AR-009-895

DSTO-TR-0420

The Physiological and Cognitive Performance of Fully Acclimatised Soldiers Conducting Routine Patrol and Reconnaissance Operations in the Tropics

D. Amos, W.M. Lau, R.D. Hansen, V.J. Demczuk and J. Michalski

APPROVED FOR PUBLIC RELEASE

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

Mar-78

The Physiological and Cognitive Performance of Fully Acclimatised Soldiers Conducting Routine Patrol and Reconnaissance Operations in the Tropics

D. Amos, W.M. Lau, R.D. Hansen[#], V.J. Demczuk and J.T. Michalski[⊗]

Ship Structures and Materials Division
Aeronautical and Maritime Research Laboratory

DSTO-TR-0420

ABSTRACT

The physiological and cognitive performance of soldiers undertaking routine patrol and reconnaissance activities in the tropics have been investigated. During both patrol and reconnaissance the soldiers experienced a degree of heat strain which did not reach levels considered hazardous by OH&S practitioners. Peak metabolic rates for individual soldiers during patrol were high, even though the weight of equipment carried was modest and the terrain not severe. In general, the soldiers were aware of the risks of dehydration and maintained adequate hydration levels during the trial. There was no evidence of significant deterioration in soldier cognitive performance during the trial. The IR tympanic temperature technique showed considerable promise as a surrogate measure of core temperature under the trial conditions. The study showed weak correlations between rectal temperature and insulated skin temperatures. The energy expenditure model coded into the CAEN battle simulation has been validated in a field environment by the use of GPS, heart rate and oxygen consumption data.

RELEASE LIMITATION

Approved for public release

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

[#] University of Sydney
[⊗] Detachment 14 Psychology Unit, DPSYCH-A

Published by

DSTO Aeronautical and Maritime Research Laboratory
PO Box 4331
Melbourne Victoria 3001

Telephone: (03) 9626 8111
Fax: (03) 9626 8999

AR No. AR-009-895
September 1996

APPROVED FOR PUBLIC RELEASE

The Physiological and Cognitive Performance of Fully Acclimatised Soldiers Conducting Routine Patrol and Reconnaissance Operations in the Tropics

Executive Summary

The deployment of the ADF to Northern Australia exposes them to the debilitating effects of high heat and humidity and the resulting thermal strain may adversely affect decision making, physical capability and the effective use of weapons. Evidence suggests that casualties as a result of environmental stress factors caused problems in the Kangaroo 95 exercise. In the present study the physiological and psychological performance of dismounted soldiers from 2 Cavalry Regiment were examined during routine patrol and reconnaissance exercises at Mount Bundey, N.T. A secondary objective of the study was to investigate the reliability of some non-invasive surrogate body core temperature measurements which might be used in the development of a soldier personal status monitor to predict and show a commander the extent of thermal strain.

The main indicators of thermal strain, rectal temperature, heart rate and sweating rate showed that the soldiers experienced a modicum of heat strain during both patrol and reconnaissance phases of the exercise. However the degree of thermal strain overall did not reach levels which would be considered hazardous by OH&S practitioners. There was no evidence of significant deterioration in soldier cognitive performance during the trial. Peak metabolic rates for individual soldiers while patrolling were extremely high, even though the weight of equipment carried was modest by Army standards and the terrain not severe. Such levels of activity could only be maintained for brief periods before having deleterious effects on performance. In general, the soldiers were aware of the risks of dehydration and maintained adequate hydration levels during the trial.

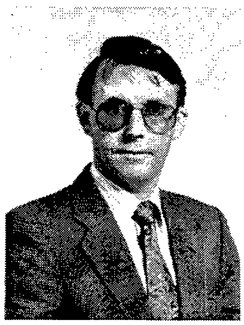
The IR tympanic temperature technique shows considerable promise as a surrogate measure of core temperature under the trial conditions and should be further developed and refined such that surrogate core temperature values can be displayed and stored automatically. The study showed weak correlations between rectal temperature and insulated skin temperatures and indicates that they may be unsuitable as field predictors of core temperature in the current format. Changes in thermistor location, means of attachment and insulator design should be investigated further under controlled conditions.

The energy expenditure model coded into the CAEN battle simulation has been validated in a field environment by the use of GPS, heart rate and oxygen consumption data. High correlations were obtained between actual and predicted energy expenditures during the study. Low correlations were attributed to position errors of individual soldiers. Heart rate consistently reflected the energy required to move over the terrain as shown by its high time correlation with terrain and energy

expenditure. The prediction model coded into CAEN appears valid for level and positive slopes. Further controlled studies are needed to determine the effects of negative slopes and more accurate position values.

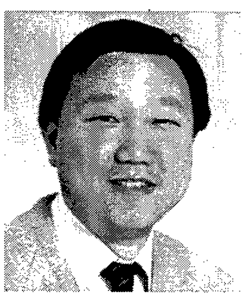
Authors

Denys Amos
Ship Structures and Materials Division



Denys Amos graduated from the University of Durham (UK) in 1960 with a BSc(Hons) and MSc (1961) in organic chemistry. He has worked with ICI and the Science Research Council and has been attached to CBDE in the UK. At AMRL he has undertaken extensive research into the decontamination and into protection of personnel against toxic chemicals. At present he is a Principal Research Scientist and manager of a program on personnel protection and physiological performance of soldiers in the tropics. Recently he has been the principal investigator into the physiological assessments of microclimate cooling systems and a newly developed Chemical, Biological Combat Suit.

Tony W.M. Lau
Ship Structures and Materials Division



Tony Lau graduated in Hong Kong in 1979 in Biology and Biochemistry and obtained his M.Phil in environmental biology in 1981. After winning a Croucher Foundation Scholarship (HK), he studied environmental toxicology at Melbourne University and was awarded a Ph.D. degree in 1987. After a short spell of employment with the Unipath Pathology Laboratory he joined MRL in 1985 and conducted pharmacological studies leading to improved prophylaxis and therapy of nerve agents. He is currently a Senior Research Scientist involved in environmental physiology and has contributed to a review of human sciences in DSTO.

Ross D. Hansen
University of Sydney

Ross Hansen is a Lecturer in Human Physiology in the Department of Life Sciences, Faculty of Nursing, The University of Sydney. He also holds a clinical appointment at The Royal North Shore Hospital, Sydney. He has extensive research experience in the field of human thermoregulatory responses to exercise, with a recent focus on the usefulness of Infrared tympanic thermometry in the prediction of heat strain.

Victor J. Demczuk
Land, Space and Optoelectronics Division

Victor Demczuk has a BA in Psychology from Flinders University. He is a Senior Professional Officer currently investigating human factors aspects of the future soldier system. His special areas of interest are modelling human performance, human-machine interaction and virtual environments.

Jaroslaw T. Michalski
DPSYCH-A

CAPT Jaroslaw T. Michalski graduated from the University of Queensland in 1991 after completing a Bachelor of Arts (Psychology) and a Post-Graduate Diploma in Psychology. He joined the Army Psychology Corps in January 1992 as a Psychology Officer and has been posted to several positions around Australia. Currently. CAPT Michalski is based in Darwin and holds the position of Senior Psychologist for the Northern Region.

Contents

1. Introduction

Strategic Review 93 (1) and the Defence White Paper (2) both indicated that the future military theatre of operations for Australia will be focussed in the North. This poses a significant challenge to the Australian Defence Force (ADF) as deployment of military staff to Northern Australia will expose them to the debilitating effects of high heat and humidity. The rugged terrain and the remoteness of a large part of Northern Australia will add further difficulties to the maintenance of an efficient defence force in this area of Australia.

From a military perspective, any advantages in superior technologies and command, control and intelligence systems could be nullified by the strain experienced by military personnel who have to work in the tropical environment. As soldiers suffer malaise, fatigue and deterioration of their physical capability; decision-making, data analysis, concentration and the correct and effective use of weapons and equipment will be adversely affected. This could have serious consequences for the accomplishment of military missions.

The human body possesses a range of interactive regulatory mechanisms to maintain constancy of its internal environment. The ability to sustain homeostasis allows an individual to adapt to environmental influences through readjusting its physiological set points in compensation for external changes (3). However, certain physiological parameters have limited flexibility and are slow to adjust. Among some of these are heat and cold adaptation, endurance, physical and cognitive performance and circadian rhythms. In military terms, the ultimate cost of the slow and limited human physiological adaptation to sudden or large environmental change is an overall reduction in the efficiency in physical and mental abilities; and in extreme cases, fatality. This is a major concern to the ADF.

Anecdotal evidence suggests that casualties as a result of environmental stress factors such as high heat and humidity caused problems in the Kangaroo 95 exercise. A total of more than 160 heat casualties were reported during the exercise (4). A better understanding of the physiological capabilities of the soldiers and the optimisation of work schedules may have reduced this high number of heat casualties.

As a result, a trial to examine the physiological and psychological performance of dismounted soldiers from 2 Cavalry Regiment was proposed and sponsored by the SGADF. The primary aim of the trial was to determine the critical physiological parameters such as body core and skin temperature, heart rate (HR), hydration status and oxygen consumption of soldiers conducting patrol duties at the Army Training Ground at Mount Bundey, N.T. The information obtained could be used as a baseline data pool to determine optimal work schedules for routine patrol and reconnaissance.

A secondary objective of the trial was to investigate the reliability of some non-invasive surrogate body core temperature measurements which might be used in the development of a personal status monitor to indicate rectal temperature and predict thermal strain. Previous laboratory and field studies involving soldiers marching on a treadmill in warm to hot conditions and fun-runners who collapsed in cool conditions, have shown that Infrared (IR) tympanic temperature (T_{ty}) correlates highly with rectal temperature (T_{re}) during and immediately after exercise, such that T_{ty} can be a useful predictor of T_{re} (5, 6). However, these and other studies have also revealed that the relationship between T_{re} and T_{ty} can be considerably influenced by environmental factors, including ambient temperature and airflow around the face (7, 8). Thus the good agreement between T_{re} and T_{ty} reported in very stable, clinical environments (9) does not guarantee consistent, accurate prediction of T_{re} from T_{ty} in unpredictable field conditions.

Bernard and Kenny (10) investigated the non-invasive measurement of core temperature and developed an insulated disk sensor to determine insulated skin temperature. They reported that there was a very high correlation between T_{re} and the disk temperature under conditions of high heat stress with air temperatures of 45°C and 55°C and proposed insulated skin temperature as a surrogate measure to predict excessive body core temperature.

In the military environment increasing use is being made of simulations to optimise system performance. In land operations this may involve synthetic soldiers in a battle simulation. Accurate human performance models are needed in low-level simulations where individual soldier behaviour is significant. Soldier movement is a crucial behaviour that must be accurately modelled. The Close Action ENvironment (CAEN) battle simulation, developed by DERA, UK, is an example of a low-level battle simulation. A walking energy expenditure formula by Pandolf et al (18) has been shown to be valid for a wide range of conditions. It incorporates subject weight, carried load, walking speed, terrain type and slope. This formula has been incorporated into the CAEN battle simulation. In the present study we also compare the predicted energy expenditure of soldiers walking under various conditions, as calculated in the CAEN battle simulation (modified to incorporate an energy expenditure algorithm), with field measurements of energy expenditure using oxygen consumption, and with HR.

In collaboration with the Land Operation Branch (LOB), Salisbury and the Directorate of Psychology-Army (DPSYCH-A), the movement of the soldiers over the terrain and the cognitive performance at various stages of the trial were also investigated. The purposes of these measurements were to determine the effects of terrain on soldier work output and the effects of the hot and humid climate and high levels of physical activity on their cognitive functions.

2. Experimental

2.1 Subjects

Twenty male soldiers from 2 Cavalry Regiment volunteered to participate in the trial after being informed of (i) the purpose and procedures of the trial, (ii) any known risks and (iii) their right to terminate participation at will and without penalty. The soldiers were considered to be fully acclimatised to tropical conditions as they were stationed in Darwin. After briefing, the soldiers gave their informed consent to participate by signing a statement of consent prior to the first day of the trial. The trial protocol was approved by the Australian Defence Medical Ethics Committee. Values (mean ± S.D.) for soldier age, weight and height were:

Age	22 ± 3 years
Height	1.78 ± 0.08 m
Weight	76 ± 11 kg

Total mean load carried during Patrol phase was 30.82 ± 4.01 kg.

2.2 Experimental Design

Following preliminary discussions with 2 Cavalry Regiment, agreement was reached on the trial activities and route of the exercise. The third week in May was agreed as a tentative date for the trial. The trial was carried out at the Army Mt Bundey Training Ground, N.T. The activities were similar to the normal training duties for foot soldiers on routine patrol and reconnaissance duty. An outline of the activities is given below.

Schedule	Activities
7.00-8.00	Weighing soldiers and equipment, installing personal monitoring equipment
8.00-10.00	Transport of troops to training ground, initial psychological assessment (by questionnaire)
10.00-12.00	Patrol with pack, webbing and weapons along a defined route through undulating terrain.
12.00-13.00	Setting up observation post, second psychological assessment
13.00-14.00	Reconnaissance patrol with webbing and weapons
14.00-14.30	Assault enemy position
14.45-16.45	Transport of troops to Regiment HQ, third psychological assessment
17.00-18.00	Weighing soldiers and equipment, removal of monitoring equipment and download data from loggers.

Each soldier was tested wearing normal disruptive pattern combat uniform, coat and sleeves fastened, with bush hat and webbing with filled water bottles and carrying his normal weapon. During the patrol phase of the trial, soldiers carried their normal pack; total weight carried during this phase was approximately 30 kg. During the reconnaissance phase soldiers carried only webbing, with water bottles, and personal weapon. The work intensity of the soldiers included light, moderate and heavy activities in accordance to US Army classification (11). Workload during the transportation phase was considered light, that during the patrol phase, heavy and that during the reconnaissance phase was considered medium. VO2 measurements on a representative soldier were taken using open circuit spirometry (Cortex Metamax) on each day of the trial. After fifteen minutes of exercise, measurements were taken for 10 to 15 minutes to obtain steady state data. Soldiers were advised to drink normally during the trial; the weight of each soldier before and after each trial phase and water consumed was recorded.

Rectal (T_{re}) and skin temperatures were measured using Yellow Springs Instrument Series 400 thermistors with the rectal thermistor being inserted 150 mm beyond the anal sphincter. The skin temperature on the thigh, T_{thigh}, was measured with a single site thermistor located on the left median anterior thigh position. Mean weighted skin temperature (T_{sk}) was estimated from T_{thigh} values using the regression equation of Goss et al (12): $T_{sk} = 5.043 + 0.832\ T_{thigh}$. Temperature data were recorded and stored at 2 min intervals. HR was monitored continuously and recorded at 1 min intervals using Polar Sport Tester Heart Rate Monitors.

Topography of the route was undulating and included a mixture of bush and grassland with the highest elevation being 93m. The environmental conditions experienced by the soldiers were assessed during each phase by several sling psychrometer readings; in addition, environmental data were automatically recorded using a Metrosonics 3700 unit at the base camp recording dry bulb temperature (DB), wet bulb temperature (WB), globe temperature (GT) and WBGT. The exercise was repeated on three separate days with three different sections of assault troops. Two medical assistants accompanied the soldiers during the entire exercise, assisted in data collection and also provided first-aid if necessary

2.3 Water consumption and fluid balance

Fluid balance of the soldiers was monitored by weighing the individuals after the completion of a designated activity. The weight of clothing, webbings, equipment carried before and after the trial was recorded to allow for calculation of the evaporative sweating rate. The loss or gain in body mass was computed and the weight loss as a percentage of the initial nude body weight was calculated and is shown in Table 2. The data in the first column were the combined results of Day 1 and Day 3 of the trial. These two groups were pooled together because of the small number of subjects available on Day 1 and also because the climatic conditions of Days 1 and 3 were similar.

2.4 Cognitive tests

Psychological tests were conducted to monitor the effects of high heat and humidity on soldier's cognitive and psychological performance. The Speed and Accuracy (ASA) test adopted is a standard test battery which involves number and name checking. Test score is recorded according to the total number of items attempted (speed component) and the total number of items answered correctly (accuracy component). The State-trait Anxiety Inventory (STAI)-(FormY) (20) monitors the psychological stress levels. The STAI is composed of two parts, the first measures the state anxiety levels of the respondents and the second the trait anxiety levels. Both tests were administered on the three trial days to all subjects. The first evaluation was conducted prior to the Transport phase. Participants were tested with STAI, then followed by ASA. Using the same test batteries, except the trait component of STAI, the subjects were again tested after Patrol and Assault phases.

2.5 IR Tympanic temperature measurements

Two medical assistants were trained in the IR technique using FirstTemp Genius IR thermometers set in core mode at the outset of the trial. The medical assistants accompanied each group of troops, taking T_{ty} at approximately 15 minute intervals during each phase of the trial. Skin temperature on the cheek (T_{cheek}) was also taken whenever a T_{ty} measurement was taken to assess the extent of facial cooling and to determine whether T_{cheek} could improve the prediction of T_{re} in combination with T_{ty}. T_{cheek} was taken with an IR thermometer (FirstTemp 2000A) set in surface mode.

2.6 Insulated skin temperature measurements

Insulated skin temperatures on the back ($T_{ins.back}$) and side ($T_{ins.side}$) were also recorded via YSI 400 series thermistors and datalogger. The thermal insulation consisted of a disk of closed cell foam, diameter 32 mm, thickness 10 mm with a recess of diameter 10 mm, depth 2.5 mm on the skin side to contain the YSI 400 series skin thermistor. $T_{ins.back}$ was located on the trapezius muscle level with the spinous process of the first thoracic vertebra. $T_{ins.side}$ was located on the left serratus anterior muscle.

2.7 Predicted energy expenditure

Position was recorded at one second intervals by a "Sokkia Spectrum" Global Position System (GPS) receiver with real-time differential correction by an "OmniSTAR" differential receiver. The two receivers and batteries were carried in a backpack (12 kg) by an observer to represent the average position of the group of subjects. The CAEN battle simulation was modified to incorporate the energy expenditure algorithm developed by Pandolf et al. (18). The original algorithm predicted a negative energy expenditure when walking downhill. An adjustment was made to the algorithm to set a zero gradient for negative gradients in the calculation. This was done based on an interpretation of results from Pimental and Pandolf (19). The data for the real position of subjects in the field were entered into the battle simulation model and the predicted energy expenditure was determined from the speed and calculated gradient.

2.8 Data reduction and analysis

Due to the cooler environmental conditions, a shorter Patrol time and a shorter Reconnaissance time for the soldiers on Day 2, data were pooled for Days 1 and 3 and that for Day 2 was pooled separately. For IR tympanic analysis, data were pooled for 14 subjects where appropriate. The relationships between T_{re}, T_{ty}, T_{cheek} $T_{ins.back}$ and $T_{ins.side}$ and environmental variables were determined by simple and multiple regression and by ANOVA and post-hoc t-tests. In addition, the ability of the IR method to predict a T_{re} of 38.0°C, an established criterion in defining heat strain, was assessed by calculating sensitivity and specificity values (13). As the T_{ty}/T_{re} responses of two soldiers were found to be atypical, data analyses were performed both with and without these soldiers' data where appropriate.

3. Results

3.1 Environmental data

Environmental conditions on the three days were similar (Table 1) but an increase in airspeed was observed on Day 2, particularly in the morning (Patrol). Also Day 2 was slightly cooler with greater cloud coverage than on Days 1 and 3. Detailed environmental parameters are shown in Appendix 1.

Table 1. Ambient conditions throughout the trial

Day/Phase	Tdb (°C)	Twb (°C)	Tg (°C)	Airspeed
<u>Day 1</u>				
Patrol	32	23	44	Low
Reconnaissance	33	23	36.5	Low
<u>Day 2</u>				
Patrol	29.5	20	40	Moderate
Reconnaissance	32	21	41	Low to Moderate
<u>Day 3</u>				
Patrol	32	21.5	44	Low
Reconnaissance	32.5	21.5	41	Low

3.2 VO2 and metabolic rates

Typical VO2 measurements for periods during the Transportation, Patrol and Reconnaissance phases of the trial are shown in Figure 1 for an individual soldier on Day 3. VO2 data on the individual soldiers on Day 1 and 2 are given in Appendix 2. VO2 measurements were not obtained during the Patrol phase of Day 1 due to battery failure in the Metamax. Overall VO2 levels during the Transportation phase were in the range 0.4 - 0.5 $L.min^{-1}$ equivalent to 130 - 160 watts and typical of resting metabolic rates. VO2 levels during both Patrol and Reconnaissance phases show the anticipated variation due to terrain topography. During the Patrol phase, VO2 levels were in the range 2.5 - 3.2 $L.min^{-1}$. Peak VO2 levels greater than 3 $L.min^{-1}$ during Patrol indicate that the soldiers were working hard. The VO2 levels during Reconnaissance phase were 1.5 - 2.0 $L.min^{-1}$ and were generally lower than those for Patrol.

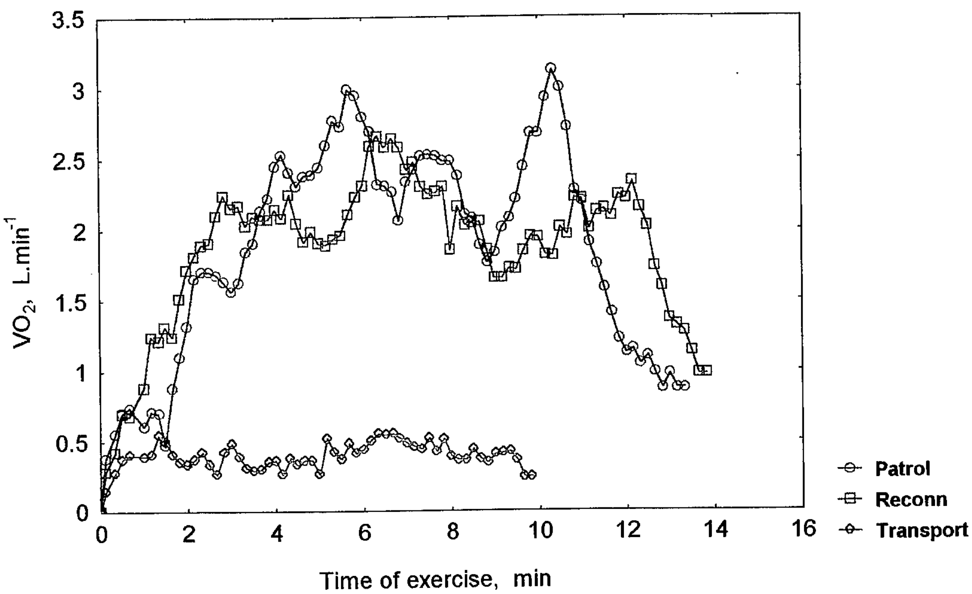


Figure 1. VO2 measurements during exercise on Day 3 of Trial.

3.3 Rectal temperature

Mean rectal temperatures for the soldiers are shown in Figures 2a and 2b for Days 1 and 3 and Day 2 respectively. As would be anticipated, T_{re} fell slightly during the Transportation phase when the soldiers were essentially at rest. Once the Patrol phase commenced, T_{re} increased steadily, reaching a maximum between 38.0°C and 38.2°C. At the end of Patrol, T_{re} fell steadily until the start of the reconnaissance phase; however the resting level of T_{re} was not reached during the observation post phase. During the Reconnaissance phase, T_{re} again increased steadily to a maximum between 38.0°C and 38.2°C. During Day 2, the soldiers completed the reconnaissance phase in a much shorter time than on Days 1 and 3. This greater work intensity is reflected in higher T_{re} recorded during the Reconnaissance phase than during the Patrol. The Assault phase of the trial had only a minor influence on T_{re} due to its short duration.

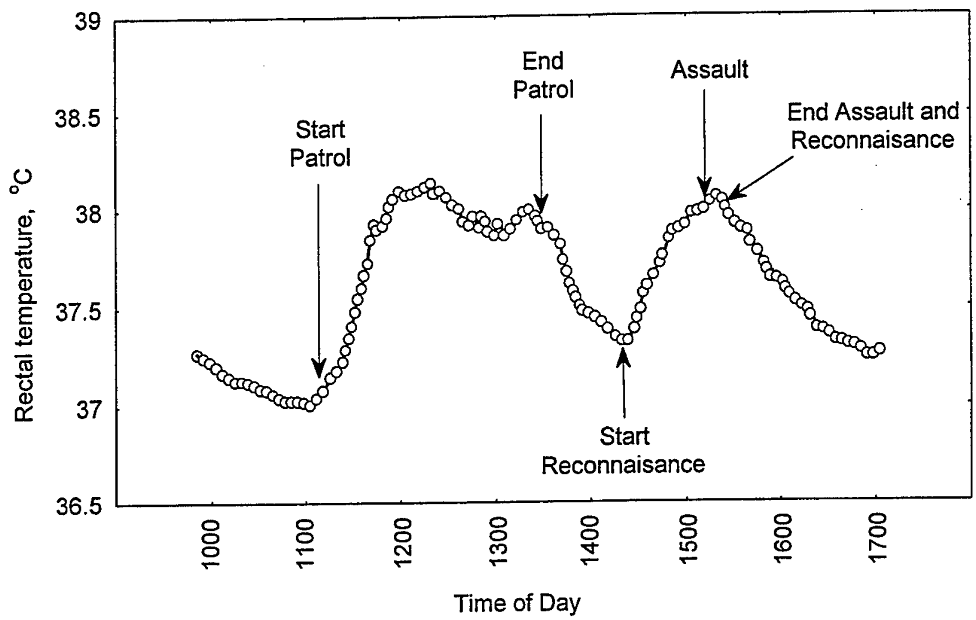


Figure 2a. Mean rectal temperature of soldiers during exercise on Days 1 and 3 of Trial.

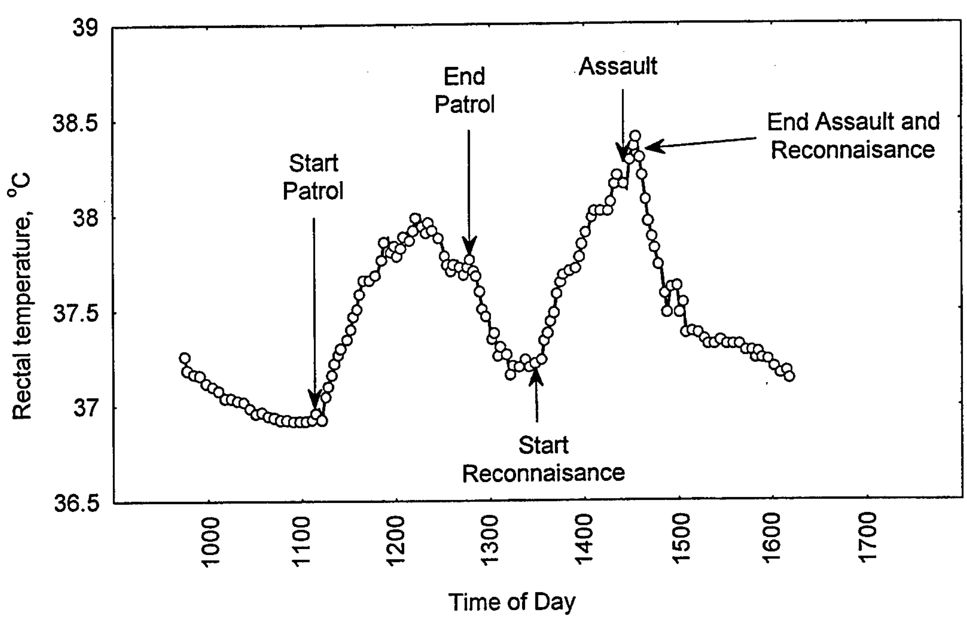


Figure 2b. Mean rectal temperature of soldiers during exercise on Day 2 of Trial.

3.4 Heart rate

Mean HR for the soldiers are shown in Figures 3a and 3b for Days 1 and 3 and Day 2 respectively. As would be anticipated, HR fell slightly during the Transportation phase when the soldiers were sedentary. Once the Patrol phase commenced, HR increased and varied between 120 and 160 b.min^{-1} depending on the severity of the terrain and whether the soldiers were walking or stationary due to navigation checks and T_{ty} measurements. Peak HR was 150 - 160 b.min^{-1} during Patrol and 140 - 150 b.min^{-1} during Reconnaissance. Such levels were well below the predicted maximum HR for young individuals and indicate that the soldiers were operating within their physical capabilities. At the end of Patrol, HR fell during the Observation Post phase but did not reach resting levels. The maximum HR of 160 b.min^{-1} was reached during the brief Assault phase after which HR declined to resting levels. Of interest is the impact of cognitive tests on the post Assault phase which are evident in brief increases in HR.

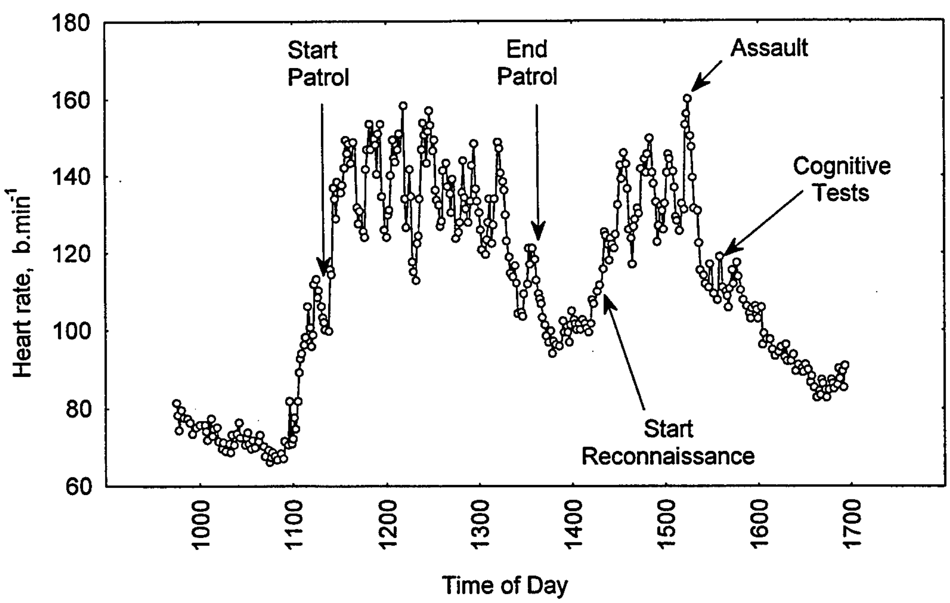


Figure 3a. Mean heart rate of soldiers during exercise on Days 1 and 3 of Trial.

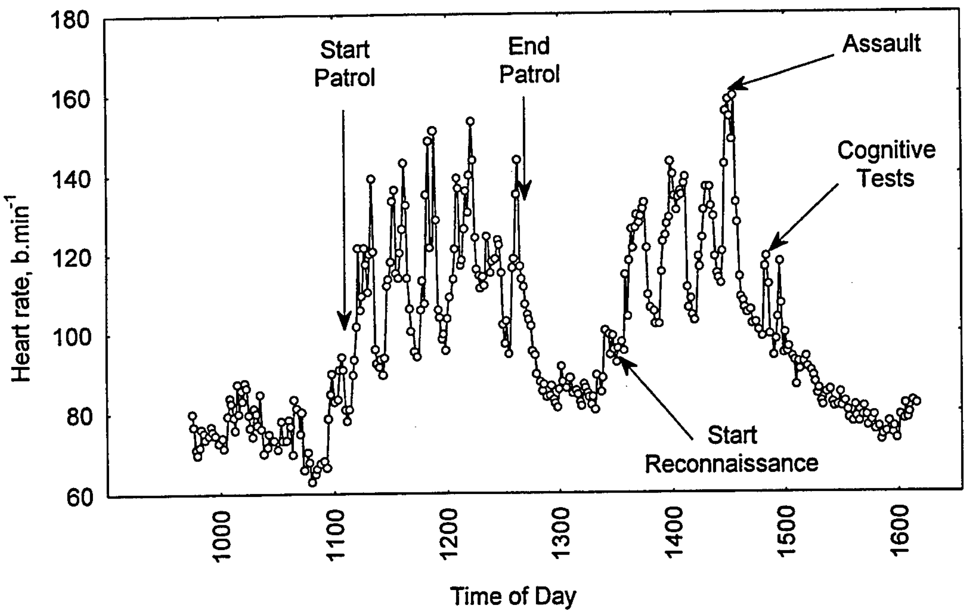


Figure 3b. Mean heart rate of soldiers during exercise on Day 2 of Trial.

3.5 Skin temperature

Mean T_{sk} for the soldiers are shown in Figures 4a and 4b for Days 1 and 3 and Day 2 respectively. As would be anticipated, T_{sk} fell slightly during the Transportation phase when the soldiers were essentially at rest. Once the Patrol phase commenced, T_{sk} increased to a maximum of 36.8°C during Patrol and to 36.7°C during Reconnaissance and Assault on Days 1 and 3. During Day 2, T_{sk} reached a maximum of 34.8°C during Patrol and 35.5°C during Reconnaissance and Assault. The lower T_{sk} evident on Day 2 could be attributed to the cooler ambient temperature and moderate air movement. On all three days, variations in T_{sk} due to pauses in physical activity resulting from navigation checks and T_{ty} measurements are noticeable. At the end of Patrol, T_{sk} fell quickly during the Observation Post phase but did not reach resting levels; the fall was more noticeable during Day 2, which could be attributable to the cooler ambient conditions.

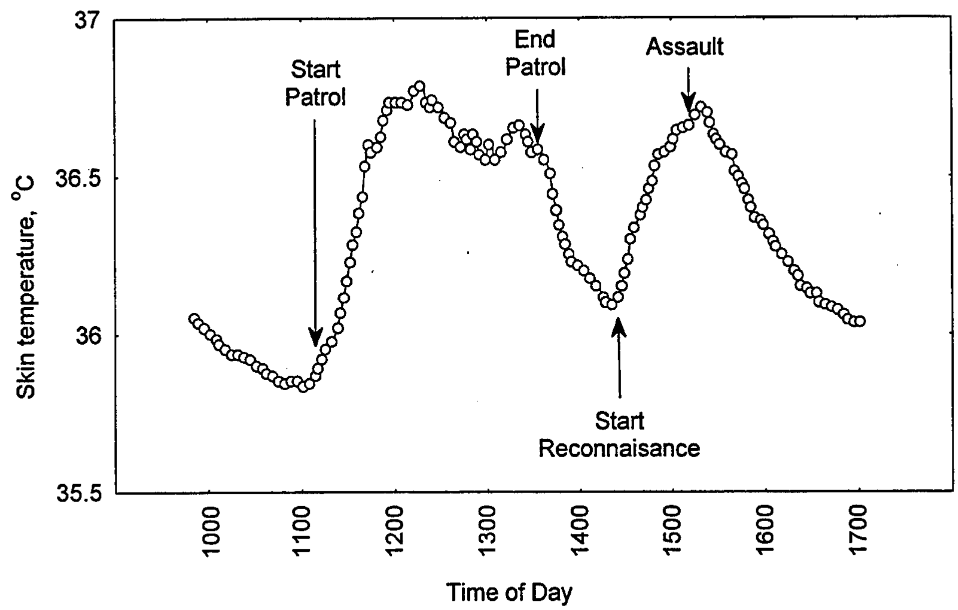


Figure 4a. Mean skin temperature of soldiers during exercise on Days 1 and 3 of Trial.

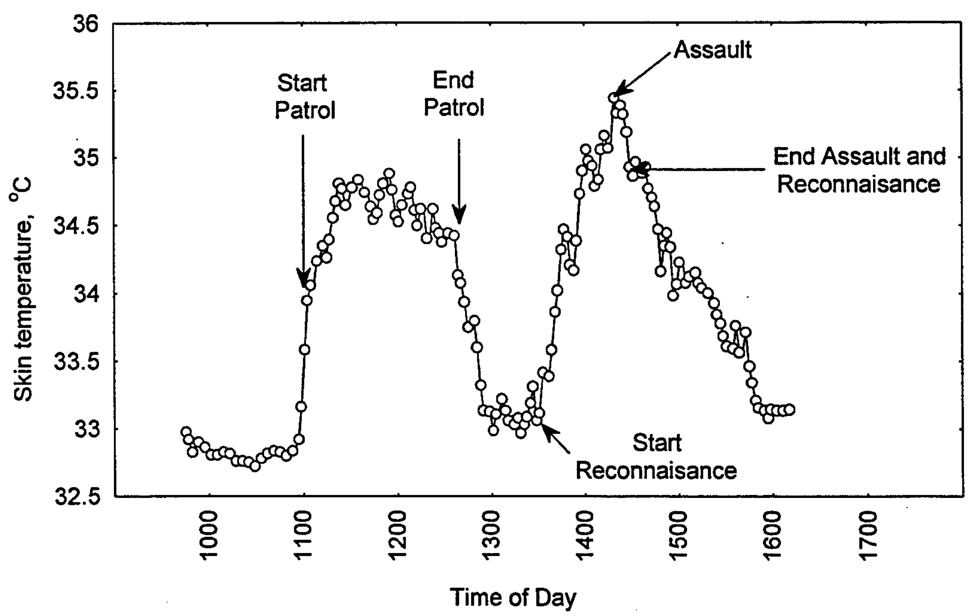


Figure 4b. Mean skin temperature of soldiers during exercise on Day 2 of Trial.

3.6 Water consumption and fluid balance

The four different activities planned for the soldiers corresponded to the very light (Transportation), moderate (Reconnaissance) and heavy (Patrol and Assault) work intensity classified by the US Army Research Institute of Environmental Medicine (11). It was observed that the biggest fluid loss occurred after the completion of the Patrol (2.31% and 1.32% for the two different groups). This was followed by the loss after Reconnaissance which recorded a 0.98 and 0.87% weight reduction for the combined and the Day 2 groups respectively. When the percentage of weight reduction was temporally adjusted (Table 2), the highest rate of fluid loss in the combined group was registered after Reconnaissance (12.72 g/kg/h). In contrast, the highest rate for the Day 2 group was recorded after the Assault (16.38 g/kg/h). Comparing these rates (except the one for Transportation) within each group did not show any significant differences. Thus, the difference in the work intensity classification of the three activities (Patrol, Reconnaissance and Assault) was not reflected in their corresponding rate of fluid loss.

The percent weight loss at the end of the trial day for the combined group was 0.79% and for the Day 2 group was 0.92%. These low weight reductions indicated that the soldiers were adequately hydrated over the course of the trial. The mean sweat rate and the evaporative sweat rate of the soldiers shown in Table 2 were relatively low, suggesting that the overall work intensity was only moderate. Again, there was no significant difference between the two groups. The evaporative sweat rates accounted for more than 93% of the overall sweat rates in both groups, indicating that evaporative cooling was not hindered by the clothing and webbing worn by the soldiers.

Table 2. Mean Percentage Weight Loss, Rate of Fluid Loss and Mean Sweat Rate for Soldiers Exercising at Different Work Intensities

	Combined Group (Days 1 and 3)		Day 2	
	Wt. Loss (%)	Rate of Fluid Loss (g/kg/h)	Wt. Loss (%)	Rate of Fluid Loss (g/kg/h)
Transport	0.43±0.36	3.03±2.54	0.24±0.14	1.69±0.98
Patrol	2.31±0.41	9.47±1.68	1.32±0.14	7.97±0.84
Reconnaissance	0.98±0.27	12.72±3.50	0.87±0.20	9.75±2.24
Assault	0.25±0.21	12.50±10.50	0.31±0.33	16.38±17.44
End of Trial	0.79±0.82		0.96±0.72	
Sweat Rate (g/kg/h)		6.34±1.23		4.93±0.65
Evaporative Sweat Rate (g/kg/h)		6.20±1.12		4.63±0.49

3.7 Cognitive performance

Table 3 shows the mean ASA and STAI scores before Transportation, after Patrol and Assault. It is interesting to note that the ASA scores increased as the soldiers proceeded with the trial. This suggests that the thermal strain experienced by the troops had no detrimental effects on the speed and accuracy aspects of their cognitive functions. Scores from STAI also showed no sign of increased stress as the trial progressed. These observations were confirmed by a statistical analysis (ANOVA) on the data in which no significant differences were detected between the scores recorded after the three phases of the trial for all three trial days. The results thus indicate that the psychological performance of the soldiers was not hampered by the physical requirements and the environmental conditions under which they were operating.

Table 3. Mean ASA and STAI Scores for Soldiers Tested before Transportation and after Patrol and Assault Phases

Activities	ASA Scores ± SD	STAI Scores ± SD	
		Trait	State
Before Transportation	122.1 ± 26.5	30.6 ± 6.3	35.3 ± 8.9
After Patrol	128.1 ± 30.8	31.4 ± 9.0	
After Assault	143.1 ± 35.6	29.0 ± 5.0	

3.8 IR Tympanic temperature

3.8.1 Agreement between T_{re} and T_{ty} at completion of Phases

Core temperature, recorded by rectal and IR tympanic measurements, generally rose steadily during each phase of the trial, such that at the end of each phase T_{re} and T_{ty} differed on average by ≤ 0.3°C. The exception to this pattern was on Day 2, when two soldiers displayed an atypical pattern, with differences between T_{re} and T_{ty} as great as 1.4°C. These data are summarised in Table 4.

When all of the data for the typical soldiers were pooled for each day, ie. temperatures during each phase not just at the completion of the phase, the differences between T_{re} and T_{ty} were similar to that noted at the completion of the Patrol phase. The (T_{re} - T_{ty}) values for Days 1 to 3 were 0.03, 0.39 and 0.14°C respectively. The value for Day 2 was significantly different ($p < 0.05$) to that of each of Days 1 and 3.

Table 4. Mean (± SD) core temperatures at completion of each phase.

Trial Day (No. of soldiers)	Patrol Phase T_{ty}	Patrol Phase T_{re}	Reconnaissance Phase T_{ty}	Reconnaissance Phase T_{re}
Day 1 (2)	38.2 ± 0.0	38.0 ± 0.25	38.6 ± 0.15	38.3 ± 0.1
Day 2 (4)*	37.3 ± 0.35	37.6 ± 0.2	38.0 ± 0.2	38.0 ± 0.15
Day 3 (6)	37.8 ± 0.4	37.8 ± 0.25	38.1 ± 0.4	38.1 ± 0.25
Day 2				
Atypical soldier #1	36.9	38.3	37.8	38.8
Atypical soldier #2	36.8	37.7	37.7	39.1

* Analysis revealed 4 typical soldiers and 2 atypical soldiers for Day 2. All subjects displayed typical responses on the other Days.

3.8.2 Correlation between T_{re} and T_{ty}

Pooled data for Patrol and Reconnaissance Phases.

When the data for the 14 subjects were pooled for all three days, the correlation between T_{re} and T_{ty} was such that T_{ty} could predict T_{re} with a standard error of estimate (SEE) of 0.43°C.

$$T_{re} = 0.23\ T_{ty} + 29 \qquad (r = 0.27,\ p < 0.001;\ 167 \text{ data sets}) \qquad [1]$$

When this analysis was repeated with the data of the two atypical subjects excluded, the SEE fell to 0.34°C.

$$T_{re} = 0.39\ T_{ty} + 23 \qquad (r = 0.47,\ p < 0.00001;\ 143 \text{ data sets}) \qquad [2]$$

The SEE was further, but only marginally, reduced to 0.31°C when the remaining Day 2 data was excluded, ie. pooled Day 1 and Day 3 data for 12 subjects.

$$T_{re} = 0.39\ T_{ty} + 23.1 \qquad (r = 0.47,\ p < 0.00001;\ 95 \text{ data sets}) \qquad [3]$$

Data at completion of Patrol and Reconnaissance Phases.

When the data were further limited to post-exercise readings only, ie. observations taken on 12 typical subjects immediately on completion of Patrol and Reconnaissance phases for all three days pooled, the resulting 24 T_{ty} values predicted T_{re} with a considerably lower SEE.

$$T_{re} = 0.42\ T_{ty} + 22.1 \qquad (r = 0.69,\ SEE = 0.21°C,\ p = 0.00002;\ 95 \text{ data sets}) \qquad [4]$$

3.8.3 Addition of T_{cheek} or environmental factors as explanatory variables

The differences in the T_{re}/T_{ty} relationship on Day 2 compared to Days 1 and 3 indicated that ambient conditions could be influencing the IR method. As noted above, facial cooling resulting from combinations of ambient temperature and airflow around the face can affect the IR method, and T_{cheek} can be used as an index of this effect. When T_{cheek} was entered as an explanatory variable, in combination with T_{ty}, to predict T_{re}, only marginal improvements in the SEE value were noted. This could be due to the relatively small range of T_{cheek} values observed; variability for each soldier was often only 1 - 2°C within each Phase and between-soldier and between-Day variability was also marginal for this variable.

Similarly, adding T_{db} or T_g as explanatory variables yielded only marginal improvements in prediction of T_{re}, presumably for the same reason as variability in these parameters was relatively small within or between Days of the trial. However the addition of T_{db} to the "end of Phase" data did improve the specificity in predicting T_{re} value of $\geq$ 30.0°C. The following equation describes this inclusion of T_{db}.

$$T_{re} = 0.293\, T_{ty} + 0.078\, Tdb + 24.4 \qquad (r = 0.72,\ SEE = 0.21°C,\ p = 0.0004) \qquad [5]$$

where T_{db} = the mean dry bulb temperature observed *during* each phase of the trial.

3.8.4 Capacity of the IR method to predict heat stress

A value of 38°C has been widely used as an integrated index of heat stress and as a criterion in the diagnosis of heat exhaustion (5, 14). Application of equation [4] to the post-exercise IR values of the subjects yielded predicted T_{re} values which agreed quite closely with the actual T_{re} values, such that a T_{re} of 38°C was predicted correctly on 90% of occasions for the typical subjects (Table 4). Sensitivity of prediction for the atypical subjects was only 33%. Hence a low sensitivity value was noted when data for all 14 subjects were analysed (Table 5).

Specificity in predicting a T_{re} of 38°C was less acceptable. For the typical subjects, when actual T_{re} was < 38°C, this was correctly predicted from equation [4] on 8 of 14 occasions ie. specificity was 57%. Specificity of prediction for the atypical subjects was 100%, but T_{re} was < 38°C on only one occasion for these subjects.

Table 5. Capacity of IR method to predict a T_{re} of 38°C.

Group/predictors	**Sensitivity** % of true cases (positives) detected by prediction	**Specificity** % of non-cases (negatives) detected by prediction
12 TYPICAL Subjects		
Using T_{ty} only *	90%	57%
Using T_{ty} + Tdb #	90%	64%
12 TYPICAL PLUS 2 ATYPICAL Subjects		
Using T_{ty} only	77%	60%
Using T_{ty} + Tdb	69%	67%

* Utilising equation [4].
# Utilising equation [5].

3.9 Capacity of insulated skin temperatures to predict T_{re}

Analysis of the data for 14 subjects at completion of Phases 1 & 2 combined revealed only weak, non-significant correlations between T_{re} and $T_{ins.back}$ ($r = 0.13$, $p = 0.52$, SEE = 0.41°C) and between T_{re} and $T_{ins.\,side}$ ($r = 0.24$, $p = 0.27$, SEE = 0.4°C). These SEE values fell when the two atypical subjects were excluded, but the correlations remained non-significant:

$$T_{re} = 0.11\ T_{ins.\,back} + 34 \quad (r = 0.24,\ p = 0.27,\ SEE = 0.33°C) \qquad [6]$$

$$T_{re} = 0.09\ T_{ins.\,side} + 34.8 \quad (r = 0.27,\ p = 0.21,\ SEE = 0.33°C) \qquad [7]$$

3.10 Global Positioning System

The position data collected by the GPS receiver was analysed to calculate speed and gradient information. Subsequent analysis of the collected elevation data indicated insufficient accuracy for the recorded elevation data. Errors of up to 40 metres were found in elevation. These data were not used in the analysis. The Northing and Easting data were accurate to 1 metre. Anomalies in the position information were observed at regular intervals. These occurred when the differential or GPS signal was lost. To compensate for these anomalies, the data was filtered by a moving mean averaging filter (using 5+15+30+60 point windows). These smoothed data were used in subsequent calculations.

Since the recorded elevation data was unusable, an alternate elevation data set was calculated. The smoothed Northing/Easting data were entered into the CAEN battle simulation which held a Digital Terrain Model of the Mount Bundey Training Area. The elevation was calculated from that data set. Simultaneous energy predictions for each subject were also calculated using the formula derived by Pandolf et al. (18). The terrain coefficients used were 1.3 for the Patrol and 1.1 for Reconnaissance. Future versions of the CAEN software will use a vegetation database to determine appropriate terrain coefficients continuously, based on location.

3.11 Energy expenditure

The actual energy expenditure for one subject was calculated from his oxygen consumption during a 10 minute sample in each Patrol phase and compared with the predicted value calculated in the CAEN battle simulation from position and load information. The effect of slope on energy expenditure is shown in Figure 5 with data points at 10 second intervals. The figure combines the energy expenditure calculation (min: 120 $J.sec^{-1}$, max: 650 $J.sec^{-1}$) with altitude (min: 56 metres, max: 60 metres) and subject speed (min: 0 $m.s^{-1}$, max: 1.8 ms^{-1}) for Reconnaissance on Day1 over the same time period as in Figure 6. At time 350 seconds the altitude rises with the speed remaining constant. The energy peaks during this positive gradient period. This is repeated at time 450 seconds.

The assumption that negative slopes can be approximated to a zero slope in the Pandolf et al. algorithm (18) was not supported by an examination of the data. Further analysis is needed to determine an accurate interpretation. Figure 6 shows a comparison between actual energy expenditure, predicted energy expenditure and HR for the subject during Reconnaissance. Subject weight was 72 kg, and carried load was 19 kg. The data points are shown at 1 minute average periods. Correlation between HR and actual energy expenditure (calculated from oxygen consumption) was 0.87. Correlation between actual and predicted energy expenditure was 0.93.

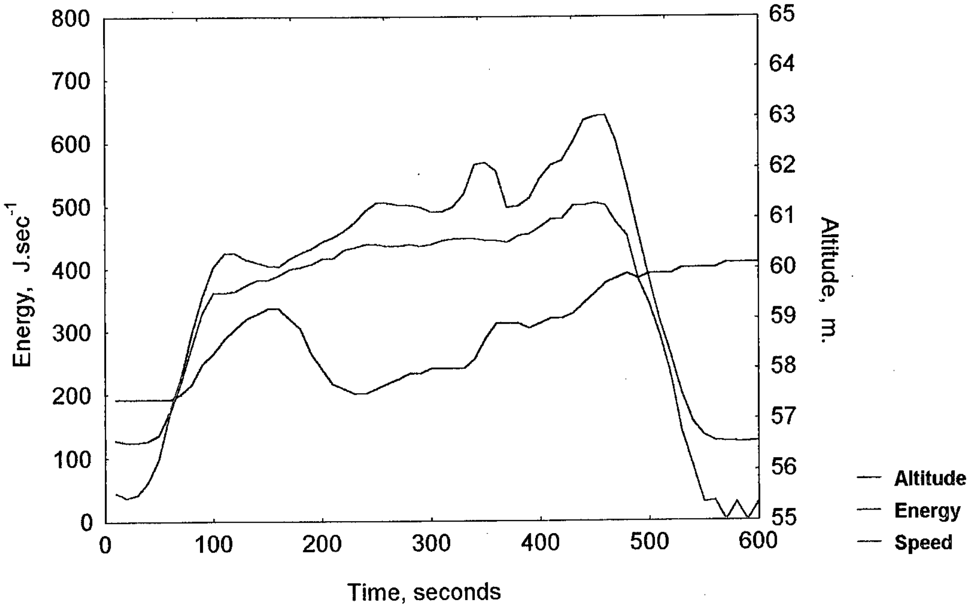


Figure 5. Relationship between Energy, Altitude and Speed during Reconnaissance on Day 1

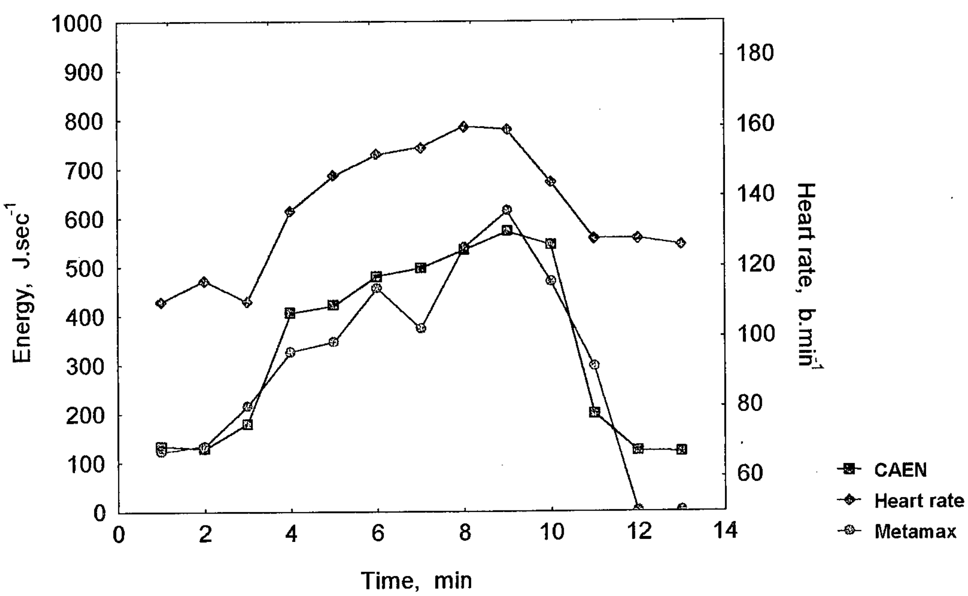


Figure 6. Energy predicted by CAEN compared to measured energy and heart rate

4. Discussion

4.1 Physiological performance

The main indicator of thermal strain, T_{re}, increased steadily from the resting level during Transportation and reached a maximum between 38°C and 38.2°C during Patrol and during Reconnaissance phases. Of interest was the variation in T_{re} due to the undulating nature of the terrain. When the soldiers were walking downhill for a significant period, T_{re} decreased slightly and then increased again once an uphill stage was reached. A value of $T_{re} \geq 38.0$°C has been widely used as an integrated index of heat stress and a criterion in the diagnosis of heat exhaustion. $T_{re} \geq 38.5$°C has also been used by OH&S practitioners as a termination level for civilian workers in hot environments. The T_{re} data from the trial indicate that while the soldiers were under a degree of thermal strain during Patrol and Reconnaissance, such strain did not approach levels at which soldier activity should be severely reduced.

Mean HR levels for the soldiers were well within the predicted maximum HR for young individuals and indicated that the soldiers were operating within their physical capabilities. The data show that mean HR fell rapidly during the brief navigation stops, indicating that the soldiers were physically fit and fully acclimatised. Similar observations can be made about mean T_{sk} for the soldiers. The metabolic rates of soldiers evident from VO2 values were typical of resting levels during Transportation. During Patrol, peak VO2 levels exceeding 3 $L.min^{-1}$ indicated that the soldiers were working hard, even though equipment weights of 32 kg were modest by Army standards and the terrain was not severe. Such VO2 levels are equivalent to peak metabolic rates of 1000 watts and would be sustainable only for brief periods of activity. While peak VO2 levels during Reconnaissance were lower than those for Patrol, the average VO2 levels for Reconnaissance (1.5 - 2.0 $L.min^{-1}$) again show that the soldiers were working at a relatively high metabolic rate as a consequence of their rapid march over undulating terrain under conditions of high solar radiation and relative humidity.

There are several competing factors that affect fluid balance in the body. Sufficient fluid must be maintained to uphold blood pressure so that normal cardiovascular functions are not disrupted. Exercising in the heat can cause severe strain to the body in balancing the fluid level. As metabolic heat produced exceeds the loss through sensible heat exchange, evaporative cooling remains the only effective heat exchange mechanism to prevent the body from over-heating. This one way heat flow will result in fluid loss through sweating and its effectiveness is governed by the sweating rate and the hydration level of an individual (15).

Comparing mean rectal temperatures (Figures 2a and 2b) with the rate of fluid loss suggests that the two could be closely linked. In the Patrol phase, T_{re} in Day 2 rose steadily and peaked at the middle of the course. This maximum rectal temperature fell only slightly towards the end of the Patrol. A similar trend was observed in the

Reconnaissance and Assault , with rectal temperature rising steadily and peaking at the Assault. Maximum rectal temperature during Reconnaissance was approximately 0.5°C higher than during Patrol. The higher sweat rate registered during Reconnaissance could be a direct response to this increase in body temperature. It is probable that the soldiers received a higher heat load from the environment during Reconnaissance. In the afternoon, the ambient temperature was much higher, with less cloud cover, and the absorption of radiant heat during Reconnaissance may have been significant. Results for Days 1 and 3 followed a similar trend with the exception that the peak rectal temperature during Patrol was almost identical to that in the afternoon. This could explain the small differences in the rate of fluid loss for the Patrol, Reconnaissance and Assault activities.

The overall weight loss of the two groups amounted to less than 1% of the nude weight (Table 2). This gives good indication that the soldiers were generally adequately hydrated. McArdle et al (16) suggested that water loss by sweating for an acclimatised person may reach a peak of 3 litres per hour and average 12 litres on a daily basis. This loss represents a 6 to 10% reduction in body mass which could have serious consequences on the physiological functions and physical work capacity of an individual. Judging from the low weight loss for the soldiers participating in the trial, it is evident that the soldiers are well aware of the danger of heat exhaustion and had regular water intake to replenish fluid loss by sweating.

4.2 Cognitive performance

Reports from other studies have indicated that intensive work and high heat and humidity can cause deterioration of cognitive performance (21, 22). The lack of evidence of psychological performance deterioration in the current study does not agree with such findings but does accord with a previous observation from this laboratory (23) in which no reduction in the scores of a number facility test was found after exercise in NBC clothing in tropical conditions. One possible explanation can be linked to the moderate work intensity of the soldiers. In combination with less humid weather conditions, the soldiers were not thermally stressed enough to show detectable signs of deterioration of cognitive functions. In addition, the soldiers may have been stressed by the instrumentation procedures at the start of the trial which set a relatively stressful baseline for comparison with the scores recorded in the latter part of the trial. As the trial progressed, the soldiers felt more relaxed about the instruments attached to their body which may have compensated for any slight increase in stress due to physical work and higher temperature and relative humidity. Furthermore, the unsophisticated ASA and STAI tests may not be sensitive enough to pick up subtle differences in the psychological performance that may occur under the activities and climatic conditions of the trial. This could be improved by using a more sensitive test battery.

4.3 Prediction of T_{re} from IR tympanic and insulated skin temperature

The data are in general agreement with the previous studies with respect to both

(i) the effect of ambient temperature on the (T_{re} -T_{ty}) difference, and
(ii) the capacity for accurate prediction of T_{re} from IR T_{ty}.

Table 4 clearly illustrates, again, that the difference between T_{re} and IR T_{ty} will vary with the prevailing air temperature, such that an optimal agreement between *end-of-exercise* T_{re} and T_{ty} normally occurs when Tdb is 32 to 33°C. The physiological rationale for this has been discussed elsewhere (5, 6, 8). The prediction accuracy for end-of-exercise T_{re} values noted in this dataset for "typicals" was promising, although the problem of having a small subset of subjects who display an atypical response remains unresolved. It is possible that these subjects have

(i) an unusual, narrow or tortuous ear canal or blocks of ear wax which precludes a clear view of the tympanum to the IR probe, increasing the contamination of the reading by ear canal temperature, and/or
(ii) an unusually high rate of heat loss from the head or face, such that T_{ty} is depressed by cooled venous blood.

It is also possible that the relative inexperience of the medics with the IR method contributed somewhat to the overall prediction errors. However, they obtained consistent results during their orientation to the method, and in any event observer error would be unlikely to contribute more than 0.1 to 0.2°C to a T_{ty} reading. The development of an ear-moulded, indwelling probe would remove these errors, and would have the considerable advantage of improving data collection efficiency.

Another important point in this regard is that the trials, especially in the Patrol phase, involved a good deal of intermittent exercise, with frequent rest breaks. Under these circumstances, rectal temperature can be expected to gradually rise throughout the phase, but tympanic temperature, being far more labile, was probably oscillating to a greater extent. The agreement between the methods should therefore be better than that presently noted in conditions where a constant workload is imposed for an extended period. As that is exactly the type of situation which can precipitate heat casualties, the effectiveness of the field application of the IR method should not be judged simply from these trials.

A further problem, regarding the evaluation of T_{cheek} as an explanatory variable, was that the soldiers were sometimes in the shade, and sometimes in full sunlight, when their cheek skin temperature was taken in the field. This could influence the relationship between T_{re}, T_{ty} and T_{cheek}. It is extremely difficult to avoid this type of error when following the protocol adopted for this study, with both T_{ty} and T_{cheek} being taken manually. Overall, the IR T_{ty} method shows considerable promise as a surrogate measure of core temperature under the conditions of this study, and should be further investigated and refined.

Bernard and Kenney (10) reported a very high correlation (r = 0.93) between insulated disk temperature on the skin and T_{re}. Reneau and Bishop (17) tested the validity of the Metrosonics, Inc. HS-3800 personal heat strain monitor in predicting T_{re}. The HS-3800 uses an insulated skin temperature disk to provide a surrogate body core temperature. Reneau and Bishop (17) reported that the correlation between the HS-3800 and T_{re} was r = 0.58 and r = 0.53 for two types of particle barrier, vapour permeable protective clothing. In our study, the weak correlations between T_{re} and insulated skin temperatures indicate that they may be unsuitable as field predictors of core temperature in their current format. The cooler ambient temperature conditions compared to those of Bernard and Kenney (10) would tend to lower skin temperatures and reduce the correlation with T_{re}. In addition, the construction of the thermistor used in our study differed markedly in size from those of Bernard and Kenny (10) and we experienced problems in maintaining good thermal contact with the skin. Other brief studies have indicated that insulated skin temperature closely follows oesophageal temperature, another indicator of core temperature, rather than rectal temperature. For these reasons we would recommend further examination under controlled conditions of insulated skin temperature as a predictor for excessive body core temperature. Changes in thermistor location, means of attachment, insulator design and other indicators of core temperature should be investigated further under controlled conditions.

4.4 Prediction of energy expenditure

The position data obtained by the GPS receiver was of marginal accuracy for the purposes of this study. Heavy filtering of the data was needed to produce useable results. The GPS elevation data was unusable due to large errors. Future studies will require more accurate position data. Only one set of position data was collected for the group as they moved through the terrain. This limited accuracy since individual subjects could move at different rates to the GPS receiver. This can be seen in the HR data where subjects rested or moved off at slightly different times to the GPS indication. During the movement periods subjects would go up or down slopes at slightly different times to the GPS recorder position. This was particularly relevant to the Mount Bundey Training Area where slopes may only take 1-2 minutes to traverse. Future studies conducted in terrain with more consistent or longer slopes may improve the discrepancies in recording. Individual GPS recorders for each subject should also be considered to avoid positioning errors due to individual movement.

5. Conclusions

The main indicators of thermal strain, T_{re}, HR and sweating rate, show that the soldiers experienced a modicum of heat strain during both patrol and reconnaissance phases of the exercise. However the degree of thermal strain overall did not reach levels which would be considered hazardous by OH&S practitioners. Peak metabolic rates for individual soldiers during patrol were extremely high, even though the weight of equipment carried was modest by Army standards and the terrain not severe. Such levels of activity could only be maintained for brief periods before having deleterious effects on performance. In general, the soldiers were aware of the effects of dehydration and maintained adequate hydration levels consistent with the environment. There was no evidence of significant deterioration in soldier cognitive performance during the trial.

The IR T_{ty} technique shows considerable promise as a surrogate measure of core temperature under the trial conditions and should be further developed and refined such that surrogate core temperature values can be displayed and stored automatically. The study showed weak correlations between rectal temperature and insulated skin temperatures and indicate that they may be unsuitable for field predictors of core temperature in the current format. Changes in thermistor location, means of attachment, insulator design and the relation to other indicators of core temperature should be investigated further under controlled conditions.

The energy expenditure model coded into the CAEN battle simulation has been validated in a field environment by the use of GPS, HR and oxygen consumption data. High correlations were obtained between actual and predicted energy expenditures during the study. Low correlations were attributed to individual soldier position errors. HR consistently reflected the energy required to move over the terrain as shown by its high time correlation with terrain elevation and energy expenditure. The prediction model coded into CAEN appears valid for level and positive slopes. Further controlled studies are needed to determine the effect of negative slopes and more accurate position values.

6. References

1. Department of Defence , Australia, Strategic Review 93, (1993).
2. Department of Defence, Australia, Defence White Paper: Defending Australia, (1994).
3. Ganong W.F., Review of Medical Physiology, Lange Medical Publications, Los Angeles, (1977): 1-17.
4. Defence Human Science Interim Steering Group Meeting, Minutes 15 May (1996).

5. Hansen R.D., Olds, T.S., Richards, D.A., Richards, C.R. and Leelarthaepin, B. (1996). Infrared thermometry in the diagnosis of heat exhaustion. Int. J. Sports Med. (17): 66-70.

6. Hansen RD, Amos D, Leake B. Infrared tympanic temperature as a predictor of rectal temperature in warm and hot conditions. Aviat. Space Env. Med.; *in press, 1996.*

7. Zehner J. and Terndrup T.E. (1991). The impact of moderate ambient temperature variance on the relationship between oral, rectal and tympanic membrane temperatures. Clin. Pediatr. (30) (Supplement): 61-4.

8. Hansen R.D., Daley W.H. and Leelarthaepin B. (1993) The effect of facial airflow on the estimation of exercise core temperature by Infrared tympanic thermometry. Aust. J. Sci. Med. Sport. (25): 26-31.

9. Shinozaki T., Deane R. and Perkins F.M. (1988). Infrared tympanic thermometer: evaluation of a new clinical thermometer. Crit. Care Med. (16): 148-50.

10. Bernard, T.E. and Kenney, W.L. (1994). Rationale for a personal monitor for heat strain. Am. Ind. Hyg. Assoc. J. (55): 505-514.

11. Burr R.E. (1991). Heat Illness: A Handbook for Medical Officers, US Army Research Institute of Environmental Medicine. Technical Report 91-3.

12. Goss, F.L., Herbert, W.G. and Kelso, T.B. (1989). A comparison of mean skin temperature during prolonged cycle exercise. Research Quarterly for Exercise and Sport (3): 292-296.

13. Broughton, P.F. Medical Statistics Made Easy. Sydney, Churchill Livingstone, 1984; p. 20.

14. Richards, R. and Richards D. (1979). Exertion-induced heat exhaustion and other medical aspects of City-to-Surf fun-runs. Med J. Aust. (141): 799-805.

15. Santee, W.R. and Gonzalez R.R., Characteristics of the Thermal Environment, in Human Performance Physiology and Environmental Medicine at Terrestrial Extremes. Edited by Pandolf, K.B., Sawka, M.N. and Gonzalez, R.R., Cooper Publishing Group, IN, USA, (1986).

16. McArdle, W.D., Katch, F.I. and Katch, V.L., Exercise Physiology: Energy, Nutrition, and Human Performance. Lea and Febiger, Philadelphia, (1991): 547-579.

17. Reneau, P.D. and Bishop, P.A., (1996). Validation of a Personal Heat Stress Monitor. American Industrial Hygiene Association Journal. (57): 650-657.

18. Pandolf, K.B., Givoni, B, and Goldman, R.F., (1977). Predicting energy expenditure with loads while standing or walking very slowly. Journal of Applied Physiology. (43/4): 577-581.

19. Pimental, N.A. and Pandolf, K.B., (1979). Energy expenditure while standing or walking slowly uphill or downhill with loads. Ergonomics. (8): 963-973.

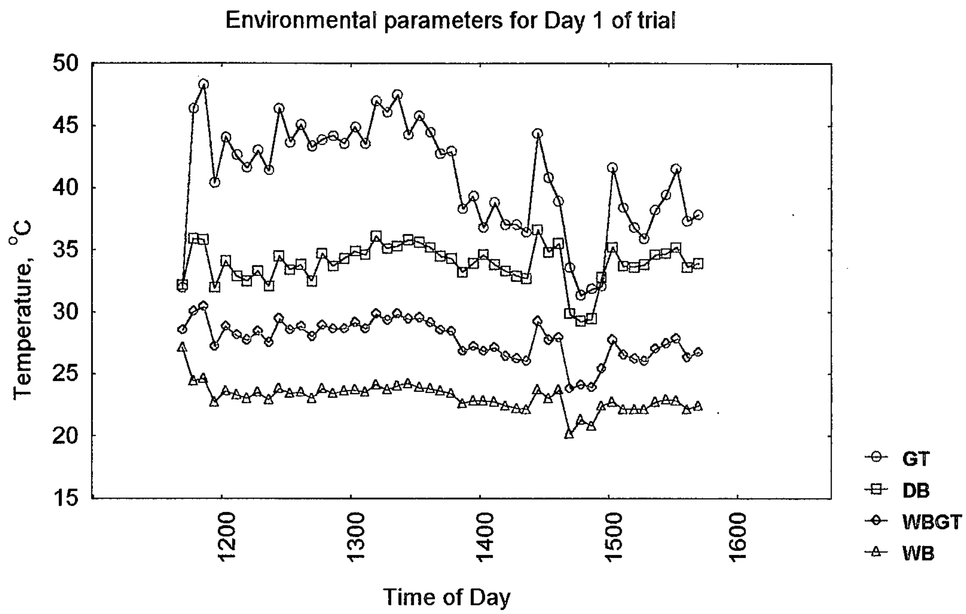
20. Spielberger, C.D., (1983). Manual for the State-Trait Anxiety Inventory. Palo Alto, Ca: Consulting Psychologists Press.

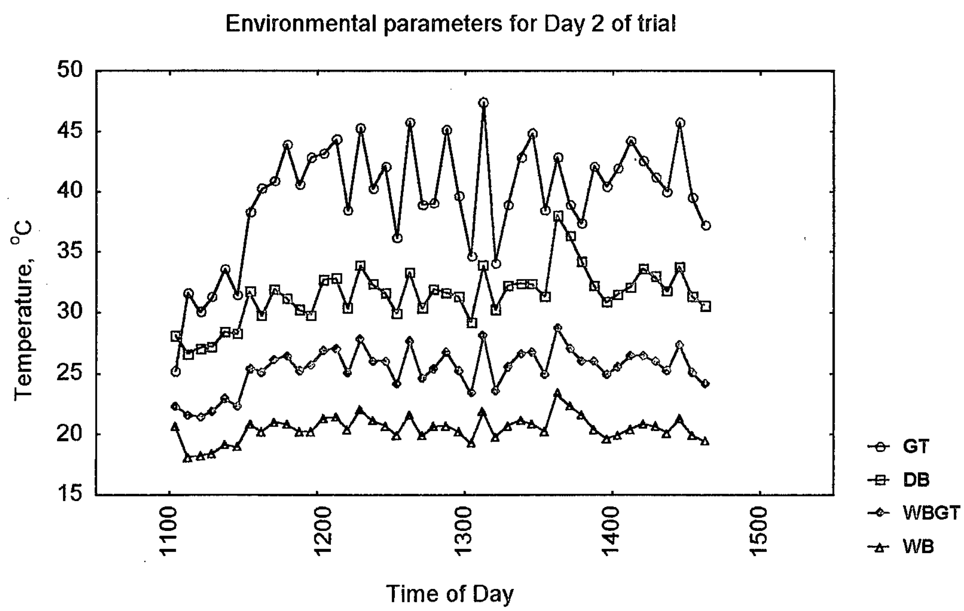
21. Curley, D.M. and Hawkins, R.N. (1983). Cognitive Performance during a heat acclimatization regimen. Aviat. Space Env. Med. (54): 709-713.

22. MacDonough, T.S. (1991). Noncombat stress in soldiers: How it is manifested, how to measure it and how to cope with it. R. Gal and A.D. Mangelsdorff (Eds.), Handbook of military psychology (pp. 531-558). New York: Wiley and Sons Ltd.

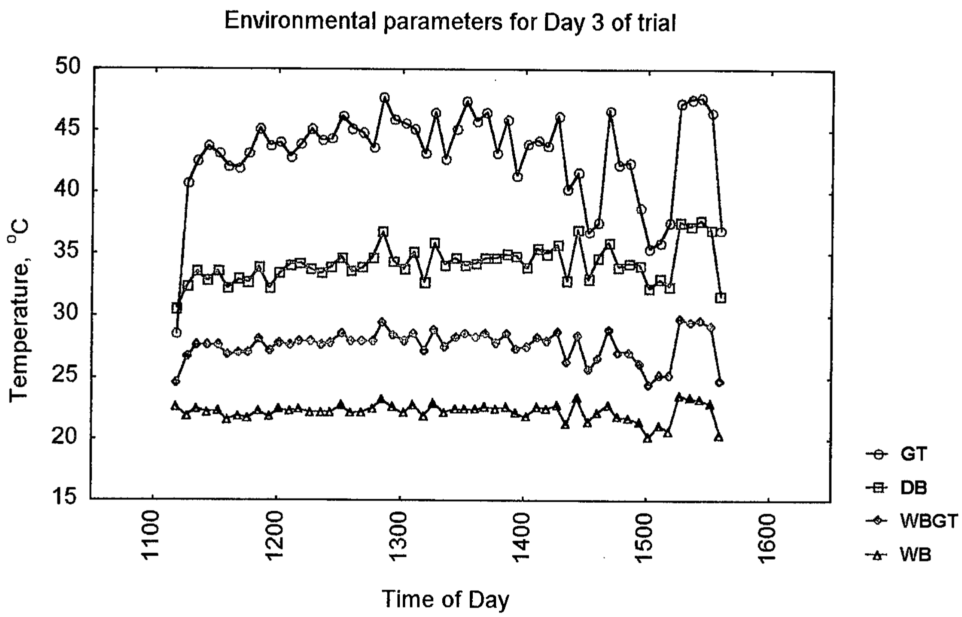
23. Tilley, R.I., Crone, H.D., Leake, B., Reed, R.I. and Tantaro, V. (1981). Defence Trial 6/425 : Performance of infantry soldiers wearing NBC clothing in hot/humid and hot/dry climates. DSTO Materials Research Laboratories Report, MRL-R-826.

Appendix 1. Environmental data

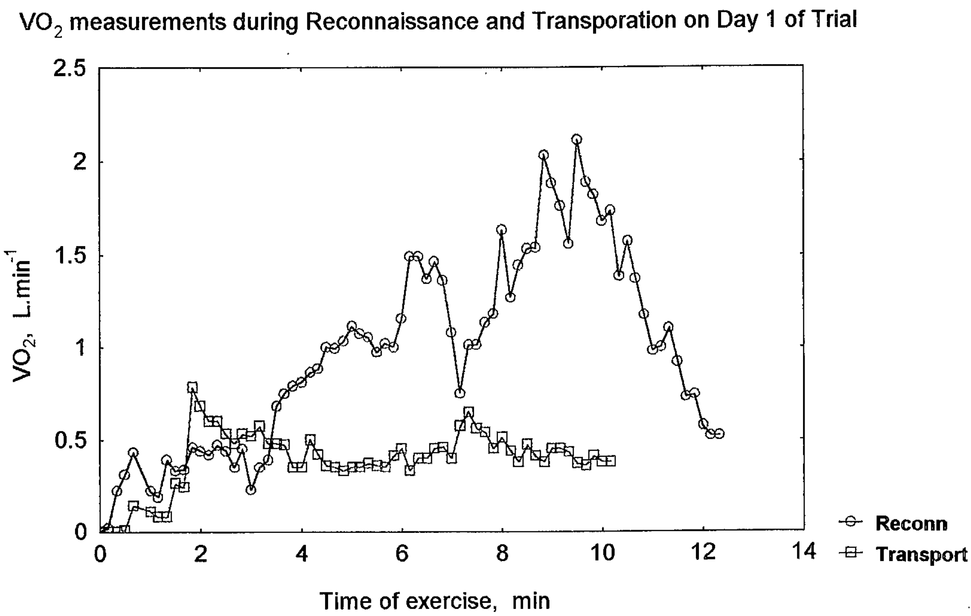


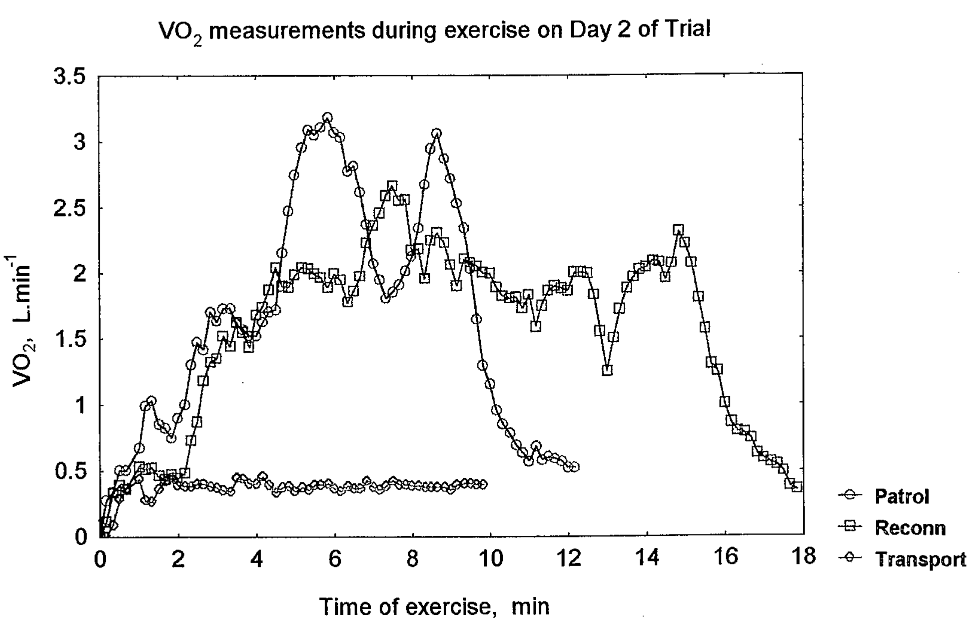


Appendix 1. Environmental data

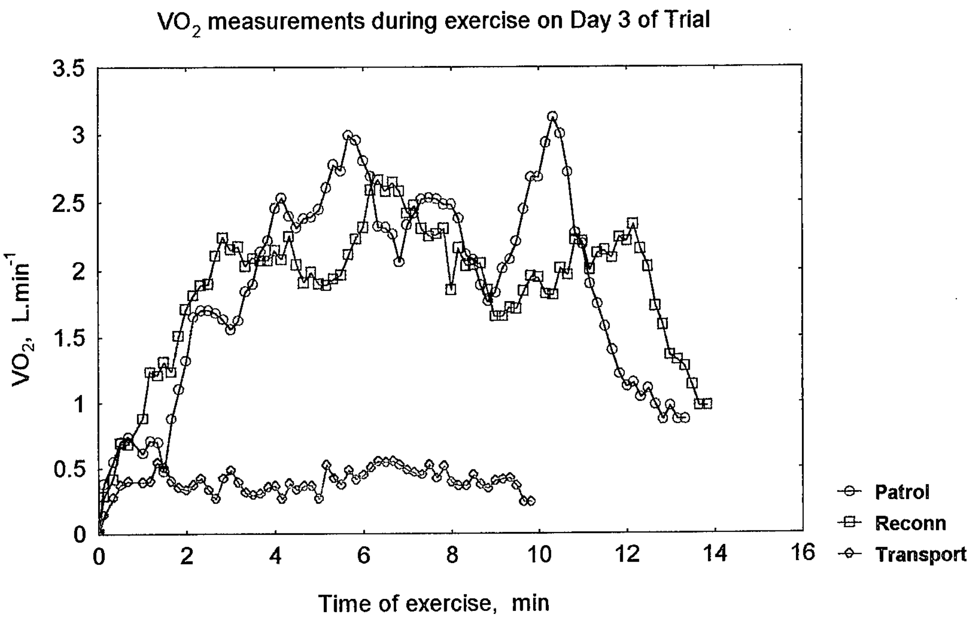


Appendix 2. VO2 measurements for individual soldiers during Transportation, Patrol and Reconnaissance Phases





Appendix 2. VO2 measurements for individual soldiers during Transportation, Patrol and Reconnaissance Phases



DISTRIBUTION LIST

The Physiological and Psychological Performance of Fully Acclimatised Soldiers Conducting Routine Patrol and Reconnaissance Operations in the Tropics

D. Amos, W.M. Lau, R.D. Hansen, V.J. Demczuk and J. Michalski

AUSTRALIA

DEFENCE ORGANISATION

TASK SPONSOR: DGOPHS

ST Program

Chief Defence Scientist
FAS Science Policy } shared copy
AS Science Industry and External Relations
AS Science Corporate Management
Counsellor Defence Science, London (Doc Data Sheet)
Counsellor Defence Science, Washington (Doc Data Sheet)
Senior Defence Scientific Adviser/Scientific Adviser Policy and Command (shared copy)
Navy Scientific Adviser (3 copies Doc Data Sheet, one copy distribution list)
Scientific Adviser - Army
Air Force Scientific Adviser
Director Trials

Aeronautical and Maritime Research Laboratory

Director
CSSMD
Dr H.D. Crone
Dr D.B. Paul
Mr D. Amos
Dr W.M. Lau
Mr R.D. Hansen

Electronics and Surveillance Research Laboratory

Director
CLSOD
Dr G. Gilman
Dr J. Manton (ITD)
Mr V.J. Demczuk

DSTO Library

Library Fishermens Bend
Library Maribyrnong
Library DSTOS (2 copies)
Library, MOD, Pyrmont (Doc Data sheet)

Forces Executive

Director General Force Development (Joint)
Director General Force Development (Land)
Director General Force Development (Sea), (Doc Data Sheet only)
Director General Force Development (Air), (Doc Data Sheet only)

Navy

SO (Science), Director of Naval Warfare, Maritime Headquarters Annex, Garden Island, NSW 2000.

Army

DPSYCH-A
CAPT J. Michalski
DEGP-A
SO (Science), HQ 1 Division, Milpo, Enoggera, Qld 4057
DENGRS-A, HQ Engineer Centre Liverpool Military Area, NSW 2174
2 Cavalry Regiment, Robertson Barracks, Palmerston, N.T.
ABCA Office, G-1-34, Russell Offices, Canberra (4 copies)

S&I Program

Defence Intelligence Organisation
Library, Defence Signals Directorate (Doc Data Sheet only)

B&M Program (libraries)

OIC TRS, Defence Central Library
Officer in Charge, Document Exchange Centre (DEC), 1 copy
DEC requires the following copies of public release reports to meet exchange agreements under their management:
*US Defence Technical Information Centre, 2 copies
*UK Defence Research Information Centre, 2 copies
*Canada Defence Scientific Information Service, 1 copy
*NZ Defence Information Centre, 1 copy
National Library of Australia, 1 copy

UNIVERSITIES AND COLLEGES

Australian Defence Force Academy
Library
Head of Aerospace and Mechanical Engineering
Deakin University, Serials Section (M list), Deakin University Library, Geelong, 3217
Senior Librarian, Hargrave Library, Monash University
Librarian, Flinders University

OTHER ORGANISATIONS

NASA (Canberra)
AGPS

OUTSIDE AUSTRALIA

ABSTRACTING AND INFORMATION ORGANISATIONS

INSPEC: Acquisitions Section Institution of Electrical Engineers
Library, Chemical Abstracts Reference Service
Engineering Societies Library, US
American Society for Metals
Documents Librarian, The Center for Research Libraries, US

INFORMATION EXCHANGE AGREEMENT PARTNERS

Acquisitions Unit, Science Reference and Information Service, UK
Library - Exchange Desk, National Institute of Standards and Technology, US

SPARES (10 copies)

Total number of copies: **69**

Page classification: UNCLASSIFIED

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION **DOCUMENT CONTROL DATA**	1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)
2. TITLE The Physiological and Cognitive Performance of Fully Acclimatised Soldiers Conducting Routine Patrol and Reconnaissance Operations in the Tropics	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION) Document (U) Title (U) Abstract (U)
4. AUTHOR(S) D. Amos, W.M. Lau, R.D. Hansen, V.J. Demczuk and J. Michalski	5. CORPORATE AUTHOR Aeronautical and Maritime Research Laboratory PO Box 4331 Melbourne Vic 3001

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TR-0420	AR-009-895	Technical Report	September 1996

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
510/207/0687	ADF 95/065	DGOPHS	30	23

13. DOWNGRADING/DELIMITING INSTRUCTIONS	14. RELEASE AUTHORITY
None	Chief, Ship Structures and Materials Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE CENTRE, DIS NETWORK OFFICE, DEPT OF DEFENCE, CAMPBELL PARK OFFICES, CANBERRA ACT 2600

16. DELIBERATE ANNOUNCEMENT
No limitations

17. CASUAL ANNOUNCEMENT Yes

18. DEFTEST DESCRIPTORS
Physiological cognitive performance, soldier patrol reconnaissance operations, tropical environments, heat strain

19. ABSTRACT
The physiological and cognitive performance of soldiers undertaking routine patrol and reconnaissance activities in the tropics have been investigated. During both patrol and reconnaissance the soldiers experienced a degree of heat strain which did not reach levels considered hazardous by OH&S practitioners. There was no evidence of significant deterioration in soldier cognitive performance during the trial. Peak metabolic rates for individual soldiers during patrol were high, even though the weight of equipment carried was modest and the terrain not severe. In general, the soldiers were aware of the risks of dehydration and maintained adequate hydration levels during the trial. The IR tympanic temperature technique shows considerable promise as a surrogate measure of core temperature under the trial conditions. The study showed weak correlations between rectal temperature and insulated skin temperatures. The energy expenditure model coded into the CAEN battle simulation has been validated in a field environment by the use of GPS, heart rate and oxygen consumption data.

Page classification: UNCLASSIFIED