted Battlespace Battle Lab CEP proposal. Approach: Synchronous, time series measurements of volunteer stride rates and the metabolic cost of locomotion, body core temperature (telemetry pill), heart rate (HR), and geolocation (GPS), were made on seven soldiers wearing individual ambulatory monitoring systems (~3 lbs, 13"x10"x2"). Results: soldier wt = 79.61±1.09 lbs (mean±SD); load weight = 17.64±3.6 kg; march duration = 230 min; velocity = 1.54 ± 0.29 meters per sec (~3.4 mph); stride rate = 49 ± 7 strides per min (mean total = 10,128 strides); heart rate = 137 ± 10 beats per minute; metabolic cost of locomotion = 7.1 ± 0.5 kcal/min (total expenditure during march = ~ 1600 kcal); exercise intensity = 45 ± 3 % of estimated VO ₂ max; core temperature = 37.3 ± 0.2 °C. Conclusion: High quality physiologic data can be reliably collected from soldiers engaged in military training. This capability should lead to better force management and improved predictive models to translate medical research into operational doctrine.				
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Concept Experimentation Program Field Study**

by

Reed W. Hoyt¹, Mark J. Buller¹, Maria S. Redin⁴, Robert D. Poor⁴, Steven R. Oliver³,
William T. Matthew¹, William A. Latzka¹, Andrew J. Young¹, Daniel Redmond², and
Christopher Kearns⁵

¹ U.S. Army Research Institute of Environmental Medicine
Natick, Massachusetts 01760-5007

² Walter Reed Army Institute of Research,
Washington, D.C. 20307-5001

³ Personal Electronic Devices, Inc.,
212 Worcester St., Wellesley, Massachusetts 02181

⁴ The Media Laboratory, Massachusetts Institute of Technology,
20 Ames St., Cambridge, Massachusetts 02139-4307

⁵ Dismounted Battlespace Battle Lab,
U.S. Army Infantry School, Ft. Benning, Georgia 31905-5800.

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FOREWORD

Medical monitoring of the dismounted soldier has two major aspects: monitoring for casualty care purposes and monitoring for force management and prediction of physiological status. The present Concept Experimentation Program effort focused on pre-casualty physiological monitoring. Specifically, prototype systems were developed and used to monitor the physiology of soldiers engaged in situational training exercises (STX) at Ft. Benning, Georgia. The STXs included a 20 km road march, and day and nighttime attacks on objectives in both woodland and urban terrain. This report describes the enabling technologies and the physiologic data collected. The discussion reviews operational criteria and issues surrounding soldier physiological monitoring, database organization, and some of the ramifications for dismounted soldiers. Learning how to gather and distill physiologic information of this type is a necessary step towards the ultimate goal of providing essential soldier status information to commanders.

ACKNOWLEDGEMENTS

This study would not have been possible without the support of a wide group of individuals and organizations. We are indebted to the Dismounted Battlespace Battle Lab, in particular to Michael E. Kennedy and Anthony Mason for their thoughtful and timely support for this research effort. We also acknowledge the indispensable assistance of USARIEM's Murray Hamlet, and Rich Landry from the Natick Research Development and Engineering Center's prototype shop, for expertly designing and constructing the packaging and pouches for the instrumentation. The professional engineering expertise of Norbert Ohlenbush, Paul Gaudette, and Thomas Blackadar from Personal Electronic Devices, Inc., was crucial to the success of this project. The contributions of Michael Hawley and Matthew Lau from the Personal Information Architecture Group at Media Lab at the Massachusetts Institute of Technology are also gratefully acknowledged. Finally we wish to extend our thanks to the soldiers from the 82nd Airborne who volunteered to participate in this study and showed a selfless and exemplary interest in the welfare of future dismounted soldiers.

EXECUTIVE SUMMARY

Soldier volunteers from Ft Bragg were studied over four days in September 1997 during situational training exercises (STX) which included a 20 km road march, assaults on objectives, and military operations in urban terrain (MOUT). The data presented here focuses on the 20 km road march. The goals of this Concept Experimentation Program (CEP) project were to (a) define baseline requirements for physiological monitoring of individual soldiers for force management, (b) use prototype ambulatory monitoring systems to record the physiological responses of soldiers during field training, and (c) address operational issues and criteria raised in the original Dismounted Battlespace Battle Lab CEP proposal. Approach: Synchronous, time series measurements of volunteer stride rates and the metabolic cost of locomotion, body core temperature (telemetry pill), heart rate (HR), and geolocation (GPS), were made on seven soldiers wearing individual ambulatory monitoring systems (~3 lbs, 13"x10"x2"). The monitoring systems used an open network architecture where a hub circuit polled sensors on the network and fed time-stamped data into a data logger for subsequent retrieval and analysis. Local weather conditions, which were temperate, were monitored with automated portable weather stations. Results from the 20 km road march: soldier wt = 79.61 ± 1.09 lbs (mean $\pm$ SD); load weight = 17.64 ± 3.6 kg; march duration = 230 min; velocity = 1.54 ± 0.29 meters per sec (~3.4 mph); stride rate = 49 ± 7 strides per min (mean total = 10,128 strides); heart rate = 137 ± 10 beats per minute; metabolic cost of locomotion = 7.1 ± 0.5 kcal/min (total expenditure during march = ~1600 kcal); exercise intensity = 45 ± 3 % of estimated $\text{VO}_{2\text{max}}$; core temperature = 37.3 ± 0.2 °C. Conclusion: High quality physiologic data can be reliably collected from soldiers engaged in military training. This information should lead to better force management and improved predictive models to translate medical research into operational doctrine.

INTRODUCTION

This Concept Experimentation Program (CEP) is part of an ongoing Dismounted Battlespace Battle Lab (DBBL) effort to define baseline requirements for physiological monitoring of individual soldiers for force management, casualty detection, and predictive modeling. Once defined, soldier physiological status monitoring will become a technology insertion in the Land Warrior System.

This DBBL CEP was supported by the U.S. Army Research Institute of Environmental Medicine (USARIEM) and the Walter Reed Army Institute of Research (WRAIR) of the Medical Research and Materiel Command. The USARIEM was responsible for coordinating the technical and scientific contributions of WRAIR, the Army Research Laboratory (ARL), and the Massachusetts Institute of Technology (MIT) to this CEP.

Various ambulatory monitoring technologies such as actigraphy, pedometry, and heart rate monitoring, have long been used to assess the physiology of free-living humans (see Montoye et al., 1996). What distinguishes the present effort is the use of an integrated system, with multiple sensors arrayed in a communications network, to monitor the physiological status of soldiers during military training. The approach offers new opportunities to understand the interrelationship of various markers of physiologic status. This study aimed to help define how sensors and information management systems might be used to gather physiological status information useful to future commanders. The data collected will also be used to refine physiological prediction models relevant to soldier health and performance.

The specific parameters monitored were: (1) core body temperature by telemetry pills, (2) the metabolic cost of locomotion from total weight and foot contact time, (3) geolocation by global positioning system, and (4) heart rate by electrocardiography. The information gathered by these sensors was stored for later retrieval. Earlier studies ensured that the sensors used in the present study provided valid physiologic data. These studies include validation of core body temperature measurement by telemetry pill (O'Brien et al., 1997; Kolka et al., 1993), measurements of the metabolic cost of locomotion by foot contact monitoring (Hoyt et al., 1994), and heart rate measurements by microcomputer (Karvonen, 1984).

Study objectives were to (1) use ambulatory monitoring technologies from a "research tool kit" to automatically collect and organize the data from multiple physiological sensors, (2) attempt to address operational issues and criteria outlined in the Dismounted Battlespace Battle Lab (DBBL) Concept Experimentation Program (CEP) proposal, and (3) consider some of the possible practical benefits soldier physiological monitoring.

METHODS

A. Test volunteers

Twenty seven test volunteers were recruited from members of the 1st Platoon, B Company, 3rd Battalion, 325th Airborne Infantry Regiment of the 82nd Airborne Division, Ft. Bragg, North Carolina, who were participating in Small Unit Operations training at the Ft. Benning, Georgia, Griswold Range and McKenna MOUT (Military Operations in Urban Terrain) Site from 22 to 26 September 1997. The platoon was briefed at the US Army Infantry School, Ft. Benning, regarding the present research study. The fact that participation in the study was voluntary was emphasized and the soldiers were encouraged to ask questions. The volunteers who participated in this study gave their free and informed consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research. The data presented in this report were from a subset of seven volunteers. Other ambulatory data collected from the remaining volunteers by the Walter Reed Institute of Research, and the Army Research Laboratory, will be reported elsewhere. Each of the test volunteers read and signed the Volunteer Agreement Affidavit after their questions had been answered.

Age, height, body weight, and body fat % of each volunteer was recorded. Percent body fat was calculated from skinfolds thicknesses measured in duplicate at four sites (biceps, triceps, subscapular, and supra iliac) using standard methods (Durnin and Womersley, 1974). The total weight of each volunteer, including the weight all clothing and equipment carried, was also measured periodically during the study. Each soldier's most recent 2 mile run for time from their Annual Physical Fitness Test was used to estimate maximum aerobic capacity (Mello et al., 1988).

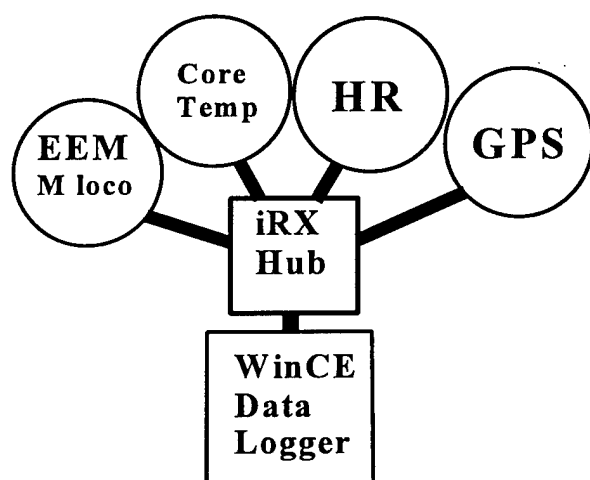
B. Description of ambulatory monitoring instrumentation

The general configuration of the soldier physiological monitor used in this study is shown in Figure 1. Each system weighed about 3 lbs and was mounted in a 13" x 10" x 2" camouflage pouch worn on either the chest or back by the volunteer. This system recorded and stored time series measurements of the volunteer's metabolic energy expended in locomotion, core body temperature, heart rate, and geolocation. The system is an evolutionary improvement of the "Marathon Man" system developed by the Massachusetts Institute of Technology (MIT) Media Lab Personal Information Architecture Group and their collaborators to study the physiology of marathon runners (<http://ttdt.www.media.mit.edu/SF/>).

The system's four sensors were connected through an interface circuit (iRX Hub) to a Windows CE palmtop computer (Model C140; Compaq Computer Corp., Houston, Texas) where the data was stored. The two new sensors, the Expended Energy Monitor and the Body Core Temperature Monitor, and the iRX 2.0 interface device, are described in detail below. The heart rate and geolocation sensors are commercial off-the-shelf devices. Heart rate was monitored with Polar Electro system (Vantage XL model; Polar Electro, Ft. Washington, NY; <http://www.polar.fi/products/products.html>) where the output of a chest strap pickup was received by a circuit board connected to the iRX interface. Geolocation was monitored with a Trimble global positioning system (Trimble Lassen SK8 GPS receiver; 3.29" x 1.30" x 0.52"; weight: 0.7 oz; http://www.trimble.com:80/cgi/products.cgi/pd_om006.htm) with an external antenna interfaced to the iRX device.

Expended energy monitor (EEM)

Movement by foot and loadbearing are common military activities (Patton et al., 1991). The Expended Energy Monitor (EEM) offers a new way to quantify the energy demands on foot soldiers during walking and loadbearing. The EEM (Personal Electronic Devices, Inc., Wellesley, MA) attaches to the outside of the ankle (1.0 X 1.0" X 0.5"; 3 oz.) and provides minute-to-minute estimates of the metabolic cost of walking and running on level terrain. The metabolic cost of human locomotion is calculated from total body weight and the time during



each stride that a single foot contacts the ground (Hoyt et al., 1994; Kram and Taylor, 1990; Taylor et al., 1985). This approach is based on the fact that the rate of metabolic energy expenditure during walking or running is primarily determined by the cost of supporting body weight and rate at which this force is generated (Kram and Taylor, 1990). Thus, the rate of force generation can be estimated as total body weight divided by the time during each stride that a single foot was in contact with the ground (Kram and Taylor, 1990; Hoyt et al., 1994).

Fig. 1. Block diagram of soldier physiological monitoring system.

Body Core Temperature Monitoring

The core temperatures of the study volunteers were measured by a telemetry temperature pill system. Each test volunteer swallowed a standard FDA-approved ingested temperature telemetry pill (7/8" X 7/16") (CorTemp™, Human Technologies Inc., St. Petersburg, Florida). The 260 kHz signal from the pill, which varies with temperature, was recorded by a pager-sized

(3.5" X 2.25" X 1"; 3.2 oz) Body Core Temperature Monitor (BCTM)(Personal Electronic Devices, Inc., Wellesley, MA). The temperature pill method, in use for over a decade, provides a valid measure of core temperature without the discomfort and inconvenience of a rectal or esophageal probe.

Although no single definitive core temperature exists because of temperature differences among sites in the body (Sawka et al., 1996), core temperatures measured at the esophagus, rectum, and gastrointestinal tract are considered the most scientifically legitimate representation. A close relationship among body core temperatures measured by esophageal probe, and rectal probe, and telemetry pill has been shown during exercise in temperate and hot conditions (Fox et al., 1961; Kolka et al., 1993; Sparling et al., 1993) as well as during cold conditions at rest and during exercise (O'Brien et al., 1997).

iRX 2.0 Interface Device

The interface device called the "iRX 2.0" was created by the Personal Information Architecture Group at the MIT Media Lab. It serves as an information hub, polling each sensor on the network and feeding time-stamped data to the Windows CE data logger for storage for later retrieval and analysis. Briefly, the iRX is a circuit card measuring 1.25" x 3" with a RS-232 serial port, containing a model PIC16F84 microcontroller (MicroChip Technologies, Inc., Marlborough Massachusetts). The PIC16F84 features thirteen general I/O ports, instruction cycle times of under 1 uSec and an efficient RISC-like instruction set. The iRX 2.0 uses five of the PIC's I/O ports, and makes the remaining eight ports available on a connector. The total cost of the iRX2 is under \$20 US when built in modest quantities. For a detailed description of the iRX circuitry, see: <http://ttt.media.mit.edu/pia/Research/iRX2/index.html>.

Weather data collection

Four portable weather stations (Weather Monitor II, Davis Instruments Inc., Hayward California) and three Wet Bulb Globe Temperature (WBGT) monitors (Model hs-371, Metrosonics, Inc, Rochester, New York) were deployed along the route of the 20 km march (Fig. 2). Air temperature, relative humidity, and wind speed were automatically measured and recorded at 5-minute intervals by the Davis weather stations. The WBGT monitors, co-located with three of the four weather stations, provided 5-minute interval measurements of black globe temperature that were used to estimate an average solar load in Watts per square meter.

RESULTS

The average age, physical characteristics and the total load weight carried by the seven soldier volunteers is shown in Table 1.

Table 1. Study volunteer characteristics.

Vol. No.	Age (yr)	Height (cm)	Nude Weight (kg)	Body Fat (%)	Load (kg)	2 Mi Run Time (min:sec)	Estimated VO ₂ max (L/min) (ml/kg/ min)	
1	25	188	79.00	15.4	16.18	12:52	4.36	55
2	21	175	68.45	15.9	19.91	12:30	4.03	59
3	22	173	70.00	16.6	19.64	12:30	4.10	59
4	21	178	87.81	18.7	17.82	13:48	4.43	50
5	24	180	81.91	20.9	15.18	14:27	4.10	50
6	21	185	85.27	21.2	11.82	12:10	4.74	56
7	21	188	84.82	18.3	22.91	14:00	4.29	51
Mean	22.1	181	79.61	18.1	17.64	13:12	4.30	54
Std. Dev.	1.7	2.4	7.63	2.3	3.6	00:54	0.25	4

Geolocation

The route of the 20 km march and an elevation profile is shown in Figure 3. The points along the route indicate the mean time the test group arrived at a given point. The terrain was essentially level, with only a modest 50 ft rise at the beginning of the march. The 20 km road march on the Ft. Benning Military Installation (DMA Map V745S) started at about 1050h and ended about 1440h on 22 Sept 1997. The terrain was generally level except for a 50 m increase in elevation between the 4 km and 7 km (~2% grade). The soldiers took a rest break from about 1300 h and 1330 h.

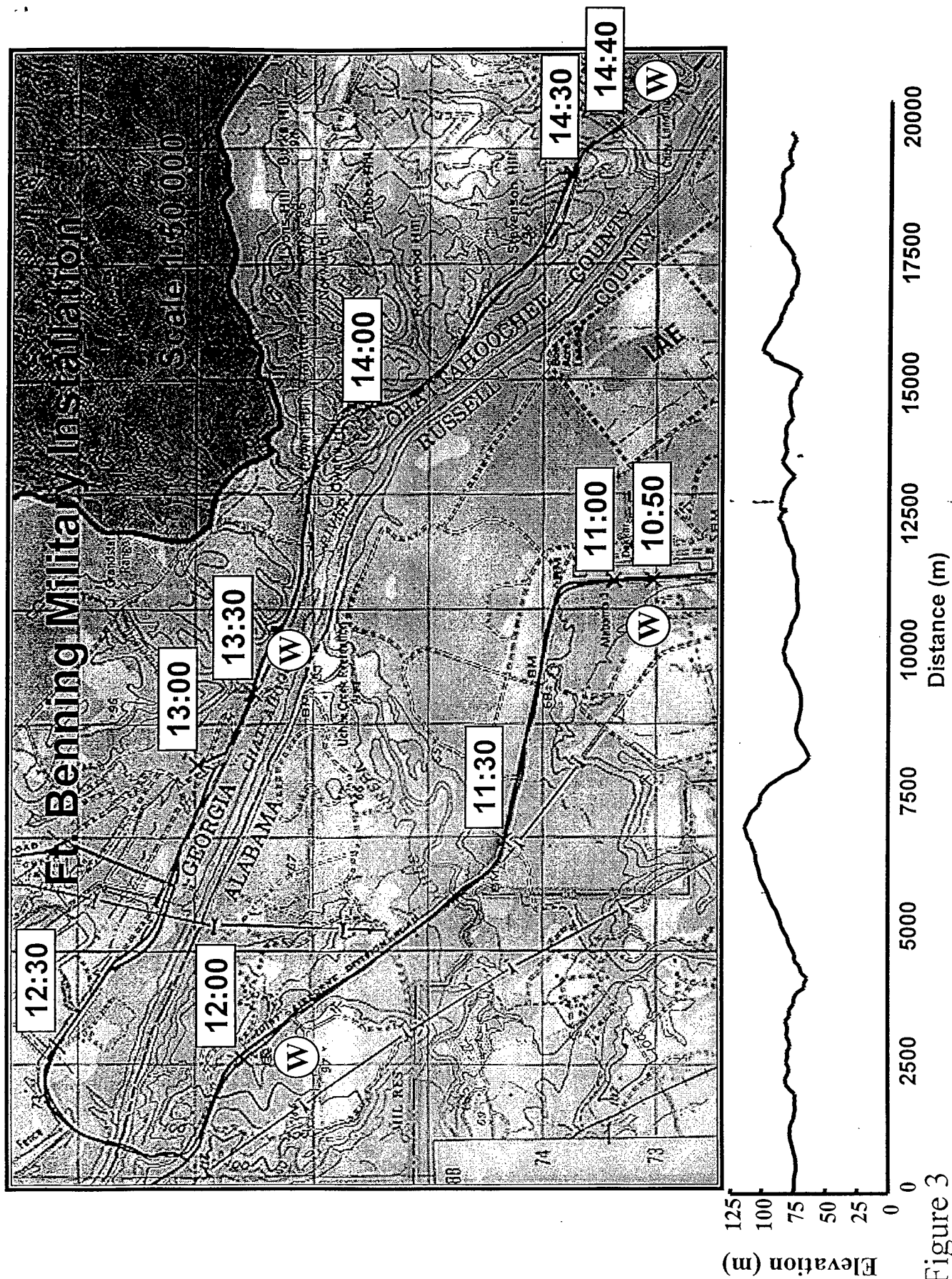


Figure 3

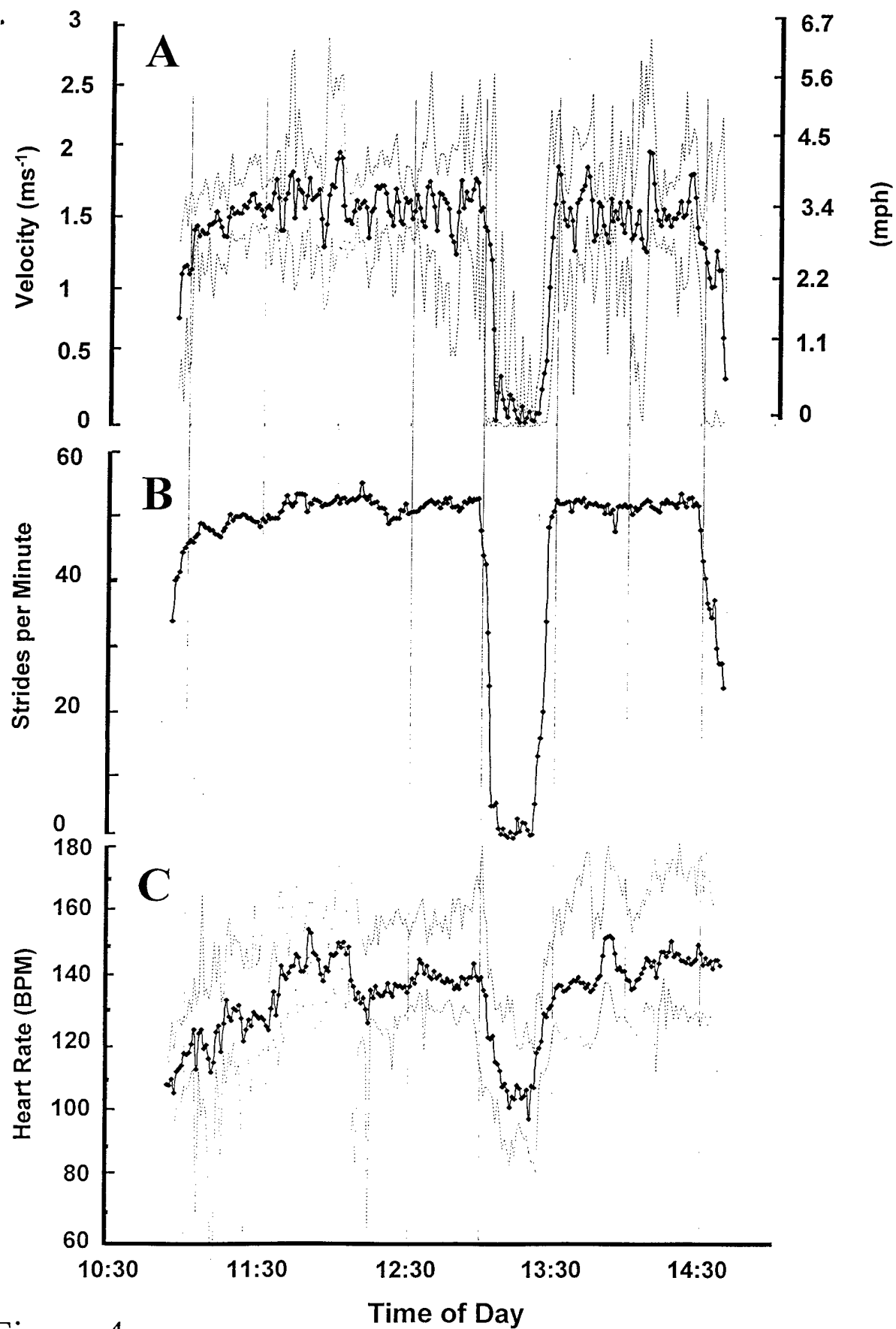


Figure 4

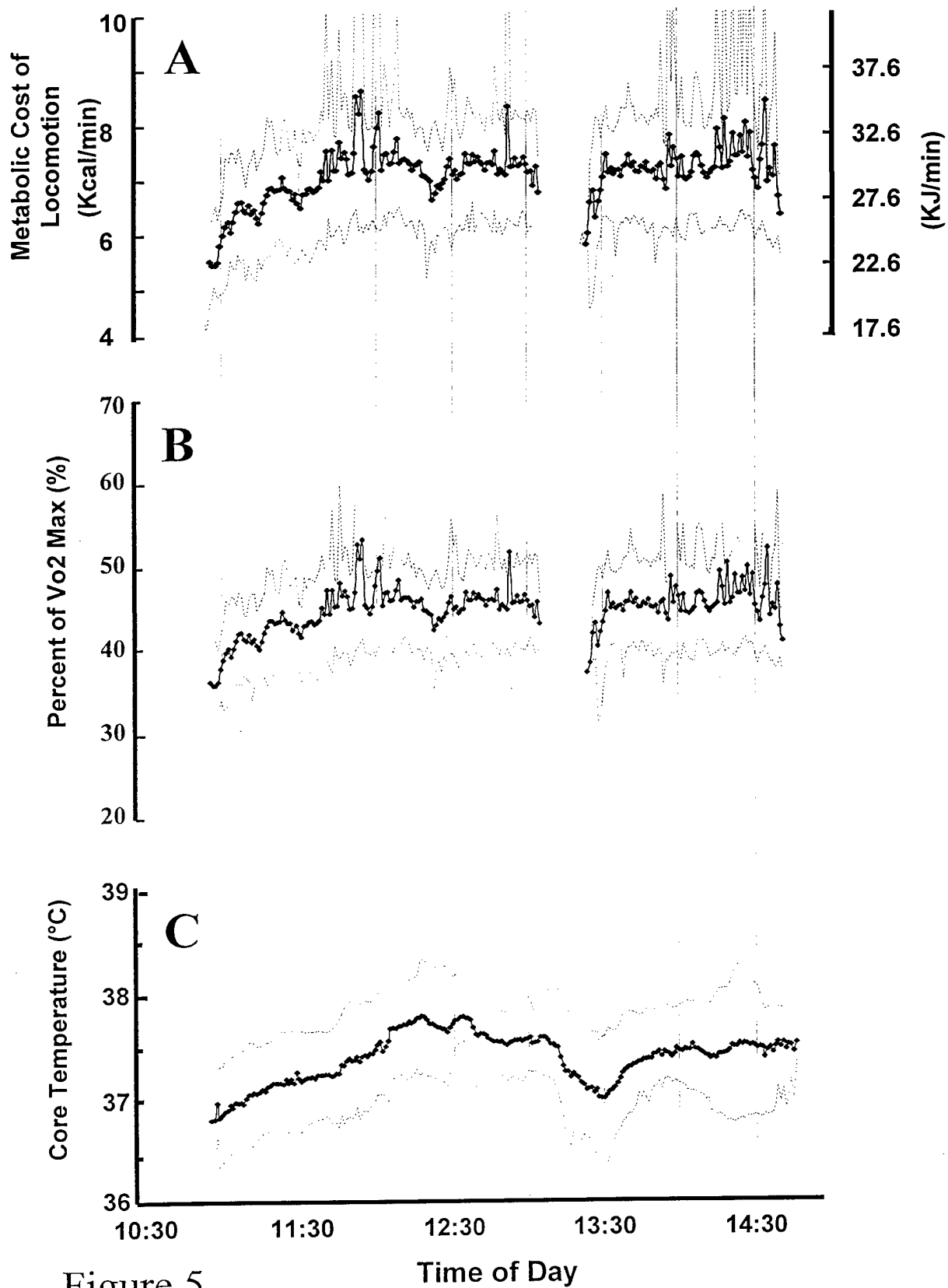


Figure 5

Meteorologic data

The air temperature, wind speed, and relative humidity during the 20 km road march is shown in Figure 2. The weather was temperate with wind speeds near zero. Solar radiation averaged

231 Watts per square meter with overcast sky conditions.

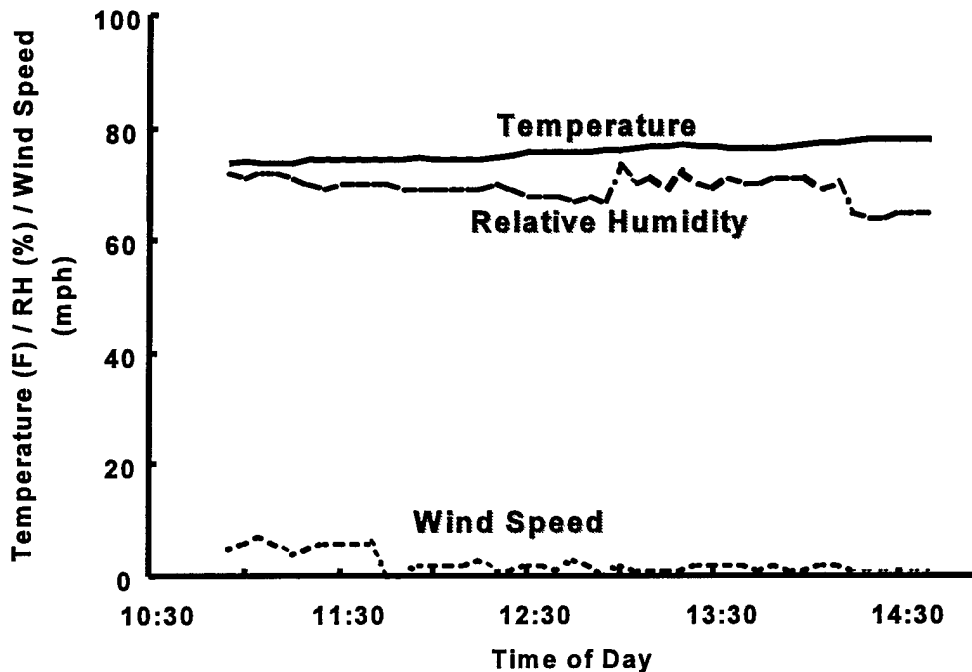


FIGURE 2. Meteorological conditions during road march.

Physiologic data

The physiological responses of the soldiers recorded during the 20 km road march are shown in Figures 4 and 5. The data plots show the average and range (minima and maxima) of the various parameters during the road march (N = 7). Due to a disconnected EEM sensor (subject 2), data on strides per minute, metabolic cost of locomotion, and exercise intensity (% $\text{VO}_{2\text{max}}$) are for six subjects. The rest break from about 1300 to 1330 h is clearly evident. The steady state rate of movement, which was achieved after about 30 minutes, was about 3.4 mph or 1.54 ± 0.29 meters per sec (mean $\pm$ SD)(Fig. 4A), with stride rates of 49 ± 7 per min (mean total number of strides = 10,128)(Fig 4B), and heart rates of 137 ± 10 beats per minute (Fig. 4C). Metabolic cost of locomotion was 7.1 ± 0.5 kcal/min, or about 1600 kcal over the 230 min of marching (Fig. 5A), with an exercise intensity of 45 ± 3 % of estimated $\text{VO}_{2\text{max}}$ (Fig. 5B). Core temperature averaged 37.3 ± 0.2 °C. A gradual increase in heat storage over the first 1.5 h of marching was followed by relatively stable core temperatures except for a period of cooling during the rest break (Fig. 5C).

DISCUSSION

By organizing this CEP on soldier physiological monitoring, the Dismounted Battlespace Battle Lab provided a unique opportunity for synergetic interactions among Government, academia, and industry groups. These groups included the U.S. Army Research Institute of Environmental Medicine (USARIEM), the Walter Reed Army Institute of Research (WRAIR), the Army Research Lab (ARL), the Massachusetts Institute of Technology, Precision Control Devices, Inc., (Ft. Walton Beach, FL) and Personal Electronic Devices, Inc. (Wellesley, MA). The results of this effort showed that high quality physiologic data can be reliably collected from soldiers engaged in military training.

The goals of the CEP on soldier physiological monitoring were to: (1) use ambulatory monitoring technologies from a "research tool kit" to automatically collect and organize the data from multiple physiological sensors, (2) attempt to address operational issues and criteria outlined in the Dismounted Battlespace Battle Lab (DBBL) Concept Experimentation Program (CEP) proposal, and (3) consider some of the possible practical benefits soldier physiological monitoring.

Increasingly smaller, less expensive, and more powerful electronic technologies are accelerating efforts to unobtrusively monitor the physiologic status of soldiers. This test successfully demonstrated that ambulatory monitoring technologies from a "research tool kit" can be used to automatically collect and organize time series data from multiple physiological sensors.

DBBL Operational Issues and Criteria

1. Issue: What are the vital signs that need to be sensed to provide necessary data to accomplish casualty management (and control medical support on the battlefield)?

This CEP focused primarily on physiologic monitoring for force management and predictive modeling rather than identifying key vital signs needed for casualty management. Nevertheless, two vital signs likely to be relevant to casualty management, heart rate and core temperature, were successfully monitored during this CEP.

2. Issue: What are the vital signs that need to be sensed to provide the necessary data (to the command) to accomplish environmental stress prediction?

Which vital signs need to be sensed, which can be sensed within "wear and forget" constraints, and which must be predicted through models to meet force management requirements are just beginning to be established. In the current CEP, sensors gathered data on heart rate, metabolic cost of locomotion, core temperature, skin temp, voice analysis, and motion. Measurements of blood oxygen saturation by pulse oximetry have also proven useful in managing high altitude induced illnesses during military operations in mountainous terrain.

These sensors are part of a research tool kit being used to gather field research data which will ultimately form the foundation for a tech base insertion. The research tool kit allows models to be developed that will predict some consequences, input realistic data for training simulations, and eventually predict risk of failure while there is still something that can be done about it. This work will be guided by the concepts from the DBBL on what a commander needs or wants to know.

3. Issue: To what extent does physiological historical data need to be recorded by the individual's system, how long and to what detail?

This question has regulatory and biotechnical aspects. From a biotechnical point of view, the physiologic data in the present CEP were gathered and stored for periods up to 12 h in intervals ranging from five to sixty seconds over the course of each situational training exercise (STX). This data will be organized into a high resolution, easily accessed database for use by researchers and modelers. For force management purposes, the tentative plan is to aggregate soldier physiologic data in 6 minute blocks. What sorts of physiological monitoring data need to be transferred to long term storage in repositories needs to be addressed.

4. Issue: When does the system, by what vital sign cues, switch from the tactical system to the medical casualty management system?

The data collected in the present CEP did not specifically address the complex issue of casualty identification. The one soldier in this CEP who suffered debilitating muscle cramps during the 20 km road march was not among the individuals who were monitored. An ongoing program of physiologic data collection from soldiers training under extreme environmental conditions should help address this issue.

5. Issue: What Human Factors issues, if any, need to be addressed during a developmental program?

Human Factors issues include: (a) minimizing the weight and volume of the sensors and data management electronics, (b) eliminating wires by implementing a low power "Body LAN" (wireless body local area network) technology, (c) improving the placement and ergonomics of the monitoring systems, (d) improving power management to minimize battery requirements, and (e) establishing automated data management routines. A key objective is to ensure that all ambulatory soldier physiological monitoring technologies are highly acceptable "wear and forget" technologies.

6. Issue: What safety and health problems, if any, are associated these types of technologies?

The Human Use Review Committee concluded the technologies used in this CEP study posed no more than minimal risk to the subjects and that no medical monitor was required. There is a risk that the heart rate sensor chest belt might cause chaffing. There are no known

risks associated with the battery powered ambulatory monitors. The risks associated with the use of ingested telemetry pills include difficulty swallowing. However, in a large-scale USARIEM field study entitled "Heat Tolerance and Exertional Heat Illness in Female Recruits" (TPMD95006-AP024-H025), only three out of 1000 volunteers having any difficulty swallowing the temperature pill. Other theoretical risks associated with the ingested telemetric pill include retention in the bowels and the small likelihood that the pill might rupture. However, there are no reports of adverse outcomes to healthy humans ingesting the pills. In addition, all components of the pill are covered with FDA-approved coatings intended to prevent exposure of the gastrointestinal mucosa to the pill contents. Should the pill rupture for some unforeseen reason, there is a small risk of "burn" or ulceration to the mucosa through exposure to the battery contents. However, there have been no reports of injury to children who have accidentally ingested the type of silver oxide battery used in the telemetry pill. Radiation exposure from the pill is well below FCC and DoD limits on radiation exposure. Nuclear magnetic resonance imaging would likely cause dangerous overheating of the electronic components, and is therefore contraindicated for as long as the pill remains in the body.

Proposed database organization

A database consisting of easy-to-read flat data files is needed so the physiologic and meteorologic information can be easily retrieved and interpreted to meet the various needs of researchers and combat developers. One approach is to organize the data in a directory which will include information on the test site, name and dates of the field experiment, weather data, and subject specific physiologic information. The directory tree structure would be:

```

Test_Site
|___ Field_Experiment (Name and Dates)
    |___ Weather data
    |___ Subject_ID
        |___ Data_files
  
```

For example, data from the present test might look like:

```

Ft_Benning_GA
|___ Phys_CEP_22oct-25oct97
    |___ CEP_22w.pdu                - Weather Transmission Format
    |___ 0039
        |___ |___ 0039_22pys.csv    - Physiological Modeling Format
        |___ |___ 0039_22pys.pdu    - Physiological Transmission Format
    |___ 1028
    |___ 3861
    |___ ...
  
```

The data files for each subject would include a header file listing: performing groups, points of contact, study dates, relevant map information, descriptions of event, data type, and data format, and specific experimental information such as subject characteristics (age, ht, wt, body fat, etc.), and instrumentation and calibration numbers, and definitions of the various fields.

File format would vary with the intended use. For example, data intended for ongoing transmission over the Internet, etc., would be configured as a physiological protocol data unit (PPDU) where each type of data is individually prefixed by a unique letter tag (Fig. 6). The tag indicates the type of data and the length of the data field. Only data that are available are transmitted via the network. If data is lost or corrupted only one portion of the data should be affected. This is similar to the system currently used by the MERCURY system to transmit meteorologic data (Appendix C). All transmitted data should include the fundamental sensor measurements and not just derived values. Alternatively, for research and modeling, the data would be organized in a physiological modeling data file format where data are in columns, separated by commas (Fig. 7). This format allows easy downloading and use of the files in various applications such as spreadsheets and data analysis and plotting programs.

Fig 6. The physiological protocol data unit (PPDU) is designed for data transmission. The tag designated data are separated by a space. Each type of data is individually prefixed by a unique letter tag. The tag indicates the type of data and the length of the data field. Only data that are available are transmitted via the network. If data is lost or corrupted only one portion of the data should be affected.

Tag Key:

i: Subject ID Number

Z: GMT Date and Time

N: Latitude Degrees and Minutes North

W: Longitude Degrees and Minutes West

z: Elevation (m)

h: Heart Rate (bpm)

c: Core Body Temperature (°C)

MA: Mean Stride Foot; Contact Time (ms)

MB: Number of Steps during 5 sec epoch

MC: Metabolic Cost of Locomotion (Kcal/min)

```
i0039 Z9709221501.48 N032.16.986 W084.56.878 z71 h104 c39.36 MA694.4 MB4 MC5.258
i0039 Z9709221501.53 N032.16.989 W084.56.879 z71 h105 c36.47 MA695 MB4 MC5.251
i0039 Z9709221501.58 N032.16.993 W084.56.880 z71 h104 c37.79 MA684.2 MB4 MC5.368
i0039 Z9709221502.03 N032.16.997 W084.56.881 z71 h104 c37.95 MA686 MB4 MC5.348
i0039 Z9709221502.08 N032.17.001 W084.56.883 z72 h107 c38.43 MA719.4 MB4 MC5.000
```

Figure 7. Example of physiologic modeling data format. The file contains three types of information: (1) a header which contains information about the subject and the study, (2) field name definitions (x1 = subject ID, x2 = date, etc.), and (3) the actual data.

```

Performing Institutes: United States Army Research Institute of Environmental Medicine (USARIEM)
Dismounted Battlespace Battle Lab (DBBL)
Walter Reed Army Institute of Research (WRAIR)
POC: Reed Hoyt PhD (USARIEM) 1 (508) 233-4802
DMA Map: Series V745S sheet FORT BENNING MIM
Data: Physiological
Format: Comma Separated Values (.csv)
Subject ID: 0039
Date: 22 SEP '97
Exercise: 20 km Road March.
Experimental Information:
Pack: 5 WINCE CPU: 1 Temp. Pill Calibration #: 37291345 Total Soldier Weight (lbs): 213.6
Field Name Definitions:
x1:Subject ID;x2:Date;x3:Local Time;x4:GMT;x5:Latitude Longitude String;x6:Latitude Degrees;x7:Latitude
Minutes;x8:Longitude Degrees;x9:Longitude Minutes;x10:UTM Coordinates;x11:Elevation (m);x12:Heart Rate
(bpm);x13:Core Body Temperature (°C);x14:Mean Stride Foot; Contact Time (ms);x15:Number of Steps during 5
sec epoch;x16:Metabolic Cost of Locomotion (Kcal/min);x17:Metabolic Cost of Locomotion (W)
x1,x2,x3,x4,x5,x6,x7,x8,x9,x10,x11,x12,x13,x14,x15,x16,x17
0039,22Sep97,11:01:37,15:01.48,N032.16.986W084.56.878,32,16.986,84,56.878,E693249N3573476,71,104,39.36,694.4,4,5.258,366.92
0039,22Sep97,11:01:42,15:01.53,N032.16.989W084.56.879,32,16.989,84,56.879,E693248N3573482,71,105,36.47,695.4,5.251,366.48
0039,22Sep97,11:01:47,15:01.58,N032.16.993W084.56.880,32,16.993,84,56.88,E693246N3573489,71,104,37.79,684.2,4,5.368,374.62
0039,22Sep97,11:01:52,15:02.03,N032.16.997W084.56.881,32,16.997,84,56.881,E693244N3573496,71,104,37.95,686.4,5.348,373.25
0039,22Sep97,11:01:57,15:02.08,N032.17.001W084.56.883,32,17.001,84,56.883,E693241N3573504,72,107,38.43,719.4,4,5.000,348.97

```

Examples of utility of ambulatory physiological monitoring information

By quantifying the physiological stresses placed on individual soldiers, ambulatory monitoring can help improve the support provided to dismounted infantry. One example is the use of ambulatory monitoring of core temperature to validate the Immersion Table Safety Limits used by the Ranger Training Brigade (Hoyt et al., 1997). Another example is the use of portable pulse oximetry during an Alaskan military mountaineering expedition in the diagnosis and management of acute mountain sickness (AMS) and high altitude pulmonary edema (HAPE). In addition, ambulatory measurements of heart rate and the metabolic cost of locomotion may be useful in monitoring aerobic fitness levels. Specifically, improvements in an individual's aerobic fitness will be reflected in a decrease in the slope of the linear relationship between heart rate and the metabolic cost of locomotion, and vice-versa (Astrand and Rodahl, 1986; Kappagoda et al., 1979). The feedback provided by periodic determinations of this relationship may be useful in adjusting the duration, frequency and intensity of exercise to be adjusted to achieve maximum improvements in aerobic capacity.

In addition, monitoring the relationship of heart rate to the metabolic cost of locomotion may also be useful in assessing the development of heat acclimation. One index of heat stress is

heart rates in excess of those needed to meet normal metabolic needs during exercise. As an individual becomes heat acclimated, thermoregulatory needs can be met with a more modest increase in heart rate at any given metabolic rate. Also, knowing the metabolic cost of locomotion, clothing characteristics, and local meteorologic conditions, body heat storage and future core temperature can be predicted (Kraning, 1991). Furthermore, the present data on energy expenditure, heart rate, and core temperature, and meteorological conditions can be used to retrospectively assess whether the dietary water intake of individual soldiers wearing open woodland BDU was adequate. Underhydrated soldiers would tend to have higher core temperatures than those adequately hydrated (Kraning and Gonzalez, 1997).

Another important example is in the area of nutritional modeling. The EEM provides the detailed information on work intensity and duration needed to quantify carbohydrate and fat fuel requirements of soldiers in the field.

Nutritional modeling: defining the fuel requirements of soldiers

The choice of fuel for exercising muscles is limited to fat and carbohydrate (protein is a minor fuel source) (Astrand and Rodahl, 1986). Quantifying the amounts of dietary carbohydrate and fat needed by physically active soldiers requires minute-by-minute information on the intensity, duration, frequency and type of exercise. During the present study, this type of information was collected by the EEM.

The EEM determined the pattern of metabolic energy expended during the 20 km road march from the total weight of the soldier and time series measurements of the length of time a single foot contacts the ground (Hoyt et al., 1994). Knowing the metabolic cost of locomotion (M_{loco}) and the aerobic fitness of each soldier, derived from Annual Physical Fitness Test two mile run for time results (Mello et al., 1988), the optimal amounts of carbohydrate and fat needed by each individual could be calculated.

This helps solve a pressing problem: how can current field rations meet the requirements of physically active soldiers (see review by Friedl and Hoyt, 1997). Negative fat balance associated with under eating can generally be managed by drawing on the body's substantial fat reserves. However, a negative carbohydrate balance can result in various physiologic problems including decreased endurance exercise capacity and loss of muscle mass, and immune disfunction. Knowing the amount and timing of carbohydrate combustion by soldiers can guide changes in ration composition and design, for example, the provision of a supplemental carbohydrate beverage in the rations. This approach could also be used to improve garrison feeding.

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APPENDIX A

**Dismounted Battlespace Battle Lab (DBBL) Concept Experimentation Program (CEP) for
Soldier Physiological Monitoring**

CONCEPT EXPERIMENTATION PROGRAM
RESUME SHEET

NEW
DATE: 31 May 1996
ATZB-WC-DFD, DSN 835-3082

TITLE: Soldier Physiological Monitoring

TEST TYPE: Concept Experimentation Program (CEP)

CATEGORY: CEP

TEST AUTHORITY: TRADOC

SYSTEM PROPONENT: Warrior Systems

TEST INSTALLATION: Fort Benning, GA.

TEST ORGANIZATION: Dismounted Battlespace Battle Lab (DBEL)

TEST UNIT: One Light Infantry Squad

TEST LOCATION: Fort Benning, Ga.

TEST DATES: START: 8 Jan 97 COMPLETION: 30 May 97 RESOURCE: 3 Jan 97

AMMO: Yes **FLYING HRS:** No **INST:** No **TGT:** No **SIM:** No

TOTAL DIRECT TEST COST ESTIMATES (IN THOUSANDS):

APPN: RDTE **FY97:** \$ 165.00

CEP PRIORITIZATION METHODOLOGY:

CEP DIRECTION FACTOR:

1. ☐ DA Directed/Ongoing
2. ☐ CG TRADOC Directed
3. ☐ BDP Deficiency
4. ☒ Refine Materiel Requirement/
Evaluate DTLO
5. ☐ Other (Provide modeling data)

URGENCY FACTOR

1. ☐ Within 1 Qtr
2. ☒ Within 2 Qtr
3. ☐ Within 3 Qtr
4. ☐ Within 4 Qtr
5. ☐ Upfront Funding

PROPONENT PRIORITY: 1. ☐ 2. ☐ 3. ☐ 4. ☐ 5. ☐ 6. ☐ Other ☐

COST FACTOR:

0-\$25K	1 ☐	\$76-100K	4 ☐	\$201-300K	7 ☐
\$26-50K	2 ☐	\$101-150K	5 ☐	\$301-400K	8 ☐
\$51-75K	3 ☐	\$151-200K	6XX ☐	\$401K+	9 ☐

97-CEP-0711-1

PURPOSE/OBJECTIVE/DESCRIPTION:

a. Purpose. To determine the baseline requirements for physiological monitoring of individual soldiers for force and casualty management.

b. Objective: To evaluate and assess, through prototype sensing and predictive technologies, the physiological data required to be able to manage the individual soldier within the context of battlefield casualties and force protection/stress management. This will enhance soldier lethality and survivability on the modern battlefield. Areas of concentration include sensor locations on soldiers, degree of detail of physiological data, and determination of soldier data vs medic data vs commander data in order to develop common data requirements.

c. Description: System descriptions will be provided at a later date.

d. Evaluation Concept: Data will be collected through the prototype technologies, integrated with GPS, and recorded manually or automatically on prepared data collection forms. All data will be analyzed statistically and subjectively.

SCOPE: Testing will be conducted at Fort Benning, GA (or another Army installation depending on troop availability) under existing weather and light conditions. Test soldiers will conduct limited force-on-force exercises using various scenarios and different terrain conditions during both daylight and night. This test will consist of several small Battle Lab Warfighting experiments (BLWE), in conjunction with AMEDD and MPMC/USARTEM looking at different technology concepts and how they would provide a casualty and force protection management capability. This effort will encompass the impact on all DTLOMS and modeling and simulation will be conducted in conjunction with specific aspects of the Battle Lab effort.

IMPACT STATEMENTS.

a. Environmental, Laser, and Energy Implications. There are no environmental or laser impacts for this test. The energy impacts of this test are not considered to be significant.

b. Training Implications. Test soldiers will gain training and practical experience in tactical operations in a field environment.

c. SIGSEC/OPSEC Implications. The prototype systems/equipment do not have SIGSEC/OPSEC implications. The Test Officer is directly responsible for the prevention of inadvertent disclosure of information and implementation of OPSEC procedures.

d. Human Volunteers. Human volunteers as defined in AR 70-25 will not be used in this test.

e. Radionuclides Certification. Not required.

POINTS OF CONTACT (POC):

LN	AGENCY	LOCATION	OFFICE SYMBOL	TELEPHONE
010	TRADOC	Ft Monroe, VA	ACTD- (Q)	DSN 680-3880
020	DBBL	Ft. Benning, GA	ATZB-WC-DEF	DSN 835-3082
030	ARIEM	Natick, MA		DSN 256-5140
040	MRMC	Ft Detrick ME		DSN 343-7377
050	DARPA	Alexandria VA		Comm (703) 696-2240
060	HRED	Ft. Benning, GA	ATZB-TS	DSN 835-1020
070	TSM-S	Ft. Benning, GA	AMSRL-HR-MW	DSN 835-5200
080	AMEDD	Ft. Sam Houston, Tx		DSN 471-3600

9387

97-CEP-0711-2

SECTION I
TEST RESOURCE REQUIREMENTS

1. TEST DIRECTORATE:

a. Personnel Requirements.

LN	POSITION	GRADE	MOS	QTY	INCL DATES	SOURCE
A010	Test Manager	GS12	301	1	T-90/C+90	DFD DBBL
A020	Asst Test Manager 1/	GS11	301	2	T-60/C+60	DFD DBBL
A030	Test Officer	04/03	51	1	T-90/C+60	DFD DBBL
A040	Test NCO	E7/E6	118	5	T-15/C+20	USAIC
A050	OR Analyst 2/	GS12	1515	1	T-30/C+60	DFD DBBL
A060	Eng Psych 2/	GS12	180	1	T-30/C+60	HRED
A070	Data collectors 1/	GS4	303	6	T-15/C+30	USAIC
A080	MED RED SME	04/05		3	T-90/C+60	MRMC/ARIEM/AMEDD 1/ Temp
	Hire/Contract					
2/	As required					

b. Equipment Requirements. All test directorate equipment will be provided by DBBL.

2. PLAYER PARTICIPANTS:

a. Personnel Requirements.

LN	UNIT/ELEMENT	STRENGTH	QTY	INCL DATES	SOURCE
DO10	LT INF Squad	TOE	1	T-2/C+2	FORSCOM

b. Equipment Requirements.

LN	TYPE	QTY	INCL DATES	SOURCE
	486 Computers (Predictive model)	2ea	T-2/C+2	COMMERCIAL

3. ITEMS(S) TO BE TESTED: Description of test items to be provided in the CEP test plan.

4. DATA COLLECTION/ADP SUPPORT:

a. Data Collection/Processing System.

LN	ADP EQUIPMENT/SUPPLIES	QTY	INCL DATES	SOURCE
H010	Laptop computers	6	T-5/C+60	DBBL
H020	HD/DS 3.5 Disk	20	T-5/C+60	DBBL
H030	Laser Printer	1	T-5/C+60	DBBL

b. ADP Facility Support. None Required.

c. Contractor or Other Government Agencies. None Required.

5. AMMUNITION/ MISSILES/PYROTECHNICS:

a. Ammunition and Pyrotechnics.

LN	DESCRIPTION	DODIC	QTY	DATE REQD	LOCATION
K010	5.56mm blank rounds	A080	10,000	T-5	Ft Benning
K020	7.62mm blank rounds	A111	10,000	T-5	Ft Benning
K030	5.56 blank link	A075	10,000	T-5	Ft Benning

b. Missiles. None

6. PETROLEUM, OILS, AND LUBRICANTS (POL) SUPPLIES:

LN	DESCRIPTION	QTY	UNIT OF	SOURCE
----	-------------	-----	---------	--------

97-CEP-0711-3

MO10

Mogas

ISSUE
600 Gallon

USAIC

7. INSTRUMENTATION: 10 prototype physiomonitoning system of each type.

8. TEST FACILITIES/INSTALLATION SUPPORT:

a. Test Facility Range Support. Fort Benning (or other installation training areas will be scheduled as required.

b. Communications/Engineering Support. None

c. Installation Support. Fort Benning (or other installation) will provide photographic support in accordance with normal support procedures. Medical support to include ambulance/helicopter evacuation will be requested as required.

d. Other Support. - None

9. SIMULATORS/TARGETS: None

10. FLYING HOURS SUPPORT: None

SECTION II TEST MILESTONES

LN	EVENT	SOURCE/ RESPONSIBLE	DATE
015	Resume Approved	TRADOC	T-60
130	Test Design Plan Submitted	DFD DBBL	T-60
140	Test Design Plan Approved	DBBL	T-30
220	Test Items Due Tester	DFD DBBL	T-15
250	Test Initiated	DFD DBBL	T-Date
260	Test Completed	DFD DBBL	C-Date
280	Test Report (Final)	DFD DBBL	C+90

97-CEP-0711-4

SECTION III
DIRECT TEST COST ESTIMATES (IN THOUSANDS).

DATE: 31 May 1996

TEST NUMBER: 97-CEP-0711

TEST TITLE: Dismounted Situational Awareness

TEST TYPE: CEP

1. CATEGORY OF COST	FY97
A. Civilian Hire	35.K
B. Civilian Overtime	8.K
C. TDY	
(1) Tester/Player TDY	23.K
(2) Ppnt Evaluation TDY	
D. Transportation of Items	4.K
E. Lease/Rental-Commo/Util	5.K
F. Contracts	40.K
G. POL	1.K
H. Supplies/Materiel	4.K
I. Equipment	30.K
J. Instrumentation	10.K
K. Threat Simulators	
L. Other Simulators	
M. Army Aviation Cost	
N. Refurbishment Cost	5.K
O. Total Direct Test Cost by FY. APPN: RDTE	165.0K
P. Other Services Direct Spt	
TOTAL TEST COST	165.0K

97-CEP-0711-5

SECTION IV
OPERATIONAL ISSUES AND CRITERIA

1.1 Issue: What are the vital signs that need to be sensed to provide necessary data to accomplish casualty management?

1.2 Criteria: Investigative in nature.

1.3 Rationale: To investigate the types of data for input to the casualty management system to control medical support on the battlefield.

2.1 Issue: What are the vital signs that need to be sensed to provide the necessary data to accomplish environmental stress prediction?

2.2 Criteria: Investigative in nature.

2.3 Rationale: : To investigate the types of data for input to the command to accomplish environmental stress prediction.

3.1 Issue: To what extent does physiological historical data need to be recorded by the individual's system, how long and to what detail?

3.2 Criteria: Investigative in nature.

3.3 Rationale: To investigate the extent of the detail needed and the duration of retention of personal monitor systems.

4.1 Issue: When does the system, by what cues, switch from the tactical C2 system to the medical casualty management system?

4.2 Criteria: Investigative in nature.

4.3 Rationale: To investigate what vital sign cues should cause the soldier system to switch from the tactical C2 system to the casualty management system.

5.1 Issue: What Human Factors issues, if any, need to be addressed during a developmental program?

5.2 Criteria: Investigative in nature.

5.3 Rationale: To investigate any potential Human Factors problem areas.

6.1 Issue: What safety and health problems, if any, are associated these types of technologies.

6.2 Criteria: Investigative in nature.

6.3 Rationale: To investigate any potential safety or health problems.

SCOPE: (This scope pertains to all issues). Testing will be conducted at Fort Benning, GA (or another Army installation depending on troop availability) under existing weather and light conditions. Test soldiers will conduct limited force-on-force exercises using various scenarios and different terrain conditions during both daylight and night. This test will consist of several small Battle Lab Warfighting experiments (BLWE), in conjunction with AMEDD and MRMC/USARIEM looking at different technology concepts and how they would provide a casualty and force protection management capability. This effort will encompass the impact on all DTLOMS and modeling and simulation will be conducted in conjunction with specific aspects of the Battle Lab effort.

97-CEP-0711-6

SECTION V
COST

TEST NUMBER: 97-CEP-0711
TEST TITLE: Soldier Physiological Monitoring
TEST TYPE: CEP

1. CATEGORY OF COST

A. Civilian Hire: This cost will pay the salary of two civilian personnel for three months and eight others for the duration of the test.

B. Civilian Overtime: This test will have segments conducted at night.

C. TDY: This will pay the cost of transporting test soldiers to Fort Benning for the sustainment training. Additionally, this will pay for test personnel to conduct coordination and train-up.

D. Transportation of Items: This will pay the cost of transporting support equipment and instrumentation in to Fort Benning.

E. Lease/Rental-Commo/Util: This will pay the cost of rental vehicles to move personnel and equipment to various test sites on Fort Benning.

F. Contracts: To pay the cost of HRED support. To pay for personnel with expertise in the subject medical disciplines.

G. POL: Fuel for rental vehicles.

H. Supplies/Materiel: To pay the cost of replenishing supplies and materials used during the test.

I. Equipment: To pay for the test support equipment.

J. Instrumentation: This will pay for the monitoring and data processing equipment needed to collect and consolidate the results of the experiment.

N. Refurbishment Cost: To pay for the reconfiguration of the personal status monitors that have been altered to allow test data collection.

97-CEP-0711-7

OBLIGATION PLAN SUMMARY

CEP TITLE: Soldier Physiological Monitoring
 CEP # 97-CEP-0711

COST CATEGORY	1QFY97			2QFY97			3QFY97			4QFY97			TOTAL
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	
1. CIV HIRE				3	9	9	9	6					35
3. CIV OVERTIME					2	4	2						8
2. TDY			2	3	6	6	6						23
1. TRANS OF ITEMS				4									4
1. LEASE/RENTAL/COMMO					2	2	1						5
1. CONTRACTS		10	10	10	4	3	3						40
1. POL					1								1
1. SUPPLIES/MATERIAL			2	2									4
EQUIPMENT	20		5	5									30
1. INSTRUMENTATION	10												10
1. THREAT SIMULATORS													
1. OTHER SIMULATORS													
1. ARMY AVN COST													
1. REFURB COST								6					6
UNNING TOTAL	30	40	50	66	110	134	168	185					
TOTALS	30	10	19	27	24	24	21	10					165

APPENDIX B

Calculation of Soldier Fuel Requirements

The availability of reasonable, minute-to-minute estimates of the metabolic cost of locomotion from the EEM opens the way to quantitative calculations of the carbohydrate (CHO) needs of soldiers.

Assumptions:

- a. The $\text{VO}_{2\text{max}}$ values estimated from 2 mile run times using the equations of Mello et al. (1988) are accurate.
- b. The metabolic cost of locomotion values estimated from foot contact time and total weight using the method of Hoyt et al. (1994) and Taylor (1986) are accurate.
- c. The ratio of carbohydrate to fat combustion during exercise should be the same for soldiers and normally fed exercising humans. That is, the respiratory exchange ratio ($\text{RER} = \text{VCO}_2 / \text{VO}_2$) = 0.80 at rest, 0.85 at exercise intensities of 10 to 50% of $\text{VO}_{2\text{max}}$, and calculated as $[(0.003 \times \% \text{VO}_{2\text{max}}) + 0.70]$ for exercise intensities from 50 to 100% of $\text{VO}_{2\text{max}}$ (Astrand and Rodahl, 1986).
- d. The dietary carbohydrate and fat intakes of the volunteers in the present study were similar to those in previous studies.
- e. Except for the 20 km road march, the soldiers slept or engaged in light activities during the study day.

The specific steps are:

1. Calculate the $\text{VO}_{2\text{max}}$ for each individual using the equations of Mello and coworkers (Mello et al., 1988). Estimated $\text{VO}_{2\text{max}}$ of the seven volunteers was 4.3 ± 0.3 L/min (mean $\pm$ SD).
2. Convert the M_{loco} in kcal/min to oxygen consumption (VO_2) in L/min using the standard conversion factor for an individual on a mixed diet of 0.2055 liters of oxygen per kcal (Lusk, 1928).
3. Calculate exercise intensity, i.e., $\% \text{VO}_{2\text{max}} = [(\text{VO}_2 / \text{VO}_{2\text{max}}) \times 100]$. During the road march, $\% \text{VO}_{2\text{max}} = 45 \pm 3 \%$.
4. Calculating exercise oxygen consumption, $\text{VO}_2 = (\% \text{VO}_{2\text{max}} \times \text{VO}_{2\text{max}})$.

Oxygen consumption during the road march = $45\% \text{VO}_{2\text{max}} \times (4.3 \text{ L/min}) = \sim 2.0 \text{ L/min}$

5. Using standard equations, calculate fat VO_2 and carbohydrate VO_2 :

$$\text{Fat } \text{VO}_2 = (\text{exercise } \text{VO}_2)[(1-\text{RER})/0.3]$$

$$\text{CHO } \text{VO}_2 = (\text{exercise } \text{VO}_2 - \text{fat } \text{VO}_2)$$

where RER, the optimal nonprotein respiratory exchange ratio ($\text{RER} = \text{VCO}_2 / \text{VO}_2$), is assumed to be 0.80 at rest, 0.85 at exercise intensities of 10 to 50% of $\text{VO}_{2\text{max}}$, and as calculated as $\text{RER} = [(0.003 \times \% \text{VO}_{2\text{max}}) + 0.70]$ for exercise intensities from 50 to 100% of $\text{VO}_{2\text{max}}$ (Astrand and Rodahl, 1986). Variations in the energy value of oxygen consumed with RER are ignored since they are <7%.

Thus, during the road march at 45% $\text{VO}_{2\text{max}}$, the ideal RER is 0.85, and the amounts of oxygen used to burn fat and to burn CHO are equal. That is, on average, fat $\text{VO}_2 = 1.0 \text{ L/min}$ and CHO $\text{VO}_2 = 1.0 \text{ L/min}$ during the 200 minutes of march (excluding the 30 min rest break), for an average total oxygen consumption of 400 L, with 50% (200 L) used to combust fat and 50% used to combust CHO.

During the balance of the day (1240 min), it was assumed that the soldiers were either sleeping or engaged in light activity, consuming oxygen at ~8% of $\text{VO}_{2\text{max}}$ (0.34 L/min) with an RER of 0.82 (ratio of fat to CHO combustion = 68:32) (Lusk, 1928), for a total oxygen consumption of 414 L. That is, average fat $\text{VO}_2 = (\text{resting } \text{VO}_2 \text{ of } 0.34 \text{ L/min})[(1-0.82)/0.3] = 0.23 \text{ L/min}$, and CHO $\text{VO}_2 = (\text{resting } \text{VO}_2 \text{ of } 0.34 \text{ L/min} - \text{Fat } \text{VO}_2 \text{ of } 0.2 \text{ L/min}) = 0.11 \text{ L/min}$, for a total fat VO_2 of 285 L and a total CHO VO_2 of 136 L.

6. Convert Fat VO_2 and CHO VO_2 to kcal/min and calculate grams of fat (9 kcal/g fat) and carbohydrate (4 kcal/g CHO) combusted.

Rest:

$$\text{Fat } \text{VO}_2 = 414 \text{ L total} \times 0.68 = 285 \text{ L}$$

$$\text{Fat use} = (285 \text{ L of O}_2) \times (4.7 \text{ kcal of fat per L O}_2) = 1340 \text{ kcal}$$

$$\text{Fat combusted} = (1340 \text{ kcal}) / (9 \text{ kcal/g}) = 149 \text{ g fat}$$

$$\text{CHO } \text{VO}_2 = 414 \times 0.32 = 136 \text{ L}$$

$$\text{CHO use} = (136 \text{ L of O}_2) \times (5.05 \text{ kcal of CHO per L O}_2) = 687 \text{ kcal}$$

$$\text{CHO combusted} = (687 \text{ kcal}) / (4 \text{ kcal/g}) = 172 \text{ g CHO}$$

Exercise:

$$\text{Fat } \text{VO}_2 = 400 \text{ L total} \times 0.5 = 200 \text{ L}$$

$$\text{Fat use} = (200 \text{ L of O}_2) \times (4.7 \text{ kcal of fat per L O}_2) = 940 \text{ kcal}$$

$$\text{Fat combusted} = (940 \text{ kcal}) / (9 \text{ kcal/g}) = 104 \text{ g fat}$$

$$\text{CHO } \text{VO}_2 = 400 \times 0.5 = 200 \text{ L}$$

CHO use = (200 L of O₂) x (5.05 kcal of CHO per L O₂) = 1010 kcal

CHO combusted = (1010 kcal)/(4 kcal/g) = 253 g CHO

7. Compare estimated daily fat and CHO requirements to dietary fat and carbohydrate intake from field rations.

Total fat requirements = 104 g used during exercise + 149 g used during rest = 253 g fat/d. The typical dietary fat intake of soldiers in the field eating MREs is about 150 g/d, resulting in a deficit of ~ 100 g fat/man per day. However, body fat reserves = (body fat % - 5% minimum body fat) × body weight (Friedl et al., 1994). In our volunteers, fat reserves = [(18.1% - 5%)/100] × 79.6 kg = 10.4 kg. A 100 g/d fat deficit requires only about 1% of the available fat reserves.

In contrast, total CHO requirements = 253 g used during exercise + 172 g used during rest = 425 g CHO/d. The typical dietary CHO intake of soldiers in the field eating MREs = 300 g/d resulting in a deficit of ~125 g CHO/man per day. Since body carbohydrate stores are limited to only ~500-600 g, this deficit represents about 21 to 25% of available CHO stores, and can rapidly lead to decrements in lean body mass and physical performance.

APPENDIX C

Description of MERCURY system

MERCURY integrates a suite of human thermal strain prediction models with automated real-time weather and terrain information resources. Current models predict scenario-dependent exposure limits in hot or cold environments and during cold water immersion. In June 1996 a test bed system was installed at the U.S. Army Ranger training facilities at Camp Rudder, Eglin Air Force Base, Florida. The MERCURY-Ranger Test Bed system uses the existing network resources and automated weather data acquisition infrastructure at Eglin to obtain required predictive model inputs such as air temperature, humidity, wind speed, solar radiation and, in the near future for the cold immersion model, water temperature and depth. Using standard Internet connections between MERCURY and Eglin's Range Automated Weather Stations (RAWS) base station computer, weather data from seven to ten RAWS stations are automatically ingested at hourly intervals. These geo-located weather data sets are then interpolated in the context of Digital Topographic Elevation Data (DTED) to provide gridded weather information at 1 km spatial resolution across a 100 by 100 kilometer Eglin area window. Individual weather parameters or predictive model outputs are then displayed over a DTED greyscale image as simple color-coded overlay products. The test bed is used to validate methods needed to extend this capability to operational settings.

Key Features of the MERCURY - Ranger Test Bed (as of 01/24/97)

- * Automatic hourly update of weather information from 7 stations in the Eglin region
- * Automatic spreading of weather data across the 100 X 100 km Eglin area using objective and heuristic methods
- * Display of derived weather data for any location in the Eglin field by point and click
- * Display of individual weather station data by point and click on station icon
- * Automatic archiving/indexing of all weather data with point and click access/analysis
- * Automatic logging of communications faults/errors
- * Area zoom
- * Point and click geolocation in Latitude/Longitude or UTM coordinates
- * Point and click color hard copy production on color laserjet printer
- * Point and click selection of physiological models:

Heat Strain

- * *User Input:* Height, Weight, Acclimatization Days, Hydration status (5 Categories), Work Load (4 Categories), Clothing Type (5 categories)
- * *Output:* DTED Color Overlays of Casualty Risk, Optimal Work/Rest Cycle Time, Maximum Safe Work Time, Hourly Drinking Water Requirements

Cold Survival Time

- * *User Input:* Height, Weight, Body Fat, Clothing Insulation, Mission Time
- * *Output:* DTED Color Overlay of Survival Time (Time to Tre=30.0 °C)

Cold Immersion

- * *User Input:* Height, Weight, Body Fat, Age, Metabolic Reserve, Mission Time, Walking Speed, Total Load, Terrain Type and Grade, Clothing Type, Wetness of Non-Immersed Clothing
- * *Output:* River Sensor Location Color Coded Icon (Based on Mission Duration and Predicted Time to Tre=35.5 °C)

The suite of physiological models in MERCURY employ the common risk representation color codes of: Green = Low Risk, Amber = Moderate Risk, Red = High Risk.

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Office of the Surgeon General
ATTN: DASG-MS
5109 Leesburg Pike
Falls Church VA 22041-3258

HQDA
Office of the Surgeon General
Preventive Medicine Consultant
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5109 Leesburg Pike
Falls Church VA 22041-3258

Uniformed Services University of the Health Sciences
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Bethesda MD 20814-4799

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ATTN: AMC-S&T, FE Unit 45015
APO AP 96343-5015

Director
Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue W.
P.O. Box 200
Downsview, Ontario Canada M3M 3B9

Department of National Defence, CANADA
Defence Research Establishment Ottawa
ATTN: Head Physiology Group
Environmental Protection Section, Protective Sciences Division
Ottawa, Ontario Canada K1A 0Z4

Head, Environmental Physiology Section
Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue W.
P.O. Box 200
Downsview, Ontario Canada M3M 3B9

National Defence Headquarters, CANADA
ATTN: Research and Development Branch
Human Performance Directorate
305 Rideau Street
Ottawa Ontario Canada K1AOK2