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PROCEEDINGS OF A SYMPOSIUM -- CONSEQUENCES OF WEARING THE CHEMICAL PROTECTIVE ENSEMBLE: ILLUSTRATIVE ASSESSMENT APPROACHES

US ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts

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13. ABSTRACT *(Maximum 200 words)*
Military personnel don the chemical protective clothing ensemble to preserve life and health in combat theaters when chemical attacks are likely. Unfortunately, the ensemble may also degrade military performance, heat balance, communication, sensation, motivation, and well-being. This symposium describes varied approaches for evaluating the chemical protective ensemble to highlight the utility of different assessment methodologies. Symposium participants contrast laboratory studies, field studies, simulations, and computer modeling. Specific military applications include: M16 rifle marksmanship, UH-60 pilot performance, soldiers performing their varied missions in the field, real-time assessment of physiological responses in the field, and prediction of physiology and behavior using biophysical models and computer simulations. Many papers include critical bibliographic references for such studies and assessment methodologies. These quantitative, assessment technologies increase our understanding of the interaction of the chemical protective ensemble with the soldier; such insights have profound implications for military doctrine, planning, and operations.

14. SUBJECT TERMS
MOPP, chemical protective clothing, military performance, MOS performance, mathematical modeling, simulation, pilot performance, marksmanship, sentry duty

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FOREWORD

This report contains a collection of the papers and the discussant's comments presented at a symposium entitled "Consequences of Wearing the Chemical Protective Ensemble: Illustrative Assessment Approaches", at the 33rd meeting of the Military Testing Association, San Antonio, TX. The symposium was held on 31 October 1991. The initial impetus for organizing the symposium developed when the chair, Dr. L.E. Banderet reviewed a draft Institute for Defense Analyses (IDA) manuscript on "The Effects of Wearing Protective Chemical Warfare Combat Clothing on Human Performance" during the spring of 1991. The IDA paper is a critical review of operational and experimental studies, completed since 1979, that report the effects of wearing chemical warfare protective combat clothing on individual and unit performance.

The symposium was structured to demonstrate the usefulness of various assessment methodologies in evaluating the effects on performance of wearing chemical warfare protective combat clothing. The participants of the symposium are from several technical and scientific disciplines and include psychologists, a biophysicist, a chemical engineer and two physicians one of whom is a flight surgeon. The papers in the symposium report results from laboratory and field studies, simulations and computer modeling.

The symposium demonstrates the value of a multidisciplinary approach to the understanding of the consequences of the chemical warfare protective ensemble on individual and mission performance. It appears reasonable to expect that one outcome of the symposium would be the development of a procedure to periodically bring together experts from the several scientific disciplines to review the contribution that their respective areas are making to the quantification of performance decrements related to wearing chemical warfare protective clothing.

ACKNOWLEDGEMENTS

The contributions of this diverse and exceptional group of subject-matter experts to the symposium are gratefully acknowledged. Collectively, they represent almost a century of professional endeavor for determining the effects of the chemical protective ensemble upon the soldier. Their academic training, methodological approaches, scientific contributions, and solutions to practical military problems attest to the utility of a multi-disciplinary approach for solving many military problems.

As Chairman for this symposium, I thank the Commander of our Institute, COL Gerald P. Krueger, Ph.D., and my Division Chief, MAJ Mary Z. Mays, Ph.D., for their support and encouragement of this effort. Lastly, Ms. Ann Simpson is recognized for her initiative and professionalism in preparing these papers into a consistent, unified document.

EXECUTIVE SUMMARY

Military personnel don the chemical protective clothing ensemble to preserve life and health in combat theaters when chemical attacks are likely. Unfortunately, the ensemble may also degrade military performance, heat balance, communication, sensation, motivation, and well-being.

- This symposium describes varied approaches for evaluating the chemical protective ensemble to highlight the utility of different assessment methodologies.

- Symposium participants contrast laboratory studies, field studies, simulations, an computer modeling.

- Specific military applications include: M16 rifle marksmanship, UH-60 pilot performance, soldiers performing their varied missions in the field, real-time assessment of physiological responses in the field, and prediction of physiology and behavior using biophysical models and computer simulations.

- Many papers include critical bibliographic references for such studies and assessment methodologies.

These quantitative, assessment technologies increase our understanding of the interaction of the chemical protective ensemble with the soldier and have profound implications for military doctrine, planning, and operations.

PROCEEDINGS OF A SYMPOSIUM--CONSEQUENCES OF WEARING THE CHEMICAL PROTECTIVE ENSEMBLE: ILLUSTRATIVE ASSESSMENT APPROACHES

L.E. Banderet, W. Blewett, R.R. Gonzalez,

R.F. Johnson, D. Redmond, R. Thornton,

H.L. Taylor, and J. Orlansky

Symposium Presented at the 33rd Meeting
of the Military Testing Association,
San Antonio, Texas, 31 October 1991.

SYMPOSIUM

Consequences of Wearing the Chemical Protective Ensemble: Illustrative Assessment Approaches

Chairman L.E. Banderet

L.E. Banderet. Varied Approaches for Assessing the Effects of the Chemical Protective Ensemble

R.F. Johnson. Rifle-Firing Simulation: Effects of MOPP, Heat, and Medications on Marksmanship

W. Blewett. Field Studies: Assessing How Well Military Personnel Perform Their MOSs in MOPP4

D. Redmond, J.R. Leu, K.A. Popp, S.W. Hall, C. Galinsky, & P. Gutierrez. Medical Monitoring: Assessment of Physiological Changes in Military Personnel during Field Studies

R. Thornton & L. Caldwell. Complex Simulation: Effects of NBC Protective Equipment upon UH-60 Pilot Performance

R.R. Gonzalez & L.A. Stroschein. Computer Modeling: Predicting the Soldier's Heat Transfer and Work Capabilities in MOPP

H. Taylor & J. Orlansky. Discussion: Approaches Which Assess the Consequences of Wearing the Chemical Protective Ensemble

Symposium Presented at the Meeting of the Military Testing Association,
31 Oct 1991, San Antonio, Texas

VARIED APPROACHES TO ASSESSING THE EFFECTS OF THE CHEMICAL PROTECTIVE ENSEMBLE

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SUMMARY

Military personnel don the chemical protective clothing ensemble to preserve life and health in combat theaters when chemical attacks are likely. Unfortunately, the ensemble may also degrade military performance, heat balance, communication, sensation, motivation, and well-being. We selected evaluation of the chemical protective ensemble as a topic to highlight the utility of different assessment methodologies. The symposium includes a flight surgeon, physician, chemical engineer, biophysicist, and several psychologists as participants and contrasts laboratory studies, field studies, simulations, and computer modeling. Participants will describe: M16 rifle marksmanship, UH-60 pilot performance, soldiers performing their varied missions in the field, real-time assessment of physiological responses in the field, and prediction of physiology and behavior using biophysical models and computer simulations. Quantitative understanding of the interaction of the chemical protective ensemble with the soldier has profound implications for military doctrine, planning, and operations. The contribution of varied measurement technologies to these processes will be evident.

INTRODUCTION

It is essential to know the impact of the chemical protective ensemble upon the soldier's well-being and his ability to perform his mission. Ensemble design, military planning, and doctrine require such information. For example, complex "war games" waged on computers have outcomes dependent upon such effects. However, determining the soldier's well-being and his ability to function in the ensemble is arduous for several reasons. The phenomena of interest involve many complex and interacting subsystems which include the soldier, his chemical protective ensemble, his micro-environment, mission, and weather. Trends of subjective reactions or performance capabilities resulting from interactive variables depend upon specific values of those variables, e.g. ambient temperature or amount of physical work. Furthermore, understanding such complex functional relationships is difficult. This symposium features selected approaches to assess the effects of the chemical protective ensemble on the soldier. This paper: 1) reviews some of the varied approaches for assessing the effects of the chemical protective ensemble on the soldier, 2) highlights each paper in this symposium, and 3) cites scientific literature which reviews and describes these measurement approaches.

MEASUREMENT APPROACHES

There are many ways to measure the effects of the chemical protective ensemble (See Table I). Different dependent variables are examined to explore biophysical, computer-modeling, human factors, medical, operational, performance, physiological, and psychophysiological phenomena. Such studies also involve professionals from several disciplines. General references describing each approach are also cited in Table I.

Historically, the operational, human factors, and performance approaches were popular. Operational studies assess the capabilities of soldiers while they perform their mission in the field. Such studies may involve small groups such as a platoon or involve several companies, e.g. CANE I. The intrusiveness of the approach to ongoing military activities and the amount of experimental control imposed differ greatly from one operational test to another. We suggest the use of different terms to distinguish how assessment is conducted during operational tests. Field exercises are those situations where military activities proceed normally with minimal intrusions to gain scientific information; measures of interest are instrumented and unobtrusive.

Table I--Approaches for assessing the effects of the chemical protective ensemble upon the soldier. References or papers in this symposium which describe each approach are also indicated.

APPROACHES WITH SELECTED EXAMPLES	PAPER (See Table II)	REVIEWED IN REFERENCE NO.
Biophysical	F	4, 6, 7
Ensemble		
Environment		
Mission		
Ensemble-Mission-Environment		
Computer Modeling	F	4-7
Performance Capabilities		
Soldier's Body Temperature		
Capabilities After Chemical Attack?		
Human Factors	B,C,E	4-7
Gloves		
Mask		
Medical	B-E	2-7
Signs		
Symptoms		
Heat Exhaustion		
Operational	C	2-7
Field Exercises		
Field Experiments		
Field Studies		
Performance	B-F	2-7
Acquisition of Skills		
Actual MOS Tasks		
Physical Work		
Simulated Complex Tasks		
Simulated MOS Tasks		
Physiological	D-F	4-6
Core and Skin Temperatures		
Energy Cost		
Heart Rate		
Respiration		
Water Balance		
Psychophysiological	B,E	3-7
Attention		
Cognition		
Dexterity		
Body Mobility		
Sensation		

For example, instrumented armor vehicles and targets provide data on gunnery accuracy and the time required to engage targets at the National Training Center, without the soldier's awareness. Another strategy for field exercises is that data are collected during lulls in activities. At mealtime, or other quiet intervals, medical or human factors questionnaires are administered to gain information. Field studies involve some scientific control over schedules, military activities, and greater intrusions to gather information. Lastly, field experiments involve extensive control of activities for scientific purposes. Scientific objectives of the field experiment drive military schedules, activities, work-rest cycles, and testing intervals.

Human factor evaluations involve assessing the soldier's efficiency and capability to perform while wearing the chemical protective ensemble. The impact of the ensemble on the soldier's vision, hearing, communications, and comfort may also be assessed. Although such evaluations may involve the total chemical protective ensemble, studies of the ensemble's mask or gloves are illustrative. The ensemble sometimes has effects which reduce the soldier's ability to perform his mission. Hence, many studies of the effects of the protective ensemble involve performance. These may investigate actual military tasks such as firing the M16 rifle at the range, reading maps, using a military radio to communicate, marching, carrying loads, lifting of projectiles, or digging fox holes. Alternatively, performance studies in the laboratory often investigate tasks which mimic military tasks, e.g. pattern recognition, computation, or number comparison. Other performance studies have employed elaborate simulations of firing of the M16 rifle, target engagements with the M1A1 tank, or the piloting of a military aircraft. Some studies have examined whether the learning of new skills is changed by the ensemble.

To understand the responses of the soldier's body to the chemical protective ensemble, medical and physiological processes are often studied. Symptoms are indicated on self-rated questionnaires or solicited during clinical interviews. Personnel are observed closely for the signs of medical disorders that may be caused by extreme body temperatures, dehydration, or impaired electrolyte concentrations. Heart rate, respiration, metabolic rate, and internal-body and skin temperatures are frequent physiological measures of the "strain" induced by the protective ensemble and demanding environmental and mission conditions. The soldier's functional capabilities and subjective reactions are sometimes assessed with psychophysiological measures such as attention, cognition, finger dexterity, body mobility, and perception.

Less common, but very important measures, are biophysical measures which reflect the impact of the physical characteristics of the ensemble, the weather, mission demands, and the environment upon the soldier. These measures are collected so that the soldier's thermodynamic responses to them can be understood, predicted, and modeled.

The low cost and availability of personal computers has fostered the computer-modeling approach. Algorithms in software programs implement the functional relationships underlying the predominant variables in a biophysical model. Calculations from these algorithms reflect the combined effects of variables such as the ensemble, weather, mission demands, physiological acclimatization, and work-rest cycles. Varying end-points and outcomes such as the soldier's body temperature or performance capabilities are often utilized with this approach. Whenever possible, predictions from such models are compared with real- world outcomes to establish the validity of the model. More ambitious models include chemical attacks by the enemy and the effects of the chemical agent, given its expected deployment and dispersion on the battlefield. These models iterate the effects of chemical warfare and predict the casualties which result or unit degradation. An extremely useful and heuristic feature of all such computer models is that they permit "what if" scenarios to be explored.

MEASUREMENT APPROACHES IN THIS SYMPOSIUM

Several of these measurement approaches are illustrated by presentations in this symposium (See Table II). Specifically, Dr. Johnson's paper describes engagement of targets with an M16 rifle-firing simulation. He uses this simulated military task to assess the effects of the chemical protective ensemble, nutrients, and medications. Mr. Blewett describes field studies in which he assesses soldiers performing their military tasks in the protective ensemble, e.g. processing of chemical casualties at the battalion aid station or decontamination of vehicles and detailed equipment. COL Redmond describes a telemetry system for monitoring of internal body temperature, heart rate, skin temperature, and other biological indices during field studies or experiments. This system is a relatively noninvasive way to monitor a test subject's internal body temperature in studies where body temperature may be increased substantially. Drs. Thomton and Caldwell describe the effects of the protective ensemble on UH-60 helicopter pilot performance in a complex simulator. Their presentation also relates data from the helicopter simulator with information collected using other measurement approaches. Dr. Gonzalez and Mr. Stroschein describe their work on the mathematical model by Givoni and Goldman which incorporates results from dozens of physiological and biophysical studies. The model incorporates variables which influence heat balance and heat-transfer characteristics of the soldier, e.g. exercise, acclimatization, and chemical protective ensemble.

REFERENCES ON THE EFFECTS OF CHEMICAL PROTECTIVE ENSEMBLE

This paper includes seven references which describe the effects of the chemical protective ensemble. Three references are recent reviews of scientific papers and reports (Ramirez & Pence, 1988; Ramirez et al., 1988; Taylor & Orlansky, 1992). Terms used to describe the ensemble, chemical agents, pre-treatments, and decontamination procedures are cataloged and ordered hierarchically in a thesaurus (Brletich et al., 1989). FM 3-4, *Nuclear, Biological, and Chemical (NBC) Protection*, describes the chemical protective ensemble, situations which warrant its use, different configurations of the ensemble, i.e., MOPP levels, and some of its effects upon operational, physiological, and psychological processes (Dept. Army, 1985). FM 22-51, *Leader's manual for combat stress control*, describes various types of warfare where the protective ensemble is likely to be worn as well as phenomena such as "gas hysteria" and other physiological and psychological reactions that may occur in such situations (Dept. Army, 1992). This manual offers many practical suggestions for training to instill confidence in the soldier for the ensemble and to minimize adverse reactions. Lastly, Goldman (1981) discusses the results of a field study and many design, tradeoff, training, and evaluation issues associated with the ensemble. He also emphasizes the utility of combining a biophysical approach with computer modeling.

Table II--Vocation and primary measurement approach of the authors of each presentation in the Symposium, "Consequences of Wearing the Chemical protective Ensemble: Illustrative Assessment Approaches."

PAPER	TITLE	VOCATION OF AUTHOR(S)	PRIMARY APPROACH
A	L.E. Banderet. Introduction: Varied Approaches for Assessing the Effects of the Chemical Protective Ensemble.	Exp. Psychologist	-----------
B	R.F. Johnson. Rifle-Firing Simulation: Effects of MOPP, Heat, and Medications on Marksmanship.	Exp. Psychologist	Performance Capabilities
C	W. Blewett. Field Studies: Assessing How Well Military Personnel Perform Their MOSs in MOPP4.	Chemical Engineer	Operational Effectiveness
D	D. Redmond, J.R. Leu, K.A. Popp, S.W. Hall, C. Galinsky, & P. Gutierrez. Medical Monitoring: Assessment of Physiological Changes in Military Personnel during Field Studies.	Research Internist Exp. Psychologist	Physiological Evaluation
E	R. Thornton and L. Caldwell. Complex Simulation: Effects of NBC Protective Equipment upon UH-60 Pilot Performance.	Flight Surgeon Exp. Psychologist	Performance Capabilities
F	R.R. Gonzalez and L.E. Stroschein. Computer Modeling: Predicting the Soldier's Heat Transfer and Work Capabilities in MOPP.	Res. Biophysicist Mathematician	Computer Modeling
G	H. Taylor and J. Orlansky. Discussion: Approaches Which Assess the Consequences of Wearing the Chemical Protective Ensemble.	Exp. Psychologist Psychologist	----------- -----------

CONCLUSIONS

This paper briefly described several measurement approaches for documenting the effects of the chemical protective ensemble. These approaches differ on which phenomena are measured, which variables are controlled, what type of process in the soldier is evaluated, and how well each approach permits synthesis of information from other sources. Such varied approaches contribute related, but necessary, information to our understanding of the effects of the ensemble (Ramirez & Pence, 1988; Ramirez et al., 1988; Taylor & Orlansky, 1992).

Quantitative understanding of the interaction of the chemical protective ensemble with the soldier has profound implications for military planning, operations, doctrine, and the design of future chemical protective ensemble or the 2001 hi-tech protective soldier ensemble. Historically, development of chemical protective ensembles was aided by the expert experience and the technical information base resulting from these varied assessment approaches. Future designs for protective ensembles, military planning, and military doctrine will require multiple measurement technologies so that the complex, functional relationships describing soldier effectiveness in these newer protective ensembles are known.

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BIOGRAPHICAL SKETCH

LOUIS E. BANDERET is a Research Psychologist at the U.S. Army Research Institute of Environmental Medicine, Natick, Massachusetts. He has studied Field Artillery Fire Direction Center teams during sustained operations in a lab simulation and in the field; developed and automated cognitive tasks; assessed U.S. Army armor, artillery, and infantry personnel wearing the chemical protective uniform during field studies; and evaluated various treatment strategies for environmental disorders. He is first author of "The Effects of High Terrestrial Altitude on Military Performance" in *The Handbook of Military Psychology.* Dr. Banderet also teaches psychology courses at Northeastern University and is the first author of a test file for a current, psychology textbook.

RIFLE FIRING SIMULATION: EFFECTS OF MOPP, HEAT, AND MEDICATIONS ON MARKSMANSHIP

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SUMMARY

The Weaponeer M16 Rifle Marksmanship Simulator was used for assessing soldier performance under environmental extremes and under procedures designed to protect the soldier from environmental threats. Experimental data indicate that rifle marksmanship is impaired by exposure to ambient heat (95°F), the wearing of combat chemical protective clothing (MOPP4), the ingestion of medications (antihistamines and *nerve agent antidotes*), *and by sentry duty (vigilance) conditions. Target* detection during simulated sentry duty is improved by caffeine, a mild stimulant.

INTRODUCTION

The Weaponeer Rifle Marksmanship Simulator is a training device used by the US Army in its basic rifle marksmanship courses. The Weaponeer utilizes a modified M16A1 rifle, simulates realistic recoil, and presents a variety of both stationary and pop-up targets (Spartanics, 1985). The Weaponeer was recently adapted for laboratory use in assessing soldier performance under varying environmental extremes (heat, cold, chemical contamination) and under procedures designed to protect the soldier from environmental threats (medications, cold weather clothing, chemical protective clothing) (Johnson & Kobrick, 1988; Johnson & McMenemy, 1989a, 1989b). The Weaponeer permits evaluation of both rifle marksmanship speed (ability to hit rapidly appearing pop-up targets) and accuracy (the variability, or "tightness," of the shot group). Soldier performance on the Weaponeer has been shown to be predictive of actual live fire performance on the rifle range (Schendel, Heller, Finley, & Hawley, 1985). This paper describes recent research which demonstrates the Weaponeer's usefulness in the evaluation of soldier performance under environmental extremes and operational requirements.

MARKSMANSHIP WHILE WEARING COMBAT AND CHEMICAL PROTECTIVE CLOTHING

The effects of combat and chemical protective clothing on rifle marksmanship were evaluated by Johnson, McMenemy, & Dauphinee (1990). The rifle marksmanship of 30 soldiers was assessed with the Weaponeer under three clothing configurations of increasing bulk: (a) the battle dress uniform (BDU); (b) the fighting load (FL) which consists of the BDU plus helmet, web gear, and full canteen; and (c) the chemical protective clothing ensemble (MOPP4). Each soldier was given 5 days practice on the Weaponeer by repeatedly firing at 32 randomly presented pop-up targets (E-type silhouettes at simulated distances of 100 and 250 meters). Rifle marksmanship was assessed on the fifth day in terms of the total number of targets hit. Rifle marksmanship was significantly poorer under the MOPP4 condition (M = 22.1 hits) than under either the FL condition (M = 26.0 hits) or the BDU condition (M = 27.4 hits). The impairment while wearing MOPP4 was attributed to the awkwardness in obtaining a rapid and proper sight alignment while wearing the chemical protective mask.

MARKSMANSHIP UNDER CONDITIONS OF AMBIENT HEAT AND NERVE AGENT ANTIDOTE

Rifle marksmanship was assessed in a large and comprehensive study of the effects of ambient heat and nerve agent antidote on soldier performance (Johnson & Kobrick, 1988; Kobrick, Johnson, & McMenemy, 1990). The rifle marksmanship of 15 soldiers was assessed in a 2 x 2 design: (a) 95°F vs. 70°F (35°C vs. 21.1°C) ambient temperature, and (b) one dose of nerve agent antidote (600 mg 2-PAM chloride, 2 mg atropine sulfate) vs. placebo (saline). Marksmanship speed (as measured by the ability to hit rapidly appearing pop-up targets) was impaired by nerve agent antidote while marksmanship accuracy (tightness of the shot group for a stationary target) was impaired by 95°F ambient heat. Compared to the placebo condition, a single dose of nerve agent antidote significantly impaired rifle marksmanship for pop-up targets such that marksmanship speed was 3% poorer; an independent measure of visual reaction time was 5 to 11% poorer with the nerve agent antidote. Compared to the 70°F condition, the 95°F ambient condition significantly impaired rifle marksmanship for stationary targets such that the tightness of the shot group was 13% less accurate; an independent measure of arm-hand steadiness was 10% poorer under 95°F ambient condition. Nerve agent antidote and ambient heat did not interact to further impair rifle marksmanship performance. Since ambient heat and nerve agent antidote each impair separate components of marksmanship (accuracy and speed, respectively), the soldier's overall marksmanship performance is likely to be degraded more if the soldier has to operate in a hot environment while also under the influence of nerve agent antidote.

MARKSMANSHIP DURING SIMULATED SENTRY DUTY

Mackworth's classic work on vigilance (Mackworth, 1950) showed that the ability to detect infrequent and brief (less than one second) stimulus changes in the visual field deteriorated after only one-half hour of sustained attention and remained deteriorated for the remainder of a two hour test session. While Mackworth's task was modelled after that of a sonar operator, the task is analogous to that of a soldier on sentry duty who must scan a visual field and detect the appearance of enemy targets. Unlike Mackworth's task, however, the soldier on sentry duty must not only detect the sudden appearance of a visual target but the soldier must also pick up a rifle, aim, and fire accurately at the target. In a study by Johnson and McMenemy (1989a), the rifle marksmanship of 8 soldiers was assessed with the Weaponeer during 3 hours of simulated sentry duty (vigilance) during which time the subject had to respond to the infrequent appearance of a target at a simulated distance of 250 meters (12 presentations per 30 minute period). When the target appeared, the soldier's task was to pick up the rifle, aim, and fire at the target. In accordance with Mackworth's findings, target detection time deteriorated with time on sentry duty;

impaiments were not evident within the first hour but were clearly evident by 1.5 hours. The ability to hit the target remained constant over time; soldiers were just as accurate in hitting the targets at the end of the 3 hours of sentry duty as they were at the beginning (M = 9.6 hits out of a possible 12). The results of this study suggest that sentry duty performance may be optimized if appropriate duty intervals are assigned.

EFFECTS OF ANTIHISTAMINES AND CAFFEINE ON MARKSMANSHIP AND SENTRY DUTY

In a study by Johnson and McMenemy (1989b) the rifle marksmanship of 12 soldiers was again assessed with the Weaponeer during 3 hours of simulated sentry duty during which time the subject had to respond to the infrequent appearance of a target (12 per 30 minute period) by picking up the rifle, aiming, and firing at the target. Prior to the study, the subject received either a clinical dose of antihistamine (either 60 mg terfenadine or 50 mg diphenhydramine), a placebo, or no pill (control). Speed of target detection was again impaired by time on the task. Both speed of target detection and marksmanship accuracy were further impaired by diphenhydramine, an antihistamine which crosses the blood brain barrier. Neither measure of marksmanship was impaired by terfenadine, an antihistamine which does not cross the blood brain barrier.

In a study just completed at USARIEM and sponsored by the P^2NBC^2 program of the US Army Chemical School, Donna J. Merullo and I used the Weaponeer to evaluate the separate and combined effects of the administration of a standard 200 mg dose of caffeine (an over-the-counter stimulant commonly used to maintain mental alertness) and the wearing of the standard M17 protective mask with hood (standard combat chemical protective headgear) on the speed of target detection and rifle marksmanship during three hours of simulated sentry duty. Prior to testing, 12 male soldiers were trained on rifle marksmanship and were familiarized with the targets to be presented. During all training and test sessions, subjects wore the battle dress uniform (BDU), helmet, web gear, and full canteen. After training, and in accordance with a 2 x 2 (drug x headgear) repeated measures experimental design, each subject was administered four separate test conditions over four separate days: (a) placebo without M17 mask, (b) 200 mg caffeine without M17 mask, (c) placebo with M17 mask, and (d) 200 mg caffeine with M17 mask. The order of test conditions was systematically varied from subject to subject so that each condition was presented first, second, third, and fourth an equal number of times. During each three-hour test session, the subject monitored the target area of the Weaponeer Rifle Marksmanship Simulator. When a pop-up target appeared, the subject lifted his rifle, aimed at the

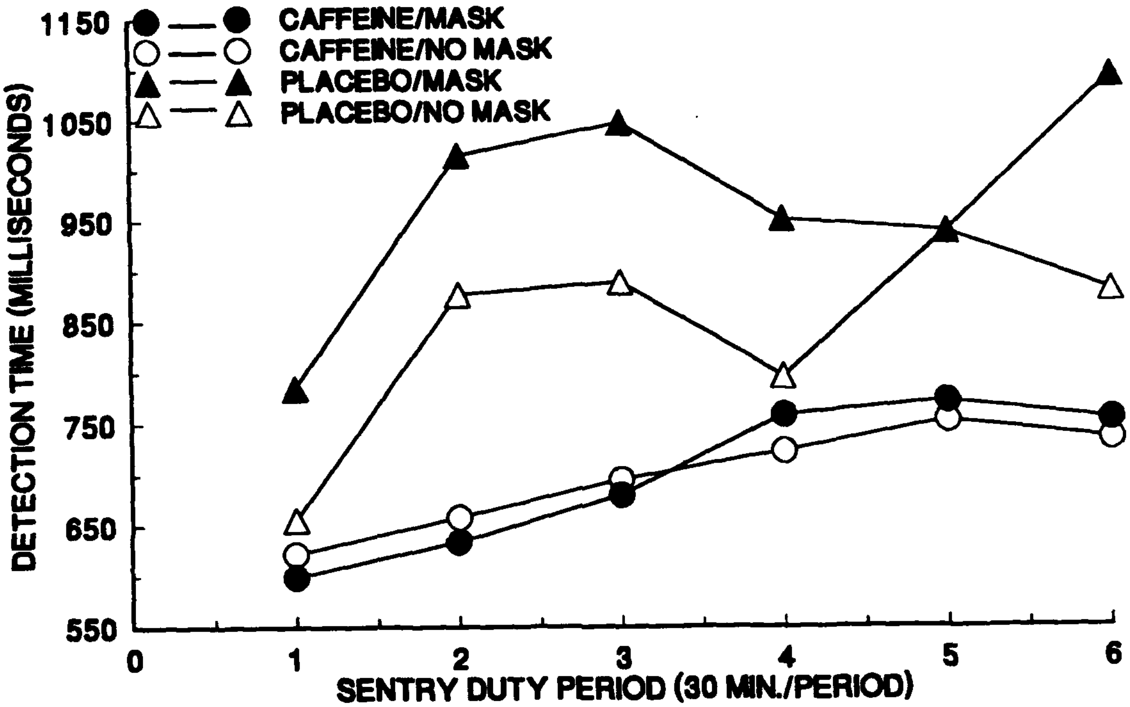

FIGURE 1. TARGET DETECTION TIME DURING 3 HOURS OF SIMULATED SENTRY DUTY.

target, and fired. Speed of target detection and rifle marksmanship for each 30 minute period were averaged for analysis. Speed of target detection again deteriorated with time on the task. However, the results also showed that caffeine improved sentry duty performance by attenuating the vigilance decrement curve (Figure 1). As was shown in earlier studies under non sentry duty scenarios, the wearing of chemical protective clothing, namely the M17 protective mask, impaired sentry duty performance by decreasing the ability to hit targets (Figure 2). It was concluded that a standard over-the-counter dose of caffeine (200 mg, equivalent to about 2 cups of coffee) improves sentry duty performance (detection of targets).

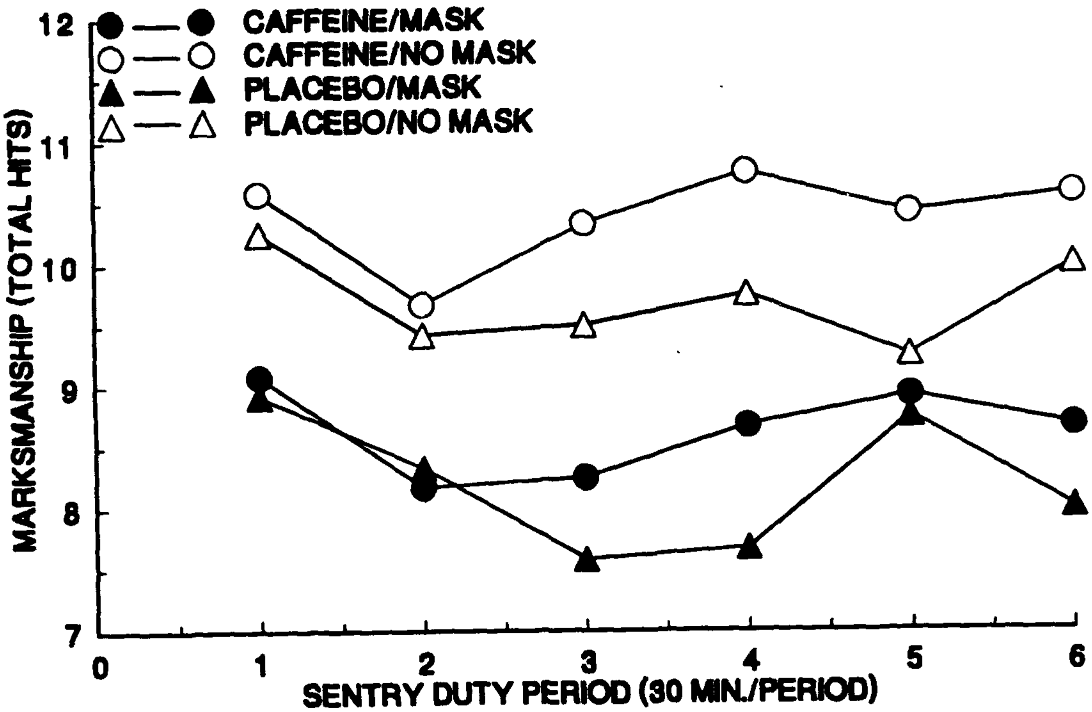

FIGURE 2. MARKSMANSHIP DURING 3 HOURS OF SIMULATED SENTRY DUTY.

CONCLUSIONS

The Weaponeer Rifle Marksmanship Simulator has been successfully adapted for laboratory use. Data have been collected which indicate that:

a. The wearing of chemical protective clothing, including the protective mask, impairs M16 rifle marksmanship, largely due to the awkwardness in obtaining a rapid and proper sight alignment while wearing the chemical protective mask.

b. Ambient heat impairs M16 rifle marksmanship, largely due to poor steadiness of the arm and hand at 95°F.

b. A single dose of nerve agent antidote (600 mg 2-PAM chloride, 2 mg atropine sulfate) impairs M16 rifle marksmanship, largely due to slowed reactivity to the appearance of the target.

c. During sentry duty, M16 rifle marksmanship and target detection speed may be enhanced if sentry duty is limited to one hour and soldiers are discouraged from using diphenhydramine (an over-the-counter antihistamine).

d. A standard dose of 200 mg caffeine improves sentry duty performance (speed of detection of targets).

NOTES

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BIOGRAPHICAL SKETCH

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FIELD STUDIES: ASSESSING HOW WELL MILITARY PERSONNEL PERFORM THEIR MOS IN MOPP4

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INTRODUCTION

Many tests have been conducted in recent years to determine how well soldiers perform in MOPP4. Generally, most of these tests have been specific to certain items of equipment. That is, they are for determining how well soldiers can operate weapons systems while wearing the protective mask, hood, rubber gloves, overboots, and chemical protective overgarment. By regulation, military equipment today must be designed to allow a soldier to operate it effectively in MOPP4. The chemical protective ensemble degrades psychomotor, visual, perceptual, auditory, and cognitive performance; it also increases heat stress and decreases endurance. These considerations must be addressed during hardware development.

I want to describe to you a type of testing that addresses not only materiel issues but also those of doctrine, training, organization, and leadership in MOPP4. These tests have been conducted since 1985 under a program entitled Physiological and Psychological Effects of NBC and Sustained Operations of Systems in Combat (P^2NBC^2), a Department of the Army program administered by the U.S. Army Chemical School of Fort McClellan, AL.

The emphasis here is on the word systems. The field testing done under the P^2NBC^2 program examines the NBC operation as a complete system--consisting of the soldier, his equipment, doctrine, training, and organization--in a realistic field environment. To achieve a realistic environment, we apply a simulated chemical agent, an element that has proved to be very important in these studies. The primary objectives of the P^2NBC^2 program are:

o To measure performance decrement under conditions of sustained operations on the integrated battlefield and,

o To identify and evaluate measures that will extend system performance. These measures, or "fixes", may be related to doctrine, training, leadership, organization, or materiel.

Many of the problems that occur in MOPP4 are not manifested in operations of a short duration. When a soldier is in MOPP4 for only a brief period, he will not experience the full range of physiological and psychological effects of MOPP4--effects such as heat strain and cognitive problems. For this reason, this testing has involved trials of from 4 to 12 hours duration. To illustrate, I will discuss three of the tests we at the Chemical Research, Development and Engineering Center (CRDEC) have conducted recently under the P^2NBC^2 program:

- o Detailed Decontamination of Vehicles
- o Rearm Operations by Tank Crewmen
- o Processing Contaminated Patients into a Medical Facility

In each of these tests we have used simulated chemical agents, most commonly oil of wintergreen (methyl salicylate, MS) which has approximately the same evaporation rate, surface tension, solubility, and detectability as the agent mustard. The MS is detectable by use of the Chemical Agent Monitor (or CAM), the Army's new automatic detector, in the same manner as mustard. This provides a tremendous benefit in achieving realism in testing. We use MS under a protocol approved by The Surgeon General of the Army and within constraints defined in an environmental assessment, written in 1989.

Use of a simulated chemical agent, the CAM, and air sampling equipment provides an important measure of effectiveness. These data are particularly important with regard to doctrinal issues; it gives us the capability to optimize the procedures for such operations as decontamination, entry/exit, and contamination avoidance. In addition to measurements of residual contamination, we acquire the following data in these tests:

o Task and event times

- o Body temperatures (core and skin) of subjects
- o Activity level and heart rate of subjects
- o Weight loss
- o Water consumption
- o Human factors data
- o Demographic information
- o Psychological data

The physiological data noted here are taken by a team from the Walter Reed Army Institute for Research led by COL Dan Redmond. Their system for monitoring body temperatures, heart rates, and activity levels telemetrically is the Biomedical Field Safety Monitor. This is a state-of-the-art system that provides real-time data on up to 30 test players simultaneously in a field environment. Psychological and demographic data are usually acquired and analyzed by the U.S. Army Institute of Environmental Medicine. The U.S. Army Human Engineering Laboratory is part of the test team as well. HEL administers human factors questionnaires and interviews the test subjects.

RESULTS

DETAILED DECONTAMINATION OF VEHICLES

We conducted this test with the Fifth Mechanized Infantry Division at Fort Polk, LA, on 13-24 May 1991. It consisted of six trials in which a team of from 17 to 28 test subjects decontaminated 24 vehicles each day according to the procedures specified in FM 3-5. There has been Army doctrine for such operations for many years; however, this is the first scientific field test of the complete process. The decontamination procedure consists of six steps, each done at a different station. At station one, soldiers rinse the vehicle; at station 2, they apply a decontaminant to all exterior surfaces and scrub with brushes and mops. Station 3 is a wait station, allowing 30 minutes for the decontaminant to react; and station 4 is a rinse station. At station 5, soldiers decontaminate the interior of the vehicle, and at station 6, they check it with the CAM. If they detect any residual agent at station 6, the vehicle is recycled through the line. The line can process about six vehicles per hour. We were tasked by the Chemical School to examine a variation in the layout of the tasks and some hardware innovations.

One of the problems with the current operation is that soldiers must wear the rain suit or a similar impermeable layer, over their MOPP4. This results in much greater heat retention than MOPP4 alone. In the conditions that prevailed during the test (humid with temperatures between 68 and 77°F), there was a dropout rate of 50% at station 2, the station with the heaviest work load (scrubbing and application of decontaminant). Many of these dropouts were involuntary; that is, the players were withdrawn by the on-site physician because of elevated core temperatures or clinical signs of heat injury. The duration of each trial ranged from 3.5 to 5 hours.

We also found that the decontamination teams were not very effective at removing the simulated agent. Our indicators of effectiveness were CAM readings and fluorescent marks when we examined the vehicle surfaces with an ultraviolet light to detect a tracer dissolved in the simulated agent. We observed that the decon team at station 2--the most critical station--could not discern between areas processed and not processed and had inadequate tools for application and scrubbing. We believe that these factors, in combination with the effects of wearing the ensemble, render the process far less effective than it should be. We identified several potential improvements, some of which have already been applied in the new edition of FM 3-5, and some of which will likely be evaluated next year in a similar test. The draft technical report is currently being reviewed for publication.

REARM OPERATIONS BY TANK CREWMEN

We conducted two field tests on rearm operations at Fort Knox, KY--one in October 1987 and one in October 1989. Again, one of the major problems was the ensemble specified for tank crewmen to wear when rearming a tank in a chemical environment. The draft NBC Operations Manual specifies that the crewmen who exit the tank to load the rounds (each weighing about 50 pounds) do so wearing the rain suit over MOPP4.

In these two tests, we applied the simulated agent as a vapor by placing evaporative panels upwind of the tanks at each rearm point. We also sprayed simulated agent on the tank surface. We found that the NBC rearm procedures were effective in minimizing the transfer of contamination into the tank. But we found that the rearm operation took far too long to accomplish, and it subjected the loaders to significant heat stress, even though the ambient temperatures were only 45-55°F. Again, a major problem was the heat retention of the ensemble. When the tank crewman exits in a chemical environment, he wears a heavy ensemble: Nomex coverall, chemical overgarment, flak vest, cool vest (unplugged upon exiting), gloves, mask, hood, overboots, and rain suit. Based upon the findings of the first test, we recommended changes to the procedures and equipment used for rearming and open hatch operations in a chemical environment. We tested these in the October 1989 test. Based upon the results of the second test program, the revised procedures were incorporated into the Armor School publication, *Tanking in the Desert*, written for Operation Desert Storm. Two technical reports were published on this testing, CRDEC-TR-209 (August 1990) and CRDEC-TR-88079 (March 1988).

PROCESSING CONTAMINATED PATIENTS INTO A MEDICAL FACILITY.

We have conducted two field tests on this type of operation. The first addressed patient processing at a Battalion Aid Station (BAS, a mobile medical shelter) in June 1989. This test is described in CRDEC-TR-148 (February 1990). We conducted the second one, on corps hospital operations, at Fort Indiantown Gap, PA, in August of this year. The report is in draft.

Before litter patients can be taken from a contaminated battlefield into a collectively protected medical facility, they must undergo a decontamination process that includes removing all their garments; decontaminating their masks, skin, and dressings; transferring them to a clean litter; and placing them in an airlock for a period of about 5 minutes. To perform this processing, a Patient Decontamination Augmentation (PDA) team of about 10 soldiers is assembled from the supported unit. They operate in MOPP4. They do not wear the rain suit but wear an apron of butyl rubber to keep the bleach solution used for decontamination off the overgarment.

In both of these tests, we challenged the PDA team with a steady flow of patients--contaminated with one or two of the simulated agents--over a period of about 7 hours. Most patients were mannequins weighing from 150 to 180 pounds. In the case of the corps hospital, there were also ambulatory patients. Each was dressed in MOPP4 except for some that arrived in a protective patient wrap (corps hospital only). For the BAS test, there were 35 patients per trial; for the corps hospital test, 92 per trial.

The work rate of the PDA team is fairly heavy. As the litter patients are cut from their garments, they have to be lifted for at least one litter exchange, and they are carried from station to station by the PDA team. We found, however, the dropout rate much lower than that of the vehicle decontamination operation, a probable result of not wearing the impermeable outer garment over MOPP4.

In the first test, we found the efficiency--based on time and rate data--to be very low. Some recommended changes to the layout and team organization were made before the 1991 test, and the result was a much greater efficiency. A higher efficiency equates to a higher rate of processing; the maximum patient processing rate of the second test was almost twice that of the first.

We observed that over the 7-hour period, the moisture retained by the chemical protective gloves caused a problem for the PDA team. Some soldiers experienced hyperhidrosis of the hands which resulted in skin loss. This injury made it very difficult for them to use scissors and perform their cutting tasks. We also found that in warm weather, (WBGT of about 80°F), PDA team members had difficulty achieving the recommended water intake while drinking through the mask. In all of our field tests, we have seen that the average water intake has been below the recommended rate, despite an emphasis upon drinking frequently and upon drinking as part of the procedure (e.g. taking a drink after each patient processed).

By use of the simulated agents, we demonstrated that contamination transfer into the shelter is more likely to occur as a result of the adsorption and desorption of ambient agent vapor on the canvas litters than by transfer of liquid agent from the patients' garments to the litter or to the skin of the patient. This finding has helped to simplify the patient processing procedures, and to make them more effective.

Several of the recommendations related to doctrine in these tests have been incorporated into publications. This is due in part to a new process called the CANE (Combined Arms in a Nuclear-Chemical Environment) Implementation Program, a formal procedure under which recommendations are further evaluated and are tracked by the Training and Doctrine Command (TRADOC) through an implementation process. This insures that the findings of such chemical operations tests are properly applied.

FUTURE PLANS

In fiscal year 92, we are continuing this type of field testing. Earlier this month, we completed a two-week test of Mobile Subscriber Equipment (communications) operations at Fort Gordon, GA. In 1992, we will conduct a test on combat maintenance contact teams at Aberdeen Proving Ground, MD, one on night decon operations at Fort Drum, NY, and one of mechanized smoke platoon operations at Fort McClellan, AL.

BIOGRAPHICAL SKETCH

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MEDICAL MONITORING: ASSESSMENT OF PHYSIOLOGICAL CHANGES IN MILITARY PERSONNEL DURING FIELD STUDIES.

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SUMMARY

A Biomedical Field Monitoring System (BFMS) has been developed to provide a practical means of monitoring the physiological and clinical status of soldiers during field tests with minimal disruption and discomfort. The BFMS is modular, with four major subsystems: 1) transducers for gut and skin temperatures, heart rate, and activity; 2) a body-worn multichannel system for logging, display, and/or local telemetry of data; 3) a long-range radio telemetric system; and 4) a base station for real-time data display and analysis. Deep body temperature ("core") is estimated using an ingestible "Temperature Pill." Thermistor leads provide skin temperature to three channels, although one of these may serve as a rectal probe. Heart rate is estimated using a single elastic chest strap, and activity is determined by an accelerometer mounted in the man-pack. The local telemetry range is about 150 meters, extended to about 2 kilometers using a single relay-to-base array. Existing equipment can monitor up to 40 soldiers simultaneously, and operates both in vehicles and the open field.

Recent deployments of the system are discussed, involving over 200 individual monitoring trials. The system is suitable for monitoring soldiers in protective clothing who are at risk for heat injury. The data displayed serve as an adjunct to

observations by medics and the Medical Monitor during a field study, since most players who discontinue activity do so through subjective complaints or symptoms, rather than by reaching preordained safety limits. However, the convergence of body temperatures and heart-rate toward those limits provides early warning.

INTRODUCTION

The use of human subjects or players in field studies imposes two main issues of methodology. Foremost is safety, a consideration totally independent of whether individual performance is being studied. Both regulation (e.g., AR 70-25) and common sense dictate that some means of assuring medical safety must be in place. Depending on the level of risk, the complexity of safety measures may vary, but the requirement to prevent casualties is never eliminated. Chemical protective clothing ensembles inherently add to the risk of field studies, depending on weather and workload. Other than accidents, the main risks of clinical injury are heat strain and dehydration. In our recent experience, subjective symptoms of stress often occur well before objective signs of injury. These symptoms are quite enough to limit the subject's capacity to continue and may impede his/her ability to perform tasks safely. Clinically, they are signs of impending serious injury. Therefore, medical safety monitoring includes the observation of pertinent indicators of distress, both physiological and behavioral. Finally, monitoring includes the means of communicating those observations to trained personnel who can act upon them.

The second issue of methodology involves data acquisition, since performance or response of individual players may be an explicit objective of the study. Data acquisition methods should be unobtrusive, causing no disruption of play and minimal discomfort or hindrance to performance. The system for acquiring data should permit full mobility within the field of play. Data collection rates and pathways to a base station should be sufficiently dense and redundant to reduce noise errors and signal loss. When telemetry is used, original data should be stored in digital memory; its subsequent retrieval both verifies the real-time acquisition and fills in any black-out periods. In studies involving the chemical protective ensemble, heart rate and internal body temperature should be recorded, as a minimum. These measures are basic indices of the metabolic status of the subject, for both investigational and safety purposes. Additional channels may be added to the extent that they add pertinent data, depending on the versatility of the acquisition system. Finally, field deployment of the system should pose a minimal maintenance and logistical burden.

We have developed and applied a system which attempts to address both issues of field monitoring. The Biomedical Field Monitoring System (BFMS) is used to support field tests sponsored by the P^2NBC^2 Program.[1] This program takes a comprehensive approach to both safety and data acquisition in the field. During the summer of 1991, studies involving Vehicle Decontamination Teams, Corps Hospital Patient Decontamination Teams, and Mobile Subscriber (Signal) Teams were completed, totaling about 100 man-days of monitoring in MOPP4. Preliminary results from this experience are the basis for this discussion of medical monitoring in the field.

MEDICAL SAFETY MONITORING IN P^2NBC^2 FIELD TESTS

All P^2NBC^2 studies are conducted under the provisions of AR 70-25, "Use of Volunteers as Subjects of Research." Test plans are reviewed by the Human Use Committees of the testing agencies, and subjects sign informed volunteer agreements. Medical risk and corresponding levels of coverage are assessed for each test, according to work levels, ambient climate, and extent of MOPP exposure. Medical coverage and equipment, personnel and procedural requirements are prescribed in "Medical Monitoring of P^2NBC^2 Tests."[2] Guidance for work/rest cycling is obtained from FM 21-40, and for water intake from TB MED 507. As a rule of thumb, continuous observational coverage is required by moderate to heavy work at MOPP4 in ambient temperatures greater than 75°F WGBT, the conditions of most tests conducted so far.

The first line of defense against casualty generation involves the subjects themselves. Players and their leaders are briefed and trained on the SOP of work/rest cycling and water intake. Self- and buddy-observance procedures are emphasized. At the second echelon, the numerous investigators, observers, and data takers on site are instructed to watch for and take seriously any reported or observed symptoms of distress. All personnel are encouraged to report their concerns forward to the medical coverage team. The last consists of on-site medics who are under the direction of the Medical Monitor, currently a contract physician. This physician, who has absolute go/no-go authority over the conduct of the trial, coordinates and briefs these various aspects of coverage, confirms the adequacy of equipment, and pre- establishes evacuation procedures and contacts with local medical facilities. During play, he/she and the medics have a dedicated radio network; in addition, both operational and test control nets give priority to conveyance of medical information. As reports about individual players reach the Medical Monitor, these are investigated. The Monitor may choose to extract a soldier from play, or to intensify direct observation of a particular player. Those extracted, whether by the Monitor or by voluntary withdrawal, are immediately evaluated, treated, and if necessary, evacuated. Subsequent return to play occurs only after clinical followup and determination by the Medical Monitor.

The importance, and successful application, of this scheme is indicated in Table I below, from the May 1991 study at Ft. Polk, Louisiana, of Detailed Equipment Decontamination (DED) Teams. The vast majority of "casualties" (players withdrawn) were extracted without reaching levels of significant hyperthermia or severe dehydration. Whether self-terminated or withdrawn by the Monitor, symptoms such as nausea, dizziness, headache, muscle cramps, and/or incoordination led to termination. The single player evacuated was never hyperthermic, but fainted from dehydration combined with an apparent vaso-vagal response to using an air-cooling device. (He was treated and released within a few hours).

TABLE I - Players Medically Withdrawn from DED Test Trials

Total In Play	Total Completed Mission	Withdrawn for Symptoms: Self Determined	Withdrawn for Symptoms: Medically Determined	Evacuated BFMS Determined
130	89	13	28	1

THE BIOMEDICAL FIELD MONITORING SYSTEM (BFMS)

Only after the above comprehensive scheme of medical monitoring is in place is the technology-centered BFMS brought to bear, and then as an adjunct to, not a replacement for, direct medical observation. As presently configured, Internal Temperature, Heart Rate, Activity, and up to three Skin Temperature channels are monitored. A schematic overview of this system is presented in Figure 1.

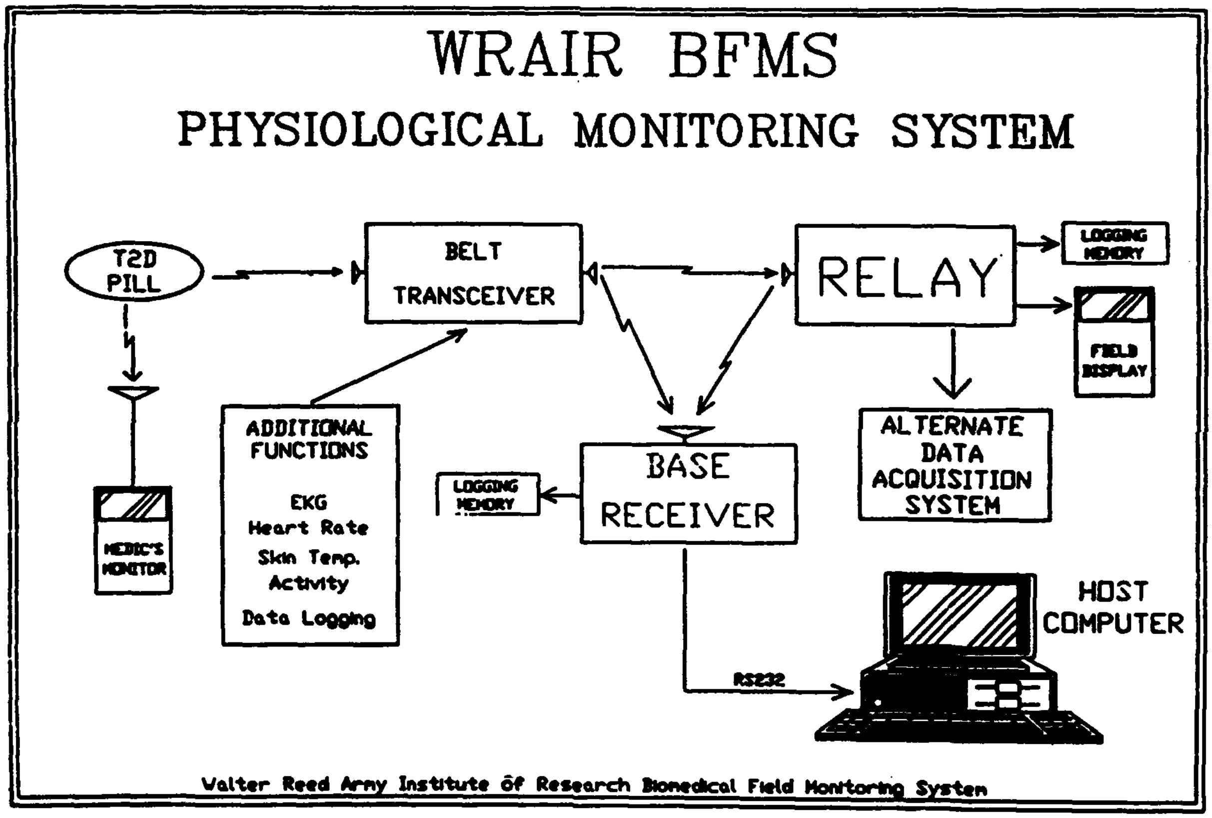

FIGURE 1. Overview of Biomedical Field Monitoring System

Under P^2NBC^2 guidelines, a "core" temperature of 39.5°C (103.1°F), or a sustained heart rate of 160 (at rest) to 180 (active) beats per minute are criteria for immediate termination of play. Skin temperature provides additional clinical information: temperature inside the clothing exceeding 37.0°C (normal body temperature) suggests that the gradient for cooling, even at rest, is reduced to the point that hyperthermia is a serious threat. This is a clinical warning, not an absolute criterion.

As indicated in Table I, no players reached these criterion levels, nor have they during studies subsequent to the DED test. In one case, a subject approached the thermal criterion at a rapid rate. Because of the strenuousness of his workload, it was elected to withdraw him. Figure 2 displays the data leading to his extraction.

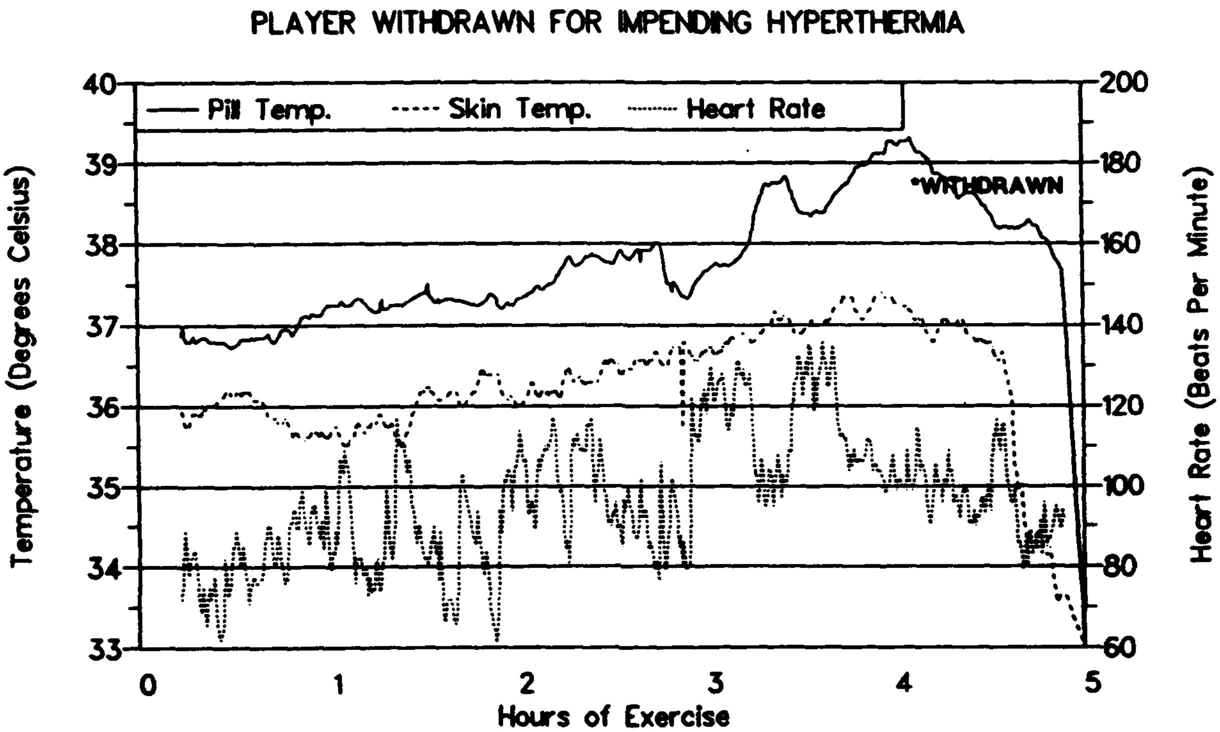

FIGURE 2. Data from Player Withdrawn for Impending Hyperthermia

In practice, the BFMS has an <u>alerting</u> function. For observers near the player, internal temperature is displayed in a window on the man-pack. This and other data are also radio- telemetered to a base station, where a visual display is updated at 30-second intervals. This observer is coupled by voice into the Medical Net. When players exceed 38.5°C, or heart rate is above 140, the Medical Monitor is notified, and those players are more closely scrutinized. During recent tests, most of such subjects leveled off below the criterion for termination, as a result of work/rest cycling. Even so, after sustained play, some players were withdrawn for cause; in virtually every case, medics had been forwarded of the potential for clinical symptomatology.

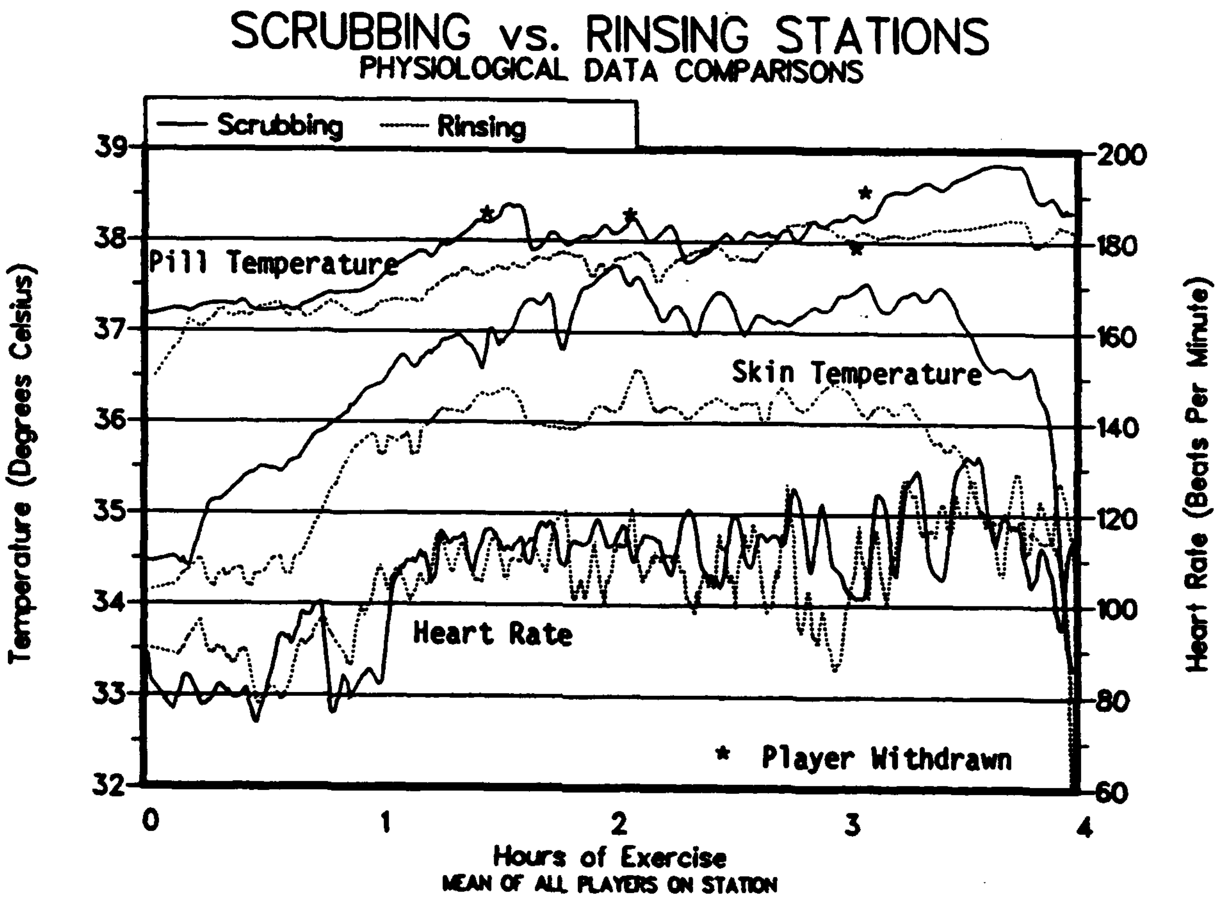

FIGURE 3. Comparison of DED Scrubbing and Rinsing Stations

Data obtained through the BFMS system may be analyzed for particular effects which are the subject of study. For instance, Figure 3 compares data between two locations, or stations, in the DED process, which differ in terms of the physical demand of the separate tasks (scrubbing vs. rinsing). Average temperatures, heart rate, and player-withdrawal rates distinguish the two stations, indicating, in physiological terms, a potential choke-point in the DED scenario. These data may be used to estimate the metabolic cost of particular DED functions, and in general may serve to augment or refine models of operational performance in this and other scenarios.

THE TEMPERATURE PILL

For the BFMS, estimation of internal or core temperature relies on an ingestible telemetry capsule. Rectal or tympanic data could be obtained on one of the other channels with little difficulty. This sensor has obvious advantages over other methods, especially the rectal probe, and as a thermometer per se it is as accurate as any used in clinical research (< ±0.05°C). A problem is that it is a moving target: one is never sure exactly where it is in the gut. Moreover, gut temperature, beyond the rectum and esophagus, is not a standard index used in heat strain models and related research. Gut temperature, mediated by blood flow phenomena quite different from those involved elsewhere in the body, is likely to have different responses to various challenges. This has not been systematically investigated. But this is primarily an issue of precision. Initial validation studies indicated excellent correspondence between rectal and pill data during graded treadmill exercise.[3] To better evaluate the range of difference, we recently collaborated with Ms. L. Levine and Dr. M. Kolka of the U.S. Army Institute of Environmental Medicine (USARIEM) in a direct comparison during and between bouts of constant exercise, in MOPP4, in the desert (Yuma P.G.). In several of the 28 trials, correspondence between the two measures appeared to be quite close. In others, however, the relationship was not as straightforward. For instance, during rest and drinking of cold fluids, the measures are differentially affected. These data are undergoing analysis at present, with the aim of defining the precision of pill temperature estimates, vis à vis the rectal standard, and limits to interpreting data obtained by the BFMS.

Temperature capsules are administered several hours before monitoring begins, and are replaced if they are voided in subsequent bowel movements. Transient drops of 1-2°C, lasting several minutes, are associated with drinking fluids, in some but not all cases. Such transients are rapid and visually noticeable during continuous monitoring; they constitute a "blind spot", which is interpreted by the Medical Monitor in the context of concurrent skin temperature, heart rate, and activity data.

OPERATIONAL STATUS OF BFMS SYSTEM

In our hands, the BFMS is fully operational for medical monitoring and data acquisition in field studies involving up to 30 subjects. System setup is performed at least one day before trials begin. Before each trial, harnessing consumes about three minutes per player, and daily maintenance takes another 5 minutes. Each test requires at least two investigator/technicians for operation and maintenance.[4]

NOTES

[1] P^2NBC^2 is a program entitled Physiological and Psychological Effects of the NBC Environment and Sustained Operations on Systems in Combat. The P^2NBC^2 program, with the U.S. Army Chemical School as executive agent, is a multi-disciplinary group of testers, researchers, and test proponents formed to investigate the impact of mission-oriented protective posture ("MOPP") on soldier performance capacity, through field tests of operational concepts, procedures and doctrine. The Biomedical Field Monitoring System (BFMS) originated in the mid-1980's as a project of the tri-service Joint Working Group for Drug-dependent Degradation of Military Performance (JWGD3MilPerf) - now evolved into the Office of Military Performance Assessment Technology (OMPAT). Design and manufacture of the BFMS was performed by Konigsberg Instruments, Inc., Pasadena, CA, under USAMRDC contract DAMD-17C-85-1852. Applications development has been an in-house effort supported by both OMPAT and P^2NBC^2.

[2] An internal P^2NBC^2 document, available from the authors.

[3] Contact authors for interim reports and detailed references.

[4] The system is undergoing a final developmental revision with size-reduction, hardening, and user software improvement, in order to reduce maintenance and logistical overhead. These changes are scheduled for completion by the warm season of 1992, and should make it easier to transfer the system to other users. At present, the completed system is not commercially available, except perhaps as an order supplemental to the current revision effort. Because of new FDA regulations, the

temperature pill subsystem continues to be an Investigational Device, which must be used under prescription by an authorized investigator, with informed consent. Critical to accuracy of temperature determination is software undergoing refinement; until this effort is completed, the system will remain investigational, limiting its availability.

BIOGRAPHICAL SKETCH

DANIEL P. REDMOND is a Colonel and Physician in the U.S. Army Medical Corps. Currently, he is Chief of the Branch for Special Studies, Department of Behavioral Biology, at the Walter Reed Army Institute of Research in Washington, DC. He graduated from Rice University with a B.A. degree in Biology and earned his M.D. from the University of Texas at Dallas in 1968. He trained in Internal Medicine and Clinical Pharmacology (68-73) and joined WRAIR in 1973. He served for two years at the University of Oklahoma Tulsa Medical College as Associate Professor in Medicine. COL Redmond exercises his interests in Biomedical Engineering, Designing, Developing and Applying Instrumentation for Laboratory and Field Studies. The widely-used wrist activity monitor (actigraph) to evaluate sleep patterns in training, deployment, operations and shift work is a product of his efforts.

EFFECTS OF NBC PROTECTIVE EQUIPMENT UPON UH-60 PILOT PERFORMANCE[1]

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INTRODUCTION

There are particular problems in measuring performance in pilots in NBC conditions. Accessibility and space often are limited, making monitoring and recording data difficult. Conditions cannot easily be controlled so that consistency of performance is hard to achieve. Most significantly, pilots cannot be subjected to conditions which might impair flight safety because of the potential consequences.

One solution is to use simulation. Modern flight simulators can accurately reproduce the demands required to fly the real aircraft. The aircraft controls are duplicated and computer generated imagery produces realistic views of the outside world. The flight scenario and external factors such as weather can be consistently repeated to ensure controlled exposure to a variety of conditions, and above all, pilots can be stretched to their performance limits in complete safety.

METHOD

The USAARL UH-60 helicopter simulator is an aeromedical version of the standard UH-60 training simulator. In addition, it has an environmental control system (ECS) to regulate the cockpit thermal environment, by specifying dry bulb temperature (T_{db}) (68-105°F) and relative humidity (RH) (50-90%). Also, it is linked to a real time data acquisition system on a VAX computer which can record and analyze aircraft flight parameters and pilot inputs.

Subjects for the study were 16 volunteer UH-60 helicopter qualified male Army aviators. All were between the ages of 21 and 39 years and in good health, as determined by a flight surgeon using a medical history questionnaire, and their medical records. They were asked to refrain from alcohol and caffeine-containing beverages for the duration of the study.

Two separate clothing assemblies were worn, non-NBC, consisting of the normal issue flight suit and associated equipment, and aviator NBC, consisting of the Aircrew Uniform Integrated Battlefield (AUIB) and M43 mask. An aircrew survival vest and body armor were worn in both conditions.

Rectal temperature, mean skin temperature, and heart rate were constantly monitored and recorded for safety reasons. A rectal temperature of 39.5°C or heart rate of 150 beats per minute for 15 minutes were used as the limits at which subjects would be withdrawn from that day of the study.

The simulator flight profile was designed to, as far as possible, represent a realistic tactical scenario. The first hour consisted of a tactical low level navigation exercise, followed by an hour of upper air maneuvers. Half way through the upper air phase the Automatic Flight Control System (AFCS) was disabled to increase the workload.

Control of the aircraft alternated between both pilots at specified intervals during flights, to allow assessment of two subjects in each flight. When it was necessary to withdraw one pilot for any reason, it was possible to continue assessing the other using the simulator operator as his copilot.

The test schedule consisted of a week of training on the experimental flight profile, followed by a test week. Training took place initially in the standard flight suit, and then in the NBC Individual Protective Equipment (IPE) for the second half of the training week. The ECS was not used. The experimental design for the second week is shown in Table I. Flight conditions were counter-balanced among subjects. The temperature conditions used were dry bulb temperature (T_{db}) 21.6°C, relative humidity (RH) 50% (T1), and T_{db} 35.9°C RH 50% (T2). The hot conditions were selected to produce a moderate degree of heat stress, while allowing the subject to remain in the cockpit for at least 4 hours to ensure an adequate volume of data. There were 2 days in the standard flight suit, one, the baseline day, flown at T1 and one at T2. There were 2 days of flying in the AUIB at both temperatures, and the final day was again in baseline conditions at T1, in order to remove any end spurt effect.

Table I

Experimental design

Mon	baseline, flight suit, T1
Tue	flight suit, T2
Wed	AUIB, T1
Thur	AUIB, T2
Fri	flight suit, T1

Each day consisted of an initial 20 minute period of treadmill exercise to reproduce the physiological workload of preflighting an aircraft (Thornton and Brown, 1982). The subjects then walked immediately to the UH-60 simulator to begin the first flight of the day. Each flight was of 2 hours duration, and the subjects flew the same sortie three times a day, contingent upon remaining within the withdrawal criteria. Individual flights were separated by a 10 minute 'refuelling' period, during which the pilots remained in the cockpit and in full AUIB, if applicable. If they needed to urinate, that was done in the cockpit. The flight profile was identical in all sorties and on all days. To allow assessment of flying performance by both pilots, control of the aircraft alternated between them at 30-minute intervals.

The flight profile is divided into nine separate maneuver types. Each maneuver is scored for several different parameters which varied with the maneuver type. For example, navigation is scored for heading, altitude, slip and roll, hover turn for altitude only. Some of the maneuvers are further subdivided, depending on whether the AFCS was used, and height of hover. Some maneuvers are repeated more than once in each flight, and the flight is repeated three times per test day. In all, there are 69 separate flight maneuvers per test day, with up to 5 parameters each. Flight performance data were recorded twice a second for 16 parameter channels, and the data were processed to produce a single root mean square (RMS) error value for each channel appropriate to that maneuver. Plotting the RMS error for maneuver parameters of one type sequentially throughout a test day showed no appreciable increase in error rate with time (Fig. 1). Therefore, the mean error rate for each of the 55 maneuver parameters was used in the final data analysis.

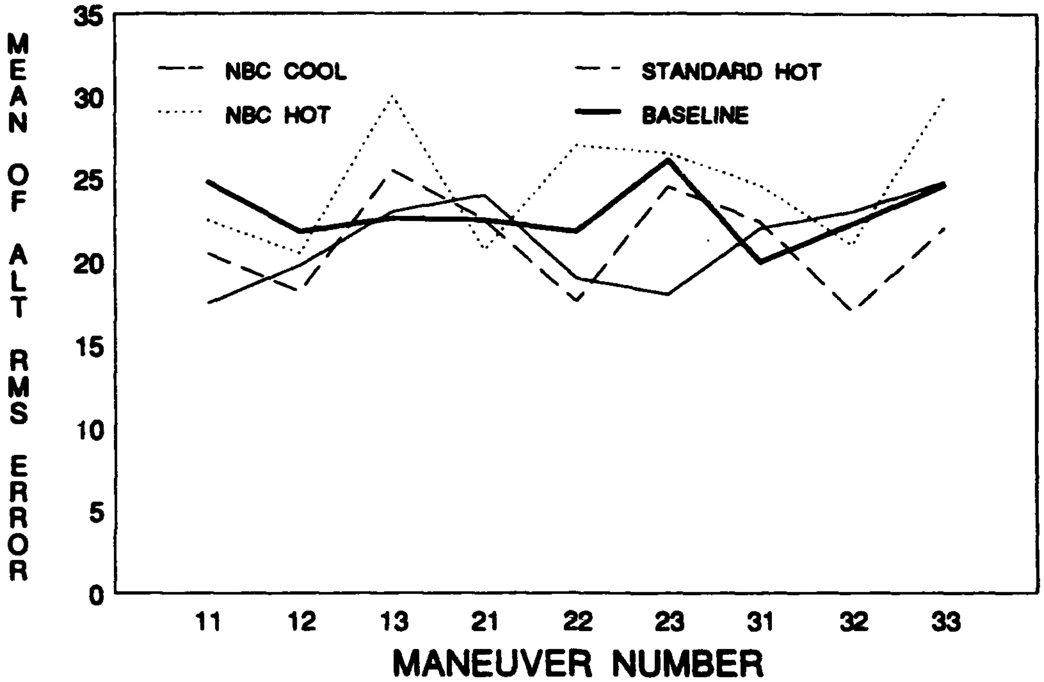

FIG. 1. Mean altitude RMS error for right standard rate turn plotted against maneuver number - test days

Analysis of variance was undertaken on the RMS error values meaned for all 16 subjects, using the SAS/STAT[2] General Linear Models (GLM) procedure and Duncan's Multiple Range Test for evaluating posteriori comparisons (Duncan, 1955).

RESULTS

The error rate during the training week showed a marked improvement between the first and second training sessions, but no consistent reduction thereafter (Fig. 2). There was no apparent decrement in performance in the second half of the week (maneuver 32 onward), when the NBC IPE replaced the standard flight suit.

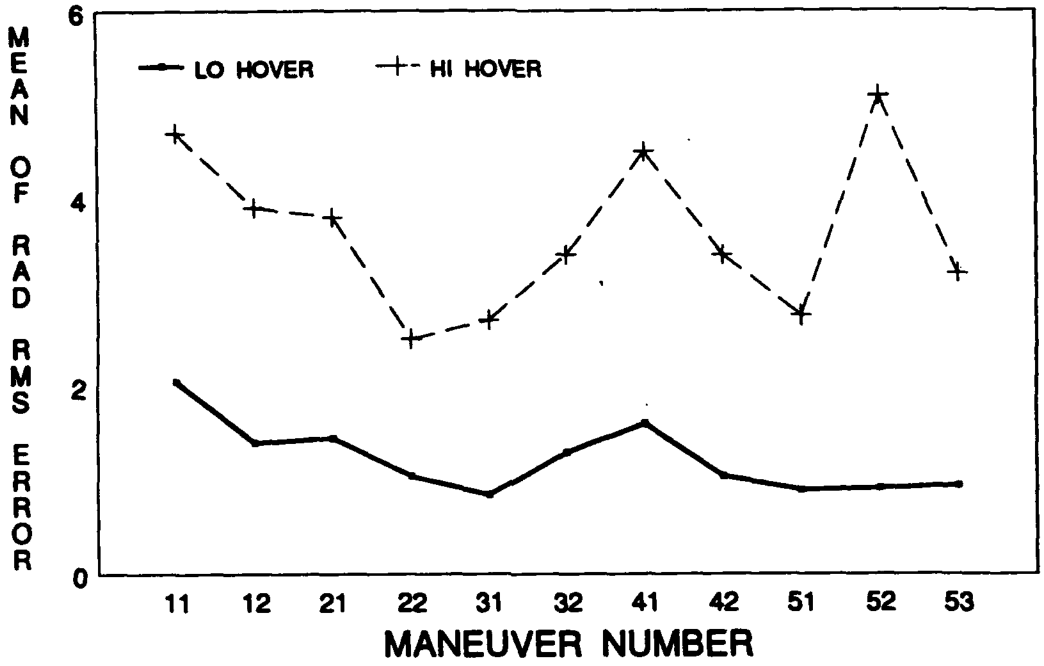

FIG. 2. Mean altitude RMS error for hover turn plotted against maneuver number - training days.

The results of the Duncan's Multiple Range Test for the four test conditions are summarized in Table II. There are 55 combinations of maneuver and parameter, each of which has a mean RMS error score for each of the four conditions. The convention used for indicating significant differences between groups is that used by the SAS/STAT Duncan's test in which means with the same letter are not significantly different. In those lines which contain both A and B, the means grouped as A are always higher than those grouped as B. The alpha value was set at 0.05. There are 21 cases in which the NBC hot error value is significantly greater than for at least one of the other groups. There were 4 cases when the error in the NBC cool condition was greater, and 2 occurrences of a baseline error value significantly greater than that for at least 1 of the other conditions. Therefore, it seems reasonably safe to say that flight performance is worse in the hot NBC condition than in the other three. The lack of consistency across the data indicates that the degree of performance impairment is minor.

Table II
Statistical Summary[3]

Maneuver	Parameter	Condition			
		Baseline	Std Hot	NBC Cool	NBC Hot
1 Navigation	Heading	B	B	A	AB
	Altitude	B	AB	AB	A
	Slip	A	A	A	A
	Roll	A	A	A	A
2a Hover (10 ft)	Altitude	A	A	A	A
	Heading	B	AB	A	AB
2b Hover (40 ft)	Altitude	A	A	A	A
	Heading	A	A	A	A
3a Hover turn (10 ft)	Altitude	A	A	A	A
3b Hover turn (40 ft)	Altitude	B	B	AB	A
4a Right std rate turn (AFCS in)	Rate of turn	B	B	AB	A
	Altitude	A	A	A	A
	Airspeed	A	AB	B	A
	Roll	B	B	AB	A
	Slip	A	A	A	A
4b Right std rate turn (AFCS out)	Rate of turn	A	A	A	A
	Altitude	B	B	B	A
	Airspeed	B	B	B	A
	Roll	A	A	A	A
	Slip	A	A	A	A
5 Left descending turn (AFCS out)	Rate of turn	AB	B	AB	A
	Airspeed	A	A	A	A
	Roll	AB	B	AB	A
	Descent Rate	B	B	B	A
	Slip	A	A	A	A
6 Descent (AFCS out)	Heading	A	AB	B	B
	Airspeed	B	A	B	B
	Roll	B	A	B	B
	Descent Rate	B	A	B	B
	Slip	AB	A	B	AB

Table II
Statistical Summary
(continued)

Maneuver	Parameter	Condition: Baseline	Std Hot	NBC Cool	NBC Hot
7a Left std rate turn (AFCS in)	Rate of turn	A	A	A	A
	Altitude	A	A	A	A
	Airspeed	A	A	A	A
	Roll	A	A	A	A
	Slip	A	A	A	A
7b Left std rate turn (AFCS out)	Rate of turn	B	AB	AB	A
	Altitude	AB	B	AB	A
	Airspeed	B	B	B	A
	Roll	B	B	AB	A
	Slip	A	A	A	A
8 Climb (AFCS in)	Heading	B	B	A	AB
	Airspeed	A	A	A	A
	Roll	A	A	A	A
	Climb rate	A	A	A	A
	Slip	A	A	A	A
9a Straight and level (AFCS in)	Heading	B	B	A	B
	Altitude	A	A	A	A
	Airspeed	A	A	A	A
	Roll	A	A	A	A
	Slip	A	A	A	A
9b Straight and level (AFCS in)	Heading	A	A	A	A
	Altitude	B	B	B	A
	Airspeed	B	B	B	A
	Roll	AB	AB	B	A
	Slip	A	A	A	A

With increasing task loading, which would occur in practice with problems such as poor weather, hostile activity directed against the aircraft, or an aircraft malfunction, or higher cockpit temperature, then the potential for making more catastrophic error can be anticipated. This is supported by the increase in the number of statistically significant errors in maneuvers 7b and 9b (automatic flight control system (AFCS) switched off) compared with 7a and 9a, the same maneuvers with the AFCS on. In most cases, the RMS error also is significantly greater with the AFCS out than with it in. One of the inconsistencies in the data is that for some maneuver parameter combinations, performance is actually better with the AFCS out than with it in.

CONCLUSIONS

Flight performance in NBC IPE in moderately hot conditions is significantly impaired, even in a relatively undemanding flight scenario.

NOTES

[1] This study was conducted under the auspices of, and partly funded by, the Department of the Army program entitled the Physiological and Psychological Effects of the NBC Environment and Sustained Operations on Systems in Combat (P^2NBC^2).

[2] SAS Institute Inc., Box 8000, Cary, NC 27512-8000

[3] Results from the Duncan's Multiple Range Test. Means with the same letter are not significantly different. In lines which contain both A and B, the means grouped as A are always higher than those grouped as B. The alpha value was set at 0.05.

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BIOGRAPHICAL SKETCH

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COMPUTER MODELING: PREDICTING THE SOLDIER'S HEAT TRANSFER AND WORK CAPABILITIES IN MOPP

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SUMMARY

This report discusses the development, thermal attributes, and use of different heat strain models that describe soldier effectiveness while wearing chemical protective clothing. Because experimental settings with human subjects are restricted to finite limits to protect the individual, modeling often fulfills the requirements to test performance at environmental extremes. In general, mathematical models of heat strain incorporate essential variables active in thermoregulation. These often describe proportionality coefficients active in the heat balance equation. Models describing steady-state responses apply appropriately when quasi-heat balance exists and are useful in the prediction of a wide assortment of physiological effector responses particularly when a given metabolic activity stays constant over time.

DEVELOPMENT OF RATIONAL AND OPERATIONAL MODELS FOR PREDICTION OF THERMAL STRAIN

In systems engineering terms a regulating system is regarded in two distinct ways: that of a passive or controlled system and an informational or controlling system. In physiological terms, the controlled system is considered as the body with its inclusive anatomical features, heat capacities, energy fluxes from various tissues: core, muscle, adipose, and skin sites, whereas the controlling system encompasses the complete central nervous system transmitting information in a network manner (Gagge, Stolwijk, & Nishi, 1971; Stolwijk & Hardy, 1966, 1977; Wissler, 1985). Early forerunners of rational models incorporated extensive descriptions of the passive system in terms of a bio-heat equation or open-loop systems without a description of control or regulatory action (Stolwijk & Hardy, 1977; Wissler, 1985). Later, closed-loop characterizations of the themoregulatory system appeared which included a rudimentary feedback control formulation of internal body temperature (Stolwijk & Hardy, 1977). The classical approach to generate a thermal model is to describe the passive state and build algorithms to validate, as closely as possible, information integrating physiological controls of the controlling system. The most complete description of the passive system to date is from the work of Stolwijk and Hardy (1977) which described the body heat exchange from six segments, further subdivided into 25 compartments or nodes. During the last 25 years, research attention to the mode of operation of the controlling system has taken precedence over description of the passive heat flux between various segments of the body (Kraning, 1991). As a result significant progress in the modeling of controller activity exists. In general, the controlling system active in body temperature regulation is divided into three components. The sensing elements consist of thermoreceptors, active in recognizing deviation in the thermal state of the controlled system. The integrating component receives thermal signals, integrates them and relays appropriate effector commands. The final component receives the effector commands, modulates a command depending on circumstances existing at the particular loci, and elicits appropriate coding to cause effector action. The thermoregulatory controlling system has been considered as existing with linear and nonlinear control operations with and without a discrete reference (set) point (Stolwijk & Hardy, 1977; Wissler, 1985). Recently, a computerized simulation has been developed (Kraning, 1991) that reliably incorporates new schemes for calculating changes in blood flow to muscle, visceral areas and skin, and changes in stroke volume, heart rate and cardiac output along with previous depictions for control of core temperature and sweating rate.

Early operational models of human performance include the formulation of a Heat Stress Index (HSI) initiated by Belding and Hatch (1955) used with some reliability by the National Institute of Occupational and Safety & Health (NIOSH). The ability to incorporate appropriate coefficients acquired from studies involving with human research, thermal manikins, and biophysical devices that measure clothing properties into some form of empirical equation used in the heat balance equation has led to the implementation of paradigms that forecast tolerance limitations to heat stress (Pandolf, Stroschein, Drolet, Gonzalez, & Sawka, 1986). In 1972, Givoni and

Goldman generated a series of predictive equations (Givoni & Goldman, l972; Goldman, l963; Gonzalez, 1988). The latter equations were modelled to estimate best case deep body temperatures and heart rate responses of individuals exposed to a wide environmental range. The empirical model assessed thermal equilibrium levels or when a person might become a heat casualty depending on clothing, work level and various other factors such as load carriage, terrain coefficients, solar coefficients, etc. (Givoni & Goldman, 1972).

HEAT TRANSFER AND WORK CAPABILITIES

In general, the net heat flux to the skin per unit time is affected by the cardiac output and by the efficacy of heat transfer as long as skin temperature is maintained below core temperture. Core temperature level during steady- state can be predicted from metabolic heat production (**M** , in watts) and more exactly by percentage of maximum aerobic power ($\dot{V}O_2max$) provided that limitations such as high ambient water vapor pressure, Ta, or restrictions due to impermeable clothing do not overwhelm the ability to reach steady-state. Givoni and Goldman (1972) obtained a relationship in which Tre= 36.7 + 0.004•**M**. Mean weighted skin temperature ($\bar{T}_{sk}$), unimpeded by clothing, can be predicted as 3.3 °C + (0.006•**M**) below Tre. This would predict a $\bar{T}_{sk}$ of about 33°C when core temperature is 37 °C and **M** is at resting level (105 watts). Roughly, for every liter of blood transferred from the deep core to the skin surface, skin heat flux to the ambient is about 1.163 watts, so at rest a Δ1 °C between core and skin heat flux would transfer 4.7 watts. During exercise with scant clothing, as long as Ta < 35 °C and dew point temperature is less than skin temperature, core temperature increases to a steady-state level depending on % $\dot{V}O_2max$ and skin temperature decreases as sweat is evaporated. Therefore, it is more productive for the body to eliminate heat by increasing work since the differential between core and skin is widened (≈ 1 °C for each 100 watts of Δ**M**). For example, with ample evaporation during a exercise bout of **M**= 600 watt, core temperature may rise to a steady-state value of 38.5 °C and skin may level off to about 29 °C. This temperature gradient facilitates the heat transfer by blood of about 11 watts, which is almost 2.5 times the rate at rest. The problem occurring during the wearing of non-porous chemical protective clothing is that the skin heat flux is impeded considerably with each layer of clothing. Skin temperature and core temperature rise more steeply and reach a higher final level since heat transfer is not wholly facilitated and evaporation is diminished. The rate of evaporative heat loss required (E_{req}, in $W \cdot m^{-2}$) to fulfill the body's heat balance must be less than the maximum evaporative power of the environment (E_{max}, in $W \cdot m^{-2}$) at any given metabolic heat production. The E_{max} is determined by several environmental factors (absolute humidity, wind speed, temperature), heat transfer and clothing coefficients. For complete heat balance, E_{req} must = **M** -(± W)- DRY - S, where W is the mechanical work done on the environment (+ in positive work,- in eccentric work), DRY includes sensible heat loss by radiation and convection, and S is the rate of heat storage due to rising core and skin temperatures. Typically, for a 75 kg person a heat storage rate of 100 watts for one hour will result in a rise in mean body temperature of 1.3 °C. Highly trained, sparsely clothed, heat acclimated individuals often tolerate **M** as high a 1000 watts for about 0.5 h entailing considerable heat dissipating mechanisms to prevent intolerable hyperthermia (Gagge, Stolwijk, & Nishi, 1971; Goldman, l963; Gonzalez, 1988; Stolwijk & Hardy, 1977).

MISSION-ORIENTED PROTECTIVE POSTURE (MOPP)

With heavy protective clothing, exensive work intensity is not as effectively tolerated. The intended use of a MOPP configuration is that a changeable clothing system of protection against threat of chemical agents is obtained. The particular level of MOPP (1 through 4) requires the soldier to don individual protective equipment that coincides with chemical threat, work intensity, and environmental stress. As such, it offers some choice by the theatre commander to impose on the unit in order to lessen both chemical and heat casualties. Often, the choice is not always optimum. For example, during a mission involving a combat assault under a chemical attack full protective gear (MOPP4) must be worn. The operational decision then becomes whether to accept more heat casualties than chemical agent casualties. Because more of the heat casualties are likely to recover from the hyperthermia, this decision often dominates provided that the troops are heat acclimated, well-trained, and fully hydrated. In such cases, application of operational models that predict limits to work and water requirements is especially crucial at the field site.

Evaluations of heat stress and strain risk analysis of a soldier completely encapsulated in chemical protective clothing often necessarily become more empirical by the nature of the fact that definitions to operational activities (such as prediction of heat casualties, status of water requirements, work:rest cycles, and tolerance times) are statistical events. Schemes addressing this problem have been accomplished by the formulation of a predictive, operationally-derived model. This prediction model developed at USARIEM, originally encoded on ROM chips for a programmable calculator (Pandolf, Stroschein, Drolet, Gonzalez, & Sawka, 1986), has been recently converted to ADA language (R.McNally, personal communication). The model utilizes and extends many of the approaches formulated in the original Givoni-Goldman equations and current experimental databases. There are three major components to the fitted equations involving : thermal, sweating, and heart rate responses reviewly briefly here; a more extensive documentation is found in other references (Gagge, Stolwijk, & Nishi, 1971; Goldman, 1963; Gonzalez, 1988; Stolwijk & Hardy, 1977).

Thermal Component:

Tref = 36.75 + 0.004•Hsk + 0.001•DRY + EVAP,

where, **Hsk** (in watts) is composed of **(M-Wex)**, **M** being a function of weight, walking velocity, grade and terrain factors; and **Wex** is a function of grade, body weight, clothing plus equipment weight.

DRY (in watts) is the sensible environmental heat load, $DRY = 6.45/I_t \cdot A_D(\bar{T}_{sk}\text{-}Ta)$, in which total clothing thermal insulation (I_t), body surface (A_D), and skin to ambient temperature ($\bar{T}_{sk}$-Ta) are evaluated for a specific garment.

EVAP is accounted for in an exponential function {i.e. 0.8 *exp* [0.0047•(Ereq-Emax)]} of the difference in required evaporative cooling (E_{req}) and E_{max} discussed previously. $E_{max} = 6.46 \cdot LR \cdot i_m/I_t \cdot Aeff(Ps,sk - Pa)$ in which LR is the Lewis Relation (Gagge, A.P., Stolwijk, J.A.J., & Nishi, Y., 1971; Gonzalez, R.R., 1988), i_m is the Woodcock water permeation factor (Gonzalez, 1988), and (Ps,sk - Pa) is skin saturation vapor pressure to ambient water vapor pressure gradient depending on an effective body surface area (Aeff) (Gagge, Stolwijk, & Nishi, 1971; Gonzalez, 1988). The change in Tre from rest to a point depending on metabolic activity can also be determined by $\Delta Tre = \Delta t \cdot S \cdot A_D)/(\lambda \cdot m_b)$, where S is evaluated from the heat balance equation, λ is the latent heat constant and m_b is the nude body weight loss (Gagge, Stolwijk, & Nishi, 1971).

Sweating rate and net water requirments:

The necessary water to supplement that lost during work and environmental heat is generally found by (Pandolf, Stroschein, Drolet, Gonzalez, & Sawka, 1986)

$$\Delta \dot{m}_{sw} \text{ (in } g \cdot m^{-2} \cdot h^{-1}) = 28 \cdot \{Ereq \cdot Emax^{-0.5}\}$$

Cardiovascular Component:

The prediction model includes options for determining final equilibrium heart rate (HR,f, beats•min^{-1}) in terms of an initial heart rate (HR,i) that is determined as a function of Tre and W,ex [HR,f= 100•(Tre,f - 36.75) + 0.4•**W,ex**] observed for well-trained, heat acclimated persons (Pandolf, Stroschein, Drolet, Gonzalez, & Sawka, 1986) in which:

$$HR,f = 65 + 0.35 \cdot (HR,i - 25), \text{ for heart rate limits of } 25 \leq Hr,f \leq 225$$

$$\text{or } = 135 + 45 \cdot \{1 - \exp^{[0.01(HR,i - 225)]}\}, \text{ for heart rate limits of } HR,f \geq 225.$$

The coefficient (0.35) above can be also shown to correspond to the ratio of $(\mathbf{M}-\mathbf{M}_r)/(\mathbf{M}_{max}-\mathbf{M}_r)$, in which **M** is the metabolic heat production, $\mathbf{M}_r$ is the resting heat production, and $\mathbf{M}_{max}$ is the maximal heat production found at $\dot{V}O_2max$.

Since 1983, specific attention has been directed to the modeling requirements of individuals working in temperate and hot environments with chemical protective overgarments having diverse clothing thermal resistances and water vapor permeation properties. This database has been garnered from evaluations in the US and NATO countries. A capability to predict (and thereby avoid) unnecessary heat stress casualities connected with certain operations in MOPP, estimate work:rest cycles, maximum work times, and estimate water requirements is available for incorporation into other Tactical Decision Aid plans. An example of the utility of the USARIEM operational model features is shown in Table I (Pandolf, Stroschein, Drolet, Gonzalez, & Sawka, 1986).

TABLE I. PREDICTED RESPONSES TO ENVIRONMENTAL HEAT STRESS. ASSUMED CONDITIONS ARE MOPP4, LIGHT HEAT CASUALTIES (< 5%), AND CALM WIND (0.5 M/S).

Ta	RH %	SKY	Lt. Work 250 watts	Mod. Work 450 watts	Hvy Work 600 watts
			W:R:M H_2O		
30 °C	20	Clear	NFW 189 1.4:0.9:NA	NFW 58 1.9:0.9:NA	NFW 40 2.1:0.9:NA
		Indoors	NL/NL 0.9:0.4:NA	24:36:82 1.5:0.4:0.8	14:46:47 2.1:0.4:0.8
30 °C	50	Clear	NFW 102 1.5:1.1:NA	NFW 50 2.1:1.1:NA	NFW 35 2.1:1.1:NA
		Indoors	NL/NL 1.1:0.4:NA	17:43:65 1.7:0.4:0.8	10:50:41 2.1:0.4:0.7
40 °C	20	Clear	NFW 78 1.8:1.3:NA	NFW 45 2.1:1.3:NA	NFW 32 2.1:1.3:NA
		Indoors	NL/NL 1.3:0.7:NA	6:54:56 2.0:0.7:0.9	NFW 38 2.1:0.7:NA
40 °C	50	Clear	NFW 58 2.1:1.8:NA	NFW 36 2.1:1.8:NA	NFW 24 2.1:1.8:NA
		Indoors	NFW 87 1.8:1.0:NA	NFW 43 2.1:1.0:NA	NFW 29 2.1:1.0:NA
49 C	20	Clear	NFW 56 2.1:1.8:NA	NFW 36 2.1:1.8:NA	NFW 24 2.1:1.8:NA
		Indoors	NFW 81 1.8:1.1:NA	NFW 43 2.1:1.1:NA	NFW 29 2.1:1.1:NA
49 C	50	Clear	NFW 41 2.1:2.1:NA	NFW 24 2.1:2.1:NA	NFW 13 2.1:2.1:NA
		Indoors	NFW 51 2.1:2.1:NA	NFW 30 2.1:2.1:NA	NFW 16 2.1:2.1:NA

NOTE: CODES FOR TABLE I ARE:

W:R:M= Work:Rest Cycle:Maximum One Time Work Period (min)
H_2O->W:R:C= Water Requirements for Work:Rest:Combined in Canteens/hr.
NL= No Limit to Work Period NFW= No Further Work
NA= Not Applicable Since No Work-Rest Cycle Possible
NFW= No Further Work; Work Rates= Light(Lt) 250, Moderate(Mod) 450, Heavy(Hvy) 600 watts
MOPP4 is closed configuration with protective butyl hood, mask, and gloves.

A recent field study was conducted that compared the responses of subjects in various stages of MOPP as the environmental stress varied from little stress early in the morning to moderate stress (from 20 ° to 30 °C WBGT). Subjects attempted a 12-mile walk (25 min of marching: 5 min of rest) on a asphalt paved training course at a pace of 2 mph (Metabolic activity of 300-400 W) with appropriate rest cycles while carrying a 22 kg pack. Figure 1 shows the data from a representative experiment in one individual dressed in MOPP4. Also shown in the figure are simulations obtained from two different models: the current USARIEM (Pandolf, Stroschein, Drolet, Gonzalez, & Sawka, 1986) and a recently developed thermoregulatory model (Kraning, 1991). The latter simulation is especially interesting because it has been validated for intermittent work and clothing experiments. In this model, convection coefficients are adjusted according to work mode; environmental heat transfer is modulated by clothing insulative and vapor permeability properties. The influence of thermal and non-thermal events also are coupled adequately and the model addresses: (a) the combined effects of posture, metabolic activity level and skin temperature on stroke volume, (b) the effect of "cardiovascular overload" during work in the heat routines on increasing muscle oxygen extraction thereby alleviating the overload, (c) incorporation of skin temperature as a modulator of the central temperature "set-point" for controlling skin blood flow and (d) effects of age as a factor in decreasing maximal heart rate on thermoregulatory responses. It is clear from this Figure that the simulations from both models predicted core temperature rise adequately (within ± 1SD) and heart rate responses imposed by the transient rise in heat stress as determined by a continuous measurement of the wet bulb, globe, temperature (WBGT).

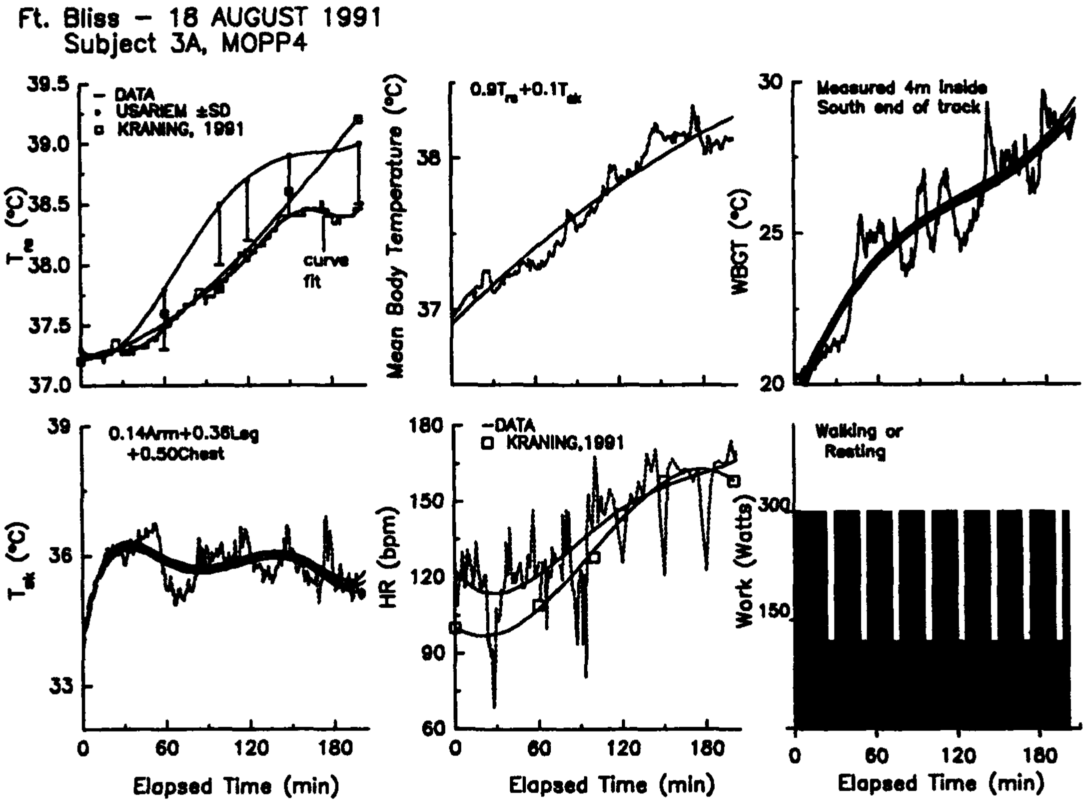

Figure 1. Responses and model simulations of a typical experiment in which a subject walked for 12 miles with appropriate work:rest cycles in MOPP4.

CONCLUSIONS

The utility of either operational or servo-control simulation approaches depends on the validity and application of a particular model to ample laboratory or field data. We have seen that the use of a prediction model has its best effectiveness in forecasting work/rest cycles, water requirements, and tolerance times in the the heat with chemical protective clothing because the database and regression analysis is concentrated in this area. At the other extreme, models developed to characterize thermal characteristics of the human body (mass and specific heat and energy flux) as well as describing the thermoregulatory controller provide better understanding of physiological mechanisms (and fidelity) to guard against hyperthermia in the unclothed state. Either approach is less well developed in forecasting mechanistic responses to cold, hypohydration, integration of environmental indices (Gagge, Stolwijk, & Nishi, 1971) to the thermoregulatory controller, and characterization of intolerance to thermal stress particularly in the dynamic state and during sustained maneuvers. To date, probability schemes of epidemiological estimates of heat exhaustion and heat stroke risks and dynamic thermal responses are poorly forecasted using steady-state simple node models. The research focus continues in all these areas.

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BIOBRAPHICAL SKETCH

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DISCUSSION: APPROACHES WHICH ASSESS THE CONSEQUENCES OF WEARING THE CHEMICAL PROTECTIVE ENSEMBLE

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SUMMARY

This paper discusses the six papers presented in the symposium entitled "Consequences of Wearing the Chemical Protective Ensemble: Illustrative Assessment Approaches." Measurement of performance decrements in laboratory and field studies presented in the symposium have been compared with studies reviewed by Taylor and Orlansky (1992). Indices for comparing performance decrements across studies are needed and two, Percent Time Decrement and Percent Accuracy Decrement, are reviewed here. Since time and accuracy data are collected for most human performance studies, these indices can permit useful comparisons. The Biomedical Field Monitoring System was discussed as a system which addresses the two main methodological issues of medical monitoring, ie., safety and data accuracy. Finally, the usefulness of computer modeling to predict work/rest cycles and water requirements for testing and combat operations which require wearing CW-protective combat clothing was described.

INTRODUCTION

The purpose of the symposium was to present selected approaches to assess the effects of wearing Chemical Warfare (CW) protective combat clothing on human performance. Six papers were presented to illustrate a broad range of assessment approaches.

REVIEW OF PAPERS PRESENTED

Banderet introduced the symposium by summarizing approaches which have been used to assess the effects of CW-protective combat clothing on performance. He also provided an overview of the approaches to measurement presented in the symposium. He described in some detail eight approaches which have been used to measure the effects of CW-protective combat clothing; biophysical, computer modeling, human factors, medical, operational, performance, physiological, and psychophysiological. He also related these selected methods of assessment to the papers presented in the symposium. Data from two laboratory studies were presented by two of the participants. Johnson's study was concerned with the effects of chemical warfare protective combat clothing on marksmanship using a rifle-firing simulation. He reported that the mean accuracy of 30 soldiers firing at 32 randomly presented pop-up targets at simulated distances of 100 and 250 meters was significantly degraded by wearing CW-protective combat clothing (MOPP4) when compared to the battle dress uniform (BDU). He attributed the degradation to the difficulty in obtaining a rapid and precise sight alignment due to the CW-protective mask. Thornton reported a study which was concerned with the effects of the chemical protective ensemble on pilot performance in a UH-60 Blackhawk simulator. His group used 16 subjects to measure the effects on performance of nine separate flight maneuvers when wearing the aviator CW-protective ensemble compared to the standard flight suit. Two temperature conditions, dry bulb temperatures of 21.6 and 35.9°C, were used for each clothing condition. They reported that there were 19 out of 55 cases (maneuvers and parameters) measured for which performance under the CW-protective combat clothing condition and the 35.9°C temperature was significantly degraded when compared to the other three conditions.

Two participants summarized field studies conducted under the P^2NBC^2 program which were concerned with vehicle decontamination, rearm operations by tank crewmen and processing contaminated patients into a medical facility. Redmond described a system, the Biomedical Field Monitoring System, which was used to support these field tests. They indicated that two requirements of a medical monitoring system were to provide for the safety of the subjects and to provide for unintrusive data acquisition. At a minimum, for studies involving test of the effects of wearing CW-protective combat clothing, the system should have the capability of measuring heart rate and internal body temperature. Blewett discussed the field test results and the impact of the findings to doctrine, training, leadership, organization and materiel. He discussed the following three tests recently conducted under the P^2NBC^2 program: (1) Detailed Decontamination of Vehicles; (2) Rearm Operations by Tank Crewmen; and (3) Processing Contaminated Patients into a Medical Facility. In the first test, the rain suit worn over MOPP4 resulted in much greater heat retention when compared to MOPP4. He also found that decontamination teams were not very effective in decontamination. Several improvements were identified, some of which have been incorporated into the decontamination procedures. For the rearm test (test two) heat retention was a problem. For test three, patient processing efficiency was found to be low. As a result of the test, changes to team organization were made and tested in a follow-on test. The latter test found improved efficiency.

The final participant, Gonzalez, discussed the use of computer modeling to predict heat transfer and work capacity while wearing CW-protective combat clothing. He described an operationally derived computer model which accurately predicts heat casualties, water requirements, work/rest cycles and physiological tolerance times. This model was developed at the U.S. Army Research Institute for Environmental Medicine in 1972, and was originally encoded on Random Access Memory chips for use in a programmable calculator. According to Gonzalez, the model was recently converted to ADA language. The three major components of the model, i.e., thermal, sweating, and heart rate were also reviewed by Gonzalez.

Taylor and Orlansky (1992) critically reviewed studies completed since 1979 that examined the effects of wearing CW-protective combat clothing on individual and unit performance. They found that heat stress seriously degraded human performance and that even when heat stress was not a significant factor, performance of many combat, combat support and combat services support tasks were seriously degraded. Their review of combined arms exercises, field studies and laboratory studies indicated that wearing CW-protective combat clothing seriously degraded performance for (1) the detection of targets, engagement time, accuracy of fire, (2) manual dexterity tasks; and (3) that a variety of psychological effects are created. They also found that the degree of performance degradation varied with the tasks performed. The data presented in the present symposium further confirms the findings of Taylor and Orlansky (1992).

PROPOSAL OF COMMON METRICS

The papers of this symposium provide a clear picture that attempts to assess the complex and interacting subsystems described by Banderet are difficult. The subsystems of interest include the soldier, the CW-protective combat clothing, the micro-environment, the mission, and the weather. The papers do not describe how the findings from the various assessment approaches can be integrated. Common metrics of performance degradation are needed to integrate performance degradation across similar studies and to be able to compare and contrast findings of performance degradation across different assessment procedures. Taylor and Orlansky (1992) developed two indices to provide common metrics to quantify the performance degradation due to wearing CW-protective combat clothing: Percent Time Degradation (D_T) and Percent Accuracy Degradation (D_A). These are defined as follows:

(1) Percent Time Degradation =

$$D_T = \frac{Yct - Yxt}{Yct} X100$$

where:

Yct = the time required by a control group wearing combat clothing (but not CW-protective combat clothing) to complete a task

Yxt = the time required by an experimental group wearing CW-protective combat clothing to complete a task.

(2) Percent Accuracy Degradation =

$$D_A = \frac{Yca - Yxa}{Yca} x100$$

where:

Yca = the number of hits (normalized per x rounds), errors, etc., by a control group wearing combat clothing (but no CW-protective combat clothing)

Yxa = the number of hits (normalized per x rounds), errors, etc., by an experimental group wearing CW-protective combat clothing.

In some reports that Taylor and Orlansky (1992) reviewed, performance degradation was computed using these or similar metrics. In other cases they calculated the performance degradation indices from available data. For some studies the available data did not permit the computation of performance degradation indices. It would be helpful if future studies would (1) compare baseline or control performance (BDU) with MOPP4; (2) compute percent time degradation and percent accuracy degradation.

In this symposium, Johnson described a study which compared the accuracy of rifle marksmanship between a control condition, i.e., battle dress uniform (BDU), and CW-protective combat clothing (MOPP4). The data from this study can be analyzed using the Percent Accuracy Degradation Index. This study found that soldiers firing at pop-up targets had a mean of 27.4 hits for the BDU condition but only 22.1 hits for the MOPP4 condition. Using the Percent Accuracy Degradation Index we find:

$$D_A = \frac{Yca(27.4) - Yxa(22.1)}{Yca(27.4)} x100 = \frac{5.3}{27.4} x100 = 19.3\%$$

In an earlier report of this study Johnson, McMenemy, and Dauphinee (1990) indicated that performance for MOPP4 was 19.3% poorer than for the BDU condition. The percent accuracy degradation for direct fire engagements in CANE Phase 1 for the M16 was reported to be 54% (Draper and Lombardi, 1986).

Hamilton, Folds, and Simmons (1982) reported comparisons of the performance of U.S. Army helicopter pilots in the control of the aircraft when wearing BDU and CW-protective combat clothing. Table I presents these data and the calculation of D_A by Taylor and Orlansky (1992) for heading error, air speed error and timing error.

Table I. Average Median Errors for Standard Flight Suit (FS) and aircrew CW-ensemble (MOPP4)

	FS	MOPP4	D_A
$\tilde{X}$ Median Heading Error	1.63°	2.02°	-24%
$\tilde{X}$ Median Airspeed Error	1.83K	2.19K	-20%
$\tilde{X}$ Timing Error	0.93	1.08	-16%

The paper by Thornton and Caldwell which was presented at this symposium reported significant differences for a number of aircraft control parameters between a control condition (flight suit) and aviator CW-protective combat clothing condition. While data to compute percent accuracy degradation were not included in the presentation, the data obviously exist. It would be interesting to compare the results presented at the current symposium with earlier aircraft performance decrements.

REASONS FOR SUBJECT WITHDRAWAL FROM STUDIES

Several of the studies discussed in this symposium were conducted under the P^2NBC^2 program. According to Taylor and Orlansky (1992) many of the studies conducted under the P^2NBC^2 program have found that volunteer subjects fail to complete a variety of sustained combat missions in moderate or hot environments. In most cases, the subjects elected to leave the study prior to being medically removed due to elevated core temperature or high heart rate. COL Redmond in this symposium stated that the first line of defense against casualties in conducting studies on the effects of CW-protective combat clothing is the subjects themselves. Redmond reported that in the Detailed Equipment Decontamination Test, 13 of the 42 subjects who failed to complete the mission voluntarily withdrew themselves. Taylor and Orlansky (1992) found a significant number of voluntary withdrawals in a number of studies which investigated continuous operations in MOPP4 in the following areas: armor, mechanized infantry, artillery and aviation. In many of the studies, the combat unit was judged to be "combat ineffective" due to the loss of personnel prior to completing the operational scenario. They reported that in some cases the operational scenario could not be completed in BDU. They further stated that in all cases in which BDU and MOPP4 were compared, the MOPP4 condition produced more "casualties" (many were voluntary withdrawals) and caused the combat unit to become combat ineffective in a shorter time when compared to BDU. Taylor and Orlansky (1992) concluded that the data related to staytime in P^2NBC^2 field trials of combat arms raises serious questions concerning sustained combat unit performance while wearing CW-protective combat clothing even when heat exhaustion is not a factor. Taylor and Orlansky further concluded that "crews dressed in MOPP4 in temperate climate conditions will have difficulty sustaining effective combat operations under CW conditions for extended periods of time" (Taylor and Orlansky, 1992, pp. 10-5).

In this symposium, Gonzalez reported that computer modeling often is useful to predict human performance for environmental extremes at which empirical data (laboratory and field data) cannot be obtained due to the need to provide for the safety of subjects. Redmond reinforced the point that safety of human subjects in field studies is one of the main methodological issues of medical monitoring. Gonzalez concluded that computer modeling has been demonstrated to be most effective in predicting work/rest cycles, water requirements, and tolerance times for humans wearing CW-protective combat clothing. He concluded that the predictive success is due to an extensive data base in these areas which has permitted regression analyses to be conducted. Taylor and Orlansky (1992) reported that if data pertaining to the level of the CW-ensemble, the ambient environment, the physical condition of subjects or forces, and the mission are available, computer modeling "can specify the physiological limit of combat personnel operating under a CW-scenario" (Taylor and Orlansky, 1992, p. I-5). Gonzales noted that under conditions of combat assault when MOPP4 must be worn, the application of operational models that predict limits to work and water requirements is especially crucial at the field site.

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JESSE ORLANSKY is a member of the technical staff at the Institute for Defense Analyses, Arlington, Virginia. He has performed studies on the cost and effectiveness of flight simulators, computer-based instruction and maintenance simulators used for training military personnel. Currently, he is studying the use of networked simulators, i.e., SIMNET, for combat training, test and evaluation of prototype systems, and for the development of tactics and doctrine.

HENRY L. TAYLOR is Director of the Institute of Aviation, University of Illinois at Urbana/Champaign, Illinois. He received his Ph.D. from Florida State University, Tallahassee, Florida, in 1965. He was a member of the technical staff Air Force Systems Command and was military assistant for Training and Personnel Technology, Office of the Secretary of Defense, Washington, D.C. As a consultant to the Institute for Defense Analysis, he has reviewed with Jesse Orlansky studies on the effects of wearing protective chemical warfare combat clothing on human performance. He currently is conducting research to identify the optimum design and instructional features of flight training simulators with visual systems.

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