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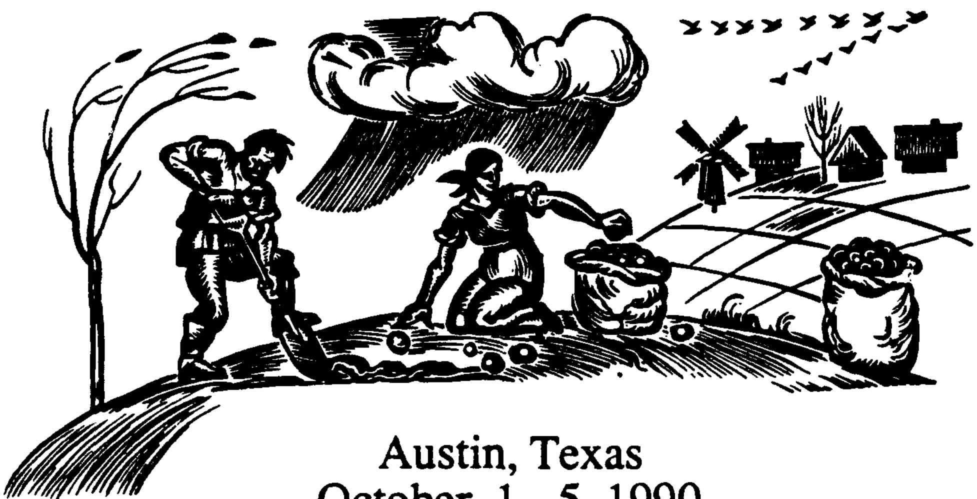
INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS - IV



Austin, Texas
October 1 - 5, 1990

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This is the Final Report for an AFOSR Grant provided to support the 4th International Conference on Environmental Ergonomics held in Austin, Texas, October 1-5, 1990. The report contains a list of registrants, and copies of the First Announcement, Call for Papers, and Proceedings of the conference. These materials present a rather complete description of the arrangments, attendance, and technical content of the conference.

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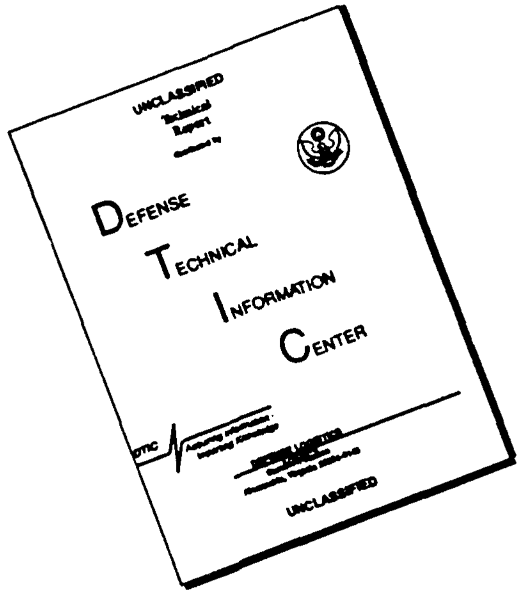

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INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS - IV

Austin, Texas
October 1 - 5, 1990

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Jean-Jacques Vogt
France

Jürgen Werner
West Germany

Meeting Content and Format

Environmental Ergonomics addresses problems of maintaining human activity under physiologically stressful conditions. This includes two general areas —human physiological responses to exercise and stress, and the properties of clothing and protective equipment. The conference has been designed to provide a congenial environment for discussion among scientists working in both areas.

Each session begins with a presentation by an invited speaker uniquely qualified to summarize current knowledge, speculate on directions for future research, and guide discussion. Contributed papers are divided between oral and poster presentations to obtain sessions that are as coherent as possible. The schedule contains ample time for viewing posters and discussion with their authors.

Notes

Meeting Arrangements

Reception

The reception on Tuesday evening will be held at the Zilker Park Club House which provides a pleasant view of downtown Austin. Transportation between the Four Seasons Hotel and the Club House will be provided by Armadillo. The first group will leave the hotel at 1730 with additional departures every 20 minutes. A selection of Texas beer and wine, soft drinks, and hors D'Oervres will be provided during the conversation hour which precedes a typical Texan barbecue dinner at approximately 1900 hours. After dinner, Ruth Alpert, a very accomplished performer from Albuquerque, will present a demonstration of clog dancing accompanied by several local folk musicians. The Armadillo will begin return trips to the Four Seasons at 2100 hours.

Banquet

The banquet on Thursday evening will be preceded by a conversation hour with a cash bar beginning at 1830 hours. Dinner will be served at 1900 hours. Registrants have a choice of two entrees -- Beef medallion and campfire shrimp with Jack Daniel sauce and lime butter, or Sauteed Pacific salmon and roasted tomatillo sauce. Please make your selection at the Registration Desk before noon on Tuesday, October 2, 1990.

After dinner Dr. Ethan R. Nadel, Director of the John B. Pierce Foundation at Yale University, will present a program on the Ergonomics of Human Powered Flight: The April 23, 1988 flight of the Daedalus across the Agean sea. Following his presentation, we will adjourn to the foyer where a glass of "Chateau La Fleurie Peyrquey" and assorted chocolates will be served.

Around Austin

Several cultural and historic sites are worth visiting in Austin. The concierge at the Four Seasons has informative brochures describing most of them, and she can also tell you how best to get there. A few possibilities are listed below.

Texas Capitol Area:	State Capitol and Governor's Mansion, Old Bakery and Emporium
The University of Texas Area:	Harry Ransom Museum Lyndon B. Johnson Presidential Library
Shopping:	Barton Creek Mall Highland Mall
Browsing:	A variety of interesting small shops and restaurants may be found along Congress Avenue and Sixth Street in the central city area.

Program for Spouses

Information about the program for spouses will be available at the Registration Desk. Please sign up for these activities on Sunday or Monday.

Acknowledgements

The U. S. Air Force Office of Scientific Research provided a significant grant which made this conference possible.

W. L. Gore and Associates, Inc. of Elkton, Maryland donated the attractive bags which were given to registrants and are becoming a traditional part of the Environmental Ergonomics Conferences.

Notes

Schedule of Sessions

	0830 - 1200	1200 -1330	1330 - 1700	1900 - 2000
Sunday	—	—	Registration	Cash Bar
Monday	Session 1	Lunch	Session 2	—
Tuesday	Session 3	Lunch	Session 4	Reception
Wednesday	Session 5	Lunch	Discussion	—
Thursday	Session 6	Lunch	Session 7	Banquet
Friday	Session 8	Finis	—	—

Each session consists of a 40 - minute invited lecture followed by five 30 - minute contributed papers, with a break midway through the session. Authors of poster presentations will be available to discuss their papers during the afternoon breaks on Monday, Tuesday, and Thursday.

Sessions and Invited Speakers

Session	Subject	Invited Speaker
1	Fundamental Considerations	Dr. J. R. Allan Army Personnel Research Establishment Farnborough, England
2	Physiology	Dr. Loren Myhre USAF School of Aerospace Medicine San Antonio, Texas
3	Measurement Techniques - I	Dr. Elizabeth McCullough Institute for Environmental Research Kansas State University - Manhattan
4	Measurement Techniques - II	Dr. Wouter Lotens TNO Institute for Perception Soesterberg, The Netherlands
5	Breathing Apparatus and Ventilation	Dr. William P. Morgan Sport Psychology Laboratory The University of Wisconsin - Manhattan
6	International Standards and Human Performance - I	Dr. Bjarne Olesen Technical University of Denmark Lyngby, Denmark
7	International Standards and Human Performance - II	Dr. Kenneth C. Parsons University of Technology Loughborough, England
8	Survival Following Accidental Immersion in Cold Water	Dr. Alan M. Steinman U. S. Public Health Service Rockville, Maryland

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FOR WHOM DO WE RESEARCH?

Dr J R Allan,
Army Personnel Research Establishment,
Farnborough, GU14 6TD.

In his search for knowledge and understanding of the world around him, the pure research scientist has no need of other justification. But for those working in the broad field of ergonomics, possible applications of our results form an important part of the overall objective. The road from the research laboratory to the factory door is long and poorly signposted, and it is populated only thinly with those who are motivated to improve the route and facilitate the flow of traffic. Here is important territory for the ergonomist. Yet too often we are content to research and publish but to leave to others the crucial task of ensuring effective application of our results to the benefit of users. The literature is full of good ideas withering on the vine for want of effective marketing.

From the users' point of view it is important for us to seek a more precise elucidation of the consequences for human performance of environmental stresses of all kinds. We may establish physiological responses - high body temperature, low arterial oxygen saturation, high heart rates - but our customers need to know whether these matter in a practical sense, and this requires knowledge of effects on performance. This is too important a matter to be left to the psychologists alone and it is essential to encourage closer cooperation between physiologists and psychologists in advancing our knowledge in this area. The otherwise excellent and impressively supported Environmental Ergonomic Conferences would be much enriched by more contributions by psychologists.

In passing, some of you may be aware of the exciting advances being made in techniques for measuring brain function. The days of the simple three lead electroencephalogram are numbered and the possibility of physiological measurement of thought processes, emotion and even personality are on the horizon. This is all a long way ahead, but have a look at the excellent work of Munoz and Guitton[1] at the Montreal Neurological Institute demonstrating, inter alia, the presence of retino-topic, tonic discharges in the superior colliculus excited during the mere planning of eye movements. This work provides a tentative mechanistic explanation (pre-excitation of relevant neural circuity), for the facilitation of a series of actions by 'thinking them through' in advance. Perhaps in the long run psychology is really only a branch of physiology that has yet to discover what to measure.

An important aid to user friendliness among ergonomists is the growing use of predictive modelling, yet it attracts both advocates and detractors. One of its most important benefits has been the provision of a basis on which practical advice to users can be developed. A good example, which has found much practical application is the use of the Texas thermoregulatory model[2] for predicting likely survival times in water. Another model, developed at the Institute of Aviation Medicine at Farnborough for predicting the performance effects of interactions between time on duty and circadian rhythms[3], has proved useful in determining, for example, flight duty time limitations for aircrew. Thus the effort devoted to modelling is of some importance to the user population who, by and large, provide our funding.

Among the advantages of modelling are its ability to focus on important issues where further experimentation could usefully be undertaken to improve predictive accuracy. But the process must be one of evolution with a continual exchange of ideas between the modeller and the experimenter in the quest for improvements. Models should not be set in concrete or applied dogmatically; to do so is to limit the benefits and to risk superficial discrediting. One must frequently return to the data and question its precision and, if necessary, repeat experimentation using more modern techniques. It is easy to be dazzled by apparent precision in a model and one must always be aware of the data upon which it was developed. For example, the models upon which flight time limitations are based are derived from laboratory performance testing, but we know rather little about the relevance of laboratory performance tests to real world activities. Perhaps more extensive job analysis techniques might help to determine more precisely those aspects of human performance that are important in a particular activity.

Human variability is often advanced as an objection to the modelling approach which is usually based on average results. But practical user policies are mostly tailored for populations rather than individuals. Much of the variability of physiological responses is not inherent in the system but determined by identifiable differences in physical and other characteristics. For example, differences in body temperature responses to immersion can be attributed to differences in fat, metabolic responses, cardio-vascular responses etc, some of which we understand. But there are many yet to be elucidated, providing both a challenge to the physiologist and an expectation for the modeller that predictive accuracy can be improved. Generally, limitations are due to lack of knowledge rather than modelling capability per se.

I mentioned earlier the important issue of marketing our expertise. User friendliness is one thing, but user ignorance of the value and applications of human factors research has been widespread. In this area there have been some new developments aimed at encouraging industry to take more cognizance of human factors when designing equipment and machinery. Led by the US Army, a management system has been developed to ensure the proper consideration of human factors in equipment development programmes. It is known as MANPRINT[4] derived from MANpower and PeRsonnel INTegration. The aim is to encourage user-orientated design by contractually obliging industry to consider, throughout the whole development process from concept to manufacture and on in to service, the six MANPRINT domains. These are Manpower (number of operators); Personnel (required aptitudes, capabilities and experience of operators); Training Requirements; Human Factors Engineering; System Safety (accident prevention) and Health Hazards. The results of competition between suppliers of equipment will be significantly affected by the extent to which they have successfully demonstrated the user benefits of their proposals.

The MANPRINT approach to a people-orientated design philosophy may be confidently expected to increase manyfold the profile of human factors expertise, recognition of its importance and demand (and funding) for research. Meeting that challenge rests significantly in the hands of human factors scientists in the broadest sense. But they also must be sure to be user-friendly.

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ENERGY EXCHANGE DURING WALKING

Paul Webb
Yellow Springs, Ohio

INTRODUCTION

While the energy cost of walking is known from VO_2 and VCO_2, energy exchange has not been measured by direct calorimetry, probably because placing a treadmill in a calorimeter room would overwhelm the heat loss from a subject. That problem is avoided with my suit calorimeter, which separates the subject from a treadmill and its heat. During exercise, the terms of interest are work (W), heat (ΣQ) and fuel, or energy cost (M). The heat balance equation relates these terms:

$$M = \Sigma Q \pm W \pm S$$

When W is measured with a cycle ergometer, the equation has been verified repeatedly since the first reliable human calorimetry at the beginning of this century. But early work with water cooling garments for controlled cooling during walking (1) suggested that there was external work (mechanical work delivered, useful work, concentric work) in level walking, since M seemed consistently to exceed heat loss. This was disturbing because biomechanical analysis of level walking traditionally assumes that all work is internal and appears as heat. Summarized here are two studies (2,3) that were designed to examine this matter with current methods of direct and indirect calorimetry.

METHOD

Ten fit subjects (5 women, 5 men) walked on a level treadmill at 3 speeds -- 2.5, 4.6 and 6.7 km/h -- for long enough that skin and rectal temperatures became stable, hence rate of heat storage (S) became negligibly small and could be dropped from the heat balance equation. M was measured with a respiration chamber and ΣQ with the suit calorimeter. We also studied level walking when the subjects carried a weighted backpack and when they walked against a horizontal load. In addition, they pedalled a cycle ergometer at 2 loads that had nearly the metabolic cost of the two faster walking speeds.

In a second study 10 fit men walked uphill at 5 and 10% grades, downhill at -5 and -10% and on the level, all at the single speed of 5.4 km/h. They walked long enough that body temperatures stabilized, thus minimizing S. M was measured with a Gould 2900 system operating in the dilution mode; ΣQ was again measured with the suit calorimeter.

RESULTS

Metabolic cost and heat loss increased with walking speed, with positive vertical grade and with added weight. M decreased and ΣQ increased with negative vertical grade, which is a power input that becomes heat internally.

Measurable external work during grade walking, during level walking against horizontal load and during cycling fitted quantitatively into the heat balance equation.

However, only during cycling and downhill walking was the heat balance equation correct as written. In 10 of 12 walking conditions (-5 and -10% were exceptions) M was greater than ΣQ by 6 to 12%, the difference being highly significant ($p < 0.01$ to 0.001). If we assume that there is external work in (level) walking, labeled W_{walk}, the data can be summarized as follows (numerical values in watts):

	M	=	ΣQ	+	W_{vert}	+	$W_{horiz\ load}$	+	W_{walk}
level walking, 2.5 km/h	239	=	225	+	0	+	0	+	14
4.6 km/h	364	=	335	+	0	+	0	+	29
4.6 km/h with loaded pack	435	=	407	+	0	+	0	+	28
5.4 km/h	414	=	390	+	0	+	0	+	24
6.7 km/h	601	=	538	+	0	+	0	+	63
4.7 km/h with horizontal load	610	=	491	+	0	+	80	+	39
Walking up 5% grade, 5.4 km/h	598	=	516	+	61	+	0	+	21
10% grade, 5.4 km/h	867	=	650	+	122	+	0	+	95

The values for W_{walk} ranged from 14 to 95 watts and were significantly different from zero.

DISCUSSION

These arduous experiments showed the need for a nonthermal energy term on the "Energy Out" side of the equation. It is possibly: (1) experimental error, which seems unlikely because cycle exercise verified the accuracy of the equipment, as does close agreement between M and ΣQ at rest; (2) due to incorrectly assuming that direct and indirect calorimetry are always equivalent (a thoroughly heretical notion!); and (3) that there is external work in (level) walking, that is, that energy is transferred to an external object but not as heat. Explanation (3) is provocative.

To date we have suggested that W_{walk} might be the result of interaction between the foot and the ground, as in compressing the heel of the shoe and bending its sole, since the term increases with speed, hence step frequency. But W_{walk} varied with grade at a constant walking speed, which led us to say that during the positive part of the step cycle (rise of body mass against gravity) some fraction of the metabolic energy is externalized which is not precisely balanced by energy internalized as heat during the negative part of the step. While this could be true, it is not exactly an explanation.

CONCLUSION

Measuring energy exchange during level and uphill walking indicates that there is unexpected external work whose nature has yet to be established.

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EFFECT OF HEAT STRESS ON SKIN AND MUSCLE BLOOD FLOW DURING DYNAMIC HAND-GRIP EXERCISE

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INTRODUCTION

In a hot environment cutaneous circulation increases, and it is linearly related to the rise in internal body temperature. During exercise a significant diversion of blood flow to the skin may lower muscle perfusion and reduce physical performance. It has been shown that in sheeps exposed to heat stress blood flow in the active muscles reduced 26-56% when compared to the control situation (1). In humans, there is no direct evidence on reduced muscle blood flow under exercise-heat stress (2).

It can be hypothesized that in a hot environment muscle blood flow may decrease particularly during light muscle work while the amount of vasoactive substances entailing muscle vasodilation is small and the activity of sympathetic nervous system contributing vasoconstriction is high (3). Consequently, the aim of this study was to examine the effect of an acute heat stress in a sauna on blood flow changes in forearm skin and muscles during very light and light hand-grip exercise.

METHOD

The subjects were nine unacclimatized, physically active and healthy men. The study procedure followed the Helsinki declaration, and was accepted by the Ethical Committee of the Institute of Occupational Health.

The experiments were carried out in a dismountable sauna (2*2*2 m) which was set up in the laboratory. The subjects performed a test serie of hand-grip exercise both in a thermoneutral (25°C), and in a hot sauna environment (65-70°C). In the tests, the hand-grip exercise was performed with the right hand. The left hand served as a control, and was kept at the similar position as the exercising hand. The test serie was started by a rest period of 5 minutes, and followed by a period of 6 minutes of very light rhytmic dynamic hand-grip exercise (~13 % of the maximal voluntary contraction, MVC). After the very light exercise the subjects rested for 6 minutes and then repeated the hand-grip exercise at the light contraction level (~34 % MVC). The rate was 30 contractions/min. Hand-grip exercise was carried out, and hand-grip strength was measured with a dynamometer which comprised a water-filled rubber tube with a pressure probe connected to an indicator and a power supply.

In the experiments forearm blood flow was measured in the right and left forearm during pauses by venous occlusion plethysmography utilizing mercury-in-Rubber strain-gauges. By venous occlusion plethysmography, changes in skin blood flow can be estimated when the underlying muscles are at rest (control forearm), and changes in muscle blood flow (exercising forearm) can be estimated when cutaneous circulation is stable. Skin blood flow was also measured by a laser Doppler flow meter in the right and left forearm using two Periflux Pfld instruments (Perimed, Sweden). Internal body temperature was measured at heart level with an esophageal probe (YSI 511, Yellow Springs Instruments, USA). Skin temperature was measured in the right and left forearm by thermistors (YSI 427). Heart rate was continuously recorded every minute in the experiments using a Sport Tester PE 3000 Monitor (Polar Electro, Finland).

A two-way analysis of variance for repeated measures and the post hoc comparisons with the Newman-Keuls procedure were employed to determine the effects of environment and hand-grip exercise on blood flow. Differences were considered to be statistically significant when $p<0.05$.

RESULTS

In the end of the thermoneutral period esophageal temperature was ($\bar{x} \pm SD$) 36.92±0.24°C, and in the end of heat stress it was 37.74±0.22°C. The corresponding values for heart rate were 58±7 beats/min and 99±11 beats/min, respectively. In the thermoneutral environment skin temperature for both forearms was 32-33°C and in the heat ~40°C. There were no statistically significant differences in skin blood flow, measured by laser-Doppler flowmetry, between the exercising and control forearm.

The analysis of variance revealed a statistically significant ($p<0.01$) effect of both an environment and exercise on forearm blood flow. In thermoneutrality, hand-grip exercise increased blood flow in the working forearm, as compared to the control forearm, by 6.0±2.3 ml 100 ml^{-1} min^{-1} at 13 % MVC, and 17.9±7.5 ml 100 ml^{-1} min^{-1} at 34 % MVC ($p<0.01$). In the heat, the increases were significantly ($p<0.01$) higher: 12.5±6.6 ml 100 ml^{-1} min^{-1} at 13 % MVC, and 32.2±17.8 ml 100 ml^{-1} min^{-1} at 34 % MVC, respectively.

CONCLUSIONS

These results suggest that heat stress of studied magnitude increases blood flow in active muscles during dynamic hand-grip exercise at 13 % and 34 % MVC.

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INFLUENCE OF BLOOD VOLUME ON BAROREFLEX CONTROL OF FOREARM VASCULAR RESISTANCE

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INTRODUCTION

During pooling of blood in the legs, arterial blood pressure is maintained by cardio-acceleration and constriction of splanchnic and cutaneous vascular beds. Cardioacceleration and the gain of the baroreflex control of forearm vascular resistance are both attenuated in physically fit individuals (1,2). The increased blood volume (BV) accompanying training has been suggested as a causal mechanism (2). This study investigated that hypothesis by measuring the gain of the cardiopulmonary baroreflex control of FVR during progressive lower body negative pressure (LBNP) before and after expansion of the BV by infusion.

METHOD

Six healthy, moderately active, male student volunteers (aged 20-28 years) were subjected to venous pooling by progressive LBNP (0 to -20 mmHg). All experiments were carried out in an environmental chamber at 30°C and low humidity and with the subject in a post-absorptive state. Subjects were asked to refrain from vigorous prior exercise on the day of each experiment.

Central venous pressure (CVP) was approximated by the measurement of peripheral venous pressure (PVP) in the antecubital vein of the dependent right arm, using the method of Gauer and Sieker (2,3). Arterial measures were taken with the subject supine. Forearm blood flow (FBF) was measured by venous occlusion plethysmography, using a Whitney mercury-in-Silastic strain gauge on the left forearm with the hand circulation occluded at the wrist. Heart rate was calculated from an electrocardiograph. Arterial blood pressures were determined by the oscillometric technique. Mean arterial pressure (MAP) was calculated as diastolic + $^1/_3$ pulse pressure. FVR was calculated by dividing MAP (mmHg) by FBF ($ml.min^{-1}.100ml^{-1}$); these values were expressed as resistance units (U). The gain of the baroreflex control of FVR was defined as the coefficient of regression of FVR on PVP.

BV was then expanded by approximately 10% by the drip infusion of 8g per kg bodyweight of 5% serum albumin in Ringer's solution and the measurements were repeated.

The main effects of blood volume and LBNP levels were analysed by two-way ANOVA with post-hoc analysis of specific differences by contrasts using the SYSTAT program. Regression slopes were tested by a one-tailed paired t-test. The 0.05 level of significance was accepted.

RESULTS

There was no significant effect of either LBNP or its interaction with BV on any of the arterial measures of blood pressure or heart rate. After BV expansion, there were no changes in heart rate or diastolic blood pressure, but there were significant increases in systolic (7 $\pm$ 2 mmHg) and pulse pressures (7 $\pm$ 2mmHg) (mean $\pm$ SE). FBF was progressively reduced during LBNP from 3.8 $\pm$ 0.7 at ambient pressure to 2.1 ± 0.6 $ml.min^{-1}.100ml^{-1}$ at −20mmHg, but, after BV expansion, was higher at all levels of LBNP by 1.0 ± 0.5 $ml.min^{-1}.100ml^{-1}$ ($p<0.05$). A corresponding progressive increase with LBNP occurred in FVR from 24 ± 4 to 63 ± 23 units. During hypervolemia, this dropped to 20 ± 3 to 37 ± 10 units ($p<0.05$).

PVP, like FBF, was progressively reduced during LBNP, from 7.2 ± 0.9 to 2.0 ± 0.6 mmHg and after BV expansion was likewise higher at all levels of LBNP by 1.4 ± 0.6 mmHg ($p<0.05$).

The coefficient of regression of mean FVR on PVP, representing the gain of the baroreflex control of FVR, was reduced from −7.0 to −2.9 $U.mmHg^{-1}$ by hypervolemia ($p<0.05$) (Fig. 1). Five of the six subjects followed the same pattern, but one had an increase in regression coefficient from −0.6 (control) to −2.2 during hypervolemia. On a previous control test his coefficient was −4.7.

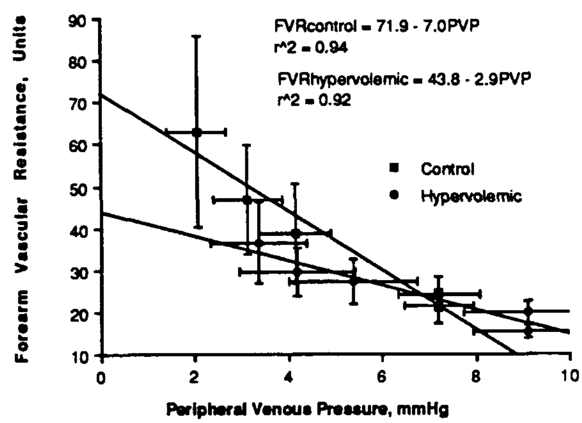

Figure 1. Hypervolemic attenuation of baroreflex control of FVR (n=6).

CONCLUSIONS

After BV expansion, PVP and FBF increased significantly with no change in sensitivity to LBNP. FVR was reduced significantly during acute hypervolemia, although the lack of interaction between BV and LBNP effects ($p = 0.815$) suggested no significant change in its sensitivity to LBNP. The coefficient of linear regression of FVR on PVP, the gain of the baroreflex, was significantly reduced by acute hypervolemia, consistent with the hypothesis that the attenuation of the baroreflex seen in fit subjects may be the result of increased blood volume, but a short-term, rather than a long-term effect.

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THERMAL RESPONSES OF NUDE AND CLOTHED SUBJECTS EXPOSED TO INCREASING LEVELS OF SKIN WETTEDNESS AT CONSTANT REQUIRED EVAPORATION

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INTRODUCTION

During exercise in the heat, the primary means for heat transfer to the environment is by evaporation. The maximum evaporative rate which is restricted in humid conditions, also appears to be limited as a function of the clothing layers : this limitation led to the permeation efficiency factor, F_{pcl} (1). For human beings exposed to warm humid environments, there is a threshold of ambient vapor pressure at which thermoequilibrium cannot be maintained and beyond this threshold, body temperature shows a continuous upward inflection as a result of heat stress. At the point at which thermoequilibrium is impossible corresponds a level of critical skin wettedness (w_{crit}). The w_{crit} threshold is obtained for lower ambient vapor pressure in clothed subject compared to nude ones, and this allows indirect determination of F_{pcl} (2).

The present study allows a reexamination of our methodology for w_{crit} and F_{pcl} physiological determination previously based on onset of upward of body drift temperature, when clothed subjects were compared to nude ones. In this work, we examined the different variables reflecting the occurrence of thermal imbalance in nude or clothed subjects while exercising in humid heat.

METHODS

Experimental tests were conducted on 2 groups of four healthy unacclimatized male subjects (Ss).

The subjects were dressed either in briefs and sport-shoes (nude) or in a 0.55 clo clothing ensemble consisting of briefs, long-sleeved shirt, trousers (all 100 % coton) and shoes (3).

After an initial 30 min rest-exposure at the thermoneutrality, the subjects started to exercise for 90 minutes at a constant work load (W = 50 Watts at 60 rotations per minute) while T_a and T_r were increase stepwise to 35°C and V_a to 0.6 m.s^{-1}. At the same time, T_{dp} was raised to the level required by the experimental test (2.3 < P_a < 4.5 kPa for nude Ss and 1.6 < kPa <3.6 for clothed Ss).

After $\overline{T}_{sk}$ had reached the 35°C level, air and wall temperatures were set at $\overline{T}_{sk}$ value with the purpose of reducing R and C to a value close to 0. The imposed ambient conditions (differing only because of Pa) where chosen arbitrarily in a semi-random schedule, alternating the nude and clothed weekly exposures.

Rectal temperature (T_{re}) and 10 local skin temperatures were recorded, as well as local chest sweat rate, using a dew point measuring technique. For clothed subjects, miniature dew point sensors allowed local skin wettedness assessments (4) Average skin wettedness was calculated from local determinations. Sweat accumulation in the clothes was also determined at the end of each experimental session on clothed Ss.

RESULTS

Local sweat rate

The chest sweat rate under a local thermal clamp of 36°C increased beyond a certain threshold in both clothed or nude subject. However the slope of the increment was more marked in clothed man ($p < 0.05$) since the slope ratio was 1.5 (clothed/nude). The humidity thresholds for an increase in local sweating was 2.6 and 3.6 kPa for clothed and nude subjects, respectively. This yields a 0.70 ratio in vapour pressure differences between the skin and the air at the treshold for sweat rate acceleration.

Drift in core temperature

The drift in temperature was determined as the slope of the Tre increase with time during the last 30 min of the test. The slope of the Tre drift was steeper in nude subjects. The rise in core temperature occurred sooner in clothed man ($P_a > 2.3$ kPa) compared to nude man ($P_a > 3.7$ kPa).

Taking into account the small but significant ($p < 0.05$) difference in $\bar{T}_{sk}$ observed at the threshold point ($\bar{T}sk$, nude = 36.2°C and $\bar{T}sk$, clothed = 35.7°C, the ratio of the differences in water vapour pressure between skin and air at the critical point was 0.66.

Skin wettedness in clothed subjects

Below 2.5 kPa, mean skin wettedness was found to be near 53% without any signficant effect of the ambient level of water vapour pressure within the humidity range used here.

When humidity was raised above 2.5 kPa, skin wettedness started to increase and rose to 82% at 3.1 kPa. For technical reasons, condensation problems disturbed the measurements at the highest level of humidity (3.6 kPa).

Sweat accumulation in the clothes

The weight gain of the clothes removed quickly from the subject after the 90 min work-period, showed that above a humidity level of 2.2kPa, the sweat accumulation occurred in the garments and increased then with P_a increases.

CONCLUSION

Comparison of data obtained on core temperature or sweat rate, skin wettedness or sweat accumulation in the clothes gives similar results and confirm that the critical skin wettedness threshold is reached as soon as some over-sweating occurs due to decrease in sweat efficiency. The present results show that the critical skin wettedness lies near 50 %. Both ratios of differences in water vapour pressure between skin and air obtained at the onset of T_{re} drift or of local sweating acceleration confirm a F_{pcl} value close to 0.70 for the considered garments (2). These experiments carried out in steady state conditions thus validate (5) our previous approach of permeation efficiency factor determination under thermal transients.

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PROPERTIES OF THE HUMAN THERMOSTAT: RESULTS FROM MATHEMATICAL AND EXPERIMENTAL ANALYSES

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INTRODUCTION

Prediction of human thermoregulatory performance in heat and cold depends on detailed knowledge both of the passive thermal system and the active thermostat(1). Insight into the structure of the latter is still insufficient. However, it has become evident that a set of assumptions according to the kind and weighting of afferent inputs and the spatial distribution of effector mechanisms has to be made. In order to evaluate the minimal structural and functional requirements to the thermostat both mathematical and experimental analyses have been carried out.

RESULTS

Essential properties become evident already by using a one-cylinder-one-dimensional model of human thermoregulation for homogeneous thermal load. The passive system is essentially based on the following differential equation taking into account metabolic heat production, conduction and convection via circulation: $\varrho(r)c(r)\delta T(r,t)/\delta t = M(r,t) + 1/r\{\delta[\lambda(r) r \delta T(r,t)/\delta r]/\delta r\}$
$+ Bf(r,t)\cdot \varrho_b \cdot c_b (T(r,t)-T_b)$,
where t=time coordinate, r=radial cylinder coordinate $0 \le r \le R_{max}$, ϱ=density, c=specific heat, T=temperature, M=metabolic heat production per volumetric unit, λ=heat conductivity, Bf=blood flow per volumetric unit, index b=blood. The boundary condition at the surface and at the central axis are
$-\lambda \cdot \delta T/\delta r|_{r=R_{max}} = \alpha \cdot (T_s - T_a) + Q_e$
$\delta T/dr|_{r=0} = 0$,
where α=heat transfer coefficient, index a = air, Q_e=heat flow due to evaporation, index s = skin. According to an approach supported by many experimental results (2) the following essentials for the controller are assumed:

1. The integrative afferent signal f is proportional to the weighted sum of a central ("core temperature T_c") and a peripheral ("mean skin temperature T_s") signal.
2. A linear superposition of these signals sufficiently describes the system within its normal operating range.
3. All three effector systems have a minimal threshold and a maximal capacity of responses. Hence the afferent signal is:

$f = (1-\tau)T_c + \tau T_s - f_o$,
where f_o is the afferent signal in the indifferent status and τ and $1-\tau$ the weights of the central and the peripheral signals. Then the output y_i of the three effector systems is, using a gain factor g_i: $Y_i = -g_i f + y_{imin}$
i = 1: metabolic heat production
i = 2: blood flow
i = 3: sweat production.

The derivative of core temperature with respect to ambient temperature dT_c/dT_a is a good measure of controller performance. The smaller this value the better is the compensation of disturbances by environmental temperatures. There is a high performance for $0.1 \le \tau < 0.25$ and $100\ W°C^{-1} \le g_1 \le 200\ W°C^{-1}$, and at the

same time a low sensitivity to morphological and environmental changes. This purely theoretical conclusion fits well to experimentally determined values of τ. In order to obtain a good compatibility of computed and measured core and skin temperatures within a range of environmental temperature from 10°C to 50°C, the following set of parameters was finally used:
$\tau=0.13$, $g_1=115\ W°C^{-1}$, $g_2=3450\ W°C^{-2}$, $g_3=0.1\ g\ m^{-2}s^{-1}°C^{-1}$, $y_1min=70W$, $y_2min=1ml(100g)^{-1}(60\ s)^{-1}$, $y_3min=300g\ m^{-2}d^{-1}$, $y_{1max}=300W$, $y_{2max}=90ml\ (100g)^{-1}\ (60s)-1$, $y_{3max}=5000g\ m^{-2}d^{-1}$, $f_o=36.5°C$(3). In particular the effect of inhomogeneous distribution of heat production and blood flow, the influence of body fat content, of controller gains, of weight of skin temperature feedback and of depth of peripheral receptors on the dynamic performance were analysed.

CONCLUSIONS

Increase of peripheral blood flow evokes essentially both an increase of energy requirement in the cold and a quicker system response. Differing rates of increase of metabolic heat production are the consequence of differing body fat content. The weight of skin temperature feedback can be limited to 5.....20 %, because values outside this range evoke dynamic responses incompatible with the experiments. The actual value can only be determined if there is a correct assumption for the depth of the skin receptors. The use of measured superficial skin temperatures brings about an underestimation of the peripheral afferent signal. Of the controller gains it is primarily the gain of the metabolic controller which affects the dynamic response of the system. The experimental fact of a delayed onset of sweat production after a transition from cold to heat is the consequence of a high gain of the vasomotor system. When using a three-dimensional model (4,5) of the true geometry of the body with a grid of 0.5 to 0.1 cm it was concluded that it is essential to take into account the spatial distribution of heat production, blood flow and sweat production, and that at least for control of shivering, distributed controller gains different from the pattern of distribution of muscle tissue are required.

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APPLIED PHYSIOLOGY

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INTRODUCTION

Man has long demonstrated an extraordinary capacity to adapt to the stresses imposed by the earth's environment. Physiological adaptations that provide us with the ability to tolerate, indeed to thrive in climates that might be considered "hostile" to human life, are complemented by man's ingenious ability to fabricate protective shields to further extend the environmental limits in which he may function both safely and productively. The disciplines of human biology identifty the challenges posed by environmental stressors on working man, and they welcome technological contributions in alleviating them. There is the risk, however, that valid physiological principles may be abbreviated and/or incorrectly interpreted by engineers in their enthusiastic attempts to reduce a biologically threatening situation to a problem that has a simple physical solution.

RESPIRATORY PROTECTION

The SCBA: An outstanding example of this can be seen in the technological advances being achieved in the field of respiratory protection. The most critical line of defense for the human organism is that of assuring an uninterrupted supply of respirable oxygen. Early high altitude balloonists were among the first to recognize this need in their specific environment, but respiratory protection has become a routine necessity for workers exposed to a wide variety of toxicants, whether or not they are accompanied by an oxygen-deficient atmosphere. The advent of modern breathing apparatus for firefighting and mine rescue operations demanded the cooperation of physiologists to define the respiratory needs of working man and the engineers to develop a breathing device that could provide for it. Serious mistakes were made in the mixing of these disciplines. The work of Silverman in 1945 (1) provided the standard figure of 40 liters/minute to be used as the benchmark value for the minute ventilatory requirement of emergency workers. Once established, this standard pushed the technology of the self-contained breathing apparatus (SCBA) industry.

Government regulating agencies then based their certification requirements (2) on that figure and new generation SCBAs were tested by a breathing machine at that level of minute ventilation when divided by piston excursions into 24 "breaths" per minute. Thus, both the (a) duration of air supply, and (b) breathing resistance criteria were evaluated according to this ventilatory demand. Since then, a closer examination of the workloads actually imposed on firefighters (3) revealed that the device firefighters had been told would last for 30 minutes was actually running out of air in as little as 10 minutes. And although certified as providing a free-flow of air to the worker, it was actually imposing a level of resistance that became the limiting factor in emergency task performance.

Unlike a machine, the human respiratory system places demands on a SCBA that are more appropriately a function of peak flow rates rather than average flow rates. For example, an instrument can be certified for passing an exhalation resistance test if it performs well when challenged with a constant flow of 85 liters per minute. Physiologically, the velocity of a working firefighter's expiratory flow is closer to 250 liters per minute (3) . Consequently, it is not surprising that the system developed by engineers to provide respiratory protection to the firefighter became an instrument that imposed severe breathing resistance and, thus, worker distress. The mistake originated with the reliance on oversimplified data describing respiratory responses of working man.

The Escape Device: A similar problem surfaced in the development of an "escape device", an apparatus designed to provide short-duration respiratory protection for the emergency evacuatiuon of a hazardous environment. Escape capsules (usually an air-supplied vinyl capsule that is pulled over the head and seals at the neck) in the early 1980's were designed to provide a constant flow of 28 liters of air per minute. Although this is a good estimate for the ventilatory requirements of an adult breathing fresh air, it failed to appreciate the fact that the capsule was very effective in storing most of the expired air in each respiratory cycle. Thus, the composition of the inspired air was not fresh at all, but rather closely resembled expired air in both CO_2 and O_2 content. Consequently, stimuli to the respiratory center included both the on-going production of metabolites plus the re-introduction of exhaled CO_2 to the lungs during the re-breathing process.

Indeed, such capsules were purchased and stocked in potentially hazardous work places primarily because of the assurance placed on the label. Further research (5) provided evidence that an air flow of about 60 liters per minute was required to assure the adequate flushing of the rebreathing bag to support the metabolic and ventilatory requirements of the worker during an emergency egress.

FITNESS FOR DUTY

Perhaps an even more disheartening event is when engineers develop a truly state-of-the-art protective device only to find that its failure can be traced to its being evaluated when worn by a physically unqualified worker. Too often entry level fitness requirements for career fields where the worker can expect to be called upon to perform unusually strenuous physical tasks are often either inappropriate or invalid. For example, since it was first described in the late 1920's, a measure of aerobic capacity has been hailed as the most valid indicator of overall physical fitness. Few physiologists would disagree with this rationale, but care must be taken not to allow it alone to govern the selection of workers for a wide variety of career fields. The limitations of aerobic capacity for describing fit-for-duty characteristics are seriously magnified when the test used to evaluate this fitness parameter is invalid in itself.

Consider the wide use of the 1.5 mile run to estimate aerobic capacity and, in turn, physical fitness. When the job applicant pushes him/herself to an exhaustive effort, the time required to complete this task becomes a fairly valid estimate of one's aerobic capacity. However, in an effort to reduce the risk of overexertion, the alternative of establishing a time standard for classifying fitness levels has become commonplace. Field research has shown that the recommended passing time of 14 min 30 sec for the 1.5 mile run is essentially meaningless for describing the physical work capacity of a 19-year old male (3,4).

Researchers must avoid falling into the dilemma of trying to evaluate prototypes of respiratory protection devices when worn by people who lack the physical fitness even to perform the required task in a shirt-sleeve environment, and then attributing this failure to the burden imposed by the protective device. Lacking appropriate control of subject selection welcomes the pitfalls of trying to determine the tolerance time for groundcrew performing operational tasks while wearing thermally stressful protective ensembles only to find that a large percentage of those assigned to that task are so unfit that they cannot work long enough to even experience heat stress--whether or not they are wearing a protective ensemble.

CONCLUSION

Applied phyhsiology is an essential partner in the pursuit of technological advances in the field of Environmental Ergonomics. A valid appraisal of the merits of these advances must depend upon the appropriate interpretation of experimental evidence obtained under conditions that are relevant to the real-life application of this technology.

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REGIONAL CUTANEOUS THERMOSENSITIVITY: ITS SIGNIFICANCE IN THE DESIGN OF THERMAL PROTECTIVE CLOTHING

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INTRODUCTION

The hyperpnea observed at the onset of cold water immersion, termed gasping (4), appears to be the result of a neurogenic drive from the cutaneous cold sensors. Thermoreceptors in the skin have been assigned a major role in autonomic thermoregulation in humans, but their population density over the body surface is not known. If thermoreceptors are distributed evenly, and if their sensititvity is equivalent, then a given thermal stimulus will elicit a similar response from all skin regions. Conversely, differential cutaneous thermosensitivity would suggest that the design of thermal protective suits should offer more insulation to regions with greater thermosensitivity, and thus a greater contribution to the gasping response.

Gasping at the onset of accidental cold water immersion increases the risk of aspirating water (1). Thermal protection offered by clothing will reduce the gasping response (2), and thus the risk of immersion drowning. Thermal protective suits for occupations at high risk of cold water immersion incorporate either the wet or dry suit principle: dry suit designs normally incorporate material with less insulative properties, and though such suits may be beneficial in reducing the gasping response, they may not provide as much thermal protection as a wet suit design (3).

METHODS

Differential cutaneous sensitivity to cooling was assessed by observing the gasp response, while separately exposing four discrete skin regions to 15°C water during head-out immersion. Seven male subjects, ranging in age from 20 to 33 yrs., in height from 177 to 184 cm., and in weight from 70 to 77 kg., participated in the present study. They were accepted on the basis of having physical dimensions within one standard deviation of a student population mean, as determined by the CANREF study (5). All subjects were familiarised with the test procedure and the possible risks associated with the trials. The experimental protocol utilised was approved by the Simon Fraser University Ethics Review Committee.

Subjects were requested to participate in a total of 10 head-out immersions: 5 immersions in 15°C water (COLD) and 5 matching immersions in 34°C water (CONTROL). During both COLD and CONTROL trials, subjects were immersed to the sternal notch in four conditions of partial exposure, plus one condition of whole body exposure. Partial exposure of the skin was achieved with a modified neoprene dry suit, allowing exposure to the water of either the arms, upper torso, lower torso, or legs, while keeping the unexposed skin regions thermoneutral.

Tha gasp response was quantified with the technique of mouth occlusion pressure described in detail elsewhere (2, 6). Briefly, the mouth pressure at 100 msec. (P0.1) following an occluded inspiration was recorded with a differential gas pressure transducer (Model 270, Hewlett Packard), connected to an AC carrier preamplifier (Model 17403A, Hewlett Packard), and the pressure signal filtered with a 1KHz low-pass filter (3rd order). The resultant signal was recorded on an oscillographic chart recorder (Model 7404A, Hewlett Packard). During the 5 minute rest and 5 minute immersion period, skin temperature was recorded from 19 sites with copper/constantan thermocouples. In addition, bath temperature was monitored with a YSI 701 thermistor (Yellow Springs Intruments Co.), and electrocardiograms were monitored for any irregularites.

The total skin area (SA) exposed during each trial was estimated by representing the body as a combination of geometrical shapes (7).

RESULTS

The differences between immersion and resting P0.1 values (ΔP0.1) were determined for every second inspiration. The integrated ΔP0.1 response during the first minute of immersion ($\int\Delta$P0.1) was considered indicative of the gasp response to the cold stimulation of the exposed skin surface area. Hydrostatic pressure effect was taken into account, by obtaining the difference in the $\int\Delta$P0.1 values between COLD and CONTROL immersions for each exposure condition. Finally, a thermosensitivity index (TSI) of each exposed area was determined by adjusting for the estimated exposed surface area and the decrease in average temperature of the exposed region (ΔT).

Results indicated that the highest P0.1 values were elicited from complete exposure, followed in descending order by the exposure of the upper torso, legs, lower torso, and arms. Correcting the P0.1 response for differences in SA and ΔT between regions, indicated that TSI for the upper torso was significantly higher than the indices for the arms, legs, but not significantly higher than the lower torso index. The TSI for both the upper and lower torso were higher, albeit not significantly, than the TSI for the whole body exposure.

CONCLUSIONS

Gasping at the onset of cold water immersion appears to be a valid indicator of regional cutaneous thermosensitivity to cooling, because stimulation of select skin regions elicited a measurable response. Present results are in agreement with the findings of Keatinge and Nadel (8), who reported that the upper torso is more sensitive to cooling than either the arms or legs. The ventilatory measurements of Tipton and Golden (9) observed during exposure of either the limbs or torso may underestimate the gasp response (2), and may explain the disparity between their observations and the present findings. Namely, their findings of equivalency in thermosensitivity of the torso and limbs is in disagreement with the ranking predicted by averaging the indices of the subregions, in both the present study and the earlier report of Keatinge and Nadel.

The equivalency of the sum of the regional responses to the whole body exposure responses suggests that regional thermoafferent signals interact in an additive manner, which agrees with the concept that, the sensitivity of a thermoregulatory response is equivalent to the sum of peripheral and central thermosensitivities (10).

Any method which retards the immediate cooling of the skin, will likely enhance survival by reducing respiratory distress. Present findings suggest that for those individuals at risk, who are unable to use complete survival suits, or to enter the water slowly, the most efficient protection against cold water immersion drowning may be a close fitting suit or life-jacket designed to provide not only flotation, but also thermal insulation of the torso. Conversely, there was a tendency for the TSI of the arms and legs to be lower than that of the whole body.

ACKNOWLEDGEMENTS

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CARDIOPULMONARY ADJUSTMENTS WITH EXERCISE IN COLD WATER AND HYPERBARIC ENVIRONMENTS

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INTRODUCTION:

Physiological adjustments to exercise include regulating cardiopulmonary responses to changes in workload. Further adjustments are required when exercise is conducted in cold water (1) or in hyperbaric environments (2) to compensate for the added effects of thermal or high pressure stress.

Ventilatory equivalent (VEQ) is the ratio of minute ventilation (V_E) to oxygen consumption (VO_2), and provides a useful index of how well V_E remains coupled to VO_2 for a given workload. Oxygen pulse (OXP) is the ratio of VO_2 to heart rate (HR), and serves as an indirect estimate of the product of cardiac stroke volume and arteriovenous O_2 differece; derived from solution of the classical Fick equation.

The purpose of this paper is to describe changes in VEQ and OXP during steady-state leg exercise in water at temperatures of 18-31°C, and during hyperbaric exposures to 31 ATA.

METHOD:

The data were derived from three human exercise studies conducted between 1987-1990. In each study V_E, VO_2, and HR were obtained while males performed steady-state leg exercise during head-out immersion. VEQ and OXP were calculated from measured variables and analyzed by a two-way ANOVA for repeated measures. Data are presented in this paper for a workload of 1.5 W/kg, which was common to all studies.

Study I (n=10) involved performing 60 min of exercise at 1.5 W/kg during immersion in 28 and 18°C water at the surface. Steady-state variables were obtained by averaging the last 40 min of exercise. Study II (n=11) entailed 4 consecutive periods of 5 min rest and 25 min exercise at 1.5 W/kg during immersion in 25°C water, once breathing air at 1 ATA and once breathing HeO_2 at 5.5 ATA (PO_2 = 0.42 ATA). VEQ and OXP did not change among exercise periods and were therefore averaged across all 4 periods. Study III (n=12) used step increases in workload (10 min each at 0.5, 1.0, and 1.5 W/kg) during immersion in 31 and 20°C water. Tests at each water temperature were conducted at 1 ATA breathing air and at 31 ATA breathing HeO_2 (PO_2 = 0.42 ATA).

RESULTS:

V_E increases exponentially, as VO_2 increases. This relationship is the same in dry and immersed conditions up to a VO_2 of about 2.5 L/min. Thereafter the immersed curve increases at a faster rate, but is not influenced by water temperature.

The table below presents VEQ and OXP for the common workload of 1.5 W/kg (mean ± SEM).

DEPTH	STUDY	WATER T°	VEQ	OXP
1 ATA	I	18	28.1 ± 1.1	17.8 ± 6.0
	III	20	30.8 ± 1.6	17.9 ± 3.2
	II	25	27.1 ± 0.6	16.9 ± 2.8
	I	28	28.6 ± 1.6	15.9 ± 4.0
	III	31	29.8 ± 1.2	15.5 ± 3.4
5.5 ATA	II	25	24.3 ± 0.7	17.3 ± 2.9
31 ATA	III	20	27.1 ± 2.2	18.2 ± 2.8
		31	27.5 ± 1.6	15.7 ± 3.1

At 1 ATA, VEQ did not vary significantly with water temperature because of concurrent increases in V_E and VO_2. OXP increased as temperature declined, due to increases in VO_2 with little change in HR. Reductions in V_E at depth, with no change in VO_2, significantly lowered VEQ. No significant change in HR occurred at depth, thus OXP was not altered relative to corresponding 1 ATA values.

CONCLUSIONS:

These findings demonstrate that colder water temperatures do not affect the coupling of exercise V_E to VO_2. Cold induced increases in VO_2 were matched by increases in V_E such that VEQ did not change. Lower VEQ at depth was due solely to a reduced V_E, which suggests a downward (and more efficient) regulation of ventilation to O_2 demand.

Increases in OXP in colder water were largely a result of higher VO_2; indicating an increase in the product of stroke volume and a-v O_2 difference. Since OXP was not significantly altered at depth (no significant changes in VO_2 and HR) it can be concluded that this index of cardiopulmonary adjustment to exercise was not affected by hyperbaric exposure *per se*.

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PHYSIOLOGICAL ACTION TREMOR AS A PRECURSOR TO SHIVER

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INTRODUCTION:

One of the first overt responses to cold stress is muscle tensing and shivering. Shiver, which is often described as a clonic oscillation or tremor, has a frequency range of 8 - 11 hz with the major frequency at 9 hz (1). Although the physiological basis of this tremor is not well understood, some studies suggest that shiver is an amplification of a tremor which is normally present. The purpose of this paper is to present data to support the concept that physiological action tremor of the hand or ankle can become continuous and resemble shivering in cold stressed subjects.

Tremors can be studied either during maintenance of posture or motion. During maintenance of postures, which is called "rest", tremors of the hand have been studied by monitoring the oscillations from the outstretched hand or finger. Frequencies of 5 - 15 hz with a major frequency of 9 hz was reported for the outstretched finger. This frequency was independent of mechanical loading, since weight added to the finger decreased the amplitude but not the frequency of the finger tremor. This evidence suggested that the servo loop was responsible for the frequency of tremor. Marshall and Walsh measured the tremor at rest at a number of sites on the body and found that the frequency of oscillation ranged from 7 - 12 hz at the wrist, elbow, shoulders, ankle, knee, and hip (2).

De Jong described the tremor associated with movement in paralysis agitans. He called these oscillations "action tremor" and differentiated them clearly from tremors at rest (3). Since that report, tremors associated with movement have frequently been called action tremor. Pozos, Iaizzo, and Petry did a quantitative study of the tremor associated with the slow extension-flexion of the ankle in normal subjects (4). They found that the tremor during movement of the ankle had a frequency range of 4 - 8 hz compared to the frequency of 6 - 9 hz for the ankle tremor during posture (rest). The amplitude of the action tremor was significantly greater by a factor of 2 - 5 times over rest tremor. They called this tremor associated with voluntary limb motion "physiological action tremor" to distinguish it from pathological tremors seen during voluntary muscular contraction. In another study, Pozos and Howard reported on postural and action tremor of the hand. In slow movement of the hand, there was an associated tremor which was different from the postural or physiological hand tremor. Action tremor of the hand had a frequency of 10 hz, and postural hand tremor had a frequency of 7.5 hz. The displacement of action tremor was 20 times greater than postural tremor (5).

One of the distinguishing characteristics of physiological action tremor of the hand or ankle is the distinct bursting associated with the tremor. This amplitude modulation occurs only during certain times of the voluntary extension and flexion of the wrist or ankle.

METHODS:

In all experiments, the seated male subject had surface electrodes which were placed on the extensors and flexors of the wrist, or on the tibialis anterior and soleus of the leg. In addition, an accelerometer was placed on their hand or on their knee. In the first experiment, to record physiological action tremor, they were required to slowly raise and lower their heel or to slowly extend and flex their wrist. In the second experiment they were required to run until they were fatigued. At that point they were seated, and then the action tremor of their ankle was studied. In another experiment the subjects were placed in a cold chamber, and their skin and rectal temperatures were recorded. After five minutes in the chamber they did the same maneuver they had done previously to record physiological action tremor. In the cold chamber it took them approximately 15 minutes before they began to shiver violently. Analysis of the various tremors and emgs was done by spectral analysis.

RESULTS:

The physiological action tremor of the hand or ankle were 8 - 9 hz for the hand, and 6 - 8 hz for the ankle. After fatiguing, the action tremor became continuous and resembled clonus. In the cold stressed subjects, the amplitude modulation of the action tremor became more pronounced and continuous. This increased in duration until it became indistinguishable from shivering of the hand or of the ankle. The frequency was approximately 6 - 8 hz.

DISCUSSION:

Physiological action tremor is characterized by distinct bursting of the emg. This amplitude modulation resembles a clonus like frequency. In normal situations, this amplitude modulation is of short duration. During cold stress, this amplitude modulation becomes gradually continuous and is indistinguishable from shivering. These data suggest that the physiological control of physiological action tremor can be altered by various kinds of stimuli. In some manner, cold stress eventually is able to influence the control of the amplitude modulation so as to prolong the duration of the action tremor so that the body is able to generate additional heat.

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EXTENT OF RADIAL COUNTER-CURRENT HEAT EXCHANGE IN THE FOREARM MUSCLE DURING COLD EXPOSURE

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INTRODUCTION

Counter-current heat exchange in the limbs is usually considered as an exchange of heat between major counter-current vessels in the axial direction. However, attention has been recently given to counter-current heat exchange between the microvessels of the vasculature away from the major axial vessels. Weinbaum et al. (1) have demontrated that such heat exchange is 100% complete three generations before the capillary level. Heat recovery by this mechanism is considered in the radial, as opposed to the axial, direction. In this study, the extent of net heat recovery by this mechanism is estimated for the human forearm during cold exposure.

METHOD

1. *Experimental.* Data were obtained from steady-state temperatures measured in the forearm (2) after 3 h of immersion in water at temperatures (*Tw*) of 15 (N = 6), 20 (N = 5), and 30°C (N = 5). Temperatures were measured every 0.5 cm from the longitudinal axis of the forearm to the skin approximately 9 cm distal from the elbow, and from these values a volume-weighted mean was obtained. These means (± SE) were 18.74 (0.52), 23.41 (0.21), and 31.78 (0.17) °C with increasing *Tw*. Arterial blood temperatures entering the forearm were measured once before immersion and corrected for axial counter-current heat exchange; mean (± SE) values at steady-state were 35.23 (0.17), 35.68 (0.12), and 36.51 (0.17)°C with increasing *Tw*. Heat flux was measured at two sites on the skin adjacent to the temperature probe; mean values (± SE) were 87.7 (7.9), 71.8 (5.7), and 46.4 (2.8) W/m^2 with increasing *Tw*. Blood flows (± SE) entering the forearm and measured by plethysmograhy were 467 (82), 727 (86), and 779 (136) l/h/m^3 with increasing *Tw*.

2. *Analysis.* The approach taken herein to determine the net recovery of radial convective heat exchange was based on a simple heat balance. First, the convective heat exchange was obtained from the measured amount of heat lost through the skin after subtraction of the metabolic contribution assuming the *Q*10 rule. Second, the potential convective heat loss (i.e., maximum possible) was determined by the difference between the average muscle temperature and the arterial blood temperature. One minus the ratio of these two quantities yields the fraction of heat recovery. All heat quantities are expressed as W/m^3 and apply to the muscle tissue only.

The convective heat exchange per unit volume (bc) was determined by

$$bc = q_v - m$$

where q_v is the heat lost and m is the metabolic heat produced per unit volume. These quantities were determined by (3)

$$q_v = 2 \cdot hf / r$$

where hf and r are the heat flux and the radius at the muscle-fat boundary, and (4)

$$m = 684 \cdot 2^{(\bar{T} - 35)/10}$$

where $\bar{T}$ is the average muscle temperature.

The potential convective heat loss (i.e. assuming no counter-current heat exchange) was determined by (4)

$$bc_{\max} = 1.13 \cdot bf \cdot (T_a - \bar{T})$$

where bf is the blood flow ($l/h/m^3$) and T_a is the arterial blood temperature entering the forearm. Heat flux and blood flow at the muscle level were determined by assuming negligible metabolic heat production and blood flow at the skin+fat level.

RESULTS

Values were calculated for each individual and means of these are reported below.

Table of mean calculated values for forearm muscle tissue.

T_w	q_v	m	bc	bf	$bc_{\max}$	$1 - bc/bc_{\max}$
15	5016	222	4794	467	9995	0.460
20	4076	306	3769	727	12032	0.678
30	2744	547	2197	779	5004	0.470

Convective heat exchange between blood and tissue accounts for most of the total heat produced (i.e., $bc + m$); the metabolic contribution is approximately 4, 7, and 20% of the total for T_w of 15, 20, and 30°C, respectively. Radial counter-current heat exchange returns about 53% of the potential convective heat available.

CONCLUSION

Through the simple approach of comparing measured heat loss to the predicted potential heat loss using average values of tissue temperature and blood flow, the results suggest that radial counter-current heat exchange does not return all the heat brought in by the blood. This can be explained by noting that while heat recovery between counter-current vessels may be 100% efficient in the tissue space between the vessels, recovery is reduced in the much larger tissue space outside the conduction path between the vessels.

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INVESTIGATIONS INTO THE PATHOPHYSIOLOGY OF MILD COLD INJURY IN HUMAN SUBJECTS

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INTRODUCTION

Although cold injury was first reported in about 400 BC, and has been studied in detail over the last 300 years, it is still capable of being responsible for 20% of all casualties even in well-trained well-equipped soldiers in relatively mild conditions[1]. Whilst some of these may be inevitable, the underlying pathophysiology of freezing and non-freezing forms and their sequelae remain poorly understood[2,3]. Following the Falklands Conflict, Golden (unpublished) established protocols at INM by which those who had suffered cold injury could be investigated, particularly with regard to the often severe late intolerance to cold seen in even mild cases. Since then, about 500 investigations have been performed using his technique. In 1986, Oakley introduced a simple neurophysiological test[4]; this paper analyses the first 100 consecutive attendances in which both techniques have been used, in the hope that the results may provide some insight into the mechanism of injury and its sequelae.

METHODS

One hundred consecutive attendances by patients and others, consisting of a total of 75 different individuals, were analysed, spanning the three years to 1990. Subjects qualified for inclusion if they were referred for the investigation of cold injury, any other peripheral vascular disorder (including sequelae of trauma, Raynaud's Complex), or were taking part as volunteer subjects in the ongoing study of cold injury. Those who attended during the first six months, or had no clinical indications, gave informed consent in writing. Patients referred with fresh cold injuries were not seen until at least two months after injury.

Subjects clad in indoor clothing entered a climatic chamber maintained at 30 ± 1°C and still mixed air, and rested recumbent on an examination couch. Sensory thresholds were measured using the Middlesex Hospital Thermal Testing System[5] with the room quiet and minimal distraction. Thresholds to cool then warm thermal stimuli were recorded from the volar surfaces of the distal phalanges of digits 2–4 in the left hand, and the whole of the volar surfaces of digits 1–3 in the left foot. Following this, infra-red thermography was carried out. The right hand or foot was exposed and allowed to equilibrate with ambient. A control picture of the volar surface was then taken using an Agaema 870 solid-state infra-red camera connected to an IBM PC which displayed and stored the images. The hand or foot was then placed in a plastic bag and plunged into a bath containing stirred water at 15 ± 0.5°C, and kept there for 2 minutes. On removal, the plastic bag was discarded and a further infra-red picture taken. Five minutes after removal, the final infra-red picture was taken. Patients with unilateral lesions were tested on their injured side, with thermography being performed on a limb only if there were indications of abnormality or injury in that limb (or the subject was uninjured).

Subjects were then interviewed and examined clinically, and their test results graded by the same doctor, following which he made a recommendation as to their disposal. Results were graded subjectively: infra-red thermograms into normal, then mild to severe degrees of cold sensitisation, sensory thresholds into normal (< 3°C for fingers, < 4°C for toes) and abnormal.

RESULTS

Two-thirds of all attendances were from Royal Marines, 12% each from a group of very experienced and exposed individuals within the Royal Marines, and civilians, and 9% from other UK Armed Forces. Average age was 28.7 years (range 14–56). Males formed 93% of the attendees. Clinical studies accounted for 86% of studies. A total of 20 of the 75 different individuals seen had sustained non-freezing cold injury during the Falklands Conflict, of whom several were presenting for the first time (up to 8 years subsequent to their original injury). Non-freezing cold injury (NFCI) of the feet was the primary diagnosis in 43 of the patients, 13 had other forms of mild cold injury, 16 were seen for other clinical causes, and 3 were found to be normal. None of those with NFCI had sustained any form of tissue loss, and only three of those who had suffered frostbite had any.

Infra-red thermography appeared to be abnormal in 31 of the 43 with NFCI of the feet, in 7 of the 13 with other cold injury, in 12 of the 16 others, but in none of the three normals. All those with normal infra-red thermography results returned to full and unrestricted duties following their last tests. Of the 18 patients seen on more than one occasion, one was never abnormal and three others returned to normal over the period of study.

Sensory thresholds were abnormal predominantly in the warm modality, and mostly in the toes. Of those with NFCI of the feet, one had an abnormally high cool threshold in the fingers, five had abnormal warm thresholds in the fingers, 13 had abnormal cool thresholds in the toes, and 32 abnormal warm thresholds in the toes. Figures for the other groups were not dissimilar, although none of those considered as normal had abnormal thresholds. All of those with normal thresholds returned to full and unrestricted duties following their last tests. All of those with multiple attendances except for one were abnormal, and only one other returned to normal during the study.

Outcomes were not good. Of the 56 with cold injury, only 26 (46%) returned to full duty. When the highly experienced group is excluded (as they came from and returned to full duties), only 17 of 48 returned to full duty, i.e. 65% remained in some employment restriction. Furthermore, 8 (17%) had to be referred to a medical board to consider whether they should be invalided as a result of their sequelae.

CONCLUSIONS

The clinical picture of NFCI in the feet has been well described[6], and cases may present during the hyperaemic phase or subsequently, the latter being when these tests were carried out. This post-hyperaemic phase appears to be one in which those with either form of cold injury commonly suffer cold sensitisation[2,3]. This study reaffirms the frequency with which this disabling consequence occurs, even in those with very mild cold injuries. The evidence is that this period of cold sensitisation may last almost indefinitely, and can certainly be longer than eight years. Furthermore, anecdotal stories of impaired warm sensation following cold injury have been confirmed, which again appears to be long-lasting if not permanent. These results re-emphasise the dramatic human and performance consequences of even very mild cold injury, and the importance of enforcing conservative limitations on permissible peripheral skin temperatures during human cold exposure studies, lest injury occur inadvertently.

Neither of the techniques used in this study has been completely validated. Infra-red thermography is notoriously difficult to use in control populations, as many of those believed to be free from cold injury appear to be abnormal. However, very few active young men have not undergone the brief exposure necessary to sustain NFCI, and there is speculation that a not uncommon disease of childhood, Pink's disease, or deprivation hands and feet, is identical with NFCI. More intense assessments of subjects are now being undertaken using laser doppler techniques, and a longitudinal cohort study of those undertaking military training is also planned. Although sensory thresholds measured at other sites have been extensively validated[5], a similar study using these sites in controls is still in progress, although the criteria of abnormality used here are believed (after examination of over 20 controls) to be conservative.

Whilst the infra-red thermography test gives an indication of sympathetic (unmyelinated fibre) function, sensory thresholds relate to both myelinated (cool) and unmyelinated (warm) fibre function. Therefore these abnormalities are consistent with a pattern of lasting damage to fine and unmyelinated fibres, and there appear to be very few who suffer from lasting damage to larger and myelinated nerve fibres. They are also consistent with the hypothesis that cold sensitisation occurs as a result of denervation supersensitivity[3]. This is in contrast to the large number of animal studies, which suggest that at least in the acute stages, nerve fibre damage from cold injury occurs to all fibre types, or is even worse in myelinated axons[4]. It is suggested that the pattern reported here occurs as a result of disruption to the axons of fine and unmyelinated fibres at a high enough level to result in neuronal death or to prevent effective reinnervation. Whilst this could happen as a result of spasm in, or blockage to, the vasa nervorum, it is suggested that this is most likely due to prolonged disruption of axonal transport, which could then propagate up the axon. This may be the primary site of injury, particularly in NFCI, with its requisite period of prolonged relatively mild cooling. The apparent similarities between mild cold injury and diabetic peripheral neuropathy may also merit further investigation.

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PHYSIOLOGICAL DETERMINANTS OF THERMONEUTRALITY IN THE COLD

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INTRODUCTION

Man responds to climatic stress by a series of physiological and behavioural reactions. Peripheral vasomotor activity and sweating are the two most important means of adjustment. It has been proposed that both factors also are important determinants of thermal sensation [2]. Indeed, it has been postulated that a certain amount of sweating is required for the experience of thermal comfort irrespective of thermoregulatory requirements [3]. However, the basis for this assumption are experiments in moderate and warm thermal environments. It can be readily questioned whether such criteria also apply to cold environments (subzero conditions) [7, 8].

Thermal neutrality can be well maintained also at very low temperatures by proper combination of adequate clothing insulation and physical activity [1, 8]. However, increased clothing insulation decreases the potential for evaporative heat loss. High levels of sweating may rapidly saturate clothing microclimate. Progressive absorption and build-up of moisture in clothing layers, impair the insulative properties and may endanger thermal balance. From a survival point of view it is not likely that conditions defining a sensation of thermal neutrality ("comfort"), are similar to those, that may present a thermal hazard.

This paper examines the relevance of existing physiological comfort criteria for exposure to cold environments.

METHODS AND MATERIALS

During the last decade several studies have been undertaken in our institute to investigate human responses to cold exposure with special emphasis on the development of criteria for acceptable exposures to cold environment in occupational work. A total of more than 150 individual experiments has been undertaken. Some of the results have also been reported previously [4, 5, 6, 7].

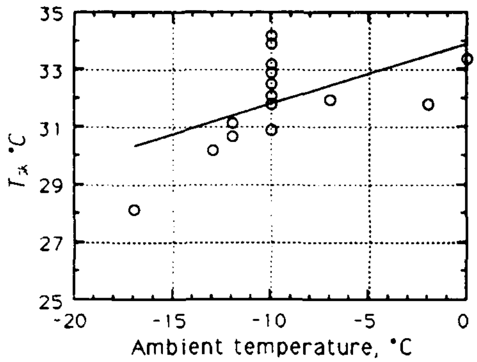
Fanger [2] has proposed a set of physiological comfort criteria that has been widely used for the assessment of moderate thermal environments and, occasionally, for the evaluation of more extreme environments. The hypothesis is that with increased activity level (M), the sensation of thermal neutrality is associated with a lower mean skin temperature (T_{sk}=35.7–0.028 M) and a higher sweat rate (E_{sk}=0.42 (M–58)) [2].

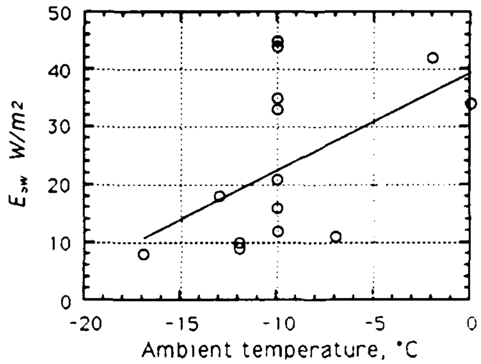
In the present analysis measured values for mean skin temperature and evaporative heat loss during steady-state conditions were compared with predicted values for thermoneutral sensation.

RESULTS AND DISCUSSION

Measured values for T_{sk} and E_{sw} obtained at different environmental conditions and activity levels are given in the figures. A general trend is that both T_{sk} and E_{sw} decrease with colder conditions. This is anticipated at equal levels of clothing insulation and activity. However, all conditions analyzed here are not directly comparable, since they vary in these two aspects. This is particularly true for –10 °C, where several different types of cold weather clothing (at different insulation levels) were tested. In other words, the maintenance of heat balance was accomplished by different degrees of thermoregulatory strain. Some of the conditions were rated by subjects as equal or close to thermoneutrality. Other conditions were rated warmer. Of all conditions only two were rated slightly cool.

Mean skin temperature of subjects at thermoneutral ratings (PMV≈0) were of the same magnitude as predicted by the comfort criteria, e.g. at –10°C (30.8 versus 30.7 °C). The narrow interval of activity levels in which thermoneutral conditions were established, does not justify a regression analysis of T_{sk} on M. It seems logical, however, that increased metabolic heat production (and core temperature) in the cold requires progressive vasoconstriction to restore heat content and thermoneutral sensation [3].





Measured evaporative heat loss for the actual conditions never exceeded 45 W/m^2. Predicted comfort sweating was 30-71 W/m^2 higher than measured E_{SW}, despite the fact that most of the conditions were rated by subjects as slightly warm or warm. It seems clear that predicted levels of E_{SW} (comfort levels) for thermoneutrality are too high.The comfort equation in its original (Fanger) or modified form [3] significantly overestimates the warmth of a cold environment. Apparently, the concept of comfort sweating does not apply to subzero environments. Man in the cold should maintain heat balance by regulation of sensible heat exchange (clothing), rather than provoke sweating by overdressing [9].

CONCLUSIONS

Low levels of evaporative heat exchange was required for thermoneutral or warm sensations during light to moderate activity in cold environments.

Established sweating criteria for thermoneutrality (comfort sweating) cannot be applied to models predicting responses to very cold climates.

Further studies are required to elucidate the important determinants of subjective thermal responses to cold exposure.

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SKIN TEMPERATURES AND THERMAL JUDGMENTS IN SEDENTARY SUBJECTS EXPOSED TO EITHER HEATED FLOOR OR HEATED CEILING.

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INTRODUCTION

When investigating local thermal discomfort (reviews in 1, 2) attention has rarely be paid to local skin temperatures (3). We studied these local temperatures under two distinct but globally equivalent indoor climate patterns, namely heated floor (HF) as heated ceiling (HC). Both produced an overall thermal state of the environment corresponding to thermal balance fit to 0.6 clo-clothed sedentary (M = 1.2 met) subjects : 24.5°C operative temperature. Both conditions were non uniform due to vertical radiant temperature asymmetry which is an important criterion for admitted comfort limits (4). They differed in respect to the localisation of the source of radiant asymmetry : either below (HF) or above (HC) the subject. The aims of the investigation were : to collect simultaneously data on body (skin) temperatures and data on subjective thermal feelings (dependent variables) ; to examine the initial adjustments and the temporal evolution of the various (dependent) variables ; to compare the results in both climate patterns.

METHOD

Two non-uniform indoor conditions (heated floor : HF at 34°C, or heated ceiling HC at 45°C) were imposed in a climatic chamber to 2 groups of 10 lightly clothed male subjects (Ss), performing a computer task. When floor and ceiling temperatures (T) were increased beyond the comfort limits, compensation of air (Ta) and of the other wall (Tw) temperatures enabled the operative T (To) to be kept constant at 24.5°C. Ten local skin temperatures (Tsl) and various thermal judgments were collected throughout the 200-min experimental test, which included an initial 30-min stay at uniform To = 24.5°C.

RESULTS

When non uniformity was generated, Ta and Tw were slightly decreased in both conditions and most of the Tsl as well as judgments of thermal sensations also decreased, although To was theoritically unchanged.

Results obtained after two hours of exposure showed that <u>under HF</u>, foot T increased steadily and leg T decreased less. <u>Under HC</u>, forehead, chest and shoulder T decreased less whereas lower back and inferior limb T showed a greater decrease. Mean skin temperature changes were -0.65°C and -1.10°C under HF and HC respectively.

In terms of thermal judgments, feet and floor were recognized as being warm <u>under HF</u> but corresponding local dissatisfaction was not expressed. In contrast to this, the shoulder, arm, back, hand as well as wall and air temperatures were estimated as being less and less warm (or cooler), inducing overall dissatisfaction (up to 6 Ss out of 10). <u>Under HC</u>, most parts of the body and of the room were judged as slightly cool, with no real change throughout the exposure : constant overall dissatisfaction was found in 4 Ss out of 10, in association with local dissatisfaction in foot, shoulder and hand.

CONCLUSION

It is concluded that the perception of the non-uniform indoor climate in our conditions was mainly influenced by those environmental components (here, floor and air) which exerted strongest influence on the thermal sensors ; the ceiling was uninfluencial. Although operative T was supposed

to be kept constant, the skin T changes demonstrated that local and overall heat exchanges were different, depending on the heating source and on the thermal state of the remaining components.

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BODY TEMPERATURE AND THERMAL SENSATION OF THE ELDERLY IN HOT AND COLD ENVIRONMENTS

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INTRODUCTION

Most Japanese do not have central cooling and heating systems in their homes, and they only use cooling and heating instruments in their rooms. Therefore, there are large temperature differences between cooled or heated rooms (e.g. living room, bedroom) and the others (e.g. toilet, passage). It is known that these large temperature differences cause serious diseases such as stroke. Especially, the elderly people tend to suffer from these diseases because of the reduction of physiological functions due to aging. The purpose of this experiment is to investigate the thermal responses of the elderly due to the temperature differences which are experienced during winter and summer in Japanese houses.

METHOD

Ten elderly females (EF), aged from 66 to 79, and 10 college-aged females (CF), aged from 20 to 22, served as the subjects in cold environment (10°C, 60% RH). Nine EF, aged from 62 to 72, and 12 CF, aged from 21 to 26, served as the subjects in hot environment (35°C, 60% RH). Air velocities were kept at 20 cm/s in both environments.

The subjects stayed in neutral environment (25°C, 60%) for more than 23 minutes, thereafter they exposed to cold or hot environments for 49 minutes. Then again, they returned to the neutral environment, and stayed for 47 minutes. Skin temperatures at 10 sites, systolic blood pressure (SBP), thermal sensation and sensation of wet were measured during the experiments (119 minutes). The subjects wore standard clothing (0.63 clo) in both environments.

RESULTS

There were no significant differences of mean skin temperature between EF and CF in both experiments. However, there were some differences of local skin temperatures between the groups. Figure 1 showed the changes in finger skin temperature in both groups and environments. Before the cold or heat exposures, finger skin temperatures were almost the same for both groups. However, finger skin temperatures of EF during cold exposures were significantly higher than those of CF. These results indicate that EF decrease their abilities of cutaneous vasoconstriction at the extremities to prevent heat loss. On the other hand, there were no differences of finger skin temperatures between the groups at the end of the hot exposures. However, the rates of increase in finger skin temperatures of EF were significantly smaller than those of CF at the beginning of the heat exposures. These results may show that the heat losses due to the increase of cutaneous blood flow of EF were delayed than those of CF.

Figure 2 showed the changes in SBP in both groups and environments. Increases of SBP by cold exposures of EF were fairly larger than those of CF. On the other hand, changes in SBP by heat exposures were small for both groups.

Figure 3 showed the changes in thermal sensation in both groups and environments. Before the cold or heat exposures, there were no differences of thermal sensations between the groups. Immediately after the cold exposure, there was a significant difference of thermal sensation between the groups. Namely, EF did not feel so cold as CF did. However, at the end of the cold exposure, EF felt the same coldness as CF. This result means that EF have a reduction of sensitivity to cold. In particular, there is a delayed sensitivity to cold for the elderly. On the other hand, there was no significant difference of thermal sensation between the groups during heat exposures.

There was a tendency that EF felt their environments drier than CF did. Especially, there were significant differences of sensation of wet during heat exposures between the groups.

CONCLUSION

In the cold environment, the elderly could not reduce heat loss by vasoconstriction as young people, and increased their blood pressures more rapidly than young people did. In the hot environment, the elderly could not promote the heat loss by vasodilation as young people. Moreover, there is a delayed sensitivity to cold for the elderly. Therefore, in the houses of the elderly, it is important to have heating and cooling systems which includes the rooms where the people do not stay for a long period of time (e.g. toilet, passage).

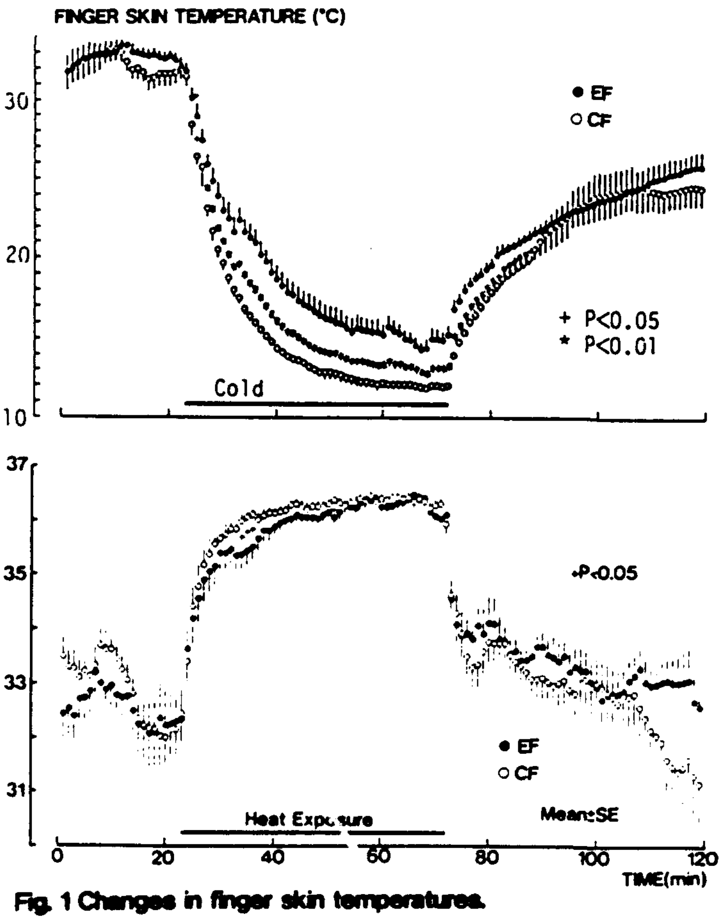

Fig. 1 Changes in finger skin temperatures.

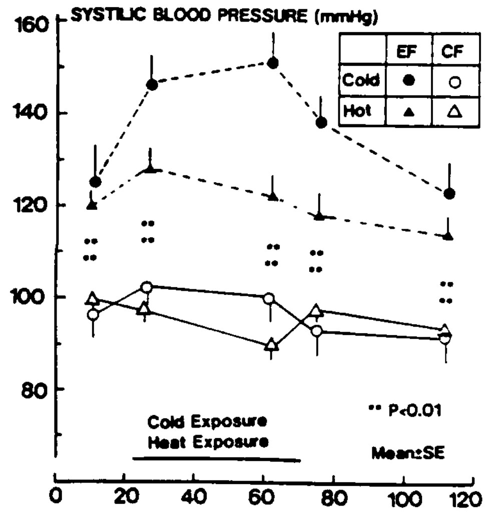

Fig. 2 Changes in SBP.

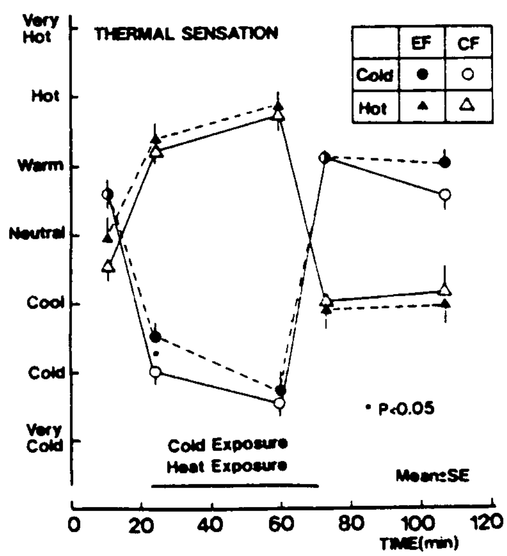

Fig. 3 Changes in thermal sensation.

EVALUATION OF THE SET-POINT MODEL OF HUMAN THERMOREGULATION BY EXERCISE IN WATER

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INTRODUCTION

The set-point model of human temperature regulation postulates that core temperature during exercise is governed by an altered set-point which is related to the relative intensity of the exercise rather than to the available capacity for heat loss. This model was evaluated during cycle ergometry by exercising eight well-trained male cyclists aged 18-30 years at 50% and 70% maximal oxygen uptake (VO_2 max) in air at 20°C and in water. With thermal inputs from the skin equated, the set-point model predicts a rise in core temperature proportional to the %VO_2 max.

METHOD

VO_2 max was determined by open circuit spirometry during an incremental cycle ergometer test. On subsequent occasions, each subject exercised for 30 min, first at 50% and then at 70% VO_2 max, in air at 20°C and then immersed to the neck in water with its temperature controlled to match the skin temperature in air. The tests were then repeated, first in water and then in air, to provide a measure of reliability and to balance any ordering effect. Tests were conducted a week apart on the same day of the week and at the same time of day. All tests were performed in a cylindrical fiberglass tank on a modified cycle ergometer linked by a long chain to a Quinton constant workload ergometer.

Core temperature (T_c) was measured as esophageal temperature and mean skin temperature (T_s) was calculated as the weighted mean of eight sites (1). Oxygen uptake and temperatures were measured in the last minute of every five minutes.

Changes in T_c were analysed by 3-way ANOVA for repeated measures with main effects of work rate, environmental condition and trial. Stability of skin temperatures and oxygen uptakes across environmental conditions was tested by paired t-tests. Significance was accepted at the 0.05 level.

RESULTS

The 8 subjects were relatively fit (VO_2 max = 4.4 $\pm$ 0.6 $l.min^{-1}$) and lean (sum of ten skinfolds = 64 $\pm$ 14 mm) (mean $\pm$ SD).

No significant differences in oxygen uptakes or T_s were observed between repeated trials in air or water at either exercise intensity, indicating good replication of these variables. ANOVA showed that there was no significant effect of test order on the rise in T_c. T_c rose significantly more in air than in water (Figure 1). Post-hoc analysis (Table 1) showed that core temperature rose significantly more at 70% VO_2 max (1.53 $\pm$ 0.46°C) than at 50% (1.11 $\pm$ 0.37°C) in air, but not in water (0.35 $\pm$ 0.68 and 0.46 $\pm$ 0.45°C repectively). In water, some subjects showed a slight drop in T_c in the first few minutes, as heat loss temporarily exceeded gain. The subsequent rise was the same for both work intensities in water, indicating that the capacity for heat loss, rather than a shift in set-point, was determining heat storage.

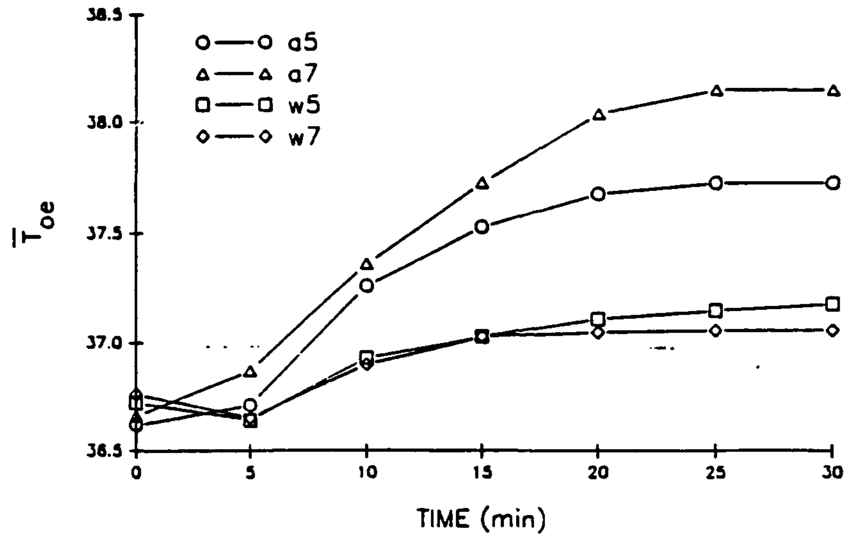

Figure 1. Mean esophageal temperature during repeated trials of ergometer exercise at 50% and 70% VO_2 max in air and water with skin temperatures equated.

a5 = work in air at 50% VO_2 max	SD = 0.36
a7 = work in air at 70% VO_2 max	SD = 0.46
w5 = work in water at 50% VO_2 max	SD = 0.47
w7 = work in water at 70% VO_2 max	SD = 0.66

Table 1. Rise in esophageal temperature (mean ± SD °C) during repeated trials of ergometer exercise at 50% and 70% VO_2 max in air and water with skin temperatures equated.

Environment	Trial	50% VO_2 max	70% VO_2 max
Air	T_1	1.08 (0.43)	1.40 (0.44) *
	T_2	1.15 (0.31)	1.66 (0.48)
Water	T_1	0.50 (0.24)	0.36 (0.67)
	T_2	0.42 (0.67)	0.34 (0.70)
		**	**

* sig. diff. between work rates
** sig. diff. between environments

CONCLUSIONS

We conclude that, within the range of thermal control, core temperature during exercise in water is not determined by readjustment of a set-point, but is related to the heat loss capacity of the system.

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DISTRIBUTION OF CORE, MUSCLE, SUBCUTANEOUS AND SKIN TEMPERATURES IN COMFORT, WARM AND COLD

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INTRODUCTION

Some years ago I became intrigued with Aschoff's (1) hypothesis that the body had a thermally invariant core and a shell of lower temperature, and that the shell expanded during cold exposure to preserve the temperature of the shell, which shrank in size. Was skeletal muscle part of the core, or the shell or a separate compartment altogether? It also seemed interesting to test Kerslake's (2) idea that "deep skin temperature" controlled sweating. My laboratory developed several special thermistor probes, and, after some pilot runs, the men of the laboratory staff were willing to undertake the following rather uncomfortable experiments.

Data were logged by hand and on a strip chart recorder, producing a difficult mass of numbers. This 1972 data has recently been read into a computer and this report comes from a first look at the graphed data.

METHOD

Four men served as subjects. They were 29 (22-40) years old (mean and range), 1.78 m tall (1.73-1.79), weighed 69.5 kg (67-72) and were healthy, physically active people. Each man sat nude and instrumented in an environmental chamber for a 6-hr session, which included 1 hr or more of thermal comfort and 2 hrs or more of heat and cold. They were encouraged to drink water but did not eat.

Chamber air temperatures were 27 C (comfort), 45 C and 15 C; vapor pressure was between 10 and 14 mm Hg (1.3 - 1.9 kPa) and air movement was less than 0.1 m/sec. Exposure times were long enough that body temperatures stabilized and there was heavy sweating in heat and strong shivering in cold. The times of onset for sweating and shivering were recorded. Two of the men went from comfort to hot to cold; the other two went from comfort to cold to hot.

Body temperatures in the core were measured in the esophagus, rectum and auditory canal. Skin temperatures were measured at 16 sites. Six subcutaneous temperatures (T_{sq}) were measured on the forearm, over the triceps, on the chest, back, thigh and calf. Muscle temperatures were measured in the anterior thigh and in the back in the midlumbar region. Standard Yellow Springs Instrument Co. thermistors were used for rectal and skin temperatures. The special T_{ac} probe was held an individually molded rubber plug and further insulated externally. T_{es} was measured with a Konigsberg Instrument Co. radio pill suspended at the level of the cardiac atria on a string anchored to a tooth, the proper length having been determined fluoroscopically for each man. T_{sq} was measured with short needle probes resembling thumb tacks; the depth was adjusted using spacers under the caps so that the probe reached to 1/2 the skinfold thickness at each site. Two muscle temperature sensors were mounted in Teflon catheters, so that T_{mu} was read at depths of 2 and 4 cm.

Because of the many needle probes and because of the awkward amount of cabling for 28 pairs of thermistor leads, no exercise was attempted.

Skin temperatures, T_{ac}, T_{re} and chamber temperatures were printed every two minutes on a strip chart recorder. The remaining temperatures were read on a digital ohmmeter and then converted by hand to temperature from calibration data unique to each probe. These were tabulated every 10 min.

RESULTS

Inspection of the newly-generated graphic records of these data leads to the following observations, most of them unsurprising. The spread between high and low temperatures in any compartment (core, muscle, subcutaneous and skin) was least in the heat and greatest in cold. Subcutaneous temperatures were higher than those on the skin, and muscle temperatures higher yet -- but there was overlapping. Core temperatures were highest except in heat, when some skin, subcutaneous and muscle temperatures were higher. Heat and cold caused exponential changes toward new steady state temperature levels that were generally reached more slowly as depth from the surface was greater.

Sweating began much earlier in the two men who went from comfort to hot than in the two who went from cold to hot, confirming that precooling delays the effects of heat (3). By contrast, shivering began after nearly the same delay whether the subject had started from comfort or heat, but those who started from heat shivered at higher levels of T_{co}, T_{sk}, T_{sq} and T_{mu}.

The core-shell concept could not be evaluated because sampling at depth was insufficient. The (resting) muscle temperatures seemed to be independent of the core and other compartments. There was so much variation of T_{sq} from site to site that it seemed unlikely that there was a deep skin temperature that controlled shivering and sweating. However, deep-to-shallow temperature gradients in the skin were consistent with the notion that thermal gradients could be sensed as heat flow.

Sweat onset and shivering onset occurred at several levels of temperature in the core, muscle, subcutaneous and skin compartments, depending on the pre-existing ambient condition. Further analysis might reveal combinations of temperature which could predict thermoregulatory response.

CONCLUSIONS

This unusually complete set of body temperature records shows how heat and cold exposure at rest develop new temperature distributions in major body compartments. The data may be useful to those who work with biothermal models. The data arrays are available to others on floppy disk, with a BASIC program for initial handling.

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COLD-INDUCED VASODILATION IN THE HUMAN FOREARM

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INTRODUCTION

Cold-induced vasodilation (CIVD) has been observed in the forearm during water immersion at 15°C and colder (1, 4, 5). Clarke et al. (1) observed that the CIVD is taking place largely in the muscle vessels of the forearm, but no rise of intramuscular temperature has been observed, possibly because it was hidden by the cooling of the tissue which was still important after 40 min of immersion in cold water. Whether a rise of intramuscular temperature during CIVD would be observed by prolonging the immersion time over 40 min has not been evaluated yet. The objective of the present study was to investigate the presence of intramuscular temperature increases in the human forearm during immersion in water at 15°C for 3 hours.

MATERIAL AND METHODS

Temperature measurements. The tissue temperature (T_t) of six healthy male subjects, aged 18 to 30 years was continuously monitored during the experiments, every 5 mm from the longitudinal axis of the forearm (determined by CT scan) to the skin surface. The temperature of the tissue was recorded with a fine calibrated multicouple probe (2) implanted on the bulkiest part of the forearm, approximatively 9 cm distal from the olecranon process along the ulnar ridge. The forearm tissue temperature values were corrected for the thermal conductivity effect along the wires of the probe (2). Skin temperature (T_{sk}) was measured, a few mm away from the site of the probe implantation, with a calibrated 40 gauge type T thermocouple.

Hunting response of the tissue temperature. The presence of CIVD response was determined under the criteria of a regular pattern of hunting reaction, as opposition to an erratic tissue temperature fluctuation. The intensity of the hunting reaction during the cold water immersion was determined for each depth inside the forearm by measuring the increase in tissue temperature during each cycle of the hunting reaction (ΔT_t in °C), and a mean value of ΔT_t was calculated for the complete immersion ($\Delta \overline{T}_t$) at each specific depth inside the forearm.

Heat flux measurements. The heat flux from the skin ($\dot{H}_{sk}$) of the forearm was continuously monitored during the experiments with two waterproofed heat flux transducers fixed on each side of the multicouple probe implantation. Each HFT was calibrated, and a correction was applied to the heat flux values for the effect of the thermal resistance of the HFT on the measured heat flux (3).

Experimental procedure. Subjects reported to the laboratory at noon of the experimental day. Following the muscle implantation of the multicouple probe, the subject, lightly dressed (T-shirt and casual pants), rested in a supine position under thermoneutral conditions (air temperature of 25°C, relative humitity of 40%) for 1 hour during which period, T_t, T_{sk}, and $\dot{H}_{sk}$ were recorded continuously. Then, the subject immersed his forearm and hand for three hours in a well-stirred water bath maintained at a constant temperature of 15°C.

RESULTS

Five of the six subjects tested showed evidence of hunting reaction during immersion at 15°C. Figure 1 depicts the hunting reaction in the forearm muscle tissue during an immersion in water at 15°C for the subject showing the maximum response. For the 5 subjects showing evidence of hunting reaction, a significant increase of skin temperature was not observed for the complete duration of the immersion. Furthermore, muscle temperature did not increase during the first 55 minutes of immersion. However, after an immersion period of 55 to 90 min (mean value of 75 ± 6 min), the muscle temperature began to increase, followed by a decrease. This pattern was repeated until the end of the immersion for an average of 2.8 ± 0.2 cycles/subjects, the duration of the hunting cycles ranging between 30 and 45 min (mean value of 36 ± 3 min). The $\Delta \overline{T}_t$ values decreased with increasing r (distance between the longitudinal axis and each junction of the probe) to eventually achieve a value of 0 at the skin surface (Fig.1). The maximum $\Delta \overline{T}_t$ values, observed in all cases at the longitudinal axis of the subject's forearm, ranged between 0.4 to 1.0°C (mean value of 0.7 ± 0.1°C). The heat loss from the forearm stabilized after ~60 min of immersion, and no concomitant increase of $\dot{H}_{sk}$ was observed during the fluctuations of the muscle temperature.

DISCUSSION

After an immersion period averaging 75 min, the muscle temperature of the forearm began to increase in 5 out of 6 subjects. Clarke et al. (1) showed no rise of muscle temperature of the forearm during 40 min of the cold water immersion at T_w < 18°C, despite an early rise of the forearm blood flow during the cold

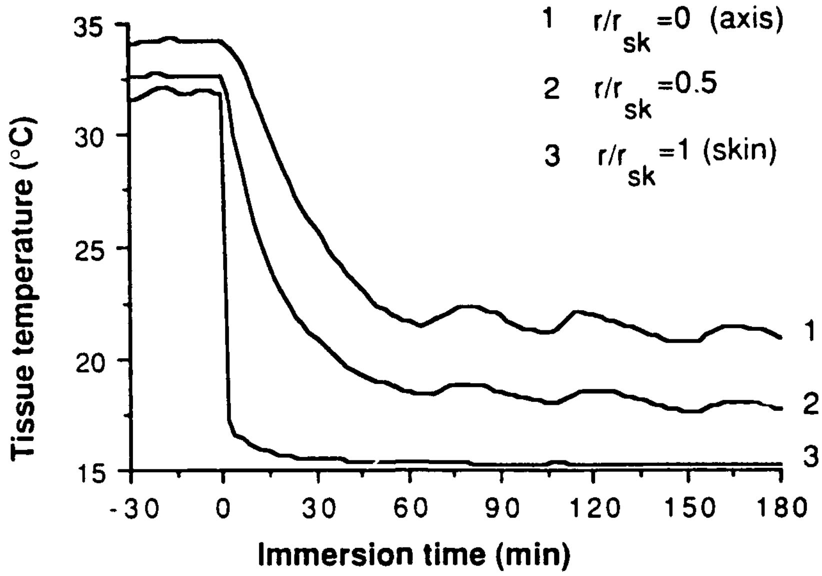

Fig. 1. Example of hunting reaction response observed in the forearm muscles during an immersion of the forearm in water at 15°C. The ratio r/r_{sk} is the relative depth inside the forearm, where r is the distance of the considered depth from the longitudinal axis of the forearm, and r_{sk} is the radius of the forearm.

stress. The absence of any rise of temperature in the forearm muscles may be due to the short period of immersion (40 min). The increase in forearm blood flow during CIVD, which would raise the temperature of the tissues as observed near thermal steady-state (75 min), merely reduces the rate and extent of cooling during the transient phase.

The observation that the tissue temperature fluctuation is limited to the muscle tissue is in agreement with the results of Clarke et al. (1), who suggested that the cold-induced vasodilatation takes place largely in the muscle vessels of the forearm. Since no increase in $\dot{H}_{sk}$ was observed during the immersions, the reduction of the forearm muscle temperature following CIVD can not be attributed to an increased heat loss to the environment, but is probably due to the cooling action of the venous blood returning from the cold extremities on the temperature of the forearm tissues. It was also observed that the magnitude of the hunting reaction response ($\Delta\overline{T}_t$) is dependent on the depth inside the forearm (Fig.1). The presence of the maximum hunting reaction response at the longitudinal axis of the forearm may be partly due to the concomitant CIVD of the hand and fingers, in addition to the cooling effect of the central venous return from the hand.

In conclusion, this study shows the presence of periodic increases of the forearm muscle temperature near thermal steady-state during water immersion at 15°C, the maximum increases being observed at the axis of the forearm.

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CONTRIBUTION OF VARIOUS MUSCLES TO SHIVERING IN COLD-EXPOSED MAN

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INTRODUCTION

In many mathematical models of thermoregulation, the contribution of the various muscles to shivering is usually either based on the mass ratio of the muscles involved (1) or on a weighting that assigns shivering activity principally to the trunk muscles (2) (see Table). The purpose of this study was to quantify experimentally the contribution of various muscles to shivering during whole body exposure to cold air.

METHOD

1. *Experimental.* Data were obtained from ten male subjects resting in a supine position wearing shorts only and exposed to 10°C air (42% relative humidity and < 0.4 m/s air flow) for 2 h. Surface EMG recordings were taken continuously using Medi Trace pediatric surface electrodes placed 3 cm apart, center to center, on the pectoralis major (PE), rectus abdominus (AB), biceps femoris (BI), brachioradialis (BR), rectus femoris (FE), and gastronemius (GA) muscles. The first two and the latter four sites represent, respectively, the trunk and limb regions of the body.

2. *Analysis.* All EMG measurements were digitized at 1024 samples/s. Background (*noise*) and maximum voluntary contraction (*mvc*) signals were recorded for 1 s each prior to the 2 h exposure. The integrated or mean rectified EMG per 1 s interval was obtained as follows:

$$IEMG_j = \frac{\sum_{i=0}^{1024} |EMG_i|}{1024}, \quad j = 1 \rightarrow 7200$$

The IEMG component due only to shivering (*sh*) was obtained by subtracting the background value from the measured value, i.e. $IEMGsh_j = IEMG_j - IEMG_{noise}$.

The periods of voluntary movement during the exposure were removed from the data. This left a total of seventeen 4-min periods; average values were obtained as follows:

$$IEMGsh_k = \frac{\sum_{j=1}^{240} IEMGsh_j}{240}, \quad k = 1 \rightarrow 17$$

Mean values were then normalized by dividing each value by its corresponding *mvc* value and adjusted for the muscle mass it represented so that EMG values of different muscle sites could be compared on a relative basis. The contribution of a muscles's shivering activity to the overall activity was determined by dividing its normalized value by the sum of the normalized values of all muscles sites.

RESULTS

Figure of the percent of normalized integrated EMG activity of various muscles to overall shivering over time during exposure to 10°C air

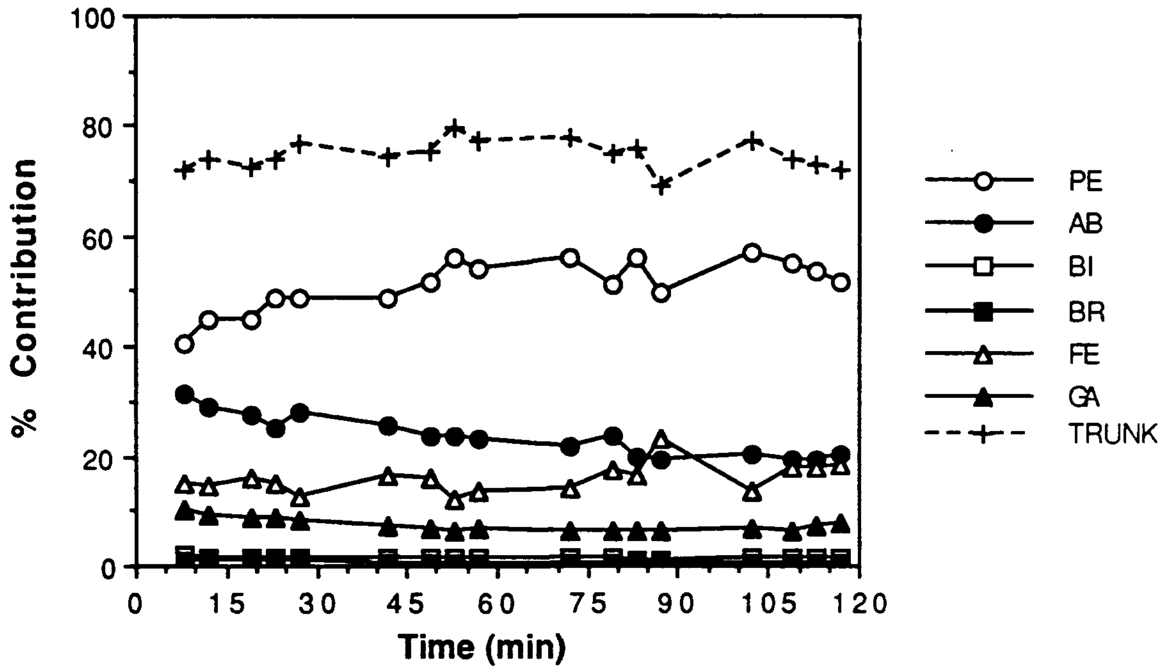

Table of percent contribution of various muscle sites to overall shivering. Experimental values are averaged over the 2 h exposure period.

Site	Mass-weighted (1)	Trunk-biased (2)	Experimental
Head	2	3	--
Trunk	55	85	75
Arms	11	5	2
Legs	32	7	23

CONCLUSION

The experimentally-determined values suggest that the trunk muscles are responsible for about 75% of the overall shivering activity of the body during nude cold air exposure. While this is greater than the trunk's proportionate muscle mass of about 55% (1), it is less than the value of 85% assigned in some models of thermoregulation (2).

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GROSS EFFICIENCY OF HUMAN LOCOMOTION IN A MODIFIED STEP-TEST IN WARM AND COLD ENVIRONMENTS

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INTRODUCTION

Relationship between energy consumption and external work is called efficiency and it is used to describe the economy of human locomotion. Environmental factors possibly modify this relationship (1,2). In this study the effects of warm (W,20°C) and cold (C,-15°C) ambient temperatures on gross efficiency (Eff_g) in three different work levels were compared.

METHODS

Clothed (1.0 clo in W and 2.4 clo in C) subjects (n=6) performed a modified step test ascending to three different heights (20 min/height). Distance from the floor to the proximal end of os. humerus was measured. From this distance 20, 35 and 50% was used as step heights (SH) aiming to correspond light (SH1), moderate (SH2) and heavy (SH3) work, respectively (3). Oxygen consumption (VO_2), heart rate (HR), 15 skin temperatures, rectal temperature (T_r) and heat flux (3 sites) were measured. External work (W_e) and Eff_g was calculated.

RESULTS

In spite of about 3 kg heavier clothing in C, the mean W_e in both environments and in each stepping height differed only by 1 W, and consequently differences in Eff_g had to be due to variation in mean VO_2 (0.2-0.5 l/min). The highest Eff_g (14.8%) was seen in C in heavy work but in W in the light work (14.7%). The lowest Eff_g was seen during light (11.2%) and heavy work (12.4%) in C and W, respectively (fig 1).

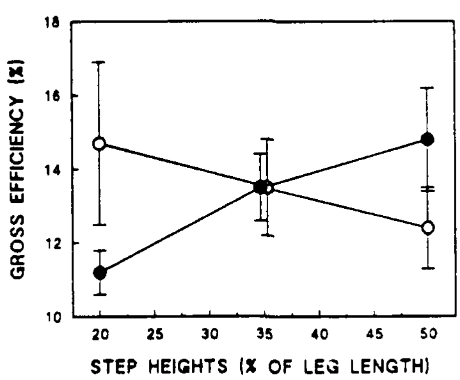

Fig 1. Eff_g (mean±SD) in cold (solid circle) and warm (open circle) temperatures in three different work levels.

Mean skin temperature and T_r did not differ between C and W experiments. However, leg skin temperature (mean of thigh and calf temperatures) and heat flux from the working calf muscles correlated rather well with the changes in Eff_g (table 1).

Table 1. Mean leg temperature (T_l, °C) and heat flux (HF, W/m^2) from the calf, mean±SD, n=6.

		step 1	step 2	step 3
T_l	cold	30.3±1.8	31.3±2.4	32.5±1.2
	warm	32.2±0.9	33.2±1.1	33.4±1.0
HF	cold	143±16	144±14	155±17
	warm	108±15	184±25	198±14

CONCLUSIONS

There seems to be essential differences in Eff_g of human locomotion in various temperatures and workloads. The differences seem to be predominantly quided by local effects. Maximal Eff_g was achieved in leg skin temperatures (indicating the superficial temperature of working muscle) (4) of 32.2-32.5°C.

In light work the poorer Eff_g in C was probably due to the need to warm up the muscles.

In W, on the contrary, the activation of heat dissipation systems could be responsible for the lower Eff_g in moderate and especially in heavy work. In addition to leg temperatures, the increasing need for heat dissipation was also seen in heat flux from the calf, which in C was virtually unchanged but in warm increased as a function of decreasing Eff_g (table 1). In hot conditions respiration, circulation, sweating and the Q_{10} effect are activated (5), thus increasing total metabolism and diminishing Eff_g.

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COMPARISON OF VENTILATORY LIMITATION IN AVIATION AND DEEP SEA DIVING

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INTRODUCTION

The limitations of breathing equipment have been implicated in loss of consciousness episodes (LOC) in both the undersea and aviation environment (1,2). In diving, LOC can occur whenever the human respiratory system can no longer compensate for inadequate equipment design. In air combat, G-induced LOC can occur whenever oxygen breathing systems impair a pilot's performance of the respiratory portion of anti-G straining (M-1, L-1) maneuvers.

Gas density (ρ) increases with water depth, markedly decreasing the performance of underwater breathing equipment. In aviation, gas density is low, but flow rates may be high. During the M-1 and L-1 maneuver peak flowrates may range from 360-450 l/min (3). We used a fluid dynamic comparison to demonstrate that the physical stresses imposed on the respiratory system by the diving and combat aviation environment are similar.

METHODS

We evaluated the pressure drop characteristics of a straight, corrugated hose from a U.S. Navy MK-15 closed-circuit Underwater Breathing Apparatus. The hose consisted of two sections joined together to form a 122 cm long, flexible, accordion-pleated rubber tube (inside diameter 3.48 cm) with pleats 0.6 cm high spaced 1 cm apart along the tube axis. The pressure drop along the length of hose was measured as a function of flow rate. Air at 1 ATA and 22-23 °C was moved through the tube at rates ranging from 100-600 l/min. The dimensionless friction factor (f) for the tube was calculated from the Fanning formula (4).

$$f = \Delta P \cdot D/(2\rho \cdot \upsilon^2 \cdot L) = \Delta h \cdot \pi^2 \cdot D^5 \cdot g/32L(S.G.)Q^2 \tag{1}$$

where ΔP is the pressure drop along the hose, D is hose diameter, ρ is gas density, υ is linear gas velocity, and L is hose length, Δh is pressure drop (energy loss) in cm H_2O, S.G. is the specific gravity (gas density relative to that of water), Q is the volumetric flow rate (cm^3/sec), and g is the gravitational acceleration (981 cm/sec^2). Gas densities were computed at body temperature (37° C).

Once f was determined, eqn. 1 was rearranged to yield the expected energy loss for the following conditions: 1) O_2 breathing at sea level with peak flows of 360 l/min and 2) 450 l/min, representing pilots performing anti-G straining maneuvers, 3) air breathing at 95 fsw and 4) 150 fsw, and 5) 2%O_2-98% He breathing at 1000 fsw. The diving conditions, 3-5, both assumed a minute ventilation of 60 l/min with peak flows of 188 l/min. Reynolds number (Re) was calculated as $4\rho Q/\pi\mu D$, with μ being viscosity.

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RESULTS

The friction factor for the diver's breathing hose was 0.094 ± 0.007 (mean ± S.D.), well outside the range of the Moody diagram (4). All experimental conditions resulted in fully developed turbulent flow (constant friction factor).

Table 1: Pressure losses for high flow/low density and low flow/high density conditions.

condition	Q (l/min)	ρ (g/l)	Re	Δh (cm H_2O)
1	360	1.26	15,200	3.2
2	450	1.26	18,000	5.3
3	188	4.4	27,700	3.2
4	188	6.30	37,800	5.5
5	188	5.60	33,600	4.9

The pressure losses for conditions 1 and 3 were similar, as were those for conditions 2, 4, and 5.

CONCLUSIONS

The pressure drops or energy losses (Δh) computed in these examples are not large, and we do not imply that they would impair the function of either diver or aviator. Actual pressures generated during exercise or anti-G maneuvers would be larger due to the additional impedance of valves and regulators. This example serves merely to show the similarities between the low flow-high density and the high flow-low density conditions, and should dispel the notion that the respiratory work required by a combat pilot is less than that of a diver.

In diving, ventilatory insufficiency due to high work demands and UBA inadequacies are not uncommon. Unconsciousness may ensue, but more frequently, breathlessness leads to a temporary suspension of work. However, neither result is desirable in real or simulated aerial combat. In the near future, the high G capabilities of new aircraft and the potential for sustained operations will undoubtedly tax a pilot physically. Therefore, new ways of reducing the pilot's respiratory work load should be considered, just as they have been for the diver.

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ANTARCTIC MEDICINE

25 YEARS AT HALLEY BAY 1956-1980

by W A Freeland
ARMY PERSONNEL RESEARCH ESTABLISHMENT

INTRODUCTION

Occupational Health involves care of the "Total Man"[1]. No where is this more true than when medicine is practised in remote and hostile environments.

A group often forgotten about when considering occupational health care is the scientific community working in Antarctica. Yet as far back as 1772 accounts of the physical manifestations of scurvy in Antarctic voyages were recorded[2]. Many doctors who accompanied those early expeditions documented their medical experiences[3,4,5,6].

Whereas previously man was only a fleeting visitor to Antarctica he has surmounted many difficulties to establish himself there on a permanent basis.

The British Antarctic Survey operate 5 stations in that cold land . Halley Bay, situated on a floating ice shelf, 1280 kms from the South Pole is the only base to have had a medical officer permanently on site since it was established in 1956. This paper is a retrospective study of the medical conditions arising at Halley Bay during its first 25 years.

METHOD

The information in this survey was obtained by reviewing the reports submitted by medical officers who wintered at Halley Bay between 1956 - 1980. Diagnoses of illness and injury were coded using the International Classification of Diseases (ICD 1975).

RESULTS

Between 1956 - 1980 a total of 552 r wintered over at Halley Bay. During that time there were 5 deaths, all due to accidents.This gives a crude mortality rate of 9.05/1000. The total number of diagnoses in the reports was 688. There were also 258 dental fillings and extractions.

34.2% of cases were due to Injury and Poisoning. Of these there were 24 fractures; 10 upper limb, 5 lower limb, 2 facial, 3 vertebral and 4 chest fractures. There were 5 dislocations, 10 concussions, 32 sprains/strains and 27 back injuries. In addition 15 men suffered from carbon monoxide poisoning.

14.2% of cases were due to Gastro-Intestinal System diseases. Three cases of acute appendicitis were documented.

11.6% of cases were categorised Skin and Subcutaneous Tissue Diseases, 22 of which were skin infections.

Injury and Poisoning plus Musculoskeletal and Connective Tissue Disorders accounted for 41.6% of those treated. Only one medical evacuation took place (a doctor who sustained a concussion, facial injuries and fractured spine after a fall)[7].No case of serious cold injury was documented although there were 14 cases of snowblindness. Records were insufficiently detailed to allow an estimate of minor cold injuries to be made.

Amongst the more unusual cases was one of Giardia Lamblia, 3 cases of Syphilophobia and one case of vestibular neuronitis.

The doctor at Halley Bay frequently had responsibility for the other 4 British bases. Consultations and treatment were carried out over the radio. From the 1978 medical log compiled by the author 25.3% of consultations were with the other 4 bases.

DISCUSSION

Analysis of the medical records indicated that more attention to detail was necessary. The results are an underestimate of the total cases seen and treated. Between 1956-71, reports included comments such as; "'several' cases of insomnia; indigestion was 'prevalent'; a 'few cases' of backache. This is not unique to British stations[8] . The results presented are similar to those obtained by other nations[8,9,10]. Using the ICD method it was evident that, as with other nations, trauma and musculoskeletal problems formed the bulk of the medical workload.

The absence of serious cold injury may reflect an awareness of the environmental hazard or the fact that man spends only 9-15% of his time outdoors[11].

With the worlds' natural resources dwindling,new and untapped reserves of energy are being sought. It seems likely, however unwelcome that Antarctica is poised for an invasion of workers seeking to exploit the Continents vast reserves. If this happens there will be a need for epidemiological information on the occupational hazards of working there, so that the care of the scientific workers can be improved.

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ROYAL MARINE TRAINING - ENERGY REQUIREMENTS AND NUTRITIONAL INTAKES

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INTRODUCTION

Throughout the 1980's it had become apparent that a very high incidence of injuries and infections amongst Royal Marine (RM) recruits was a major contribution to training losses, demonstrated by much back-trooping and discharge. The Institute of Naval Medicine (INM) was tasked to investigate the causes of these losses and where possible to produce solutions so that unnecessary wastage could be avoided. A series of multi-disciplinary studies commenced in 1988 to look at many aspects of recruit life. The aim of the nutritional studies was to determine both the energy and nutrient intake, and the energy and nutrient requirement of recruits undergoing the physically demanding 30 week course.

In 1981, INM provided a theoretical estimation of energy expenditure determined through study of the physical activity as outlined in the course programme (1). The average daily energy expenditure was estimated to be 4200 Kcals. A major increase over the Ration Scale Allowance (2900 Kcals net) was recommended on this basis, but a more detailed study was required of the feeding habits of recruits before full implementation of this increase could be achieved.

METHODS

The study was performed in three parts:

Study 1 - Intake from the Dining Hall. Accurate intake was determined by a 'double-plated weighed meals inventory' method on one troop of (initially) 46 recruits on three occasions during training (weeks 5, 19 and 28/29), chosen to be representative of the whole course. Subjects also completed a check list for additional items such as bread, butter, etc. Items eaten were separated into basic menu items which were then weighed to determine all intake, (i.e. original plate minus wastage, bones, fact, etc. left on the second plate). The net weight, together with items from the check lists were then coded for nutritional analysis on an individual basis using the UK National Nutrient Databank (Royal Society of Chemistry and MIFF). Where necessary recipes were obtained from the catering staff. During one 24 hour period (three meals), aliquots of food from the whole troop were collected, homogenized and analyzed directly for total nutrient content.

Study 2 - Snacking. Foods and beverages obtained from non-service sources were believed to play a major role in the recruit's diet. In order to quantify the degree of snacking, details of all eating and drinking occasions were recorded by the same subjects as in Study 1 in a diary-questionnaire. This data provided a detailed description of the product, including size or volume, the amount if any discarded, the place of purchase and the time of consumption.

Study 3 - Vitamin status. Bloods were collected for the analysis of vitamin status on entry (week 1) and toward the end of each of the three weeks in which Studies 1 & 2 were conducted. Aliquots of whole blood and centrifuged plasma were prepared and sent to Switzerland for analysis by Hoffmann LaRoche, Basel.

Study 4 - Energy Expenditure. The O^{18}, H^2 double labeled water technique was used to assess energy expenditure over a period of 2 weeks, on three occasions, commencing on the first days of Studies 1 & 2.

Study 5 - Anthropometry. Anthropometric measures of height, body weight and % body fat from skin-fold thickness (2) were conducted in weeks 1, 4, 12, 18, and 26.

RESULTS

Intake from the Dining Hall. Energy provided by food eaten in the dining hall was estimated to be an average per recruit per day of 2530 Kcals in week five, 2760 Kcals in week nineteen and 2710 Kcals in week 28/29). From the raw data it was possible to deduce patterns of attendance for means amongst the troop. In week five 84%, in week nineteen 87%, and week 28/29 only 65% of all possible means were attended. Attendance rates at breakfast were consistently lower than for the other two meals. Some 40% of energy was supplied by fat and 49% by carbohydrate. Protein and fibre intakes were some 94 and 28 gms per man per day, respectively. Snacking. Diary-questionnaires (completed in week 5) of 14 subjects were randomly selected for early analysis. Intakes of foods and beverages from non-Service sources amounted to an average of 2175 Kcals per man per day. The average reported weekly personal expenditure on these foodstuffs for all subjects was £23.00 in week 5 and £19.10 in week 28/29. Total Energy Intake. Amalgamation of dining hall intakes with non-Service intakes amounts to 4845 Kcals per man per day, of which only 55% is derived from Service (dining hall) foods, while the remainder is purchased privately. Energy Expenditure. The majority of the urine samples collected in this study remain to be analyzed. However, an initial, crude assessment of 8 subjects in week 5 gave a mean expenditure of 400K Kcals (S.D. 1250). Although further analysis is required, this is in line with the values in Studies 1 plus 2. Changes in Body Weight. Total body weight increased insignificantly from week 1 (69.1 kg) to week 26 (72.4 kg), whereas % fat fell from an initial mean level of 12.2% to 10.2% in week 12, before increasing again to 12.7% at week 26. Vitamin status. Mean values of all the vitamins measured with the exception of folate were within the normal range throughout the study. Folate levels appeared to fall throughout the course.

DISCUSSION

The RM recruit has been shown to derive a maximum of 2760 Kcals from dining hall food. This figure is close to the Ration Scale target. Foods and beverages purchased privately boosted total energy intake by 81% to 4845 Kcals per man per day for the 14 subjects whose diary-questionnaires were analyzed. From a survey of expenditure for the whole troop the snacking performed by this sub-group appears to be representative of the whole troop at the two occasions surveyed. Assessments of energy expenditure lend support to a figure of over 4000 Kcals.

The anthropometric study showed that against a background intake of 4845 Kcals there is no increase in body fat, but that there is a 4% increase in fat free mass (taken to be muscle) in the first 12 weeks of training. It is reasonable to assume therefore that the total average intake of 4845 Kcals is an equilibrium value between actual intake and actual expenditure.

The intake of fat from the dining hall is a little on the high side, but further analysis of the diary data is required to estimate the overall contribution of fat and carbohydrate to energy supply.

CONCLUSIONS AND RECOMMENDATIONS

Modification to current feeding practices is required to allow a greater energy intake to be derived. Since the final meal is presently served at 1700 it is little surprise that young men, still growing and pursuing a physically strenuous programme of work consume large quantities of foods and beverages in the late evening. This fact alone indicates a severe need for an additional meal at about that time. However it would be imprudent nutritionally to make-up all the energy shortfall in one single episode. If more food was to be available at the current 3 meals, and dining hall attendance rates were to increase, a further increase in intake would be brought about so long as the training programme allowed adequate time for digestion and absorption. The time interval between meals is great and thus provision of a mid-morning and mid -afternoon snack could be a simple method of providing an additional 300-400 Kcals per occasion.

There is yet insufficient evidence that the overall composition of the diet is deleterious to performance. In considering the composition of the diet, and in particular the additional snack-meals required, attention should be paid to increasing the overall proportion of energy derived from complex carbohydrates and decreasing that derived from fat. A high carbohydrate diet is important to ensure that muscle glycogen stores are replenished after periods of intense exercise.

The production of high carbohydrate diets which will, inevitably, be of low energy density can only be brought about by high volumes of foods. Thus recruits will need to be allowed additional time to eat the greater quantities involved. In the formulation of such diets care needs to be taken to avoid enriching the carbohydrate with fat to increase both its energy supply and its palatability. If the meals provided in the evening were to be the high carbohydrate ones, sufficient time throughout the night would allow glycogen repletion. To ensure the diet is palatable, providing 55% of total energy from carbohydrates and 30% from fat would appear a reasonable goal.

A report on these finding has very recently been sent to the Royal Marines who are now assessing, with us, the most effective method of implementing these recommendations within their current supply, manpower and finance limitations.

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A SURVEY OF OVERUSE LOWER LIMB INJURIES IN BRITISH ARMY RECRUITS

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ARMY PERSONNEL RESEARCH ESTABLISHMENT

INTRODUCTION

In recent years the problem of training injuries in British Army recruits has aroused much concern. This has centred on the repetitive strain or overuse type of Lower Limb Injury (LLI).

The problem is not unique to the British Army, overuse injuries and stress fractures have been recorded in other military organisations[1,2].

In 1986 the Army Personnel Research Establishment (APRE) was tasked to undertake a wide-ranging study of recruit training, an integral part of which was to assess the medical and training implications of overuse LLIs.

The aims of the study were to; define the incidence of LLI during basic recruit training ; assess the influence such injuries had on training outcome and wastage ; attempt to identify physical characteristics which might predispose to overuse injury.

METHOD

Two different training establishments were chosen for the study. A total of 519 recruits took part in the survey. Of these 408 were infantry recruits and 111 were adult artillery recruits.

On arrival at the training depot each recruit completed a Physical training questionnaire designed to assess their level of pre-training physical activity and fitness.

A medical examination of each recruit was completed and a battery of tests to assess simple anthropometric characteristics and aspects of physical performance was carried out. These included ; anthropometry ; isometric muscle strength and endurance; indirect maximal aerobic power cycle ergometer test.

Medical officers in the two establishments completed a LLI overuse record form, when recruits presented with an injury.

Administrative data on the outcome of training was also collected.

RESULTS

The mean age of the recruits on entry was 18.9 years for the adult artillery soldiers and 16.6 years for the infantry soldiers.

From the physical training questionnaire 72.5% - 76.6% of all recruits had endurance training as part of their school PT. Between 84.6% - 92.8% of recruits had attempted to improve their fitness level in preparation for basic training.

The pre-training assessment of physical performance showed,as might be expected, the adult recruits to be generally taller, heavier and stronger than the junior infantry soldiers. The latter however demonstrated greater aerobic fitness.

No association between anthropometric characteristics and LLI was demonstrated. However a weak association between thigh strength (measured as knee extension) and LLI was shown. Those who suffered a LLI had a mean knee extension of 111.25kg against a mean of 120.17 kg in those with no injury ($p>0.01$).

The overall incidence of overuse LLI during training was 18.7%. In infantry recruits, 13.1% of junior soldiers (n=183), and 20.4% of junior leaders (n=225) suffered a LLI while 20.7% of adult artillery recruits (n=111) presented with an injury. In the infantry soldiers 67 suffered an injury 90% of which were to the knee. All medical discharges in the study (n=16) were due to knee problems.

In adult recruits 23 suffered an injury; of these 8 (35%) were to the knee and 11 (47%) were to the calcaneum. None of the adult recruits were discharged due to LLI.

A total of 51 recruits (9.8%) successfully completed training after having suffered a LLI. They spent 1143 days away from training due to their injury. The mean injury absence was 22.4 days.

37% of infantry soldiers with a LLI had a previous history of the same complaint.

The combination of equipment and type of training most provocative of overuse LLI was identified; in junior infantry soldiers, running in boots especially with backpacks was closely associated with knee injury; in artillery recruits, wearing boots during physical training was closely associated with heelbone injuries.

Of those discharged from the Army as a direct result of their injury (3.1%), the mean time in training before leaving was 63 days. The annual recruit population is about 20000. Therefore 620 recruits might be expected to suffer a LLI each year. This would result in 39,060 wasted training days .Injury absence would account for a further 43,000 lost training days. There is an obvious cost benefit to be obtained by reducing this injury rate.

CONCLUSIONS

From the study it was apparent that greater emphasis must be placed on the previous medical history of all recruits especially juniors.

The earliest stages of recruit fitness training should concentrate on gymnasium work designed to increase thigh muscle strength and tone.

Training which combines distance running in boots and load carriage should be forbidden for junior recruits. In adult recruits such training should be reduced or modified to reflect true operational requirements.

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FRICTION BLISTERS: A REVIEW OF 100 YEARS KNOWLEDGE

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The friction blister is a soft tissue disorder that is caused by the cumulative trauma of repetitive frictional action on exposed skin. For today's recreational society and for those populations who use their feet to earn a living, the morbidity from friction blisters must be measured in grand terms. Armies annually loose thousands of men hours of training time to the pain and complications of the blistered foot. Throughout history few military campaigns are won or lost without official mention of the ground soldiers feet and his blisters. Sporting groups annually spend millions of dollars on treatments and preventions for the blistered feet of their tennis players, marathon runners, joggers, walkers and hikers. Yet over the last 100 years there has been a paucity of literature examining this most ubiquitous problem and even less study on their prevention.

This review article summarizes existing literature in the following categories:

(a) incidence

(b) friction physics

(c) pathophysiology

(d) histology

(e) footwear dynamics

(f) risk factors

(g) treatment

(h) prevention

It also assesses why there has been little progress toward effective prevention mechanisms and offers a new concept for developing blister prevention systems.

The complete review paper will be presented as a poster display.

REFERENCES

(A extensive Reference list will be available at the poster display).

PHYSICAL TECHNIQUES FOR DETERMINING THE RESISTANCE TO HEAT TRANSFER PROVIDED BY CLOTHING

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It is necessary to quantify the thermal insulation and evaporative resistance properties of clothing systems so that the heat exchange between the body and the environment can be determined and a person's performance in that environment can be predicted using biophysical models. This paper reviews the physical methods for directly measuring resistance data on fabrics and clothing ensembles and discusses problems associated with different techniques. In addition, methods for estimating the resistance values for clothing from different fabric and clothing properties will be mentioned.

FABRICS

The resistance to dry heat transfer (i.e., insulation) can be measured using the rate of cooling method, the constant temperature method (e.g., guarded hot plate), and heat flow meter. Flat plate instruments or cylinders have been used, with each type having advantages and disadvantages over the other. Fabric insulation can be estimated from thickness, so the compressometer, micrometer, and pendulum methods will be discussed. The evaporative resistance of fabrics can be measured using a sweating hot plate device or cylinder. A liquid barrier of known resistance is needed to keep the fabric dry during the test. Measurements can be made with and without a temperature gradient between the hot body and the environment. Other methods for measuring the diffusion of water vapor through a fabric include the ASTM control dish method and the Canadian DND apparatus. [1-10]

CLOTHING TESTS

Thermal manikins are constant temperature methods for measuring the insulation values of clothing ensembles. They take into account several variables that affect heat transfer from the body (i.e., the amount of body surface area covered by clothing, the distribution of the insulation over the body, the looseness or tightness of fit, and the increased surface area for heat loss. Manikins can be divided into body segments with independent temperature control and measurement or consist of one circuit. They can be made to sweat externally by using a cotton knit skin saturated with water, but this test is a transient one. Efforts to develop manikins with steady-state sweating capability are still underway. Manikins also can be attached to auxiliary motion systems so that clothing ventilation can be studied. [11-20]

DYNAMIC VS. STEADY-STATE TESTS

These test methods have been criticized because they are conducted under steady-state conditions whereas, a person wearing clothing is moving around--changing body position, movements, and environments. Thus, quantifying the thermal responses of clothing to transient conditions is important. A thermal manikin can be used to quantify the changes in insulation due to temperature and humidity transients by moving the manikin from one environment to another, or by changing the environment around him. A manikin can be used to quantify the effect of body position and motion on the insulation value of the clothing also. Unfortunately, these tests have not been conducted with the manikin sweating, so changes in evaporative heat transfer must be estimated from fabric and clothing data. [21]

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TRANSIENT THERMAL RESPONSE OF CLOTHING SYSTEMS

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INTRODUCTION

Clothing parameters such as thermal insulation and moisture permeability are based on steady state measurements and provide useful predictions of how the clothing will perform in applications where conditions do not change rapidly. There are also situations where the ambient environment changes or physiological responses occur with sufficient rapidity that transient effects become important. Examples of these situations include: going from a dry space to a humid space, exposure to a hot environment, and the onset of sweating. The heat exchange between the body and the environment may be affected significantly by the dynamic response of the clothing system in these instances. In cases where only short tolerance times are possible, such as the exposure to extreme heat or cold, the transient response of the clothing may dominate. The objective of this study was to develop a computer model which could simulate a variety of clothing systems and predict how they respond under rapidly changing conditions.

METHOD

In previous work, it was shown that computer models could be developed that can accurately predict both dry and evaporative heat flow through clothing systems [2]. These models divide the body into a number of segments such that each segment represents a well defined part of the body (e.g., head, chest, upper arm, etc.). The segments are divided into subsegments such that each subsegment is uniformly clothed. The subsegments are modeled as cylinders with the clothing treated as concentric cylinders. Each fabric layer is described in terms of thickness of the fabric, thickness of the trapped air layer, thermal resistance, and moisture permeability. Equations for radial heat and moisture flow are solved for each subsegment. Data bases describing the clothing geometry were developed to use with the models. Manikin measurements were used to validate the accuracy of the model predictions.

The same approach was used to model transient response. In addition, there are two main transient effects that must be modeled: the changes in fabric temperature, and sorption and desorption of moisture by the fabric. These effects can be described in finite difference form by

$$\frac{dR_i}{dt} \; r \; Q_s(R)_i \; th = \frac{P(T,R)_{i-1} + P(T,R)_{i+1} - 2\,P(T,R)_i}{R_{ef}} \times \frac{tf}{th}$$

$$\frac{dT_i}{dt} \; r \; c_p \; th = \frac{T_{i-1} + T_{i+1} - 2\,T_i}{R_f} \times \frac{tf}{th} + \frac{dR_i}{dt} \; r \; th \; Q_s(R)_i$$

where R is the local regain, T is the local temperature, P is the equilibrium vapor pressure at the local temperature and regain values, Q_s is the heat of sorption for the fabric, c_p is the heat capacity of the fabric, r is the fabric density, R_{ef} is the evaporative resistance of the fabric, R_f is the dry resistance of the fabric, tf is the thickness of the fabric, th is the thickness of the layer, and i is the finite difference index. For thick clothing layers, such as in outdoor winter clothing, each fabric layer is divided into a number of sub-layers for the finite difference solution. For thin fabrics, such as typical indoor clothing fabrics, one layer of clothing can be treated as one layer in the finite difference solution. In addition to the parameters needed for the steady state model, the density, heat capacity, moisture regain, and heat of sorption are required for each fabric. Moisture regain for a given fabric is a function of relative humidity; and the heat of sorption is a function of moisture regain. This information is represented in the model in the form of look-up tables.

To validate the model, data where collected for a number of clothing ensembles on a manikin subjected to humidity transients. Data collected at the Technical University of Denmark (TUD) for a wool ensemble were also used.

RESULTS

The model predictions agree well with the measured responses on the manikin. A sample result is shown in the figure. Although agreement between the model and data is not as close as in the previous steady state studies, the comparison is surprisingly good considering the complexity of the sorption process and the coupling between the heat and mass transfer in the transient case. In fact, the agreement between the model and the manikin data is comparable to the agreement between our data and the TUD data for the ensemble that was evaluated at both laboratories. It should be noted that the computational time for the model is not trivial. Typically about ten minutes of computing time on a modern PC are required for each minute of simulated time.

CONCLUSIONS

A computer model was developed which can simulate the transient response of clothing systems and predict the effect of this response on heat flow from the body. For the conditions tested, the model proved to agree with laboratory data indicating that the model does correctly descr∴e the key transient processes in clothing systems. Computational requirements are such that each condition to be simulated should be selected carefully.

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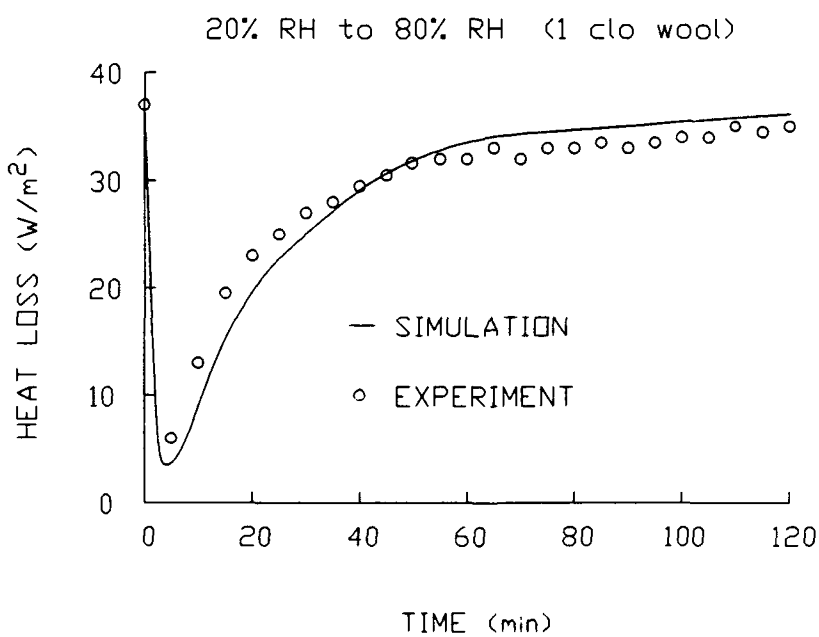

PREDICTING THE COMFORT OF NONWOVEN BARRIER FABRICS IN EXTREME ENVIRONMENTS

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INTRODUCTION

An important end-use for nonwoven fabrics is in surgical gowns and chemical protective clothing. They are also used as insulation materials in apparel worn for cold weather protection. For these end-uses, nonwovens must possess a diverse and often contradictory set of properties: they must provide a barrier against external environmental agents such as bacteria or body fluids, or they must prevent the penetration or permeation of hazardous chemicals or vapors. Nonwovens used in cold weather apparel must insulate against the loss of body heat that can result in hypothermia. The essential protective properties of nonwoven fabrics frequently conflict with the need to provide a comfortable thermal environment for the wearer. Failure to provide a comfortable thermal environment is a serious deficiency since some materials, including surgeons' gowns and chemical protective suits, are worn in hot and humid environments or where the wearer is engaged in strenuous activity that produces excessive amounts of body heat and sweating. At the other extreme, nonwovens used in cold weather clothing must prevent the loss of body heat while reducing moisture condensation that can lead to a deterioration in cold insulation performance and discomfort associated with sensations of wetness or chilling. This research demonstrates new and highly useful laboratory procedures for measuring the heat and moisture transfer properties of textile materials. An analytical model is described for predicting the thermal comfort of clothing systems from laboratory measurements. These tools were used in a program that analyzed the comfort performance of specially selected groups of nonwoven barrier fabrics exposed in hot and humid or extremely cold conditions. The effects of parameters related to heat and moisture transfer are examined: The effects of fabric type, skin conditions, skin-clothing configuration are reported for single and multilayer clothing ensembles. This research produced a deeper understanding of the role of wicking, absorption and condensation phenomena in the transfer of heat and moisture through single layer fabrics and through multiple layer clothing ensembles. The observed correlations among objective and subjective measurements of thermal comfort phenomena provide verification of the comfort models developed by this program.

METHOD

The thermal analyzing system consists of three parts: an environmental control chamber, a sweating hot plate component that simulates the skin or body, and a computer analyzing system.

Control of environmental conditions. Tabai ESPEC's Platinous Lucifer Model PL-2G, programmable low temperature and humidity chamber was used to produce artificial environmental conditions. A skin simulating guarded hot plate, or sweating hot plate, was placed inside the chamber. The chamber controlled temperature in the range -40~100°C, and humidity in the range 30~98%. Air currents were varied from 0.12 to 0.36 m/sec.

Simulated skin models. Thermal resistance and thermal conductivity were measured, using a specially modified Thermolabo Kawabata thermal analyzing system [1]. Simultaneous heat and moisture transfer was measured using a sweating hot plate featuring simulated sweating glands supplying water to the heated surface at the rate of 0.002-0.2 ml/min. per gland. The water flow was controlled using a peristaltic pump. Three skin models were used to simulate dry, dry/space and wet/space conditions and clothing configurations. A fourth model was used to simulate skin partially wet with sweat.

Distribution of heat and moisture in clothing systems. Micro-thermocouples and thin film micro-hygrometers were used to measure temperature and vapor pressure levels on the simulated skin surface, between fabric layers and in the ambient air surrounding the test ensemble.

RESULTS

We analyzed the physical and structural properties, as well as the heat and moisture transfer, of various nonwoven fabrics. We used simulated skin models to determine transfer properties at different levels of temperature, humidity, and air velocity. This allows us to examine the relationship between nonwoven structure and heat and moisture transfer properties related to comfort. Laboratory predictions of comfort are correlated with subjective ratings of warm/cool and wet/dry sensations.

CONCLUSIONS

The predicted comfort zone for nonwoven barrier fabrics can be extended to include environmental temperatures several degrees in excess of skin temperature (34°C). The factor of fabric design most influential in extending the range of the comfort zone, as indicated by predicted maximum tolerable environmental temperature, is the ability of the nonwoven to transmit moisture vapor. Our research confirms several previous studies [2] that have shown that structural features, not the component fiber, are the most important controllers of moisture vapor diffusion.

Our results also indicate that the properties having the greatest impact on combined heat and moisture transfer are fabric thickness, fiber volume fraction, optical porosity, air permeability, and moisture diffusion. Key structural properties are controlled by the type of nonwoven, post treatment and the presence of impermeable coatings or films.

ENVIRONMENTAL EFFECTS

Environmental variables including air velocity, ambient temperature, and humidity significant affect heat and moisture transfer through nonwoven materials. The rate of heat and moisture transfer through most nonwoven barrier fabrics is proportional to the square root of air velocity. In highly porous materials, heat and moisture transfer is proportional to the square of the wind velocity, due to the effect of wind penetration through low density samples. Thermal resistance increases with decreasing ambient temperature. If the skin is dry, environmental humidity has only a slight effect on heat transfer through hygroscopic materials: the higher the relative humidity the greater the heat transfer rate due to the increase in the moisture regain of the fabric. If sweating is involved, heat transfer decreases with increasing ambient humidity, due to the lower potential for evaporative heat loss to the environment. The degree to which humidity affects heat transfer depends more on the structural properties of the fabrics than the hydrophilicity of component fibers.

EFFECTS OF SWEATING

Our experiments show the effect of sweating on the evaporative heat transfer through nonwoven materials. They show that evaporative heat loss increases in proportion to the area of the skin that is wet with liquid moisture. They show that the temperature and vapor pressure measured in the air layer between the skin and fabric surface are lower over the dry portion of the skin than over the wet fraction, when the skin is partially wet with sweat. The difference between readings of temperature and vapor pressure made over dry and wet regions of a simulated skin surface decreases as the moisture permeation resistance of the nonwoven fabric increases. The buildup of temperature and vapor pressure in the microclimate over the dry fraction of the skin surface is undoubtedly one explanation of why impermeable materials generate a sensation of wetness in clothing wear. Wicking occurs readily in hydroscopic nonwovens in contact with a wet simulated skin surface. Liquid water transport by wicking of moisture condensed in fabric layers is far less likely to occur, simply because sufficient water is not accumulated through condensation to initiate capillary transport. The wicking of water from the skin surface accelerates heat transfer, primarily because it increases the effective evaporating area.

EFFECTS OF CONDENSATION IN COLD WEATHER SYSTEMS

We performed experiments to determine the effects of moisture condensation in a multiple fabric system in a cold weather environment. One system examined consisted of a semipermeable outer layer nonwoven fabric, three thermal insulating layers, a highly permeable nonwettable nonwoven and a highly absorbent next to the skin layer. Thermal transfer was measured for an extended period before, during and after the simulation of sweating. Data show that the vapor pressure beneath the semipermeable outer fabric reaches a saturation level within a few minutes after onset of sweating. The rate of heat dissipation reaches a maximum in about 10 minutes and steady-state conditions exist for several hours after sweating has stopped, due to the accumulation of excess sweat. The temperature and energy loss through the cold weather system drops sharply after the skin surface dries. This temperature drop lowers the saturation vapor pressure and causes moisture to condense with the insulating layers. In a cold environment, water condensed beneath the outer fabric layer freezes to form a thin layer of ice. This phenomenon lowers the effective insulation of cold weather clothing systems.

SUBJECTIVE TESTS

The comfort index predicted by analytical models from laboratory measurements of fabric heat and moisture transfer properties correlates with subjective comfort rating given in a simple test devised by this research. These experiments show that the sensation of warmth or coolness is associated with skin temperature and the thermal energy dissipation rate. The importance of the next-to-skin layer in clothing comfort was confirmed. A wet or strongly hydroscopic next-to-skin fabric layer produced sensations of coolness in a warm/cool subjective rating. Wet/dry subjective comfort correlates with the water vapor pressure measured on the skin surface. The higher the perspiration, sweating or ambient humidity, the less the feeling of comfort associated with wetness.

ACKNOWLEDGEMENTS

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"THERMO-MAN" FULL SCALE TESTS OF THE THERMAL PROTECTIVE PERFORMANCE OF HEAT RESISTANT FABRICS

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INTRODUCTION

The ability to predict the actual performance provided to the user from laboratory test results is often difficult but is always an important requirement of any laboratory procedure. Correct interpretation of test results is especially critical in the evaluation of thermal protective clothing where human responses are the measures of performance. The objective of these evaluations is reducing burn injury and saving of lives.

Correct thermal protection evaluation uses test conditions that are the best representation of the actual conditions experienced by the wearer. These must include a thermal exposure representative of the hazard, measurement techniques and interpretation of the heat transfer that relates to human tissue response, and physical/mechanical conditions that represent the protective garment configuration on the wearer.

The DuPont Company has developed an instrumented manikin, "Thermo-man" which is the best and most realistic test currently available to measure the thermal protective performance of garments. This technology will be shared with the University of North Carolina and will be one of the most important test procedures of their Thermal Hazards Laboratory.

METHOD

The important components of the "Thermo-man" thermal protection evaluation system are; 1. Generation of the thermal exposure, 2. Measurement of the heat transfer through the protective garment, and 3. Interpretation of the test results.

1. Test exposure. A major hazard in industry, fire fighting and the military service is a sudden, intense flash fire which can cause serious burn injury in one second or less. The intensity of these flash fires varies widely, but has been estimated to have temperatures approaching 2000 degrees F. and a heat flux that can reach 2.0-2.5 cal/cm2*sec. The body coverage and duration of the exposure depends highly upon the situation and can vary from a brief exposure of a small area of the body to complete immersion in flames for several seconds. The test heat flux is about 2.0 cal/cm2*sec and 8 torches are arranged so that flames cover about 85% of the manikin surface. These conditions with exposure durations of 3 to 6 seconds represent a serious thermal threat, and a challenge to protective clothing materials.

2. Heat transfer measurements. The heat transfer through the garment is measured to determine the effect of the exposure on the wearer, or in other terms, the protective performance of the garment. One way to accomplish this is to use animal tissue, exposed under a sample of the test material, and evaluate the amount and severity of the burn injury. This was the original technique, until sufficient data was collected to develop an understanding of the tolerance of human tissue to thermal exposure which can be used with thermal measurements.

The thermal evaluation techniques of the "Thermo-man" system use a sensor system that has some of the thermal inertial characteristics of human tissue and a computer program to estimate the location, amount, and severity of the burn injury. High temperature resistant sensors are uniformly located on the manikin surface to measure the heat transmitted through the protective garment. The heat flux is calculated which can then be used to calculate the temperature of human tissue at several depths. From the calculated time/temperature history of human tissue, and the known human tissue damage rate vs temperature, the degree and severity of burn injury that would occur in human tissue can be predicted from the manikin sensor temperature measurements. These data are summarized as the area and location of second degree, third degree, and the total burn injury which could be expected to result from a flash fire represented by the laboratory flash fire exposure.

3. Interpretation of results. Great care has been taken to develop a test procedure that can be used to realistically predict the performance of thermal protective clothing. The exposure is intense and representative of a real potential hazard and test conditions are carefully controlled. The thermal measurements are precise, and the burn injury predicted is based upon human tissue tolerance to heat. In addition, the manikin is life size, and full size garments are used as the test specimen. However, there are several concerns about the relationship of laboratory test data and actual performance. Differences in thermal exposure intensity, duration, or body coverage between the laboratory conditions and actual experience will affect the amount of protection actually provided. The protection performance is a measure of the total system tested, so any changes in fabric weight and garment fit on the wearer vs the manikin, will also change the actual protection provided by the test material. Finally, the "Thermo-man" test is a static test, and in a real thermal exposure, movement of the wearer to escape will add a mechanical force to the thermal situation.

RESULTS

The predicted performance of materials in the "Thermo-man" test range from over 90% total body burn area with flammable garments, to as low as 20-30% with flame resistant materials such as Nomex® and Kevlar® aramid fibers.

SUMMARY

The "Thermo-man" thermal protection evaluation system developed by DuPont has been used to develop improved thermal protective materials. It combines the key elements of a test procedure of a realistic exposure to garments on a life size manikin. The heat transfer is measured and compared to human tissue response to provide predictions of garment protective performance. The College of Textiles at the North Carolina State University, using this technology, and other laboratory thermal protection tests, will be able to provide fundamental studies, graduate research programs, and thermal testing service to the textile and apparel industry. This work will provide the information for wider use, greater confidence, and further improvements of thermal protective clothing.

MEASUREMENT OF THERMAL AND WATER VAPOR RESISTANCE OF PROTECTIVE GARMENTS WITH A MOVABLE MANIKIN

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INTRODUCTION

In order to evaluate the physiological performance of protective garments and to determine their temperature range of utility a predictive model can be applied, based on man's energy balance (1). As an input this model uses the resultant thermal and water vapor resistance of the clothing worn. Consequently, the accuracy of the prediction depends on the precision of these garment resistances. For their determination we have developed an evaluation technique using a movable thermal manikin ("Charlie") and a sweating hot plate (Skin Model) (1, 2).

However, in a recent publication (3) the validity of our evaluation method has been doubted, argueing with water vapor resistance values determined with a manikin sweating by means of a cotton knit "skin" sprayed with water to simulate skin saturated with sweat. These values are about 60% higher compared to the results of our evaluation technique. In this paper results of wear trials with subjects with 2 garment ensembles are presented which are in good agreement with the physiological performance of the clothing predicted by our evaluation model, proving its validity.

METHOD

The resultant thermal resistance R_c of the garment ensemble is directly measured with the electrically heated sectional manikin Charlie, distinguishing between a value $R_c(1)$ for the manikin standing and a value $R_c(3)$ for the manikin moving which includes the pumping effect (2). From these R_c-values the thermal resistance R_{cT} intrinsic to the fabric combinations in the ensemble (measured separately with the dry Skin Model) is subtracted, yielding the effective thermal insulation R_{cL} of the air layers within the garment ensemble and adhering to its outer surface (1).

By a basic physical relation out of R_{cL} the equivalent water vapor resistance R_{eL} of these air layers is calculated. By adding the intrinsic evaporative resistance R_{eT} of the ensemble's fabric combinations measured with the sweating Skin Model the resultant water vapor resistances $R_e(1)$ and $R_e(3)$ of the clothing are gained with the wearer either standing or moving, respectively.

The resultant R_c- and R_e-values, thus determined, are used in a thermophysiological model (1, 2) predicting the ensemble's range of utility, limited by a minimum ambient temperature T_{amin} at which the wearer is just not feeling too cold, and a maximum ambient temperature T_{amax} at which he is just not suffering from hyperthermia. Vice versa, with a given climate and activity condition, as an indication for the wearer's physiological strain, the model predicts his skin and rectal temperature, heart rate and microclimate humidity as well as his subjective comfort sensation.

RESULTS

Two clothing ensembles (shorts and sports-shirt; jeans and shirt) have been tested in controlled wear trials with 4 subjects in a climatic chamber performed under warm climate conditions near the ensembles' upper limit of the range of utility with medium and heavy physical activity. Sensors on the subjects' body registered relevant physiological data out of which the effective thermal and water vapor resistance of the garments could be determined. Additionally the test persons' subjective comfort sensation was registered by multi-step scale votes.

All these data collected in the wear trials were in close agreement with the results of our evaluation technique with the manikin "Charlie" and the Skin Model as well as of our predictive model applied. Examples are given in Figures 1 and 2. In contrast the published data from the manikin sweating with a water-sprayed cotton skin (3) largely disagreed with the results from the wear trials.

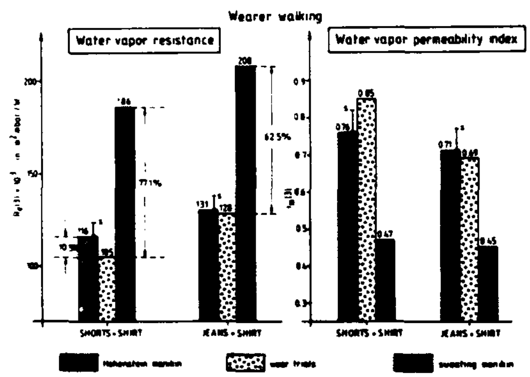

Figure 1

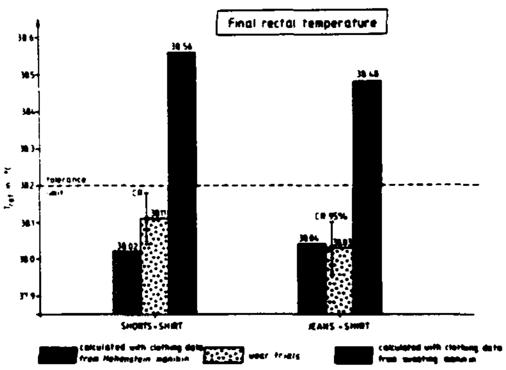

Figure 2

CONCLUSIONS

The Hohenstein measurement and evaluation technique with the movable thermal manikin "Charlie" and the sweating Skin Model yields the thermal and water vapor resistance of a garment ensemble as they are effective in use. With these clothing data applied in a predictive model the physiological performance of protective garments and their wearability in specific climate and activity conditions can be determined in good agreement with practical results.

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RELATIONSHIPS BETWEEN PHYSIOLOGICAL STRAIN AND PHYSICAL PROPERTIES OF DIFFERENT PROTECTIVE GARMENTS.

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INTRODUCTION

Protective garments induce an increased load on the wearer. Hence, it is natural to look for the garment that causes the least strain while offering sufficient protection. Therefore, there is an interest in methods by which differences in physiological strain can be accurately assessed or estimated, preferably without using human subjects. For ensembles designed for different purposes parameters such as thermal insulation and water vapor resistance have been shown to be valuable predictors of physiological response (1). However, the problem is often to chose one out of several ensembles designed for a given purpose where the range in vital parameters tends to be reduced. The aim of the present study was (i) to investigate the possibilities to use physical parameters as indicators of physiological strain of protective garments which are made for a specific task, (ii) to compare the level of physiological strain induced by different garments designed for a given purpose, (iii) to compare different methods for measuring thermal insulation.

METHODS

Six different ensembles (A to F), which gave sufficient protection against external heat, were studied regarding physiological response to exercise, thermal insulation of ensembles and heat and water vapour resistance of the materials. Ensembles D and E were coveralls while the other ensembles were composed of a jacket and trousers. The exercise consisted of three 25 min workbouts (stationary cycling at 75 W and walking at a speed of 1 m/s) interspersed by 5 min of rest. Six male fire-fighters volunteered as subjects. Mean values and range for age, stature, and weight were: 37 (16) years, 178 (14) cm, 75 (17) kg, respectively. Measurements and subjective ratings: maximal reach in five different body positions, 5 min before the first exercise bout; heart rate (HR) every min; metabolic rate (MR) every min during cycling; rectal temperature (T_{re}) and body mass nude (BM_n) before dressing and after undressing; mass of body + equipment (M_t); perception of exertion (RPE), temperature (RPT) and comfort (RPC), before and after each exercise bout; thermal insulation of the ensembles (i) on the thermal manikin Tore (I_{manik}) and (ii) with heat flux sensors (2) on six male subjects during standing (I_{stand}) and treadmill walking at a velocity of 1 m/s and a windspeed of 1 m/s (I_{walk}), thermal insulation (I_{mat}) and water vapor resistance (R_{mat}) of the samples cut from these ensembles according to the standards BS 4745:1986 and DIN 54 101, respectively. Systematic differences between the methods for measuring the thermal insulation were evaluated by comparing the values obtained for all garments. Analysis of variance was applied to test differences. Regression analysis (simple or multiple) was used to test the strength of correlations between physical and physiological variables. A critical level of 0.05 was used.

RESULTS

Extreme values for the mean values over subjects for the different garments are displayed in table 1 and 2. No significant differences were found between ensembles regarding HR, MR, I_{mat}, R_{mat}, RPE, RPT and RPC. Significant differences were found in: ΔBM_n and ΔM_t for which B was < C; $\Delta M_t / \Delta BM_n$ where B was > C; ΔT_{re} for which A was < C and E; maximal reach where B and C were > E; I_{stand} where D < A and E; I_{walk} where D was < A, B and E while E was > C, D and F. Between coveralls and two-piece garments no significant difference was found.

Table 1. *Physiological variables for the different ensembles. Lowest and highest mean value.*

HR (beats/min)	MR (W)	ΔT_{re} (°C)	ΔBM_n (kg)	ΔM_t (kg)	$\Delta M_t/\Delta BM_n$ (%)	Reach (m)
132-143	613-641	0.9-1.4	1,387-1.629	0.486-0.534	32-38	0.81-0.86

Table 2. *Physical parameters for the different ensembles. Lowest and highest mean value.*

I_{manik} (m^2K/W)	I_{stand} (m^2K/W)	I_{walk} (m^2K/W)	I_{mat} (m^2K/W)	R_{mat} (m^2Pa/W)
0.384-0.405	0.352-0.413	0.234-0.283	0.176-0.296	24-34

Table 3. *Correlation coefficients between physical and physiological parameters.*

	I_{manik}	I_{stand}	I_{walk}	I_{mat}	R_{mat}	Thickness
HR	0.23	-0.21	-0.05	-0.05	-0.22	0.05
MR	0.78	0.06	0.25	0.20	0.17	0.25
ΔBM_n	0.27	-0.26	-0.07	-0.02	-0.11	0.04
ΔM_t	0.13	0.15	0.52	-0.01	-0.07	-0.02
T_{re}	-0.03	-0.51	-0.24	-0.19	-0.04	-0.22
Reach	0.44	-0.20	0.37	-0.87	0.46	-0.73

None of these physical variables was significantly correlated to more than one of the physiological ones (table 3). Combining different physical parameters (multiple regression analysis) did not produce more significant relationships than what would be expected to occur by pure chance. For I_{manik}, I_{stand}, I_{walk} and I_{mat} average values were 0.393, 0.392, 0.252, and 0.237 m^2K, respectively. Thus, no systematic difference was found between the heat flux sensor and the thermal manikin techniques. On the other hand, I_{walk} and I_{mat} differed significantly from I_{manik} and I_{stand} but not from each other. The explanation is that I_{manik} and I_{stand} were measured at natural convection conditions, while I_{walk} and I_{mat} measuerements included forced convection. For all physiological variables, except ΔT_{re}, the differences were much (two to three times) greater between subjects than between garments.

CONCLUSIONS

If ensembles are designed for a specific purpose the choice of materials, ensemble thickness and design tends to become restricted to such an extent that the differences in physical properties and physiological strain will be close to what can be detected with available methods and with a limited number of subjects and garments. In these type of investigations the inter-individual differences are likely to be considerably greater than the differences caused by the garments.

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Clothing thermal evaluation using heat balance techniques

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The heat balance

Since many years the well known heat balance technique is used to determine the heat resistance of clothing. Human subjects are used as a heat and vapour source and the dry heat loss is calculated as: Dry = M - Wext - Resp - Evap - Sto. This is called partitional calorimetry (1) and the partition that is called Dry is calculated because it is the only one that is not so easily measured directly. The heat resistance is calculated from Dry and the temperature gradient. For Sto a weighted sum of internal and skin temperature is taken. The weighting depends on the blood distribution over the body. In the heat the weighting of the skin should be .1. Farnworth and Havenith (2) showed that in the cold the weighting should be higher than the usual .33. In any case the accuracy of Dry can be improved by waiting for equilibrium so that Sto is small.

The heat balance might be used to determine heat and vapour resistance at the same time, but this also goes at the expense of accuracy since the relative error in Dry will increase with increasing Evap and the other way around. Also the variability in sweat production within and between subjects is a problem. The complications in the measurement of skin wetness and the statistically required large number of measurements lead Lotens and Havenith to an alternative method. To optimize Dry, Evap is excluded by wrapping subjects in plastic foil (3). Vapour transfer is measured with a tracer gas instead of water vapour (4). The advantages are that Dry is determined more accurate and that a vapour resistance measurement is taken some factor of 20 faster and reproduces better.

Interaction between heat and moisture

The above method has its limitations. Absorption or condensation of moisture in the clothing may occur. In such conditions only water vapour gives realistic results. This might be real sweat or water vapour from a wetted liner, worn over plastic covered skin. It becomes important then where the heat balance is measured. When moisture is absorbed in the clothing less moisture leaves the clothing compared to the skin, while due to liberated heat of absorption more dry heat leaves. The heat balance at the skin thus may be different from that at other locations. Usually Evap is determined by weighing subject plus clothing. It thus holds for the total system and the heat balance is taken for an imaginary envelope around the system. This should be done for the other terms of the heat balance as well. In particular for Sto the heat storage in the clothing is often neglected. For thermal stress and discomfort ratings the heat balance at the skin is more relevant then that outside the system. This heat balance is difficult to measure directly and if the heat balance at the outside is taken instead, it is absolutely neccessary to wait for equilibrium, when the two converge. Absorption processes may take a long time to complete. The estimated response time is 100/hcl min per 100 g/m2 of absorption capacity of the clothing (hcl = heat transfer coefficient in W/m2C) (5) and at least 3 response times should be waited after stabilization of the skin and environmental condition. The place where the heat balance is takens is also critical for the determination of heat and vapour resistances. It becomes even more pressing with condensation. The clothing surface will show an increased temperature due to liberated heat of condensation and few vapour will escape. In experiments the heat resistance of an impermeable garment varied over a factor of three depending on the rate of condensation (6).

Radiation

Radiation causes problems with the correct calculation of the heat production term in the heat balance, which comprises of metabolic heat and the absorbed part of the radiation. Metabolic heat flows from skin to clothing surface, whereas from that surface to the air both metabolic and radiant heat flow. Thus the determination of the intrinsic clothing insulation and of the air insulation should be based on different heat flows (7). Calculation of total insulation is not meaningful then. When radiation penetrates into the clothing the situation becomes complicated.

Motion, wind, and nude skin

Clothing is basicly irrelevant material that creates still air layers. The heat and vapour resistance for standing persons in quiet air can be calculated from the geometry of the clothing without knowledge of the materials (8,9). When the air is moved, heat and vapour resistance decrease due to internal circulation, ventilation, and reduced adjacent air layer. The decrease is more or less typical for all clothing, depending on posture, wind, activity and thickness (9). An exception is impermeable clothing. The vapour resistance of this type of clothing is strongly dependent on the ventilation, which cannot compete with vapour permeability, and certainly not with air permeability (10). For the intrinsic heat and vapour resistance also the exposed skin parts may play a large role, particularly for thick or vapour barrier clothing, when these become a major avenue of heat.

4-Layer model of clothing

Most of the above phenomena are quantitatively described by a mathematical model for clothing ensembles which comprise of underclothing, trapped air, outer clothing, and adjacent air layer. No distinction is made between one or more layers of underclothing. Ventilation through apertures is taken into account. When the clothing properties are specified, for any boundary condition the heat and vapour gradients, the flows, and the resistances can be calculated. This model was evaluated by means of heat balance techniques for the effects of (transient) moisture absorption (5), condensation (6), semipermeability (11), heat radation (7), and ventilation (10). The 4-layer concept proved succesful in the quantitative description of dry and evaporative heat transfer. Currently it is being interfaced with the Gagge 2-node thermoregulatory model (12) to obtain a comfort and thermal stress evaluation tool that only requires easy to obtain input data. Such a model will provide more detailed information on physiological strain of clothed humans than can be derived directly from the heat balance (e.g. required sweat rate, 13). It also allows the calculation of subjective comfort or thermal stress ratings, using their physiological correlates.

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THE PHYSIOLOGICAL IMPACT OF SORPTION HEAT IN HYGROSCOPIC CLOTHING

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The nature of many textile fibres is hygroscopic as their content of water depends on the relative humidity (RH) of the ambient air. During absorption heat is generated and during desorption heat is required. Especially in wool the transient sorption heat changes are of a magnitude that garments made of this natural fibre are often attributed exceptional buffering qualities by people who must frequently shift between places with dry and humid air respectively. For various reasons it has proved difficult to establish the virtually perceived effect of such transient conditions. One reason being that less than half of the generated heat is expected to affect the body.

In a recently published study (1) the present situation was reviewed and the result of experiments with mittens was reported. The authors were fully aware of the difficulties in the use of hands to perceive warmth. At about the same time a comprehensive study of the impact of air humidity on thermal comfort (2) was finished. The design of a number of the experiments performed was made so that the influence of the textile fibres used could be brought into focus. The objective of the present study was thus to identify the sorption heat effects in hygroscopic clothing during certain air humidity transients and to investigate their physiological impact.

The experimental work included use of two adjacent climate chambers, one with 20% RH and the other with 80% RH, both maintained at the same temperature. Also a thermal manikin and a group of twelve college-age male subjects of a size corresponding to the manikin were involved. For experiments in both cases clothing ensembles with long, tight-fitting sleeves and legs made of wool or the practically non-hygroscopic polyester fibre were applied. The oven-dry weight of each ensemble was approx. 1500 g and the insulation value approx. 1.0 clo (equivalent to that of indoor winter clothing).

The experiments involved a quick shift from one chamber to the other with a resting period of 90 minutes in both chambers to attain apparent steady-state conditions. The climatic changes were in either direction and at the outset of the preparation period clothes were put on which had been brought into equilibrium with the actual climatic conditions. Experiments in the nude were also performed as the human skin was expected to respond to humidity transients. As a control measure in each experiment the mean skin temperature and the deep body temperature were measured on two of the subjects. During their stay in the chambers the subjects were asked to give thermal sensation votes according to a scale from -3 (cold) to +3 (hot) units. The voting was a first impression vote at t=0 after the step-change followed by votes at 1-minute intervals for 5 minutes and 5-minute intervals for the remaining period up to 90 minutes.

The separate manikin experiments provided physical information about the progress and size of the heat changes and their effective impact on the body. In figure 1 an absorption period for wool is depicted. Desorption is slightly different because of hysteresis in the exchange of water. Calculation indicates that about 40% of the total heat changes will affect the body, which confirms original findings. The effect of polyester clothing was less than 5% of that of wool and dissipated within 20 minutes.

Some results of the subject experiments based on mean votes are depicted in figure 2. Common features of the two contrasting materials are strong immediate responses to the step-change with that of the down-step considerably larger than that of the up-step. Specific features include a return within 20 minutes to an apparent steady-state for polyester while wool is still out of balance at the end of the period. The graphs are derived from a set of experiments, the results of which were submitted to a factorial analysis with 3 factors at 2-levels: RH-change, temperature and the materials used. The model proved significant for all points tested on the time axis ($p > 0{,}01\%$). This was, of course, also the case for the direction of the RH-step. The interaction between RH and material is highly significant except for t=o and showed clearly an active effect of wool.

At t=o a complicated process is presumably initiated comprising cutaneous perception of the climate change at accessible skin surfaces, sorption heat changes of the skin and beginning transfer of textile heat changes. It adds up to an instant jump followed quickly by an apparently decreasing effect which is soon superseded by the textile material effect, if any, or an apparent steady-state. This interpretation may be supported by the shape of the initial part of the manikin's heat loss graph as the manikin has neither skin nor cutaneous receptors. A visual comparison of the plots of skin temperature changes with the voting graphs makes similar patterns visible, with an initial delay governed by the skin reaction rather than by the thermal sensation. The instant jump in the polyester case was sizable, even overshooting the apparent steady-state in both directions of RH-change. In the wool case the jumps at both directions were markedly smaller. This may be explained by the hygroscopic property which would cause a delay of the impact on the body of climate changes.

In order to estimate the magnitude of the wool effect it must be separated from the general effect of the humidity change of the air. However, this seems not possible in the present case. Both skin temperature and deep body temperature measurements indicate that steady-state of the subjects was not attained. A provisional approach to circumvent this problem may be based on other experiments where the climatic conditions were modelled so that the thermal sensations before and after the applied step-changes were of the same magnitude. The deviations from the above mentioned study were small. In principle the only important parameter left would then be the hygroscopic effect. Tentatively applied to the present case of wool up-step the mean effect over 60 minutes might be in the region of 20 to 30% of the human metabolic heat at rest.

Although the effect of the material was studied to a limited exent only and at some favourable level, the findings showed that heat changes of wool due to changes of RH can be of a magnitude easy to perceive. Moreover, there were indications that the buffering quality of a hygroscopic fibre is not just a question of heat changes but also of the capacity of the fibre to damp the instant impression of a change. However, further target oriented research is required to quantify the hygroscopic effect in a way that would make it most useful in everyday life.

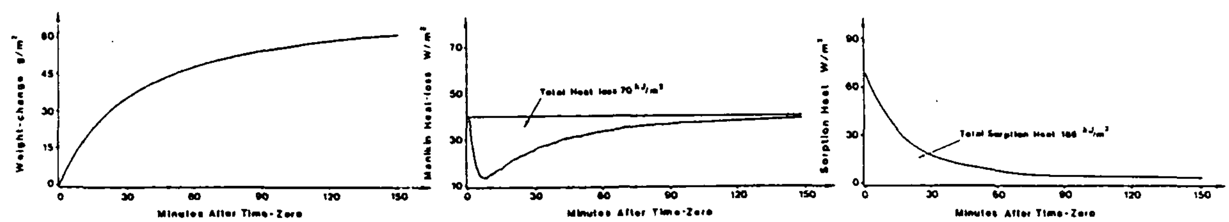

Figure 1. Response to absorption in manikin experiment using 1.0 wool ensemble.

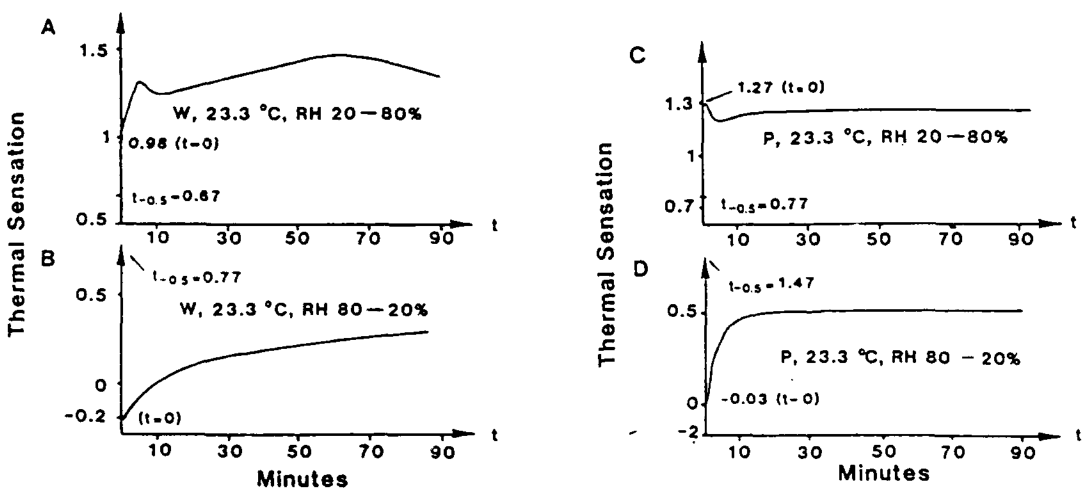

Figure 2. Mean thermal sensations during humidity step-changes while wearing 1.0 clo wool (W) or polyester (P) ensembles.

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A NEW PERSPECTIVE ON THE ROLE OF FIBER PROPERTIES IN COMFORT

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INTRODUCTION

Interest in the area of clothing comfort is increasing as its importance to consumers is recognized [1-4]. Studies of clothing comfort based exclusively on the measurement of physiological parameters have been unable to identify any interaction between fiber type and metabolic performance [5,6]. This is mainly because the body sees clothing as a resistance to heat and moisture transfer, and these parameters are determined by fabric construction rather than fiber properties. The use of human sensory perception analysis [7] enables subtle differences between fabric properties to be distinguished. The present paper describes how this technique has been utilised to investigate the role of fiber properties on parameters which contribute to the perception of comfort.

METHOD

The general details of the procedure have been described in detail elsewhere [7]. Experimental garments were worn by 30 subjects who rated a number of different descriptive terms appropriate to clothing comfort. Grouping of these descriptive terms during analysis provides information about the moisture, surface, and handle/fit characteristics of a fabric. Trials have been conducted to study the influence of fabric surface energy and fiber hygroscopicity on the perception of these descriptors. In both instances, the fabric was lightweight knitwear, made up into a spencer (a skin contact, long sleeved undershirt).

In the first trial the surface energy of 100% wool fabric was increased by chlorination or decreased by the addition of a hydrophobic fluorocarbon based product. Both treatments modify fiber properties such as surface friction and surface structure as well as surface energy, and this factor must be considered in the interpretation of the experimental data.

The second trial compared a series of blend fabrics whose fiber contents increased in steps of 25% from 100% wool to 100% acrylic. After initial dry cleaning, these fabrics were found to have similar surface energies. A comparison of the subjective evaluations of these fabrics identified differences which could be attributed largely to fabric hygroscopicity.

In both trials, fabrics and garments were very carefully matched in all possible aspects of construction and fit so that the influence of steady-state heat and moisture transport properties could be minimized. Evaluation took place in both sweating and non-sweating conditions for the surface energy experiments, and in sweating conditions only for the hygroscopicity experiments. Surface energy was ranked by means of a modified drop test which measures the length of time for 30µl of a liquid of known surface characteristics to be absorbed into the fabric.

RESULTS

During conditions of light sweating, subjects perceived descriptors associated with moisture, such as stickiness, dampness, clinginess, clamminess, absorbency and breathability, more intensely as the surface energy of the fabric decreased. As only very small quantities of liquid sweat were present on the skin during the greater part of the trial cycle, these differences cannot be directly attributed to differences in the wicking bahaviour of the fabrics. Such differences are believed to be the result of the higher surface energy changing the way moisture is perceived by the skin. There are several mechanisms which could be contributing to this, and work is in progress to clarify this hypothesis. There were no significant differences ($P > 0.05$) perceived in the tactile properties of the fabrics (prickliness, scratchiness) when evaluated under these conditions.

When the same garments were evaluated during non-sweating conditions, only the tactile-related parameters were perceived as differing significantly between garments. The overall mean values for these descriptors were compared to those obtained during light sweating conditions. It was found that although light sweating increased tactile-related discomfort, there were no significant differences between garments while moisture-related sensations were present. This indicates that the presence of moisture in the clothing microclimate dominates other sensations typically perceived during wear.

The second trial used conditions of light sweating to compare the perception of fabrics of varying hygroscopicity but constant surface energy. These fabrics were perceived as having similar moisture-related properties, but differed significantly in tactile sensations. These differences corresponded to small dimensional changes which occurred as a results of laundering between wearings, with the looser garments being less scratchy, prickly, etc. The lack of perceived differences in the moisture-related descriptors suggests that, during conditions of light sweating, the hygroscopicity of this fabric construction did not significantly influence the perceived moisture sensations.

Hygroscopicity has been shown to have a significant influence on the perception of thermal sensations, coolness in particular, during non-sweating conditions [8]. These differences were most noticeable when the fabrics were brought into momentary contact with the skin and then removed. This sequence causes desorption to occur in the hygroscopic fibers, which is sufficient for subjects to rate the hygroscopic fabric as cooler than a matched non-hygroscopic fabric. This enhanced coolness was perceived for a range of warm humid conditions in the absence of thermoregulatory sweating.

CONCLUSION

The use of human sensory perception techniques has shown how fiber properties can affect the perception of parameters that relate to garment comfort. It has been found that when liquid moisture is present in the clothing microclimate, fiber surface energy has a significant influence on garment comfort.During non-sweating conditions, neither fiber surface energy nor hygroscopicity has a perceivable effect on moisture-related comfort sensations. However, under these conditions, other characteristics of the fabric, such as the tactile properties, become more noticeable to the wearer. It has been shown that hygroscopicity influences the perception of thermal sensations in non-sweating conditions.

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LOCALIZED TEMPERATURES AND WATER VAPOR PRESSURES WITHIN THE CLOTHING OF WORKING MAN IN THE COLD

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INTRODUCTION

The thermal phenomenons and the interactions between avenues of heat exchange taking place within the clothing of sweating man have been simulated with introduction of water on a hot plate covered with layers of fabrics (Woodcock 1962; Mecheels 1970; Farnworth and Dolhan 1985). However, few actual measurements of temperatures and humidities within the clothing of man have been reported (Vokaç et al. 1976; Fujitsuka and Ohara 1977).

The purpose of this study was to determine the variation of localized skin temperatures, clothing surface temperatures and water vapor pressures within a prototype clothing system when worn during alternating work/rest cycles in a cold environment. The effects of different fiber type and knit structure in the innermost layer of the clothing system on the various temperatures and water vapor pressures inside the clothing ensemble were also investigated.

METHODS

A two-layer prototype clothing system comprised of 100% polypropylene underwear (1-by-1 rib knit), a uniform, socks, shoes and gloves was tested on eight subjects ($T_a = T_r = 5°C$; $T_{dp} = -4°C$; $v_a = 0.3\ m \cdot s^{-1}$; $I_{tot} = 0.25\ m^2 \cdot K \cdot W^{-1}$). In addition, measurements were done with five different fiber type materials (cotton, wool, polypropylene, and two polyesters with different finish) and five different knit structures (1-by-1 rib knit, fleece, interlock, fishnet, and double-layered interlock) in the underwear. The 2-hour experiment comprised a twice repeated bout of 40-min cycle exercise ($W = 56\ W \cdot m^{-2}$; $M = 313\ W \cdot m^{-2}$) followed by 20 min of rest ($M = 65\ W \cdot m^{-2}$). Esophageal, skin, clothing and ambient temperatures, as well as dew-point temperatures near the skin, in the clothing and in the environment were monitored. In addition, evaporation of sweat and sweat accumulated in the various clothing parts were determined.

RESULTS & DISCUSSION

In the prototype clothing system with polypropylene underwear, the temperatures and water vapor pressures in all clothing layers varied significantly with the human thermoregulatory responses (skin temperature, sweating) to alternating work/rest cycles. There were large differences at the various body sites in temperatures and vapor pressures observed. The different patterns of change in temperature and water vapor pressure in separate body areas indicated a different importance locally of influencing factors as the pumping effect, the intrusion of wind in the micro-environment, and the transfer between insensible and sensible heat exchange.

During the first exercise period clothing temperatures changed more than skin temperatures. On the exercising lower part of the body clothing temperatures decreased, whereas they increased on the less moving upper part of the body. The water vapor pressures at the upper back, at the chest and at the thigh all increased significantly with 2-3 kPa near the skin and with 1-2 kPa in the outer clothing compartment during the bout of exercise. Thus, water vapor pressures changed more near the skin during exercise than in the outer clothing compartment although most sweat/water accumulated in the outer clothing layer.

During rest mean skin temperature, mean underwear temperature and almost all local temperatures decreased significantly ($p<0.05$). However, on the legs skin temperatures did not decrease, and the temperatures on underwear and BDU on the legs actually increased. This is the result of an abrupt decrease in convective heat loss with cessation of bicycling. On torso, arms and hands skin temperatures decreased with 1-2°C. All water vapor pressures near the skin decreased ($p<0.05$) to values of 1.5 or 2.2 kPa. Also, the water vapor pressures in the outer clothing compartment decreased (<0.05) during the course of the rest period, where sweating came to an end, and clothing began to dry out.

A repeated bout of exercise and rest, respectively, did not result in much lower temperatures; however, mean underwear temperature was significantly lower after the second bout of exercise compared to the value at the end of the first bout. Locally, the skin temperature on the upper arm and the forearm were lower

(<0.05) compared to at the end of the first bout of exercise and rest. At the end of the second rest period, hand temperature was also lower. Clothing temperatures in all layers at the chest were lower after the second exercise. At the end of the second rest period hardly any of the clothing temperatures were lower compared to at the end of the first rest period. No differences in end-values of the water vapor pressures in the two compartments were found between exercise 1 and exercise 2, and between rest 1 and rest 2.

The fiber type material of the underwear had little influence on the vapor pressures near the skin and within the clothing. Skin temperatures were not influenced by the fiber type of the underwear material (Nielsen and Endrusick, 1988). However, surface temperatures on the underwear, and temperatures observed inside and outside the jacket were significantly influenced by the fiber type material of the underwear. Generally, the clothing surfaces were warmest with one of the polyesters (Thermax), and coldest with wool as the underwear fiber type material.

Underwear knit structure influenced the vapor pressures near the skin more than it influenced the vapor pressures within the clothing. However, for the temperatures in the system the influence of underwear knit structure was significant both at the skin (Nielsen and Endrusick, 1990), and at the surface of the underwear. The heavy fleece construction resulted in the warmest thermoregulatory responses, but on its outwards surface the lowest underwear temperatures were measured. This can probably be ascribed to a greater thickness than of the other constructions. The warmest clothing temperatures were recorded over the 1-by-1 rib knit construction.

CONCLUSIONS

In conclusion, the present study showed that the thermoregulatory responses to alternating work/rest cycles can be quantified in all clothing layers. When sweating occurs with various underwear fiber type materials it creates even more important temperature differences within the clothing than on the skin surface.

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INFLUENCE OF ACTIVITY AND WIND ON THE LOCAL CONVECTIVE HEAT AND MASS TRANSFER FROM NUDE MAN

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INTRODUCTION

Convection is frequently the dominating mechanism balancing the heat production of the human body. As convection affects both the heat and the mass transfer, this physical process is of importance in warm as well as in cold conditions. There have been attempts to estimate the convection coefficient at the body surface from the theories valid for simple geometries as spheres and cylinders (1, 2). However, there are few studies on the local convection of the human body (3, 4), especially in regard to shape, activity and interacting parts of the body. The aim of the present investigation was to survey the convection coefficients at various parts of the body and their dependence on characteristic dimensions, wind speed and angle to the wind. An essential part of the investigation was also to compare the formulas describing the human convection coefficients with the empirical correlations valid for simple geometries such as cylinders.

METHOD

In the present investigation heat-flux sensor technique was used to measure the local (30-75 measuring sites) convection coefficients (5) at the various parts of the body of a male subject during standing still, walking (0,9-1,9 m/s) and running (2,0-3,2 m/s) on a treadmill in a wind tunnel. Convection coefficients were also measured on two male subjects during running (1,9-3,8 m/s) on an indoor running track. Duplicate measurements of the whole body convection coefficients of six male subjects with similar physical characteristics were performed using only 10 measuring sites. In this case the activities were standing still at wind speeds of 0 m/s and 1,9 m/s, and walking at 1,4 m/s facing the wind (1,4 m/s).

RESULTS

When standing still at no wind the convective heat transfer coefficient, h_c, depended on height, L (m), according to $h_c=2{,}9 \cdot L^{-0{,}27}$ W/(m^{2}K) up to a height of about 1,1 m. Above this level the h_c-value was almost constant, 3,3 W/(m^{2}K). The average whole body value was 3,6 W/(m^{2}K) at a temperature difference of 9°C. When standing still in wind, v (m/s), the equation, $h_c=a \cdot v^b$ defining the whole body convection coefficient, was $h_c=7{,}3 \cdot v^{0{,}61}$ after correction for turbulence and wind tunnel blockage effects. The convection coefficient was related to the characteristic diameter, d (m), as $a=3{,}8 \cdot d^{-0{,}36}$ and the exponent b ranged from 0,53 to 0,77 for the various parts of the body. The average, weighted Nusselt number of the whole body was $Nu=0{,}17 \cdot Re^{0{,}61}$. The local h_c-value varied with the angle to the wind similar to that of a circular cylinder in cross air flow. Adjacent parts of the body affected the local h_c-values. However, measurements with adjacent cylinders showed that the average h_c-value was only slightly reduced (≈ 7%) at a wind speed of 2 m/s when the distance between the cylinders was approximately 5 mm. Walking and running on the treadmill at no wind produced more complicated local h_c-pattern especially for the swinging limbs. The convection equations of the whole body were $h_c=7{,}6 \cdot v^{0{,}49}$ and $h_c=6{,}5 \cdot v^{0{,}65}$ during walking and running, respectively. The greatest h_c-values occurred for those parts having the highest velocity, the lower leg and the lower arm. Walking and running in the wind tunnel produced very similar equations, $h_c=12{,}9 \cdot v^{0{,}55}$ and $h_c=12{,}7 \cdot v^{0{,}59}$, respectively. During walking the h_c-value of the lower leg was affected almost exclusively by the walking velocity whereas the trunk value was only influenced by the wind speed. In running activity and wind affected the h_c-value equally. The whole body h_c-value obtained at free running on the track was slightly lower than when running on the treadmill in the wind tunnel. However, the h_c-values of the leg were roughly the same. The trunk and arm h_c-values differed between the individuals. The differences between the repeated whole body h_c-values calculated from 10 measuring sites were not statistically significant (5%-level) for any activity. Neither there were any significant differences between subjects when standing in still air or when walking.

However, when standing at a wind speed of 1,9 m/s two subjects showed significantly different h_c-values.

CONCLUSIONS

The h_c-values of a human standing still at no wind were very close to those calculated for a vertical slim cylinder. Consequently, there are reasons to believe that the human convection coefficient can be estimated from the empirical relationships valid for cylinders also in other positions than the vertical one. When exposed to wind the dependence on the characteristic diameter was similar to that of vertical circular cylinders resulting in a cooling effect which is maximum on the windward side of the part of the body. Furthermore, as the convective heat transfer increases at reduced diameter the drop in tissue temperature in cold weather can differ from that expected from the wind speed (wind chill index). Wind chill indices are valid only for a certain diameter and therefore the actual heat loss can be considerably higher for those parts of the body having smaller diameters. The Nusselt numbers of the various parts of the body indicate that the limbs and the trunk can be considered as vertical cylinders with a circular, hexagon or square geometry. The whole body can be considered as a vertical cylinder with a circular or hexagon shape with a characteristic diameter of 0,16 m. The swinging arms affected the leg and trunk h_c-values differently during walking compared with running depending on the position of the lower arms. Running technique seemed to influence mainly the position of the swinging arms, affecting the h_c-values especially at the trunk. The differences in h_c-value between the various parts of the body were reduced when wind was added to the activity. Also the difference between the windward side and the leeward side was less compared with standing still in wind. The differences in whole body h_c-value between individuals seemed to be small during standing still exposed to natural convection and walking in the wind. As the dependence of the characteristic diameter on the h_c-value is greatest when standing still in wind significant deviations between subjects differing in size could be expected in this condition. However, the differences were to small to be detected with the actual number of measuring sites. By using the heat and mass analogy (Lewis number) the maximum evaporative mass transfer from the nude body can be calculated. When standing still in the wind, the sweat rate must exceed the maximum evaporation rate with roughly 2,5 times to keep the whole body wet. This is similar to those results obtained when investigating the maximum evaporation rate (6, 7). Activities such as walking or running affect the convection pattern around the body due to increased turbulence reducing the local differences. Hence, the cooling efficiency should be improved during activity compared with standing still in the wind due to less sweat dripping.

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EVALUATION OF TWO COLD WEATHER GLOVES DURING ACTIVE NON-CONTACT AND PASSIVE CONTACT ACTIVITIES.

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INTRODUCTION

Handwear testing with human subjects is conducted primarily because measured dry insulation values (I_T) from models may not reliably predict actual thermal protection experienced in the field. Total clothing insulation, sweating, individual activity level or thermal contact with external objects also affect hand temperatures. In this study, the physiological responses of eight volunteer subjects wearing the Combat Vehicle Crewman cold weather (CVC) and Light Duty (LD) gloves were tested in an environmental chamber. The CVC glove is an insulated one piece glove of knit fire-retardant fabric with a leather reinforced palm. The LD glove is a two piece glove consisting of an uninsulated leather shell and a separate liner knit of wool and nylon. Glove total dry insulation (I_T) values were measured on two biophysical hand models (1). I_T for the knit fabric CVC glove was measured as 0.16 $m^2{\cdot}K{\cdot}W^{-1}$ (1.00 clo) and for the LD glove, I_T was 0.12-0.14 $m^2{\cdot}K{\cdot}W^{-1}$ (0.80-0.92 clo).

METHOD

Subjects were tested while performing two activities at chamber temperatures of -7°C (20°F) and -15°C (5°F) in a wind speed of 2.2 $m{\cdot}s^{-1}$ (5 mph). The activity mode was walking on a level treadmill at 1.3 $m{\cdot}s^{-1}$ (3 mph) for 120 min. The second passive activity utilized a "contact simulation device" (2) designed to simulate contact with a cold-soaked surface. This device required subjects to push against an polyethylene envelope containing propylene glycol which was maintained at chamber temperature. This was the first study which utilized the device. During testing, subjects repeated a scenario of 5 min of pushing or "contact" followed by 1 min of rest for a total of 60 min. Electronic timers recorded cumulative pushing or contact time (CT) and total elapsed or endurance (ET) time. All testing activities were preceded by a 10 min baseline period. The eight subjects were divided into two groups and alternated days of walking (morning) and contact (afternoon) testing activities. The primary physiological limit for subject exposure was a finger temperature of 5°C (41°F). Parameters monitored included four finger temperatures, rectal temperature and heart rate. Subjects wore the CVC uniform (overalls, jacket, cotton/wool long underwear, leather combat boots, balaclava and face mask with goggles and CVC helmet).

RESULTS

Mean parameters (s.d.) for the eight subjects were height 178 (7) cm, mass 74.6 (7.8) kg, and A_D 1.92 (0.12)m^2. Table 1 summarizes the results for ET and CT. Repeated measures MANOVA analysis was applied to the combined data for both environments by activity. In all cases, mean ET and CT (activity 2 only) times were greater when the subjects wore the CVC glove. Figure 1 illustrates patterns of finger temperatures during the walking activity. Results were significant ($p<0.001$) only for ET and CT during the contact activity. Post hoc comparisons of paired data using Tukey's t-test ($p=0.05$) found no significant differences between glove types affecting the responses when results were analyzed by individual environment. A variety of relationships involving finger temperatures, including a comparison of slopes for each glove for the temperature drop from 15 and 10°C, were analyzed. Only significant differences between digits (middle>little) and hands [right>left (walk) or non-push>push (contact)] were found. Figure 2 illustrates a time lag in the onset of cold induced vasodilation (CIVD) between the middle and little fingers. The offsets were often less pronounced or even absent in some cases, but differences in finger temperatures were observed in all cases.

Table 1. Mean endurance (ET) and contact (CT) times in minutes (s.d.), n=8

Activity	ET-CVC glove	ET-LD glove	CT-CVC	CT-LD
walk at -6.7°C	108 (39)	61 (13)	......	......
walk at -15°C	88 (41)	46 (18)	......	......
contact at -6.7°C	57 (48)	30 (15)	40(11)	16(12)
contact at -15°C	33 (40)	19 (8)	30(14)	7 (6)

FIGURE 1
MEAN FINGER TEMPERATURE AT -7°C (WALK)

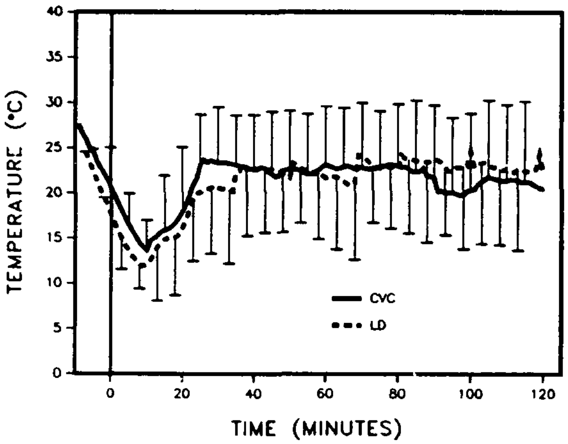
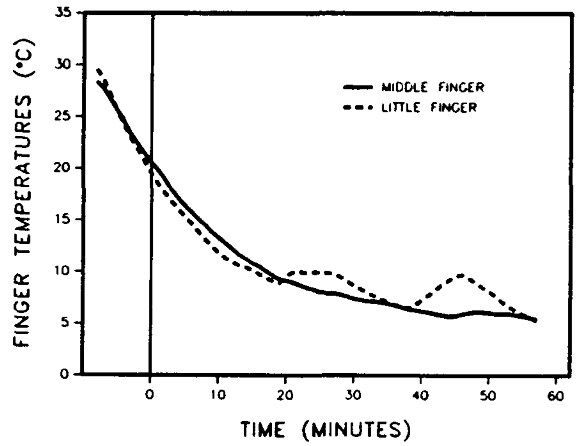


FIGURE 2
RIGHT HAND TEMPERATURES AT -7°C (CONTACT)



CONCLUSIONS

Although a small difference in I_T occurred between gloves and a lack of a significant difference in digital temperature between gloves, subject endurance and contact simulation times indicate ($p<0.001$) that the CVC glove provides better cold protection than the LD glove. The simple relationship between measured handwear insulation and subject performance and hand warmth is confounded by the ratio of relative mass of hands to total body mass and variations in peripheral blood circulation. The effects of clothing and activity were controlled in this study, but individual variability is also a confounding factor, which cannot be entirely resolved by results derived from a small and relatively homogeneous subject population. Humans subjects are used to test handwear because activity levels, sweating, and total clothing insulation have confounded simple efforts to translate measured dry insulation values into predictions of human performance. Observations of differences in finger temperatures on the same hand, particularly cases where the onset of CIVD was asynchronous between fingers, suggests that the onset of CIVD was in response to local temperatures rather than a centrally mediated response. Adequate thermal protection for a military user is defined primarily in terms of function and prevention of injury, not thermal comfort. Emphasis is therefore on temperatures at the most vulnerable locations (finger tips), rather than at the palm or dorsal surface. It is particularly interesting that although the tendency of the smaller extremities to cool faster is well known (3), other studies used either the middle finger (4) or other less vulnerable region to estimate thermal protection.

DISCLAIMER

The views, opinions and/or findings in this report are those of the authors, and should not be construed as official Department of the Army position, policy or decision, unless so designated by other official documentation. Human subjects participated in these experiments after giving their free and informed voluntary consent. Investigators adhered to AR-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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RESULTANT OR BASIC INSULATION – WHICH IS THE BEST PREDICTOR OF CLOTHING PERFORMANCE?

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INTRODUCTION

Most predictive models or indices accounting for the effects of clothing, assume or predict a value for the actual clothing that is relevant for its actual performance during the given conditions – the resultant value. The interpretation, however, of such predictions are complicated by the fact that most information about clothing performance is based on its basic insulation value (I_{cl}) and basic evaporative resistance value(R_e). Both values are standardized measurements referring to ideal, wind-still, static conditions [9], rather than values representing the ultimate function of the ensemble during realistic conditions (resulting values). Total insulation values (I_{Tot}) decrease as a result of the action of wind and body motion on the boundary air layer. However, in addition the pumping action of clothing with body movements and the penetration of wind through porous outer layers, reduce the insulating capacity of clothing itself (I_{cl}). Several investigators have reported significant differences between the standard insulation value (I_{cl} or I_{Tot}) and the resulting insulation during realistic conditions [4, 5, 8, 12, 14]. Some investigators have attempted to derive generalized formulas to describe the relationship between standard values and resultant values [4, 5]. Umbach [14] has adopted standardized tests with a moving manikin for his predictive model of clothing performance.

The present paper examines reported differences between standard measurements of clothing insulation and resultant values under wear conditions and the impact of such differences on the accuracy of predictions using heat exchange models.

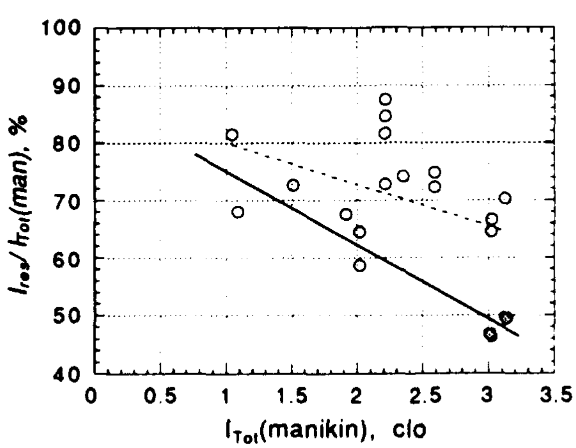
METHODS AND MATERIALS

Thermal insulation of clothing is measured with a thermal manikin under standardized conditions [9]. The manikin is static and standing in a climatic chamber with negligible air velocity (<0.1 m/s). Under these conditions each garment has a characteristic basic insulation value (I_{cl}) and a total insulation value (I_{Tot}). Many reports and standards contain tables with standard insulation values for many different types of clothing [9, 10, 11].

This review is based on an analysis of data published in the literature and on data from a series of experiments in our laboratory on human subjects exercising in cold environments wearing different types of cold weather clothing.The experiments comprise many different combinations of activity level, type of activity, clothing insulation level and cold climate.

RESULTS AND DISCUSSION

In the figure below measured total insulation values are compared with standard manikin values. Clothing has been measured on subjects during walking or bicycling under a variety of climatic conditions in our laboratory [2, 3, 6]. Manikin values have been measured according to ISO [9]. It can be readily seen that the resultant values for I_{Tot}, were always lower than the standard values. Variation in reduction depended on such



factors as intensity of work, amount of sweating, type of clothing etc. Greatest reduction in I_{Tot} was observed in experiments with significant sweating (filled circles). The detrimental effect of moisture absorption on clothing insulation and body heat heat loss has been reported by many invesugators [1, 7, 13].

Olesen et al. [11] found reductions in I_{cl} during walking by up to 46%. Havenith et al. [5] derived a set of formulas describing the reduction caused by wind, body movements, and insulation thickness. One of their regression equations is drawn in the figure (solid line). In comparison with our results their formula seem to overestimate the reduction, particularly at high insulation levels. Apparently, there is an effect of insulation thickness. Sweating and moisture absorption by clothing resulted in greater reductions in I_{Tot} and can explain some of the large variation among data. In fact, the absorption process contributes to the heat transfer, but the magnitude is difficult to measure.

It is evident, that significant errors arise in predictions of thermal responses, when insulation values used in calculations, are assumed equal to resultant values. The higher the activity level, the greater will be the error. Accordingly, in the heat prediction models are likely to overestimate heat stress at moderate temperatures and underestimate at high temperatures. In the cold actual heat losses will be significantly greater, than predicted on the basis of tabulated values for typical cold weather clothing. The obvious lack of sufficient knowledge about the dynamic behaviour of clothing in terms of heat exchange, certainly justifies more research in this field

CONCLUSIONS

Standard values for clothing thermal properties are in most applications not representative for the actual performance of clothing during given conditions.

In a first approximation standard values should be reduced by 20–40% to compare with resultant values predicted for dynamic, active work.

Predictions of thermal stress based on standard values may severely over– or underestimate dry heat losses.

More research is required to develop a better understanding of clothing thermal function during realistic conditions.

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TEMPERATURE AND HUMIDITY WITHIN THE CLOTHING MICROENVIRONMENT: DETERMINANTS OF HEAT STRAIN

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INTRODUCTION

For workers employed in occupations ranging from deep mining to aerospace industries, elevated environmental temperatures cannot be avoided as it is either impractical or impossible to remove all or part of the excessive heat from the workplace and the active worker. Quantification of the heat stress to which the worker is exposed has in the past been attempted through the development in heat stress indicies which are based primarily on measures of dry-bulb temperature, radiant temperature, relative humidity and velocity of the ambient air (1). Field studies in hot environments have demonstrated that there may be no universal index of heat stress which would predict the heat strain of workers for a wide range of conditions (2). The ineffectiveness of these indicies is to a large extent due to the variety of thermal protective clothing worn and the difficulty in quantifying overall garment heat and water vapour resistance with variations in fabric characteristics and garment design (vents and openings).

For a fully suited worker with only the head exposed, 93% of the body surface area will be exposed to the suit microenvironment, the volume of air above the surface of the skin but directly beneath the suit. A reduction in the transfer of both heat and water vapour due to the addition of clothing may result in a build up of heat and water vapour within the clothing microenvironment, the level of which will depend on the characteristics of the fabric and the design of the garment. The present study was designed to investigate the changes in the temperature and vapour pressure of the microenvironment which may arise as a result of heat exposure when wearing a variety of thermal protective suits worn by helicopter personnel operating over Canadian coastal waters. The suits were designed to provide thermal protection in the case of emergency ditching but should not impair performance despite elevations in cockpit temperature.

METHODS

Before donning a suit, five physically active male university students were instrumented for measurement of rectal temperature (T_{re}), skin temperature (T_{sk}) and microenvironment temperature and relative humidity 8mm above the skin surface (T_μ and RH_μ) at three sites (upper arm, chest and thigh). In addition suits were instrumented for measurment of outer clothing temperature (T_{cl}). Subjects then donned a helicopter personnel suit over cotton thermal underwear and were seated in an environmental chamber. Chamber temperature was then increased from 20°C to 40°C over a period of 90 minutes and then held constant at 40°C for an additional 90 minutes (total duration of exposure was 180 minutes). Throughout the exposure chamber relative humidity was uncontrolled, decreasing from 50% to a final value of 28%.

The suits utilized in this study were constructed of Cotton Ventile (CV), Gore-Tex (GT), Nomex/Insulite (N/I) and Nomex/Neoprene (N/N). Both the CV and GT suits were of the dry-suit design with airtight seals at the ankles, wrists and neck such that the exchange of microenvironment air could only occur through the fabric, which have reportedly low water vapour resistances. In contrast, the N/I and N/N suits were of the wet-suit design thus allowing some measure of ventilation through openings at the ankles, wrists and neck. The N/I suit consisted of a 3-6mm insulite layer sandwiched between two layers of Nomex material throughout the entire garment, whereas the N/N suit consisted of a single layer Nomex coverall worn over a neoprene shorty wet-suit (arms and legs not covered by neoprene). During the exposure subjects wore leather gloves, wool socks and heavy leather boots.

RESULTS

Increased environmental heat load was accompanied by increases in the temperature of air within the microenvironment (Figure 1a). Average T_μ for all suits increased from 31.4°C to 35.9°C with no significant differences observed between suits. In contrast, microenvironment vapour pressure (VP_μ, calculated from T_μ and RH_μ) displayed trends that appeared to be dependant on the type of suit worn (Figure 1b). Initial RH_μ and VP_μ values for the CV and GT suits were much lower than that of the N/I and N/N suits. Throughout the exposure the N/I and N/N consistently produced the highest VP_μ, achieving near saturation levels of 96.1 ± 1.5% and 97.7 ± 0.7% respectively. In contrast, the microenvironment air below the CV and GT suits achieved saturation levels of only 76.5 ±6.6% and 88.4 ± 4.1% respectively. One way analysis of variance showed no difference in RH_μ or VP_μ

between the N/I and N/N suits over the last 60 minutes of the exposure, whereas relative humidities and vapour pressures within the GT and CV suits were significantly lower ($p<0.05$).

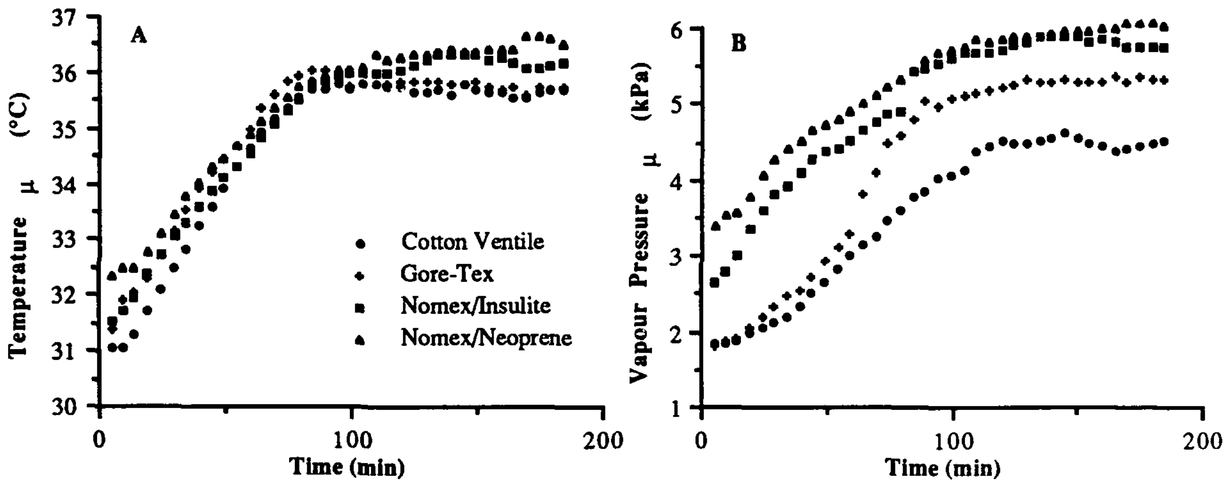

Figure 1: A) Microenvironment temperature (T_{μ}) and B) vapour pressure (VP_{μ}) within the Cotton Ventile, Gore-Tex, Nomex/Insulite and Nomex/Neoprene suits. Data are displayed at 5 minute intervals.

Similar elevations in T_{sk} were observed in subjects for all 4 suits tested throughout the exposure, whereas there were significantly greater increases in T_{re} (1.2°C) when subjects wore the N/I suit as compared to the CV (0.29°C), GT (0.23°C), and N/N (0.39°C) suits.

CONCLUSIONS

Despite the differences in suit design and construction, the temperature within the microenvironment was similar for all suits, suggesting that the resistance of the fabric and garment to dry heat transfer plays little role in the thermal status of the wearer during hot air exposures of this magnitude. However, analysis of the component thermal gradients indicates that the temperature of the microenvironment air may be 1.0 - 1.5°C higher than that of the skin and outer layer of the suit particularly during transient increases in VP_{μ}. The liberation of heat observed in this study may be attributed to either condensation or absorption (3).

Most interesting in this study was the effect of suit design and construction on the microenvironment conditions. Although suits of the dry-suit design would limit the path of diffusion of water vapour to that of the fabric only, the dry-suits utilized in this study were both constructed of a water vapour permeable fabric (Cotton and Gore-Tex). As a result of its high vapour permeability the CV suit tended to maintain the lowest VP_{μ} throughout the duration of the exposure. Only the N/I suit, whose Insulite layer provides a water vapour barrier throughout the whole suit with exception of the neck, wrists and ankles, demonstrated a significant elevation in rectal temperature (1.2°C). This is in contrast to the N/N suit which had similar VP_{μ} values as the N/I suit, however, the ΔT_{re} developed by the wearers of this suit was minimal (0.39°C). It is assumed that the areas of the body not covered by the neoprene in the N/N suit (legs, arms and head) were effective in permitting sufficient evaporative cooling to maintain body core temperature, as might be expected considering the lower water vapour resistance afforded by the Nomex fabric alone in these areas.

Since differing protective clothing assemblies will vary in their pro ties of insulation and water vapour permeability, it is proposed that assessment of conditions within the micr vironment of the suit may enhance predictions of heat strain as they reflect the true environment to which the individual is exposed.

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KINETICS OF PHASE TRANSFORMATION AND CAPILLARITY THEORY: NEW INSIGHTS INTO HEAT TRANSFER AND MOISTURE HANDLING IN HUMAN CLOTHING AND ANIMAL INSULATION SYSTEMS

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INTRODUCTION

Arctic mammals and birds routinely survive immersion in water and are able to dry themselves in subfreezing weather, yet man in most "high tech" gear is threatened with cold injury and hypothermia by simply sweating. Moisture accumulation in insulation is a major problem. An arctic expedition in 1986 reported a 50 lb. weight gain in sleeping bags used over a four-week period. The authors have been made aware of a clothing system that affords protection from cold injury after water immersion and excessive sweating. It is made of open-cell polyurethane foam surrounded by a thin, vapor permeable, wind resistant shell. Total moisture accumulation of a foam sleeping bag at temperatures of 0 to -20 ^{o}F for one week was 3.5 oz. When this gear is saturated with water in sub-freezing temperatures, water disappears from the gear without forming ice, and minimal cold stress and no cold injury occurs. The remarkable performance of this system prompted the authors to reexamine what is known about vapor condensation and ice formation (1). A theoretical analysis of the surface parameters of solids in insulation systems provides a basis for understanding how foam insulation allows its wearers to survive without fire or shelter for weeks in extreme cold with no significant weight gain or frost build-up in their gear and to survive water immersion accidents and periods of excessive sweating without cold injury. The same analysis argues against the use of wool blankets, space blankets, vapor barriers, down, and most synthetic fibers in cold weather gear.

PHASE EQUILIBRIA OF WATER SUBSTANCE AND HEAT-WATER VAPOR TRANSFER

The Clausius-Clapeyron equation describes the relationship among saturation vapor pressure of water and ice, the latent heats of condensation for water and ice respectively, and temperature. According to Fick's law of diffusion, the vapor flux from the body to the environment is proportional to the vapor diffusivity (which varies inversely with atmospheric pressure), the cross-sectional area, and the vapor density gradient. Consequently, water vapor tends to diffuse rapidly away from the body in cold environments. Heat transfer takes place similarly under the influence of the thermal conductivity of the materials surrounding the body. Ice has a thermal conductivity 92 times and liquid water 23 times that of air. The effect of fiber material for thermal conduction can generally be ignored. The thickness and cross-sectional area of the still-air layer created by a garment are the principal determinants of the insulating properties of a dry clothing system.

THEORIES OF CAPILLARITY

The contact angle of water on a solid surface is determined by the balance of three surface tensions at the edge of the spherical water cap and is described by the Young-Dupre equation. This angle is zero for totally wettable or very hydrophilic surfaces and 180^{o} for totally non-wettable or highly hydrophobic surfaces. Teflon has the highest observed contact angle, 108^{o}, while glass has a wetting angle of 0^{o}. Most"hydrophobic" fibers however have contact angles of roughly 90^{o}. Detergents, salts, and dirt can lower contact angles and may substantially change their moisture handling characteristics. The Young-Laplace equation describes the relationship between the radius of the curved water meniscus in the capillary and the capillary pressure. Capillaries of materials with contact angles greater than 90^{o} tend to push water out of them. The menisci there are curved convex outward or by convention are said to have positive radii of curvature. Capillaries of materials with contact angles less than 90^{o} tend to suck water into them and have concave outward menisci which have negative radii of curvature.

THE KELVIN EQUATION AND NUCLEATION OF CONDENSATION

The saturation ratio, better known as the relative humidity, of capillary condensed water is the ratio between the saturation vapor pressure over the capillary water and that over a flat water surface. The Kelvin equation describes either the elevation or depression of the vapor pressure of capillary water or tiny droplets compared to that over a flat water surface. The radius of curvature of a droplet on a flat solid surface is always positive (convex outward), and under this condition, the Kelvin equation shows that its saturation ratio is greater than 1. Evaporation is favored for such a droplet. In a parallel capillary of a material with a contact angle less than 90^{o}, the water meniscus is concave outward and therefore has a negative radius of curvature. The saturation ratio of water vapor in this configuration is less than 1. Condensation into this capillary is favored since the vapor pressure is low relative to a flat water surface. This effect becomes significant for capillaries of 0.1-0.001 µm. The smaller the capillary the more marked the effect. This is important because virtually all woven fiber systems have capillaries of this size at every contact point and sometimes within the fibers themselves. With a contact angle of 90^{o}, a parallel capillary would hold water with the meniscus flat, and there would be no tendency for water to move into or out of it under the saturated condition. Therefore, condensation would occur at saturation there. With contact angles greater than 90^{o}, evaporation would be favored out of such capillaries, and the effect would be greatest when capillary size is very small (less than 0.001 µm). In a system with very small capillaries with a contact angle slightly above 90^{o}, as is true for many hydrophobic fiber materials, a slight deterioration in contact angle could cause a huge deterioration in moisture handling since moisture would avidly accumulate in the very small capillaries when the contact angle drops below 90^{o}. For most woven fiber systems, wettable tiny capillaries cause moisture accumulation and thermal insulation deterioration. However, in synthetic open-cell foams, cell radii vary roughly from 0.1 to 1 mm. The vapor condensation on their surfaces requires nucleation (initiation) of tiny droplets. The cells of these foams can be treated as a flat surface for the nucleation of the droplets. This implies that, for contact angles greater than zero, evaporation is favored from such a system--hence the remarkable self-drying characteristics of foam insulations. When the foam is worn in cold weather, supersaturation (saturation ratio greater than 1) develops in the system without condensation, but breakdown of the supersaturation happens only when the ratio exceeds 2.9, as predicted by the nucleation equations described by Hirth and Pound (2). It always leaves, however, a nucleation-free zone near the body, avoiding drastic deterioration of the thermally insulating property. Contact points shift in live animal fiber systems due to active movement of the fibers. Evaporation from the surface of such fibers is favored once contact with another fiber is canceled. Ice formation is inhibited in tiny water droplets on flat surfaces because of the compressive stress of its positively curved surface. Ice formation is favored in tiny wettable capillary-held water because of the decompressive effect of its negatively curved surface. The smaller the capillary or droplet the greater the absolute value of the effect. This explains why ice has never been observed to form in foam gear while it is being worn.

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HEAT FLUX TRANSDUCER MEASUREMENT ERROR IN RELATION TO CLOTHING AND TISSUE INSULATION — A SIMPLIFIED VIEW

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INTRODUCTION

Heat flux transducers (HFTs) are useful devices for the direct measurement of heat exchange between the body and the environment. As with all systems, however, the very act of making a measurement perturbs the system under observation to some degree. With HFTs, this perturbation can be considerable under certain conditions of use. In simple terms, the measured heat flux is less than the true heat flux because of the extra thermal insulation introduced by the transducer itself.

Correction of the measured heat flux to arrive at true heat flux has been the subject of numerous studies, and several equations have been derived to achieve this correction (1-3). None of them, however, provide an estimate of the error introduced by the transducer. This information could be useful in planning a study, since correction of the measured heat flux often entails making additional high precision temperature measurements in order to use the equations. Depending upon the objectives of the study, the size of the error may not warrant the extra effort of obtaining these precise temperatures.

This paper presents a graphic method of estimating the magnitude of the error to be expected under specific experimental conditions. If the precision temperature measurements are made and the correction equations are applied, the graph can be used to estimate either the clothing or the tissue insulation, assuming the other parameter is known.

METHODS

Consider heat being transferred from the body core (at temperature T_c) through body tissues and clothing insulation to an ambient environment (at temperature T_a). Let the thermal resistances of the HFT, the tissue beneath the HFT, and the insulation over the HFT be R_{hft}, R_{tis}, and R_{ins}, respectively. Note that the clothing insulation referred to is the total insulation between the skin (or HFT) and the "infinite sink" of the environment. Note also that this insulation need not involve clothing – in the case of nude subjects or uncovered skin it could be simply a layer of still or unequilibrated air or water.

The true or correct heat flux (H_{corr}) passing through only the tissue and the insulation is given by Eqn 1:

$$H_{corr} = (T_c - T_a) / (R_{tis} + R_{ins}) \qquad [1]$$

while the measured heat flux (H_{meas}) passing through the tissue, the HFT, and then the insulation is given by Eqn 2:

$$H_{meas} = (T_c - T_a) / (R_{tis} + R_{hft} + R_{ins}) \qquad [2]$$

The heat flux correction factor is given by the ratio H_{corr} / H_{meas} and can be reduced to the form shown in Eqn 3:

$$H_{corr} / H_{meas} = 1 + 1 / (R_T + R_I) \qquad [3]$$

where R_T and R_I are the ratios of the thermal resistances of the body tissues and clothing insulations, respectively, to the thermal resistance of the HFT being used. If R_T and R_I are used as the ordinate and abscissa of a log-log plot, then plotting Eqn 3 for various values of the correction factor produces a family of lines, each representing a constant correction factor as R_T and R_I vary. Thus, knowing the thermal resistance of the HFT from the manufacturer or from independent measurements, and having reasonable estimates of the body tissue and clothing insulations from measurements or from values published in the literature, one can readily obtain an estimate of the correction factor that would apply under the given test circumstances.

RESULTS

Data from a series of water immersion experiments designed to measure the ratio H_{corr} / H_{meas} for a broad range of simulated "tissue" insulation showed excellent agreement with the theoretical relationships described above. In addition, physiological data from a human forearm water immersion experiment in which tissue insulation was carefully measured using an implanted multi-junction thermocouple probe (4) again confirmed the theoretical relationships.

The correction equations predict, and experimental results confirm, that the measurement error introduced by HFTs is minimized under conditions where tissue is vasoconstricted and insulation such as clothing covers the body. The effects on the measurement error of changing tissue and/or clothing insulation are vividly clear from the graphic presentation of Eqn 3. What is most informative is to limit the variation in R_T to the physiological range (about 1.6 - 40 using popular commercial HFTs) and observe the effects of variations in R_I on the measurement error. Using typical values for R_{hft}, useful ranges of R_I can be calculated and marked on the graph. For example, a layer of still water 1 - 2 mm thick would result in an R_I range of 0.2 - 0.4. In this range the correction factor lines are almost vertical, thus independent of changes in the insulation (i.e., thickness) of the water. The correction factor is, however, very sensitive to changes in tissue insulation under these circumstances, ranging from as much as 1.5 for vasodilated tissue down to 1.03 for vasoconstricted tissue (i.e., 50 - 3% error). By comparison, with clothing insulation ranging from 1 - 4 clo, R_I varies from about 20 - 80, and the correction factor lines are almost horizontal in this region. In fact, the correction factor now varies from about 1.05 - 1.01 (i.e., 5 - 1% error) and is almost unaffected by changes in the vasomotor state of the tissues.

CONCLUSIONS

A theoretical equation has been derived to show how the thermal resistance of an HFT interacts with body tissue and clothing insulations to underestimate the true heat flux. This relationship can be graphed to facilitate estimation of the magnitude of the measurement error knowing the clothing and tissue insulations. Alternatively, the graph can be used to examine the sensitivity of the correction factor to variations in body tissue or clothing insulation under various test conditions.

Allowing tissue insulation to vary over the physiological range, measurement errors ranging from 3 - 50% can be expected from nude skin during water immersion, the magnitude depending almost entirely upon the vasomotor state of the tissues. For subjects clothed in 1 - 4 clo of insulation, the measurement error is greatly reduced to between 1 - 5% . Considering other sources of experimental error and variation in physiological parameters, it may be reasonable to use uncorrected values of heat flux under these circumstances, thereby obviating the requirement for additional high precision temperature measurements.

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BREATHABILITY MEASUREMENTS OF FIREFIGHTER PROTECTIVE CLOTHING

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INTRODUCTION

Firefighter protective clothing is made of water impermeable materials thus limiting evaporative and convective heat loss from the body. If the metabolic heat generated during physical activities exceeds the capacity to eliminate the heat from the body, the firefighter will be at risk of becoming incapacitated due to excessive heat stress.

The ventilation of the airspace between the skin and the protective clothing, i.e. breathability, depends on the location and magnitude of openings at the neck, wrist, the front of the coat, ankles, and at the waist of the pants. Utilizing the test method developed by Reischl and Dukes-Dobos (1) measurements were performed to establish the effect of the above mentioneu openings on the breathability of the firefighter protective clothing.

METHOD

A male manikin was dressed in a firefighter protective garment made by Morningpride Mfg. Co., including a turnout coat and turnout pants, and was exposed to wind-tunnel air flow conditions of 0.5 m/sec. in four orientation angles (0^0, 90^0, 180^0, 270^0). Breathability was measured at eleven location on the manikin. Six garment closure configurations were tested (Table I). Measurement procedures were repeated three times and the means calculated. The mean values of the four orientation angles were then averaged to obtain an overall mean ventilation value for each garment configuration.

RESULTS

Table I shows the effect of closing and opening different features of the garment. The greatest increase of the ventilation at the chest was achieved by opening the turnout coat in the front and at the collar, however, this did not influence the garment ventilation at the arms and back. Opening the sleeves at the wrist resulted in only a small increase in arm ventilation. Opening the pants at the ankles resulted in a more substantial increase of ventilation both at the legs and at the crotch. When the belt was removed from the pants and replaced by suspenders, ventilation increased at all five sites but most significantly at the back, legs and crotch.

CONCLUSIONS

Breathability measurements of firefighter protective clothing provided quantitative data on the increase in garment ventilation due to the opening of the cuffs at the sleeves, at the pants, opening of the turnout coat in the front and at the collar. Wearing suspenders increased the ventilation throughout the garment. Thus, appropriate use of these openings and replacing the belt with suspenders can reduce heat stress imposed upon the firefighter significantly.

TABLE I Ventilation in five regions of a firefighter protective garment using six closure configurations

GARMENT COMPONENT	CLOSURE CONFIGURATION #1	#2	#3	#4	#5	#6
Sleeve Cuffs	C	C	C	C	C	O
Pant Cuffs	O	O	C	C	C	C
Coat in front and the collar	C	O	O	O	C	C
Suspenders	yes	yes	yes	-	-	-
Belt	-	-	-	yes	yes	yes
BODY REGION	**Ventilation Rate (l/min.)**					
ARMS	1.59	1.29	0.97	1.02	0.95	1.33
CHEST	2.69	10.17	10.69	11.41	2.22	2.14
BACK	3.52	3.64	3.14	0.95	1.00	1.28
LEGS	3.68	4.34	3.34	1.34	0.38	1.35
CROTCH	5.36	5.94	4.10	2.02	2.91	2.79

* C = Closed
O = Open

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DESIGN OF A TRANSIENT SWEATING HOT PLATE

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INTRODUCTION:

In studying the combined heat and water transport through clothing, it has been found necessary to treat the phenomenon as the dynamic one that it is [1,2]. During the time a garment is worn by an active person, the heat flow through it is rarely constant. Heat flow mechanisms such as water vapour diffusion and wind can be highly unsteady due to the nature of their sources. Their interaction with the other major heat transfer mechanisms of air conduction and thermal radiation make the overall heat transfer highly unsteady.

An apparatus used to study heat and water transport through clothing is the Sweating Hot Plate or Guarded Hot Plate. A steady state version is used to measure heat and vapour resistances under steady state conditions. However, to truly characterize the dynamic situation, a Sweating Hot Plate capable of simulating the transient behaviour of water vapour and measuring the resulting dynamic heat loss is required. Such an instrument has been developed and used by Dr. Brian Farnworth and Patricia Dolhan at Defence Research Establishment (DREO), Ottawa, Canada [1,2]. This paper describes the design of a new transient Sweating Hot Plate which is a state of the art version of the DREO prototype.

THE ORIGINAL DESIGN:

The DREO version consisted of what can be called a thermal sandwich assembly mounted in a cut out in an insulated box containing the sweat mechanism. The whole unit could then be placed in a small environmental chamber for studies at other than room conditions.

The thermal sandwich consisted of a paper (and later cotton) top covering over a 3 mm thick aluminum plate. This plate was divided into an inner circular test section of area 0.01 m^2 and an annular guard ring of the same area. Each of these sections had four (4) evenly distributed water feed lines to simulate sweat. Under the aluminum plate was a 50 mm thick piece of insulation and under that a 3 mm thick aluminum base plate. Thermocouples imbedded in the plates and heaters attached to them allowed the test plate, guard ring and base plate to be controlled to the same temperature so that all heat flow from the test plate was vertically upwards through the specimen that was placed on top of it.

The sweat mechanism consisted of two (2) syringe pumps and eight (8) solenoid valves. The syringe pumps could be started and stopped manually from the computer keyboard and the solenoid valves were sequenced by the computer to ensure uniform water delivery to the eight (8) water feed lines.

The box served as a mounting for the thermal sandwich and as a thermal protective environment for the sweat mechanism when the unit was placed in an environmental chamber.

THE NEW DESIGN:

A new Sweating Hot Plate has been designed and built by The CORD Group Limited which brings the design up to the state-of-the-art and adds features that make it more versatile.

THE NEW DESIGN (Cont.)

The thermal sandwich of the CORD Hot Plate is of a lower mass design in order to improve the transient response. This has been done by thinning the test and guard plates to 1.5 mm and eliminating the base plate. The insulation has also been thinned to 6.4 mm. The transverse temperature uniformity at all levels within the thermal sandwich has been improved by changing the metal to copper (because of its higher thermal diffusivity) and by the use of etched foil heaters. The accuracy of temperature measurement and heat flux blocking by the guard ring and base insulation has been maintained or improved by the use of 2000 OHM thin film distributed RTDs for temperature measurement. The result is that the total thickness of the CORD thermal sandwich is only 9.5 mm as compared to 56 mm in the old design.

The sweat mechanism of the new Hot Plate has also been improved. Instead of eight (8) feed lines to the plate, there are twenty-four (24) and each is fed by a separate piston eliminating the need for in-line solenoid valves. The larger number of feed lines improves the uniformity of sweat distribution over the old design. The new Hot Plate also has a Lycra covering with a special wicking finish which improves its response time during the onset and decay of transient sweat profiles.

The individual sweat pistons are driven by a single micro step drive stepping motor through a lead screw. This makes possible the accurate and automatic control of virtually any sweat profile by the software. The sweat reservoir holds enough water for twenty-four (24) hours and can be refilled on the run providing the ability to run tests indefinitely.

The CORD sweat mechanism also has applications elsewhere; for instance, it could be incorporated into a sweating manikin.

With the CORD Sweating Hot Plate, the specimen can be subjected to differing environmental conditions in several ways. The whole unit itself is designed to be placed in a small (24" X 24" X 24") environmental chamber for ambient temperature simulation. Also, a small environmental housing has been designed to attach directly to the Hot Plate itself. This housing allows for temperature, medium and pressure control over the thermal sandwich. For instance, one can do tests on a specimen immersed in water and include the effects of pressure on the specimen thickness.

A further feature of the design is that the thermal sandwich can be rotated through 180 degrees so that specimens can be tested in different orientations including completely upside down. This allows for studies including the effects of the thermal boundary layer as a function of orientation.

The Hot Plate can be run from a P.C. computer using a data acquisition and control system having proportional power output capability or it can be operated directly from a P.C. using its own data acquisition and control board, interface unit and software.

The CORD transient Sweating Hot Plate is a very versatile device that can be of use to researchers who do transient or steady state studies. It is available for purchase or lease from The CORD Group Limited. Testing services can also be provided on a contract basis.

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DEVELOPMENT OF A THERMAL HAND TEST SYSTEM

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INTRODUCTION

A series of Thermal Hand Test Systems (THTS) have been developed by Measurement Technology NW to measure the thermal insulation of handwear both in field and laboratory tests. The THTS's include a multi-sectioned, partially articulated cast aluminum hand and a micro-computer based thermal measurement and control system. The development leading to the construction on the most recent THTS is discussed here.

METHOD

Thermal Analysis: A thermal model was constructed using ANSYS finite element code to investigate the effect on two dimensional surface temperature profiles of heater placement, non-uniform wall thickness, material conductivity, and convection coefficient variation. The design criteria was a surface temperature uniformity of ±0.5 °C across any single region. Minimum heater size was based on published, total body, maximum sensible and latent heat rejection values (1). Because it was assumed that the finger sections rather than the palm or wrist presented worst-case conditions relative to achieving isothermal temperatures at the surface, a quarter-symmetry model of a finger was developed. This analysis established minimum aluminum skin thickness and heater spacing for anticipated heat fluxes.

Casting: Hand dimensions from a number of male subjects were compared with the anthropometric 75th percentile American male right hand(2). A silicon rubber mold was made from the best candidate. Wax forms were then splash cast in the master mold for investment casting. A cast plug was also pulled from the master mold for use as a dimensional standard during assembly of the thermal hand.

Error Budget Analysis: A worst case error budget analysis of the thermal measurement and control system was implemented on a computer spreadsheet. The design criteria were accuracies of ±0.25 °C for temperature measurement, and ±10 mW for heat flux measurement for each region . This analysis considered the effects of A/D and D/A quantization, power supply regulation, sensor tolerance, temperature coefficients in the heaters, and signal conditioning component tolerances. The resulting design met all performance criteria.

Construction: The cast skin region supports were machined from a tough epoxy-glass composite material to near fit. The integration of the composite substructure, cast skin regions, and heaters and sensors was done by labor intensive cut-and-fit techniques. The interface electronics are mounted on printed circuit boards located in a standard industrial enclosure. The menu driven software was developed on a PC 286 in the ASYST high level control and instrumentation language.

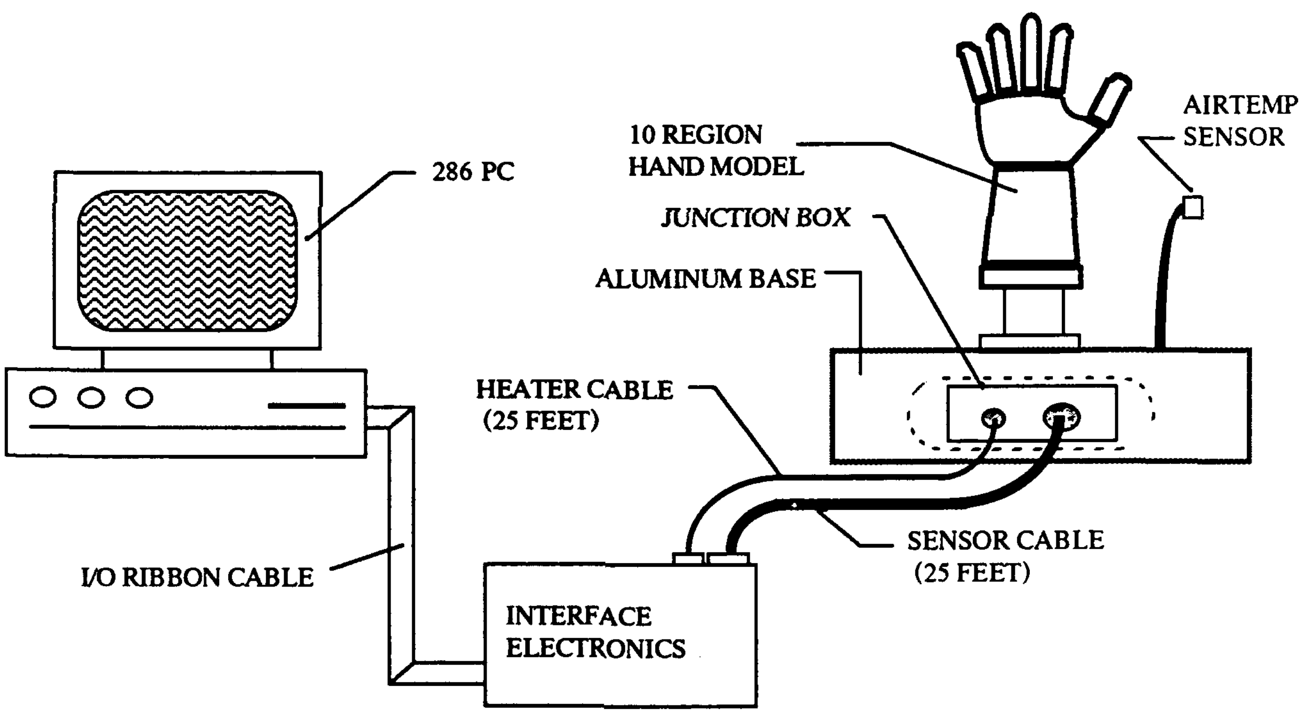
RESULTS

The THTS is shown schematically in Figure 1.0. The hand model consists of 10 thermally isolated regions including a thermal guard at the proximal cross-section of the wrist/forearm section. Partial articulation of the digits facilitate donning and doffing of hand wear. All wires are terminated inside a sealed, desiccated box so that a water soaked glove can be tested without harming the model. The Hand model is connected to the interface electronics by two 25 foot all-weather cables. The operator interface is implemented on a dedicated PC 286 microcomputer located near the interface enclosure. The system control software provides menu access to all operating parameters, data analysis and storage, and debug functions.

The THTS was tested in an environmental chamber using setpoints of 25.0° C, and 3.0° C, respectively. Surface temperature settling times to zero mean error typically took between 50 and 65 minutes for gloves and mittens with Clo values from 0.7 to 2.0. A bare hand clo of 0.3 was measured. Skin temperatures measured by the system compared well with those measured with small gage thermocouples glued to the outer surface. The PID control algorithm was able to control surface temperatures to zero mean error with $\pm 0.25°$ C maximum excursion for set points from 5° to 35° C, in each region.

CONCLUSIONS

A development effort has resulted in the successful construction of a series of THTS's. The design approach, beginning with a thermal and an error budget analysis, resulted in a robust operator friendly instrument for the accurate measurement of clo values in handwear.



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COMPARISON OF METHODS FOR DETERMINATION OF HANDWEAR INSULATION WITH A BIOPHYSICAL MODEL

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INTRODUCTION

The conventional use of biophysical hand models has been to measure dry insulation from area weighted power demand values (1,2). This report describes two alternate methods for measuring dry insulation. One method is to determine the combined heat transfer coefficient for convection and radiation from the slope between power demand and multiple temperature differences. The second method consists of determining the total cooling rate of the model. The later method is of interest because it is analogous to complete blockage of blood flow to the human hand as would occur with a severe wound, application of a tourniquet, total peripheral vasoconstriction or blood shunting. The analogy is not wholly complete because the specific heat coefficients (c_p) and masses of the model and a human hand are not equal.

METHOD

A seven section, water resistant aluminum hand model was used to calculate total thermal insulation by determining the change in cooling rate and by measuring power demand while maintaining constant surface temperatures. Insulation is calculated from the slope of power versus the difference between surface and air temperature. Cooling curves for both bare and covered models were generated by heating the model to a selected surface temperature setpoint (30°C), then cutting off the power supply. In this case, insulation is estimated from the relationship between the rate of temperature decline versus time. Power consumption versus temperature difference slope values were generated by measuring the sectional power consumption required to maintain a 30°C surface setpoint at different test chamber temperatures. Insulation values obtained with a 22-zone copper hand model were used as reference control values. Cooling curves were evaluated by calculating the slope for the natural logarithm of the temperature difference between the model surface temperature and the test chamber over time. Molnar (2) presents a similar calculation method.

TABLE 1. RESISTANCE AND INSULATION (CLO) VALUES FOR ISSUE MILITARY HANDWEAR

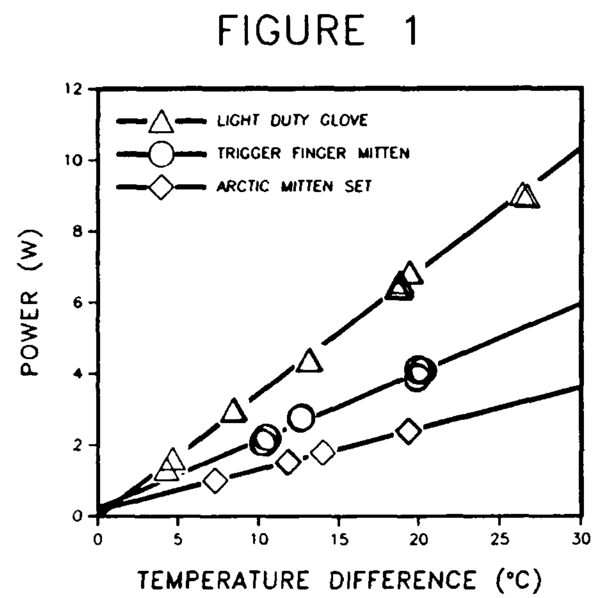
Table 1a. Comparison of two calculation methods and control values

	control	weighted average*	slope
	$m^2 \cdot K \cdot W^{-1}$ (clo)	$m^2 \cdot K \cdot W^{-1}$ (clo)	$m^2 \cdot K \cdot W^{-1}$ (clo)
bare hand	0.06 (0.4)	0.04 (0.2)	0.05 (0.3)
arctic mitten set	0.38 (2.4)	0.35 (2.2)	0.35 (2.3)
three finger mitten	0.23 (1.5)	0.21 (1.3)	0.21 (1.4)
light duty glove	0.14 (0.9)	0.12 (0.8)	0.12 (0.8)

Table 1b. Comparison of adjusted insulation values to control

	control	weighted average*	slope
	$m^2 \cdot K \cdot W^{-1}$ (clo)	$m^2 \cdot K \cdot W^{-1}$ (clo)	$m^2 \cdot K \cdot W^{-1}$ (clo)
bare hand	0.06 (0.4)	0.05 (0.3)	0.05 (0.3)
arctic mitten set	0.38 (2.4)	0.38 (2.5)	0.39 (2.5)
three finger mitten	0.23 (1.5)	0.23 (1.5)	0.23 (1.5)
light duty glove	0.14 (0.9)	0.14 (0.9)	0.13 (0.8)

*mean of three repetitions, three values per repetition



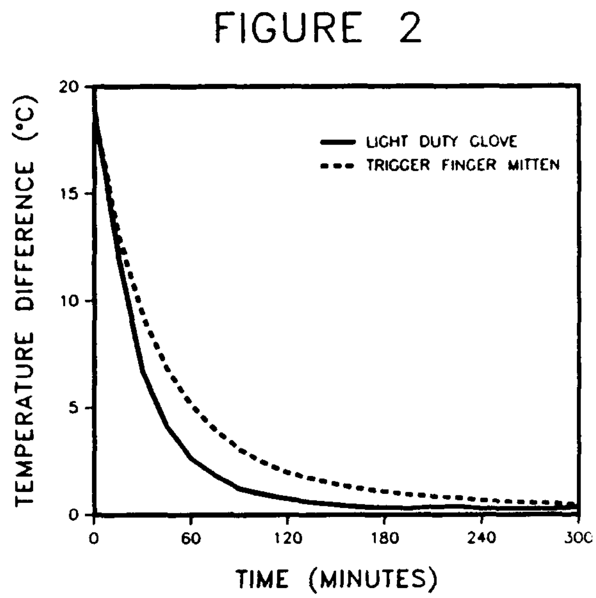


Figure 1. Power demand vs. temperature difference (ΔT)   Figure 2. Temperature difference (ΔT) vs. time

RESULTS

Total insulation values (I_T) were calculated for current issue military handwear using both the area weighted power demand and slope methods (Table 1a). The insulation values for the new hand calculated by either method were 0.01-0.02 $m^2 \cdot K \cdot W^{-1}$ less than the control values obtained with the original copper hand model. Values calculated by the slope method were closer to the control values, but values were lower for both methods. When values were recalculated using a 10% larger total surface area to compensate for gaps between model sections, agreement with the control values increased (Table 1b). The relationship between power and the temperature difference is linear, whereas the relationship between surface temperature and time is curvilinear (Figures 1,2). The data obtained by cooling down the insulated hand model did not provide comparable calculated values for insulation, but relative levels of insulation of different handwear are indicated.

CONCLUSIONS

The power gradient slope method demonstrates an alternative method for calculating total handwear insulation (I_T) from power demand, and indicates that the values are constant over a range of temperature gradients. However, the cooling curves generated by terminating the power supply are not, at this time, an acceptable alternative method for calculating insulation.

DISCLAIMER

The views, opinions and/or findings in this report are those of the authors, and should not be construed as official Department of the Army position, policy or decision, unless so designated by other official documentation.

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EFFECTIVENESS OF WATERPROOF, BREATHABLE HANDWEAR IN A COLD ENVIRONMENT

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INTRODUCTION

Cooling of the hands has been implicated as a cause for reduced endurance time, loss of manual dexterity and general discomfort during cold exposure. An extended exposure to cold-wet weather can result in rapid cooling of the extremities from the conduction of heat through wet layers of insulation. Historically, military campaigns conducted in cold-wet conditions have resulted in a high incidence of immobilizing cold injuries to ground troops wearing clothing incapable of providing adequate insulative and moisture protection relative to the combat theater. In a questionnaire given to 2000 United Kingdom troops immediately following the Falkland Islands War in 1982, cold hands were recorded as one of the three major medical problems during all ground operations (1). The purpose of this present study was to evaluate physiological responses when subjects wore waterproof, breathable handwear while sitting and exercising in a cold environment. Specifically, the study was designed to show if the handwear would meet certain performance requirements and provide adequate protection to military personnel wearing a recently-developed cold weather clothing system.

METHODS

Eight subjects each wore a leather work glove that incorporated either a polytetrafluoroethylene (PT), polyethylene (PE) or polyurethane (PU) membrane. The total thermal resistance, I_t ($m^2 \cdot K \cdot W^{-1}$) of the four layers of materials that comprised the entire glove (separate polyester inner glove, and the actual work glove which utilized a nylon tricot-faced foam liner, the membrane liner, and a leather outer shell) when measured on a thermoregulatory model of the human hand was similar for all test gloves ($I_t \approx 0.150$). Subjects wore an extended cold weather clothing system (ECWCS, $I_t = 0.561$, total evaporative resistance, R_{et} [$m^2 \cdot kPa \cdot W^{-1}$]= 0.082 when measured on a thermal manikin) that utilized three synthetic, hydrophobic inner layers and one waterproof, breathable outer layer containing PT. Testing was conducted in a cold environment (-9.5°C, 20% r.h.) with subjects who wore dry gloves while sitting on a bench (S1), walking with dry gloves on a treadmill at 0.98 $m \cdot s^{-1}$ (W1), sitting with wet gloves (S2) or walking with dry gloves in an air velocity of 4.4 $m \cdot s^{-1}$(W2). Endurance time (ET, max = 120 min) was dependent on exposure responses and pre-set safety criteria. Rectal (T_{re}), middle finger (T_{mf}) and mean skin temperature (T_{sk},10 sites) were measured periodically.

RESULTS

Table 1. shows mean endurance times while wearing the test handwear during the four exposure conditions. ET was significantly lower ($p<.0005$) for all gloves during S2. ET was maximum when wearing dry PU but was reduced to the lowest ET (58 min) when the gloves were wet during S2. Several subjects reported a sensation of dampness within all three gloves during S2. The complete disassembly of PU gloves which were found to contain an inordinate amount of moisture at the completion of S2 revealed small tears in the actual membrane material. The fastest drop in T_{mf} also occurred during S2 (mean drop ranged from 0.26 to 0.30°C$\cdot min^{-1}$ for the three gloves). ET was greater during S2 when PE and PT were worn (74 and 83 min, respectively). Final T_{mf} and T_{sk} values during W1 were significantly higher than W2 values. There were no significant effects of glove type on final T_{re} and T_{sk} values.

Table 1. Mean values (8 subjects) of endurance time, ET (minutes, maximum=120) while wearing the three test gloves during the four exposure conditions.

Exposure Conditions	S1	W1	S2	W2
Glove	ET			
PT	107	120	83	120
PE	107	120	74	120
PU	120	120	58	120

CONCLUSIONS

These data show that a decrease in thermal resistance of wet handwear and a moderate wind affected physiological responses of subjects who wore gloves incorporating waterproof, vapor-permeable membranes. A protective membrane material which is claimed by a manufacturer to be "waterproof" and "breathable" can possibly be penetrated by moisture during a prolonged soak in water. Whether this is due to the particular physical characteristics of the actual membrane or to membrane damage during the manufacture of the glove cannot be fully concluded from these results. Currently, it is the manufacturers practice to test membrane inserts for leakage with an air inflation test immediately after their construction, before incorporation into a finished glove. Damage to the membrane during the glove assembly and the resulting ingression of water appeared to contribute to a reduction in endurance times with one of the test gloves in this study. Furthermore, the leather outer shell of the test glove absorbed a quantity of water during S2 which when combined with the relatively large surface area presented by a glove allowed for a increased degree of heat loss via conduction from the hand. Finally, the results suggest that a similar glove with a small increase in thermal insulation which is protected from environmental water contact by an undamaged PT or PE protective membrane would probably increase subject endurance times toward the desired maximum when wet and better complement the excellent cold-wet weather protective capabilities of the ECWCS ensemble.

DISCLAIMER

The views, opinions and/or findings in this report are those of the authors, and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other official documentation. Human subjects participated in these studies after giving their free and informed consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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Effect of Hand and Foot Heating on Diver Thermal Balance

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INTRODUCTION

Divers at rest immersed in cold water for long durations wearing passive thermal protection garments are limited by painful and numb fingers and toes due to low digit temperatures which occur well before rectal temperatures fall to unsafe levels. Increasing passive insulation is detrimental, as doing so results in decreased manual dexterity. It was reasoned that low levels of hand and foot active heating might improve diver comfort without decreasing manual dexterity. Supplemental heating to maintain digit temperatures at either 12 or 18 °C was chosen to minimize potentially counter-productive increases in local skin conductivity (1).

METHODS

A total of 32 divers participated in 3 series of immersions for periods of up to 8 h in 3 °C water. Divers wore a dry suit with Thinsulate undergarments. In the first series, divers wore warm water perfused gloves and socks. The gloves and socks were heated to maintain finger and toe temperatures of 12 °C or 18 °C. The diver was questioned as to his comfort, and tested for grip strength and ability to do fine tasks of manual dexterity every 2 h. In the second series, divers wore electrically heated socks and gloves, which continually delivered 21 W of heat to each extremity to establish whether sufficient power was available to achieve the desired digit temperature. A third series was conducted with intermittent energizing of the gloves and socks to determine the average power required to maintain 18 °C finger and toe temperatures.

RESULTS

During the first series the divers reported that 12 °C finger and toe temperatures were uncomfortably cold, with 50% reporting numbness by the end of an 8 hour-immersion. Divers without supplemental heating were unable to complete the immersion due to pain and numbness occurring between 2-4 hours. Heating fingers and toes to 18 °C resulted in greater perceived comfort, with divers reporting some cold sensation but no discomfort or numbness. Hand grip strength was not different between the heated and unheated groups, as forearm muscle groups that provide grip strength were presumably not affected by hand heating. There was no increase in forearm skin temperature or heat flux. Manual dexterity was not different between groups heated to 12 or 18 °C, but was improved over the unheated group, whose fingers became painfully cold or numb between 2 and 4 hours of immersion.

The second series of continuous electrical heating produced finger temperatures of 25 ± 3 °C and toe temperatures of 29 ± 2 °C when 84 W was applied to the hands and feet. In the third series, ON/OFF control was used to maintain digit temperatures of 18 ± 0.5 °C. The duty cycle (ON time/ON+OFF time) was 62 ± 5% for hands and 49 ± 3% for feet during the last 2 h of immersion. Average heating power for each hand was

13.4 ± 3.4 W, and each foot 9.8 ± 2.4 W. The rate of fall in mean skin or rectal temperature in heated divers was not different from those of unheated divers during the course of the immersion. Metabolic rate rose in response to falling body temperatures, and was sufficient to offset the rate of heat loss, resulting in a rectal temperature plateau at 36 °C. Whole body heat fluxes were similar to those reported by Thalmann (2) for resting divers immersed in 2-4 °C water wearing comparable amounts of dry suit insulation.

CONCLUSIONS

The energy required for extremity supplemental heating to 18 °C in this study (50 W for electrical, 211 W for warm water) is in the range of only 10-25% of the energy cost of whole body heating in 0-5 °C water estimated by Lippitt (3). However, Lippitt's calculations assumed no change in core temperature, while in this study core temperature decreased 1.2 ± 0.3 °C in 8 h. This is similar to that reported for similarly insulated, unheated resting divers (2). The major advantage of extremity supplemental heating is the improvement in perceived comfort and manual dexterity, as there was no demonstrable effect on diver core temperature change during immersion in cold water.

This study has demonstrated that electrical resistance heating at the hands and feet has a lower power requirement than the hot water perfused system that was tested. The entire electrical resistance system was assembled from off-the-shelf components that are readily available. It is a thin glove or sock with electrical resistance wire woven in the fabric, permitting overlying passive insulation to reduce energy requirements and still providing good diver manual dexterity while affording some passive thermal protection in the event of a heating power failure.

Supplemental heating of the hands and feet does provide increased comfort to the diver wearing passive insulation at low energy cost. However, it does not affect the loss of body heat during cold water immersion. The rate of body cooling remains a function of diver activity level, garment insulation, and water temperature. The duration of exposure determines the amount of total body heat loss, and how much of a decrement in performance will occur.

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A NEW MATHEMATICAL MODEL OF FINGER COOLING USED TO PREDICT THE EFFECTS OF WINDCHILL AND SUBSEQUENT LIABILITY TO FREEZING COLD INJURY

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INTRODUCTION

Originally conceived for largely military applications[1], wind-chill indices are now commonly used and misused in a very large range of circumstances, and quoted in weather forecasts[2]. Original attempts to derive expressions of the cooling power of wind for given ambient temperatures were based on physical analogues, the katathermometer and frigorimeter[3]. It was Siple and Passell[1,4] who first produced curves for popular use and their study remains the basis for most wind-chill tables in current use, in spite of having a number of major flaws[2,3]. Understanding of the physics involved in convective cooling has shown that models designed for one situation, such as the clothed whole body, are not applicable to others, such as naked fingers[3,5], although it is common to ignore this. An attempt in 1985 (Oakley, unpublished) to build a mathematical model of cooling in naked fingers, for use in the prediction of frostbite, appeared promising, and this paper reports continuing development of this model.

METHOD

For the purposes of this model, many simplifications and assumptions were made. In the first instance, the model is of a perfect cylinder which has one free end exposed to the environment. The other end does not gain or lose heat. The interior of the cylinder is divided into a number of concentric cylindrical layers in such a way that the inner cylinders do not touch the free end at the surface, but lie under their more superficial layers. The tissues within the layers are even in all respects, and parameters and variables uniformly and evenly distributed between layers, except with regard to blood flow. Axial transfer of heat is neglected in this second-generation model.

Heat production, gains and losses are computed for each discrete time period, and as a result the heat content of each layer is adjusted and its temperature recomputed for the start of the next time period. Each layer may produce heat by metabolism, dependent on temperature according to the Arrhenius relationship, may gain it by conduction from an adjacent layer, or may gain it from blood flowing through the layer. Thermal conductivity of tissue is varied between a minimum and a maximum according to an exponential relationship, as is blood flow. If the model is used in single layer mode, a chosen proportion of the heat available in the blood is given up uniformly to the whole tissue; if two or more layers are present, heat is delivered directly into one or more layers only. Heat loss from the outermost surface of the whole cylinder occurs by convection and radiation. Convective formulae offer free convection, dependent on the Grashof number, or forced convection, dependent on the Reynolds numbers, which in turn are related to the Nusselt number according to empirical relations for cylinders[5]. Radiative loss occurs according to Stefan's Law, to an assumed uniform ambient.

The model has been implemented in the Pascal language under MacApp® (Apple Computer, Inc.) on a Macintosh® IIcx computer. The finite differencing procedure is called as a result of interactively setting parameters and variables in a modeless dialog. Iteration is continued until a predetermined surface temperature (typically −0.55°C, the freezing point of tissue fluids) is reached. The results are delivered into a text document formatted for easy entry into popular spreadsheets, for further analysis. The model has been run using a range of different time intervals for the iteration, various numbers and thicknesses of layers, dimensional settings, and with output of layer temperatures and heat transfer by mode, as well as for different combinations of air temperatures and windspeed.

RESULTS

Convergent stability was found to occur with time increments of 0.5 s, which performed as well as increments down to 0.1 s. However, increments of 1.0 s and greater progressively diverged from those curves. Similar convergent stability with respect to the number of layers was found to occur with 3, 5 or greater than 5 layers, which produced remarkably similar cooling curves to those resulting from 12 or more layers (of the same total thicknesses). Dimensional effects were found to be very significant even for small (anthropometric) changes in length and diameter of the cylinder. At an ambient temperature of −30°C and a windspeed of 20 m/s, time to freezing varied by over 20% from a cylinder of length 90 mm and diameter 18 mm to one of length 70 mm and diameter 22 mm, and at −10°C and 5.0 m/s, this variation rose to 50%.

Examination of heat transfer by mode demonstrated that convective heat loss from the surface consistently accounted for the largest amount of heat transferred, with conduction to the outermost surface also being large.

Heat delivered by blood was significant only in the initial period of cooling, before blood flow fell to minimal levels, whilst conductive losses from the innermost layer rose inversely with blood flow. Radiative losses were relatively small and only slightly non-linear, whilst metabolic heat production was so small as to be insignificant at all times. Examination by layer exhibited a gradient through layers which steepened rapidly and non-linearly during cooling.

Predicted times to freezing (in s, for three layer model at 0.5 s increments):

Windspeed (m/s)	0.0	2.5	5.0	7.5	10	15	20	25	30
Temperature (°C)									
-5	∞	∞	∞	∞	∞	373	285	238	207
-10	∞	∞	432	303	242	179	144	122	106
-15	∞	497	277	204	165	121	97	81	70
-20	∞	357	210	155	124	91	72	60	51
-25	427	285	169	124	99	72	57	47	40
-30	334	238	142	104	83	59	47	39	33

∞ = time in excess of 500 s; freezing not certain.

CONCLUSIONS

Whilst the performance of the model in terms of heat transfer by various modes and the temperature distribution between layers appears consistent with expectations, and the model appears to satisfy other internal validations, satisfactory external validation is more difficult. Only one study[6] has been published which includes sufficient actual observational data to be useful for comparison, and there are substantial differences between the experimental conditions and those assumed for the model, and it no longer appears ethical to attempt to repeat such work. However, in each condition reported, the values predicted from the model lie within the observed range, and they are usually very close to the median, as shown below.

***Predicted* and observed[6] times to freezing (in s):**

Windspeed (m/s)	5.0		10		15	
Temperature (°C)						
-15	*277*	352	*165*	90-168-∞	*121*	87-355-535
-25	*169*	49-85-310	*99*	43-152-285	*72*	–

Observed times given as medians between extremes, ∞ = did not freeze.

Comparison with the Siple and Passell[1] predictions is also difficult. However, the general form of the isotachs derived from this model is in accord with theirs, although the actual values are quite different. For instance, this model predicts that –10°C at 25 m/s is of equivalent risk as –25°C at 7.5 m/s, whilst Siple and Passell would offer a difference of about 15% (with the latter being the 'colder'). There is also controversy regarding the way in which wind-chill equivalent temperatures are expressed, in terms of the reference windspeed for no convective incremental loss[2,7], which the use of times in this model may circumvent.

This model offers insights into factors which determine the risk of freezing cold injury. For instance, the excess incidence of injuries in those of Negroid extraction when compared with Caucasians has been attributed to a combination of more rapid finger cooling and poorer subsequent vasodilation[8]. Substantial differences resulting from dimensional changes may be significant too, and future studies of this should include anthropometric factors. The next step in the development of this model is to incorporate axial heat transfer.

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SIMULATION OF ROUGH SEAS IN A WATER IMMERSION FACILITY: PART I - THERMAL MANIKIN EVALUATION OF VARIOUS TECHNIQUES

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INTRODUCTION. Accidental water immersion is a serious problem that threatens all sailors. When immersed in cold water, the loss of body heat will be exacerbated by rough seas. To examine this effect, the U.S. Coast Guard (USCG) conducted unique field evaluations in which the thermal protection of various operational protective garments was evaluated when worn in cold water (11°C) under calm and rough sea conditions (1,2). Testing was conducted in the Columbia River near Cape Disappointment, WA. These studies demonstrated that with loosely-fitted, wet-suit concept garments, the rough seas caused significant flushing of cold water through the garment's seals, resulting in body cooling rates 1.5 to 2.0 times those measured in calm seas. Field evaluations such as those performed by the USCG are time-consuming, expensive and can only be conducted at specific times of the year when the required environmental conditions are expected. It is more desirable to simulate a rough seas environment in the laboratory, where controlled human and thermal manikin studies can be conducted. This study evaluated various methods for simulating rough seas in a small pool chamber. Part I describes the simulations and the results on the thermal manikin (TM). Part II describes the human evaluations, both in a field setting and in the laboratory.

METHODS. Eight techniques were evaluated on our aluminum TM in a temperature-controlled water tank measuring 4.6x2.7x2.1 m (lxwxd). For all evaluations, the TM was dressed in an aviator's anti-exposure ensemble. Water and air temperatures were maintained at 15.5°C; wind speed was 0.3m/s. The methodologies included:

M1) Diffuse Compressed Air - An air line (2-cm id) released controlled volumes (1.4, 2.8, 4.2, 5.7 liters per second (l/s)) of compressed air from the bottom of the pool. As the air rose, it expanded and created water agitation over a wide area. At the highest flow rate, the observed water agitation took the form of waves, 0.3 to 0.4 m in height.

M2) Concentrated Compressed Air - An air line pipe (10-cm id; 122 cm length) was positioned either 30 or 60 cm below the water surface and controlled volumes (1.4, 2.8, 4.2, 5.7 l/s) of air were released from a compressed air line secured to the bottom of the pipe. The observed water agitation took the form of a wave that peaked at 0.8 m and dissipated to 0.2 m at the sides of the pool.

M3) Pump Current - A single 3.7 kilowatt (KW) water pump delivered metered volumes of water (up to 28.4 l/s) from a 10 cm id pipe, 13 cm below the water surface and 60 cm from the TM. At 28.4 l/s, the observed wave agitation was in the form of wavelets and water current.

M4) Pump Spray - A single 3.7 KW water pump delivered metered volumes of water (up to 28.4 l/s) from a 10-cm id pipe, 1.4 m above the pool surface and at a 65° angle toward the surface. As the pumped water hit the pool surface, a surface current was generated with little or no wave action in the form of wavelets.

M5) Pump Current and Spray (M3 and M4 combined) - Two 3.7 KW pumps were utilized to pump and spray up to 56.8 l/s of water. Water agitation took the form of random wavelets less than 0.1 meter in height.

M6) T-Wave Maker - A digitally timed, pneumatically-driven T-bar was utilized to create standing wave(s). Depending upon the rate of the T-bar movement, the observed water agitation took the form of one to three standing waves that measured .17 to .30 meters in height.

M7) Vertical Displacement - The TM was periodically (1-4 times/minute) pulled out of the water. The resulting water turbulence was very small, with only very small disruptions of the water surface.

M8) M1 and M7 combined - A constant vertical displacement of 4 times per minute was combined with releasing volumes of compressed air (1.4, 2.8, 4.2, 5.7 l/s) from the bottom of the pool. The observed water agitation was in the form of waves 0.3 to 0.4 meters in height.

RESULTS. In calm water, immersed clo was 0.29. Test results follow.

	Air Flow (l/s) =		1.4	2.8	4.2	5.7
M1) Diffuse			0.15	0.09	0.08	0.08
M2) Concentrated, 60 cm			0.25	0.22	0.20	0.17
Concentrated, 30 cm			--	--	--	0.12

	Water Flow (l/s) =	9.5	18.9	28.4	37.9	56.8
M3) Current		0.19	0.12	0.07	--	--
M4) Spray		0.22	0.10	0.07	--	--
M5) Current & Spray		--	0.14	--	0.09	0.08

	Mode of Operation =	Level 1	Level 2	Level 3	Level 4
M6) T-wave maker		0.09	0.08	0.07	0.05

	Displacement (per minute) =	1	2	3	4
M7) Vertical Displacement		0.22	0.19	0.17	0.16

	Air Flow (l/s) =	1.4	2.8	4.2	5.7
M8) Combination M1 & M7 (4x/min displacement)		0.16	0.16	0.16	0.16

CONCLUSIONS. The lowest clo value was obtained using the T-wave maker, with two standing waves, each 28 cm in height. However, this technique proved stressful for the pool itself, and therefore could not be utilized on a daily basis. The second lowest clo values were obtained using M1, M3, M4, and M5. For continued use, we recommend M1 (Diffuse Compressed Air) because: 1) it was the easiest technique to set up and maintain, 2) results were easily repeatable on the TM, and 3) the method did not create undue stress on the pool.

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EMPIRICAL MODEL OF TEMPERATURE RESPONSE TO COLD WATER IMMERSION

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INTRODUCTION: Linear extrapolation and the Texas Human Thermal Model (1) are widely used to estimate core temperature during cold water immersion. The purpose of this study was to examine the validity of both tech .iques by comparing estimates with human data obtained from cold water immersions lasting up to 360 minutes.

METHODS: Rectal temperature (T_{re}) data were obtained from cold water immersion studies conducted in Finland and Norway (F) (2) and the United States (US) (3) over the past 9 years. Two types of garments were used in these studies, constant wear anti-exposure coveralls with vapor-permeable membranes (Gore-Tex) (CW-F, CW-US) and neoprene quick-don anti-exposure coveralls (QD-F). Water temperatures for the CW-F and QD-F studies were 1°C and 7°C for the CW-US study. Maximum exposure durations for the CW-F and CW-US were 120 minutes and for the QD-F it was 360 minutes.

The actual T_{re} data was compared with linear extrapolations and T_{re}'s predicted from Texas model simulations. Linear curve fitting was performed on the data for given intervals of time (e.g. 90, 120, 180, 240, 300, and 360 minutes). Comparisons of the correlation coefficients and predictive accuracy were based upon both the curves generated from individual trials and from pooled data. The QD CLO values input into the Texas model were assumed to be equivalent to previously reported values (immersed regional CLO values $\approx$ 0.9-2.6, mean=1.2) (4). Overall CLO values were available for the CW-US (immersed CLO $\approx$ 0.8) and insulation of the CW-F was assumed to be equivalent. Garment CLO values accounted for the water thermal boundary layer. Anthropometric data from individual subjects was input into the model during simulations. A temperature offset was used to correct for differences in initial temperatures between actual data and simulations. M. del fidelity was analyzed by directly comparing actual human T_{re} data (T_a) with model estimates (T_e) and by comparison of the estimated changes to actual changes in T_{re} relative to the initial T_{re} (T_o). Paired-t tests were used to compare data and significance was determined at a p=0.05 level.

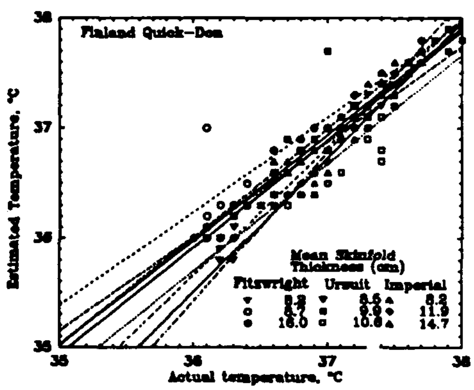

Figure 1. Relationship of estimated T_{re} to actual T_{re} for QD-F.

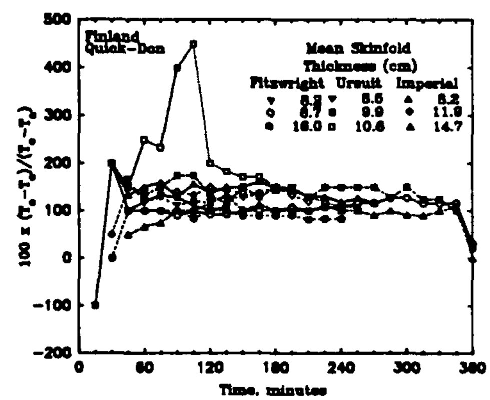

Figure 2. Percent difference between actual change in T_{re} versus time and estimated change for QD-F.

RESULTS: Linear Estimates: Linearity can be demonstrated throughout the extended trials (i.e., >180 minutes), but the slopes change significantly (p<0.05) over time.

Texas Model: Model simulations of the QD-F were fairly reliable throughout most of the exposure period. As seen in Figure 1, the slopes of the regression lines representing the correspondence of actual and estimated T_{re} did not significantly vary from 1.0.

The percent difference between the estimated and actual change in T_{re} had means ranging from 86% to 198%, with the mean of the means of 122% (SEM±11) (Figure 2). As no data was available past 36(minutes, it was not clear whether the over-estimation of T_{re} observed among the final values was a transient phenomena.

Simulations of the CW trials were less reliable. The CW-F simulation regression line slopes deviated significantly from a slope of 1.0 ($p<0.01$) (Figure 3). The percent difference between the estimated and actual change in T_{re} had a mean of the means of 203% (SEM±36, range of 116% to 325%) (Figure 4). While the percent difference in T_{re} in the CW-US simulations had a mean of the means of 96% (SEM±11, range of 39% to 139%), considerable variation was noted for both CW studies. The regression line slopes obtained from the CW-US simulations did not significantly differ from 1.0.

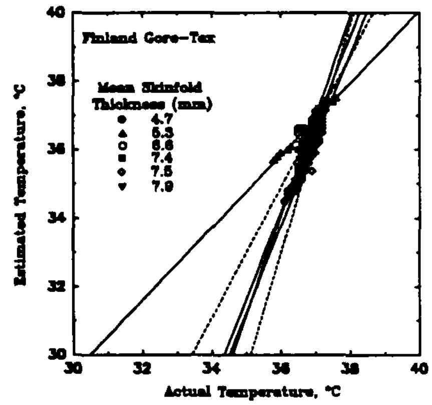

Figure 3. Relationship of estimated T_{re} to actual T_{re} for CW-F.

CONCLUSIONS: It appears that linear extrapolation of T_{re} for extended periods based only upon short term responses (i.e., <120 minutes) will be inaccurate. The Texas model provides a reasonable simulation of human T_{re} responses to cold water immersion under some conditions. The cause of the deviation of estimates from the simulated studies with the actual T_{re}'s is unclear. It is likely that use of regional CLO values would have improved the accuracy of the estimates for the CW studies. Additional validation studies of the Texas model using other garments and environmental conditions appears warranted.

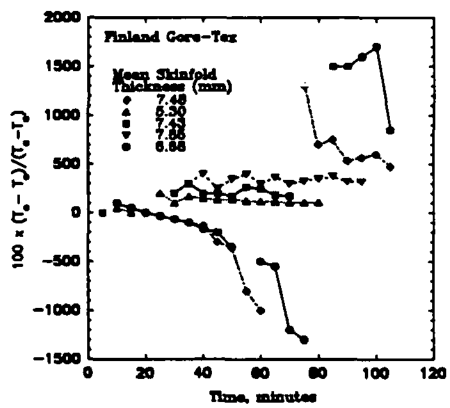

Figure 4. Percent difference between actual change in T_{re} versus time and estimated change for CW-F. Missing data is due to division by zero.

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A UK VIEW OF THE TEXAS MODEL

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INTRODUCTION

Whole body thermal models are potentially valuable tools in the prediction of thermal strain in stressful conditions. However it is important that their general behaviour is well understood if they are to be used to extrapolate to conditions which are too hazardous to be reproduced in the laboratory. Essential components of both real and model systems are negative feedback loops - e.g. sweating and shivering - which tend to maintain body temperature within a prescribed range. As a result, the use of absolute levels of predicted variables such as rectal temperature as the sole comparison between experimental and model behaviour can be misleading. A more precise description of model response is provided by a comparison of the change in observed and predicted variables as a consequence of changes in the subject parameters or the environment.

The Texas model (1) is among the most highly developed thermal models, and has been employed by a number of nations for the prediction of survival time in cold water (2). In this paper, the model predictions are compared with the results from an experiment involving 15 subjects undergoing nude immersion in cold water, while both resting and exercising on a submerged cycle ergometer.

METHOD

The data on which these validations were based were obtained from a series of immersions in well stirred water at temperatures between 12°C and 35.5°C, each subject undertaking two immersions at each water temperature, one resting and one exercising intermittently at a randomly ordered series of levels between 10% and 50% of the subject's $\dot{V}O_2$ max. Exercise lasted 10 minutes and was followed by between 10 and 15 minutes rest. Metabolic rate for each rest and exercise period was determined by indirect calorimetry to yield one value per period. Rectal temperature, and skin temperature and surface heat flux at 9 sites, were recorded every 2 minutes. Immersions continued for 2 hours or until rectal temperature fell to 35°C or until the subject asked to be removed from the water. Total heat flux was calculated by correcting for the thermal resistance of the transducer (3) and weighting the corrected values according to body surface area (4).

The model was set up to simulate as closely as possible the exact conditions of the experiments for the 12 subjects for whom the data were most complete at each water temperature. The subject's mass, height, and mean weighted skin fold thickness was supplied to the model, as were the precise times of rest and exercise for the exercising immersions. Values of heat flux, metabolic rate and rectal temperature were recorded every 5 minutes during resting immersions, and every 2 minutes during exercising immersions.

The observed and predicted values of rectal temperature, heat flux and metabolic rate were compared initially using analysis of variance. For the resting immersions, the first 20 minutes of each run was discarded, as the rapid changes in heat flux during this period were not described in sufficient detail by observations taken every two minutes. Twelve subjects had relatively complete results for runs at 18°C and 24°C, while only 6 completed runs at 12°C. Two sets of analyses were therefore undertaken. The effect of mean weighted skinfold thickness (MWST) was examined by allocating the 12 subjects into three groups, and the 6 subjects to 2 groups. Five factors were identified in the analysis of variance : T (5 minute interval), W (Water temperature), F (Body Composition), S (Subject) and M (Observed vs Model). T, W, F, and M were treated as fixed effects, while S was treated as a random effect nested under F and crossed with the remaining factors. A similar analysis was undertaken for the 6 subjects at three water temperatures. For the exercising immersions a similar analysis was carried out on the data from the experiments at each water temperature separately, using 4 levels of exercise and the first post-exercise rest period.

RESULTS

For the resting immersions, there is a tendency for the model to underestimate metabolic rate ($p < 0.01$), and this varies with water temperature ($p < 0.05$). Similarly, there is a tendency for the model to underestimate total heat flux ($p < 0.01$), although this effect varies with water temperature ($p < 0.001$), subject MWST ($p < 0.05$) and both together ($p < 0.05$). Overall the model predicts too small a fall in rectal temperature ($p < 0.01$) and there was evidence that the time course of the decline is not reconstructed correctly.

For the exercising immersions, comparison was confined to rectal temperature and heat flux. For all three temperatures, the difference between observed and predicted values varies with time and temperature ($p < 0.001$) with the model predicting too high a heat flux at high exercise rates, and too small a flux at rest. Similarly, the difference between observed and predicted rectal temperatures varies with exercise level ($p < 0.001$) with the model forecasting too large a drop at high exercise levels, and too small a drop at rest.

For some of the resting immersions the model predicts an oscillation in metabolic rate with a period of approximately 10 minutes. This oscillation only occurs when the predicted rate of fall of core temperature approximates 0.01°C per minute - the criterion for extra shivering (1). This causes an increase in shivering which produces an increased heat loss which then increases the rate of fall of core temperature. A further increase in metabolic rate occurs until the increased heat production reduces the rate of fall of core temperature below the critical value. Metabolic rate then declines and the cycle repeats.

The metabolic response to cold predicted by the model is less than that observed in these experiments. In general, the dominant contribution to metabolic rate is the term derived from the deviation of skin and rectal temperature from set point values (1). The value of this contribution was compared with the observed metabolic rate, using the observed skin and rectal temperatures. The pattern of predicted response follows that of the full model, indicating that the inconsistency between observed and predicted values is determined mainly by the deviations in this term rather than those in body temperatures.

CONCLUSIONS

In general the Texas model predicts the behaviour of rectal temperature at 18°C and 24°C in the resting immersions realistically over the first hour of nude immersion at rest. The behaviour at 12°C is not predicted as reliably, particularly for the thinner subjects, and this poorer prediction is associated with an underestimate of heat flux. The effect of increased metabolic rate on heat flux is not predicted well by the model, and this appears to be reflected in the presence of the oscillation in metabolic rate for some subjects. Overall, the analysis suggests that the key weakness in the model at high core skin gradients is in the representation of the redistribution of blood flow and, therefore, heat transport, although the effect is only marked under relatively extreme conditions.

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A BIASED VIEW OF THE TEXAS MODEL

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Development of the TEXAS human thermal model covers more than 30 years. During that period, an effort has been made to identify dominant factors affecting physiological responses to environmental stress and exercise, and incorporate them rationally into the model. That effort has been strongly dependent on experimental data generated in various laboratories, but biological variability and a general paucity of reliable experimental data for cold immersion has hampered the work. Therefore, the extensive set of cold immersion data generated by the group at IAM and their effort to evaluate the model quantitatively is most welcome.

Although twelve subjects participated in the IAM study described in the preceding minipaper by Belyavin, Sowood, and Stallard, this paper will focus attention on the resting series for two fairly thin subjects (3 and 11), whose weights (73.0 and 73.4 Kgms) and mean skinfold thicknesses (9.02 and 9.04) closely match those of Subject JA (weight = 73.5 Kgms and mean skinfold thickness = 9.4 mm) in a similar experiment performed by Webb using the Craig bath calorimeter at DCIEM in Toronto. Subject JA was older than the two IAM subjects. While this sample is too small to support any general conclusions, these results are representative of those for the entire data set, and they illustrate the kind of problem one has in trying to "fine tune a model.".

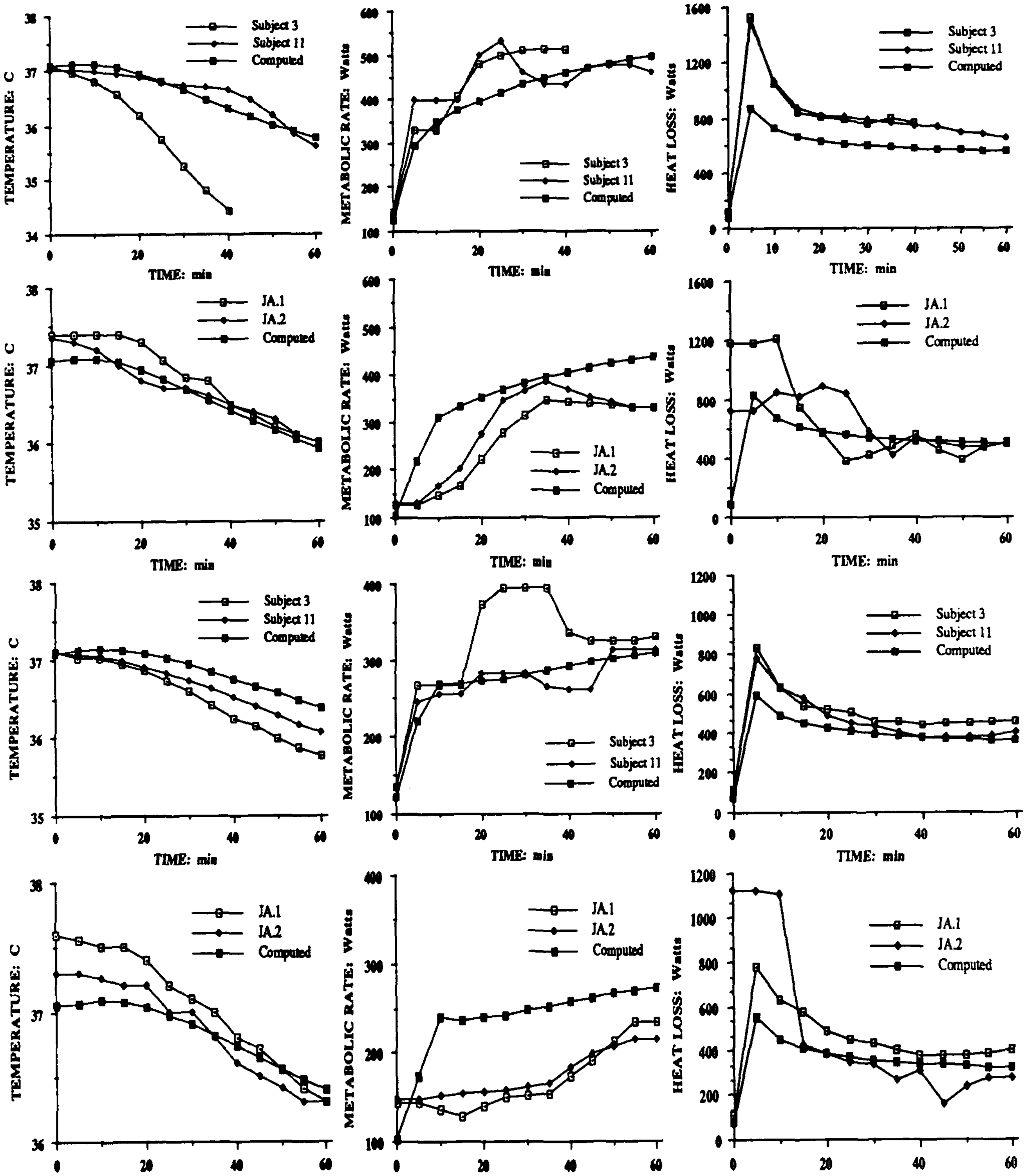
Computed and measured rectal temperature, rate of surface heat loss, and metabolic rate are shown on the next page for these three subjects during one hour immersions in 18 and 24 C water. It must be emphasized that <u>the model discussed here is not exactly the same model evaluated at IAM</u>; the shivering controller gain has been increased by 50 percent and the vasoconstriction controller gain has been decreased by 50 percent to obtain higher rates of shivering metabolism and surface heat loss, as recommended by Belyavin, et al..

The principal problem is that experiments which should produce similar results do not always do so. Results shown on the next page indicate that significantly higher metabolic and surface heat loss rates were measured in the IAM experiments than in the DCIEM study. That presents a dilemma for the analyst, since there is no basis for preferring one set of data over the other, although the use of thermal flux transducers to estimate total rate of heat loss from the skin is probably not as accurate as using a bath calorimeter. Nevertheless, one must assume that a rational basis exists for the observed differences, and the most plausible one is that conditions in the IAM pool were significantly different from those in the DCIEM calorimeter.

Since heat transfer coefficients at the skin-water interface were probably higher in the vigorously stirred water of the IAM pool than in the slowly flowing water of the DCIEM calorimeter, a higher water velocity was used in the IAM simulations than in the calorimeter simulations. Increasing the water velocity caused computed rates of metabolism and surface heat loss to increase approximately 60 Watts each after 60 minutes of immersion in 18 C water. Even so, the model yields values that are smaller than those measured in the IAM pool and higher than those measured in the DCIEM calorimeter. Unfortunately, there is no obvious explanation for the residual differences.

Differences in the time course of shivering metabolism are also apparent in the central vertical panel of figures on the next page. The IAM subjects tended to shiver more quickly than subjects in the DCIEM calorimeter. Results computed with the new parameters mentioned above are reasonably consistent with the IAM observations, but that leaves unresolved the reason for the slower responses observed in the calorimeter.

Additional suggestions from the IAM study can be incorporated into the TEXAS model. For example, the oscillation observed in computed metabolic rate, which does not seem to have a physiological basis, was eliminated by requiring an exponential decrease in the shivering component driven by decreasing central temperature. The observation that fat subjects probably shiver less vigorously than thin subjects having identical skin and central temperatures provides welcome confirmation of something that we have felt was true. Although a considerable amount of computational effort will be required to modify the model so that it agrees more closely with the larger data set now available, it needs to be done andt should yield a model that can be used with greater confidence.



Comparison of computed and measured values of rectal temperature, metabolic rate, and rate of surface heat loss for IAM Subjects 3 and 11 and DCIEM Subject JA (replicate runs) during immersion in water at 18 C (upper two panels) and 24 C (lower two panels). Note especially the difference between metabolic rates measured in the two laboratories. The IAM rates tend to rise more rapidly and reach a higher level than the DCIEM values, for reasons that are not well understood.

BREATHING APPARATUS AND VENTILATION

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INTRODUCTION

Some individuals who are required to perform physical exercise while wearing self-contained breathing apparatus (SCBA or SCUBA) sometimes experience respiratory distress and/or panic behavior. This behavior is often associated with morbidity and mortality, and it is not uncommon to find that a breathing apparatus is functional and air remains in the tank at follow-up. It has been recognized for many years that factors of a psychogenic nature can influence resting as well as exercise metabolism. Most of the experimental literature dealing with this topic has involved the hypnotic manipulation of metabolism, and it has been found that heart rate, cardiac output, forearm blood flow, respiration rate, ventilatory minute volume and oxygen consumption can be influenced systematically with hypnotic alterations in perception (1). Furthermore, independent of hypnotic perturbation of effort sense, it has also been shown that selected psychological states and traits influence ventilation and behavior in exercising subjects wearing breathing apparatus (2,3). This research will be summarized in the present address, and recommendations for screening and training paradigms will be suggested.

SCBA RESEARCH

Despite the fact that major advances have taken place in the design of respirators, it is still widely recognized that "psychological" problems continue to exist. Unfortunately, very little research has been directed toward an understanding of the "person" component of the ***respirator-person*** interface; that is, research has focused on ***respirator*** variables with little attention paid to ***person*** variables. While it has been proposed that certain "types" of individuals be eliminated from work tasks requiring the wearing of SCBA, there has not been a concise diagnostic statement presented to enable such a screening approach to be adopted (2). The purpose of our first experiment was to address this problem.

The purpose of the investigation (3) was to evaluate the effectiveness of trait anxiety in predicting respiratory distress resulting from heavy physical work performed while wearing an industrial respirator. Spielberger's trait anxiety scale was administered to 45 male volunteers in order to identify individuals with elevated trait anxiety. This testing was followed by a pulmonary function test, resting 12-lead electrocardiogram (ECG), and an exercise ECG. Individuals with cardiovascular and/or pulmonary impairment did not continue with subsequent tests. The subjects next completed three treadmill tasks varying in intensity from 35% to 80% of $\dot{V}O_2$ max, and each trial lasted for 10 minutes. Twenty-five of these individuals performed the exercise tasks while wearing a self-contained breathing apparatus (SCBA) in the demand mode, whereas the remaining 20 subjects used a pressure-demand SCBA. The reason for terminating exercise was classified as respiratory or non-respiratory on the basis of self-report responses on a 7-point dyspnea scale, as well as general responses concerning muscular fatigue and respiration. It was predicted, based upon trait anxiety scores, that six individuals would have respiratory distress, and five (83%) of these predictions were correct. It was also predicted that 39 of the 45 subjects would not experience distress and 38 (97%) of these predictions were correct. These results (3) have since been replicated in a second experiment. It is concluded that objective measures of trait anxiety can be used to identify those individuals who are most likely to experience distress while wearing an industrial respirator and performing heavy physical exercise.

SCUBA RESEARCH

Approximately 40% of the fatalities associated with SCUBA diving each year are classified as "unexplained" or due to "undetermined" causes. There is both a theoretical rationale and empirical evidence supporting the view that a substantial number of these "unexplained" cases are associated with factors of a psychological nature, and our survey of 300 experienced divers revealed that 54% had experienced panic or near-panic behavior on one or more occasions (4,5). While some authorities maintain that individuals who experience panic behavior while scuba diving will discontinue this activity, it is now apparent that panic behavior can occur in experienced, as well as novice scuba divers. Our subsequent laboratory research has indicated that:

1. It was possible to predict (double-blind) panic behavior in beginning SCUBA divers with 88% accuracy using a measure of ***trait anxiety***.

2. Experienced scuba divers differing in levels of ***trait anxiety*** tend to have similar responses on selected perceptual and metabolic variables studied during an underwater SCUBA simulation. The exception to this generalization was the observation that respiration rate was significantly ***lower*** in ***high trait anxious*** divers.

3. Elevated ***trait anxiety*** in male test subjects was associated with respiratory distress during arm ergometer exercise on land, but this relationship was not observed in female test subjects.

4. Females judged a paced surface swim at 90% of maximum velocity to be ***less effortful*** than did male swimmers despite a higher exercise heart rate in the females.

5. Anxiety responses during and following underwater swimming was associated with the interaction between water temperature and protective apparel.

CONCLUSION

It is concluded that high ***trait anxious*** individuals are at risk when wearing SCBA or SCUBA and performing vigorous physical activity. It is recommended that efforts should be made to identify these individuals ***a priori*** with an aim toward (a) screening them out, or (b) evaluating efforts to develop selected stress minimization strategies.

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ANOMALOUS REACTIONS TO RESPIRATORY LOADING DURING DRY EXERCISE AT DEPTHS TO 305 m

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INTRODUCTION

New breathing resistance limits for Underwater Breathing Apparatus were tested during 7 research saturation dives involving 31 divers at depths to 450 msw. The limits were derived by a retrospective analysis of earlier data (1), and describe in probabilistic terms the influence of breathing resistance on exercise tolerance. As predicted, divers frequently could not complete 20 min of heavy exercise when breathing through moderate resistances. Surprisingly, however, two divers nearly lost consciousness. Those two incidents and the unusual symptoms accompanying them are described below.

METHODS

One event occurred at 46 msw while the diver was breathing air (1.2 ATA O_2), the other at 305 msw while the diver was breathing 0.4 ATA O_2 in He. Divers exercised dry on a cycle ergometer for 5 min at 50 watts, then for 20 min at 150 watts. Wearing an AGA full face mask, the divers breathed through a resistor with a two-way valve separating inspired and expired flows. Inspiratory flowrate was monitored by a Rudolph screen pneumotachometer, and the diver's EKG was recorded on a strip chart or FM recorder. A mass spectrometer continuously analyzed gas sampled at the mouth. The divers provided a modified Borg dyspnea score at 2 min intervals.

Neither diver was a smoker, but both had significant pulmonary histories. The first was allergic to ragweed, the second had childhood asthma and exposure to both asbestos and granite dust as a young adult.

RESULTS

Both divers completed exercise without difficulty in control runs with low resistances. At 46 msw with a moderate resistance (incident 1) one diver suddenly experienced graying of vision and vertigo after 2 min at 150 watt. Immediately before the event the diver had described only slight breathlessness (score of 2, with 11 maximum). Inspiratory flowrate was low ($1.3\ l \cdot s^{-1}$) and minute ventilation (RMV) was only $30\ l \cdot min^{-1}$, but end-tidal CO_2 did not exceed 59 mm Hg. Before the event, peak-to-peak mouth pressure (DP) averaged 21 cm H_2O.

A different diver at 305 msw gradually experienced increased breathlessness to a very severe level (score 9 of 11) during the 150 watt workload. The sudden appearance of visual symptoms caused the diver to stop work abruptly after 11 min at 150 watts. Just before termination, RMV was $50\ l \cdot min^{-1}$, and DP was 30 cm H_2O. The diver reported lightheadedness, dizziness defined as an inability to maintain balance, scotomas, and tunnel vision. Tunnel vision lasted about 1 min after the diver removed the mask, but dizziness cleared within seconds.

Both divers maintained normal sinus rhythm with no unusual changes in heart rate. In the first diver, maximal exercise heart rate was 120 min^{-1}, in the second it was 163 min^{-1}. Headaches were absent. Peak-to-peak mouth pressures never exceeded 30 cm H_2O, and were equally distributed over inspiration and expiration. There was no hydrostatic loading since divers were not immersed, so mean intrathoracic pressure should have been nil. From the probabilistic model, the predicted probabilities of diver discomfort were similar, 0.14 and 0.17.

DISCUSSION

There is no obvious explanation for these incidents. A common cause of unconsciousness in divers, CO_2 narcosis secondary to hypoventilation, was unlikely because end-tidal CO_2 was normal for exercising divers, and the characteristic CO_2 headache was absent.

In some individuals, syncope can be caused by large positive intrathoracic pressures created by straining or Valsalva maneuvers. Although not a common occurrence, venous pooling may paradoxically result in vagal induced bradycardia and severe hypotension. However, in these cases intrathoracic pressures should not have been elevated (mouth pressure was low) and there was no bradycardia. Furthermore, inspiratory efforts against a resistance promote venous return more than expiratory efforts impede it. Consequently, resistances with equal inspiratory and expiratory components cause few cardiovascular perturbations. Breathing through resistors can induce large increases in peripheral bloodflow (2), but there are no reports of associated changes in arterial or central venous pressure.

Exertional syncope is usually a pathological sign, as in aortic stenosis. In normal individuals, leg exercise promotes forearm vasoconstriction, thus reducing peripheral blood flow. However, when ventricular baroreceptors are stimulated by high left ventricular pressures (due to stenosis) vasodilatation can occur, resulting in syncope (3). While we cannot rule this mechanism out, its action in healthy divers is unlikely.

Pulmonary history may provide the only clue to the cause of these unusual events. We have postulated that the hyperbaric environment accentuates physiological differences among divers. Theoretically, minor functional deficits that do not impair exercise at the surface can be magnified at depth, to become apparent when the diver is subjected to cardiopulmonary stress. Just how those stresses could elicit the observed symptoms, however, is not known.

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RESPIRATORY INDUCTANCE PLETHYSMOGRAPHY: AN EVALUATION FOR USE IN NORMOBARIC AND HYPERBARIC ENVIRONMENTS

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INTRODUCTION

This laboratory is evaluating Respiratory Inductance Plethysmography (RIP), commercially known as Respitrace[R], for the measurement of ventilation in diving and non-diving applications where direct connection to the airway is impracticable. RIP is based on the assumption that the respiratory system has two degrees of freedom of movement: one is the rib cage (RC), the other the abdomen (AB). Two independent self-inductance coils supplied by a small oscillator unit are used to monitor changes in the cross-sectional area of the RC and AB components respectively during respiration. Following calibration against known volume changes (in this study using a spirometer, SP), the demodulated output from each coil is summed to give the corresponding changes in lung volume.

This paper presents results taken from trials in which the minute volume by RIP (V_{RIP}) was compared with simultaneous measurement by a pneumotachograph (V_{PN}) or dry gas meter (V_{GM}) during exercise on a cycle ergometer. An accuracy of ± 10% or better was generally considered necessary for the use of RIP to measure minute volume in diving experiments. The experiments were carried out in the laboratory and in a dry compression chamber at 1,3 and 5 bar during trials of other equipment. Calibration was routinely carried out at 1 bar (normobaric). An important part of this work was to determine if calibration needed to be carried out under hyperbaric conditions for experiments at 3 and 5 bar.

Various methods are available for calibrating RIP. Work carried out in this laboratory (Garside 1984; unpublished) indicated that the original simultaneous equation method of calibrating RIP was unsuitable for diving applications. Therefore a multiple linear regression calibration technique (MLR) used successfully by Stradling et al.(1) for resting subjects was tested in this study. Segadal et al.(2) have used RIP during shallow and deep simulated dives, calibrated by means of a least squares technique.

METHOD

3-4 male subjects with diving experience took part in the experiments. 32 experiments compared V_{RIP} with V_{PN}. Each gave 1 measurement of minute volume during steady-state cycling. 4 experiments compared V_{RIP} with V_{PN}, covering workloads from rest to moderate or heavy. All measurements were of 60s duration. The transducers were modified by sewing the coils into neoprene bands since they were more stable and easier to put on than commercial transducers. Transducers and oscillator were held in place by a close fitting elasticated net. Outputs from the RIP calibrator/ demodulator were sampled and analysed using an Acorn Archimedes 310 computer with ±15 bit A/D converter (CIL PCI 6480). Sample rates were 13.4 Hz and 19.4 Hz for calibration (RC, AB, SP) and test (RC, AB) signals respectively.

A Fleisch pneumotachograph was used to measure inspiratory minute volume (V_{PN}). A dry gas meter (Parkinson Cowan CD4) was used to monitor expiratory minute volume (V_{GM}). The spirometer, pneumotachograph and gas meter were calibrated with a 1 litre syringe. Volumes were expressed as BTPS (spirometer and gas meter) or BTP with 60% RH (pneumotachograph).

RIP calibration procedure: The subject breathed on a closed-circuit rolling-seal spirometer for 20s or 30s (0.8-3.6 litres tidal volume) while changes in cross-sectional area of chest and abdomen were measured by RC and AB transducers. The MLR technique was used to determine the two volume-motion (V-M) coefficients (MRC and MAB) and their standard errors (SE). The procedure was repeated up to 8 times before and after cycling. Calibrations in which either MRC or MAB were negative were rejected. In each experiment, an average value of V_{RIP} was calculated from the remaining calibrations. In one study the effect of additional selection criteria for calibrations was also tested. These criteria were the SE of MRC <5.0%, the ratio of tidal volume for RIP/SP between 0.95 and 1.05 and the standard deviation of the ratio <0.05. Since preliminary experiments using commercial bands confirmed the observation that MLR is posture-dependent (1), calibration was carried out with the subject resting on the ergometer. The volume of CO_2 removed when soda lime was present in the spirometer had little or no effect on the value of V_{RIP}.

RESULTS

The main results of the RIP-pneumotachograph studies obtained in 4 experimental conditions are summarized in the Table. Columns 2 - 5 give the linear regression analysis for the relationship of V_{RIP} upon V_{PN}. Mean-RIP (column 6) is the mean of the percentage difference between V_{RIP} and V_{PN}, defined as $(V_{RIP}-V_{PN})100/V_{PN}$. The relationship between V_{RIP} and V_{PN} was not significantly different from the line of identity at the 5% level, irrespective of the pressure during cycling (cyc), the calibration pressure (cal) or whether the experiment was carried out in the laboratory (L) or the compression chamber (CC). Mean-RIP ranged from -3.07 to 9.84% and was not significantly different from zero in any condition shown ($p>0.05$). Thus although mean values of V_{RIP} were within ±10% of V_{PN}, the variation was such that individual measurements of V_{RIP} were not necessarily accurate to this level.

The slope of the regression line for V_{RIP} upon V_{GM} in 4 subjects (4 experiments) was significantly greater than 1. The slope was 1.08 ± 0.01 (n=76, $p_1<0.001$). The intercept (-0.49 ± 1.83 l/min) was not significantly different from zero ($p_2=0.7$-0.8).

When mean-RIP was recalculated for one set of conditions using the additional selection criteria given in Methods, the standard deviation was reduced by 34% . (Mean-RIP ± SD was 9.97 ± 5.85% and 9.84 ± 8.83% with and without the use of the criteria, respectively). This suggests that one important source of error in individual values of V_{RIP}, is the reliability of individual calibrations.

When minute volume was measured during cycling at 3 bar, there was no significant difference in the calculated values of V_{RIP} based on calibration at 3 bar (before and after cycling) relative to calibration at 1 bar (before and after hyperbaric exposure). The mean difference ± SD was -3.01 ± 3.68% (n=5, $p>0.1$). At 5 bar, the mean difference in V_{RIP} based on calibrations at 5 bar compared to 1 bar was more marked (-6.26 ± 1.32%, n=2), however more data is required to confirm this result.

TABLE: Comparison of minute volume by RIP and Pneumotachograph during exercise

Experimental conditions (1)	Slope ± SE (2)	p_1 (3)	Intercept ± SE (litres/min) (4)	p_2 (5)	Mean-RIP ± SD (%) (6)	n (7)	Range (l/min) (8)
1 bar cyc, 1 bar cal, L	0.99 ± 0.11	>0.9	3.34 ± 3.01	0.2-0.3	9.84 ± 8.83	10	21- 49
1 bar cyc, 1 bar cal, CC	1.06 ± 0.29	0.8-0.9	-3.18 ± 6.65	0.6-0.7	-3.07 ±18.61	12	22- 45
3 bar cyc, 1 bar cal, CC	0.98 ± 0.03	0.5-0.6	2.81 ± 2.86	0.3-0.4	4.37 ± 4.52	5	28-134
3 bar cyc, 3 bar cal, CC	0.95 ± 0.03	0.1-0.2	3.04 ± 2.51	0.2-0.3	1.26 ± 5.37	5	28-134

p_1 & p_2 are probabilities that the slope and intercept equal 1 and 0, respectively. n = no. of observations

CONCLUSIONS

The RIP technique described here is able to measure the mean minute volume during cycling to an accuracy ± 10%. However, individual measurements of minute volume by RIP (each based on a one minute sample) may be in error by more than ± 20%. The use of preset criteria for the selection or rejection of calibrations is one method of improving reliability. Calibration at pressure is not required for hyperbaric experiments in dry conditions up to 3 bar. Further work is needed to investigate higher pressures and wet environments.

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CLOSED-CIRCUIT COMPRESSED OXYGEN BREATHING APPARATUS FOR USE UNDER ELEVATED AMBIENT PRESSURE

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INTRODUCTION

A Problem which had remained unsolved for some time was that of respiratory protection in underground installations which have to be kept under overpressure to prevent the infiltration of water.

Anyone entering or working in such areas must enter and leave through an air-lock system, a method which is called "Caisson Method". At present, the overpressure necessary for such projects lies between 0,8 and 4 bar. In case of a fire safe protection is necessary.

For protection compressed-air or closed-circuit mixed gas breathing appparatus can be used. However compressed air breathing apparatus have the distinct disadvantage that duration of use drops with increasing ambient pressure. Therefore, the problem posed can be solved by using mixed gas closed-circuit breathing apparatus only.

SELECTION OF BREATHING APPARATUS

Oxygen is essential to life, but it is higly dangerous under some circumstances. It can damage the lung. As is known, a human being can breathe oxygen with the requisite safety only up to a pressure of around 1,8 bar (and above for a very short time) for a period limited to a few hours without detrimental effects. When selecting apparatus for "Caisson Areas" this fact must be taken under close consideration.

Filter apparatus are unsuitable, since in the case of a caisson it is a matter of an enclosed area, so that while respiratory protection is necesarry, the danger of oxygen deficiency cannot be excluded. Moreover, in the case of rescue work, the inhalation resistance would become uncomfortably high because of the higher air density.

As it was stated, the limit of the admissible oxygen partial pressure lies at 1,8 bar. Since, however, the oxygen content in the circulation of normal oxygen protection apparatus with a constant flow of 1,5 L/min plus lung-controlled addition supply rises up to 100 %, the admissible oxygen partial pressure of 1,8 bar is only reached with a elevated over pressure of 0,8 bar. For applications having a higher ambient pressure than 0,8 bar 100 % oxygen protection apparatus are unsuitable.

Physiologically speaking, there are no problems connected with the use of compressed-air breathing apparatus. The phenomena of "depth intoxication", known from diving experience as a result of the increasing nitrogen partial pressure, only arise at a pressure of around 4 bar.

However, for "Caisson Areas" compressed air breathing apparatus have the distinct disadvantage that the duration of use drops proportionaly with increasing ambient pressure. Hence at caisson construction sites, compressed air breathing apparatus may be used only as an escape apparatus, but not as a working or rescue apparatus.

I can, therefore, be seen that caisson-application cannot be solved with normal breating apparatus.

SOLUTION AND RESULTS

Because of the problems listed above, the development of a special breathing apparatus become acute. The BG 174 was the basis for the new apparatus. Theoretical calculations and men tests were object to modify the BG 174 as follows:

- mixed gas (60 Vol.% O_2, 40 Vol.% N_2) 800 L instead pure oxygen
  - constant flow 6,4 L/min only
  - duration 2 h
  - weight 17,2 kg
  - length 620 mm
  - max. ambient over pressure 2,2 bar

Practical trials were carried out with kind support of the Main Rescue Office in Essen. The test results obtained confirmed that the design was correct.

EFFECT ON THERMAL BALANCE OF BREATHING COLD GAS DURING DEEPER DIVING.

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INTRODUCTION

In deep saturation diving, the divers thermal balance are influenced by the temperature of the breathing gas and the hot water supply to the diving suits. Using heliox as breathing gas, a significant respiratory heat loss may be experienced. Reduction of divers body core temperature, with or without symptoms, have been reported (1-6). The aim of the present studies was to investigate whether a cooling of the body core could take place at high ambient pressure without mental awareness or compensatory heat production.

METHODS

Dry and wet experiments were performed. During all trials the skin temperature was kept within comfortable limits while the inspired gas temperature was regulated to the lowest comfortable level. At rest and in a dry chamber atmosphere, 6 divers inhaled the cool gas mixture for 2 hours at 37 bar (1,2) and 4 subjects for 3 hours at 46 bar (4). Diving in 4°C water with standard deep diving equipment were performed by 4 divers for 3.5 hours during work routines at 21 bar (7). Similarly, 3 divers performed 3 hours work and rest routines at 37 bar (8).

RESULTS AND CONCLUSION

No significant reduction in rectal temperature was recorded during the wet trials. Mean skin temperature was 36°-37°C and accepted lower inspired gas temperatures were 11°-13°C (21 bar) and 16°-18°C (37 bar) for extended periods (7,8). In the dry situation, all divers had significant reductions in core temperature when breathing a gas temperature of 16°-18°C (37 bar) and 19°-21°C (46 bar). This cooling did not cause any discomfort for 9 of 10 divers. A comfortable mean skin temperature were obtained at 32.5°-33°C. Thus, our results from the dry experiments at 37 bar and 46 bar indicate that it is possible to induce heat losses that result in symptomfree core cooling (1,2,4). It has not been possible to produce such situations when simulating diving with hot water suits due to the high level of acceptable and comfortable skin temperature and thereby a negligible heat loss over the skin. In the wet test situations that resultated in nearly stable rectal temperatures, the divers lost about the same amount of heat through the respiratory system as they produced by metabolic processes.

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A SYSTEM OF EQUATIONS FOR COMPUTATIONS ABOUT PULMONARY MECHANICS

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INTRODUCTION

A mathematical description of the mechanical system of a person's lungs can be analogous to the description of an electrical circuit with pulmonary resistance (electrical resistance), compliance (capacitance), and inertance (inductance). However, to be useful and realistic, computations about respiratory equipment or work of breathing in unusual environments should recognize the limits of attainable forces and volumes and should account for several mathematical complications; the limitations and complications can be of crucial importance in exercise or in persons with pulmonary disease. One complication is that resistance is far from a simple constant; the pressure to cause air flow depends on lung volume, gas density and the flow itself. Furthermore, there can be a mathematical discontinuity -- when a person exhales rapidly, airways may become "choked"; when it occurs, this "dynamic airway compression" causes a step increase in pressure for flow.

METHOD

With a system of equations which are solved by a numerical method on a Macintosh IIcx microcomputer, I estimate the total pressure generated by the respiratory musculature, as a function of time, from the flow-resistance, elastic-recoil, and inertance components; calculate the instantaneous pressure-flow product (power); and integrate the power to estimate work of breathing and oxygen requirement for a breath (1).

RESULTS

Figure 1 shows sample computations for a normal person who is exercising vigorously in a normal environment. The top panel shows volume during a breath. The second panel shows total pressure, composed of pressures to cause air flow and to overcome elastic recoil. Note that total pressure is not in phase with either volume or rate of change of volume (flow), and that during the expiratory phase, choking of otherwise open airways causes a sudden increase (downward) of flow pressure and total pressure. The next panel shows flow pressure divided by flow (= resistance); it varies by a factor of 5 during the breath. The lowest panel shows instantaneous power and work for the breath. The oxygen cost of the breath is expected to be proportional to the height of the work curve reached by the end of the breath; it includes a ramp-like rise during the choked-airway phase of expiration.

DISCUSSION

Literature about pulmonary mechanics tends to focus on one or another isolated aspect; this computer model allows one to develop an overview of how the parts fit together. Application of the system of equations to a person without breathing apparatus in a hyperbaric environment has predicted that the very high pressure necessary to cause air flow overshadows the small pressure needed for overcoming inertia of the dense gas (1), and that in hyperbaric environments, an exercising person's ventilation and breathing pattern are limited by the muscular forces which can be exerted; mechanical work accomplished is inversely related to ambient pressure. Non-linearity of compliance is important for large breaths, and inertance is negligible except when the subject breathes very dense gas.

Although Fig. 1 illustrates the consequences of choked airways, exercising people may sometimes sense the approach to a choked condition and avoid it by decreasing the airflow; this would save energy but would require adjustments in other parts of the breath if decrease of overall ventilation is to be avoided (2).

Those concerned with ergonomics of utilizing respiratory apparatus would be well advised to calculate the total work done by a person (work done on the person's body structures plus work occasioned by the apparatus) rather than just the work of breathing through the apparatus divorced from the person. The phase of maximum pressure to move gas through the apparatus will depend on elastic, resistive and inertial properties of the apparatus. The phase relations of the apparatus could interact favorably or unfavorably with the phase relations that are intrinsic to the human body.

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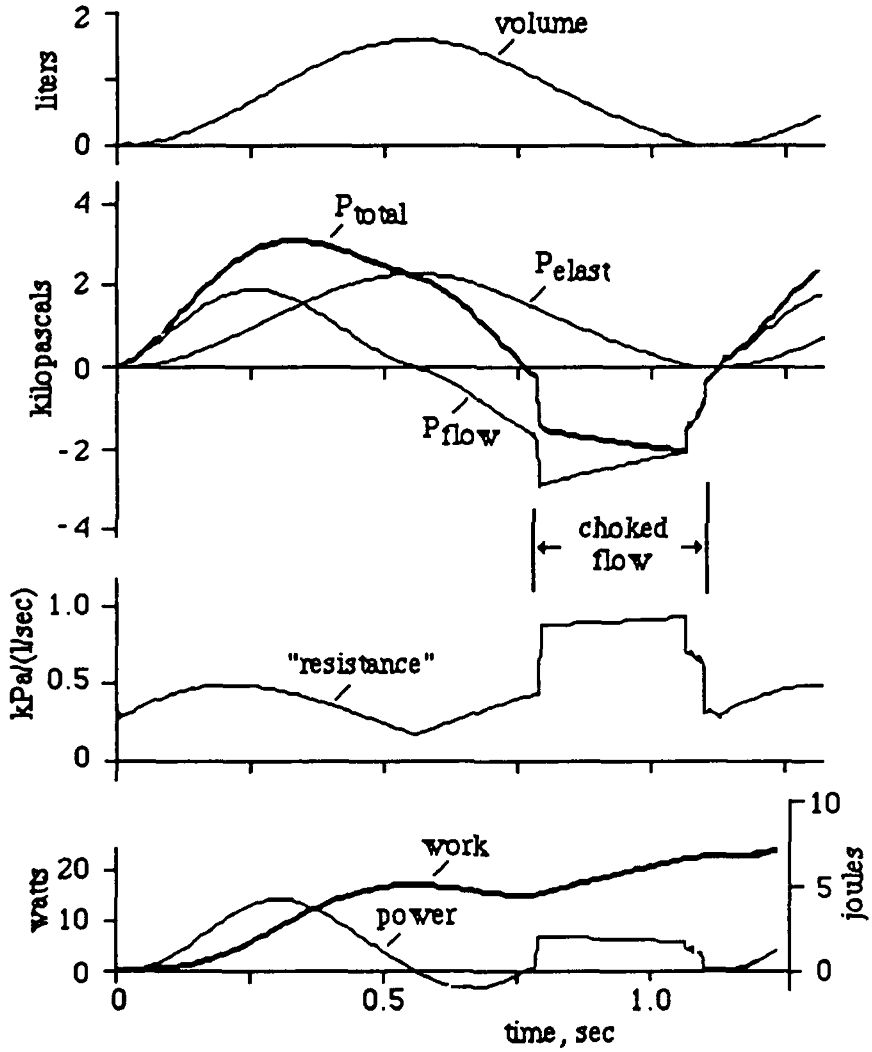

Figure 1. Breath variables vs time during strenuous exercise. For convenience, inflating pressures are shown as positive, as would be the case if the breaths were imposed on a person by a positive-pressure ventilator pump.

INTERNATIONAL STANDARDS AND HUMAN PERFORMANCE - I

Bjarne W. Olesen

INTRODUCTION

In the 1980's a series of standards for the assessment of the thermal environment and it's influence on people have been proposed by ISO (International Organization for Standardization). These include standards for cold, hot and moderate environments together with supporting standards for estimation of the thermal insulation and evaporative resistance of clothing ensembles, estimation of the metabolic rate, performing subjective assessment and measurements of the thermal environment. While standardization related to the thermal environment is well developed only few standards related to indoor air quality and ventilation has been published. The present presentation deals with standards related to cold and moderate thermal environments, subjective assessments, measurement of the thermal parameters, indoor air quality and ventilation.

STANDARDS FOR THERMAL ENVIRONMENTS

Moderate Thermal Environments

ISO 7730 (1), provides a method of assessing the thermal environment using the PMV PPD thermal comfort index. The PMV index is calculated from the air temperature, mean radiant temperature, air velocity and humidity of the environment and estimates of metabolic rate and clothing insulation. The PMV-value is a number on a 7-point thermal sensation scale (+3 hot, +2 warm, +1 slightly warm, 0 neutral, -1 slightly cold, -2 cool and -3 cold). The PPD index is calculated from the PMV index and provides the predicted percentage of thermally dissatisfied persons. The standard provides also guidelines on how to asses the risk for local thermal discomfort, i.e. radiant temperature asymmetri, draught (air temperature, air velocity) vertical air temperature differences and cold or warm floors. Similar recommendation is found in ASHRAE Standard 55-81 (3).

Cold Environments

While there has been published many suggestions for a heat stress index only few methods have been proposed for evaluation of cold environment. A new method, IREQ (Required Clothing Insulation) is being proposed by ISO in a technical report (3). The index is based on a calculation of the thermal insolation required for being in heat balance under the given environment (air temperature, mean radiant temperature, air velocity, humidity) and actively level. The calculated IREQ value can be used to select a clothing ensemble for work in a cold environment. It can also be used as a cold stress index. The higher the value of IREQ, at any given activity level, the greater is the cooling power of the environment. If the persons at a given work place is wearing less clothing than required, then the method provides a procedure for calculating the recommended max. exposure-time.

Subjective Assessment

ISO/DP 10551 (4) presents subjective scales for assessment of the influence of the thermal environment. The standard provides scales for thermal sensation (cold-hot), thermal preference (colder-warmer) and acceptability.

Instruments and Measurement

ISO 7726 (5) provides a description of the parameters which should be measured (air temperature, mean radiant temperature, plane radiant temperature, air velocity, humidity). Together with methods of measurements and specifications for the instruments (accuracy, respond time, measuring range).

Clothing

ISO/DIS 9920 (6) provides a large database of thermal insulation values, which have been measured on a standing thermal manikin. One set of tables give the insulation values for a large number of ensembles. Another set of tables give insulation values for individual garments, based on which the insulation for a whole ensemble can be estimated. The data on evaporative resistance is not so extensive. A few data are given in the standard and a method to calculate the evaporative resistance based on the thermal insulation is also given.

STANDARDS FOR INDOOR AIR QUALITY AND VENTILATION

For industrial air pollution the TLV's (Threshold Limit Values) have existed for many years, while there has only been limited standards or guidelines for non-industrial environments. Due to increasing problems in non-industrial spaces (homes, schools, offices, etc.) more emphasis is now being paid on the required ventilation rate and air quality at these places. The most important standard is ASHRAE 62-1989 (7). One procedure in the standard is the ventilation rate procedure, where the ventilation rate in l/s per person is given for a large number of spaces. Another method is the indoor air quality procedure, where the concentration of containments are restricted and the required ventilation rate is calculated by a delution model. Recently the CEC (Commission of European Communities) has started a project to develop a guideline for ventilation requirements, COST 613 (8). In this proposed guide the ventilation rate is based on the perceived indoor air quality and the use of the new units for perceived air quality, "decipol" and for source strength of pollution sources, "olf". This guide also introduces the efficiency of the ventilation.

CONCLUSION

The package of standards for evaluation of the thermal environment presented here and in the following presentation provides a valuable tool wherever problems have to be solved.

Regarding standards for indoor air quality there is a need for more information on dose-response relationships for many pollution scurces.

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DO WGBT HEAT STRESS LIMITS APPLY TO BOTH PHYSIOLOGICAL AND PSYCHOLOGICAL RESPONSES?

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INTRODUCTION

Both the International Organization for Standardization (ISO) and the American Congress of Governmental Industrial Hygienists (ACGIH) have adopted limiting values for heat stress which are intended to protect nearly all workers from adverse health effects. These limits are based on those combinations of environmental and work characteristics (environmental heat and metabolic heat) which produce a total heat load below the point of onset for increased risk of heat strain (i.e., maintenance of a deep body temperature less than 38°C). NIOSH has recommended an additional alert limit for persons who are unacclimatized (NIOSH, 1986). These limits have served industry well for several years as guidelines for physiological responses to the heat. Figure 1 depicts the Recommended Alert Limits (RAL) and the Recommended Exposure Limits (REL) proposed by NIOSH for occupational exposure to hot environments. Points A, B, and C represent these limits at levels of metabolic heat normally associated with sedentary or standing activity found in performing most perceptual motor tasks.

RESULTS

The effects of heat on psychologically-based responses and on perceptual motor task performance have been less well defined and even contradictory. Over 150 research studies concerning perceptual motor task performance in the heat and reported in the literature were collected and evaluated (Ramsey and Kwon, 1988). Equivalent WBGT temperatures were determined and compared with reported performance results. Previous research has indicated differing effects of heat on performance based on the category or type of task (Ramsey and Morrissey, 1978). These data were separated into only two task categories: a) mental and very simple tasks, b) all other perceptual motor tasks. This categorization removed much of the contradictory nature of published results. The mental/simple tasks (Category a) tended to show no performance decrement and indeed enhanced performance was often associated with short duration high temperature exposures. Figure 2 displays data for the other (Category b) tasks. Also shown are the equivalent A, B and C levels which represent the onset points for increasing risk of physiological heat stress.

CONCLUSIONS

There are many variables other than heat which affect performance on such tasks. However, these data do show a dominant heat effect on performance, in that decrements onset for most such tasks at the temperature levels suggested by the ISO, ACGIH and NIOSH limits. Results also indicate that task performance is much less sensitive to the length of time a worker is exposed to the heat than it is to the environmental temperature level of the exposure. Further, performance decrements appear to be more highly correlated with the rapidly responding body temperatures (e.g., cranial, blood) than with the deep body temperatures (rectal) which have appreciable lag time in response.

The levels of environmental heat (30°- 33°C) which create onset of physiological heat stress for the worker performing sedentary or very light work tasks appear to be the same levels where perceptual motor performance will deteriorate for all but the strictly mental or very simple tasks.

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Figure 1. Recommended Heat-Stress Alert Limits (RAL) and Exposure Limits (REL), (NIOSH, 1986)

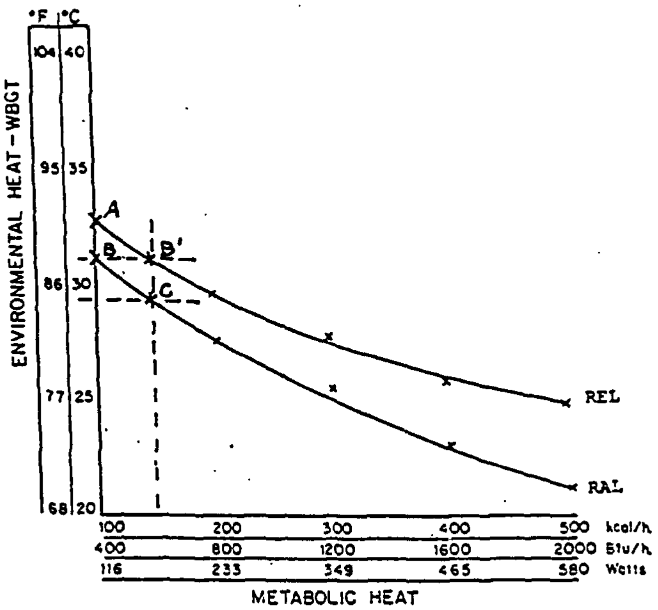
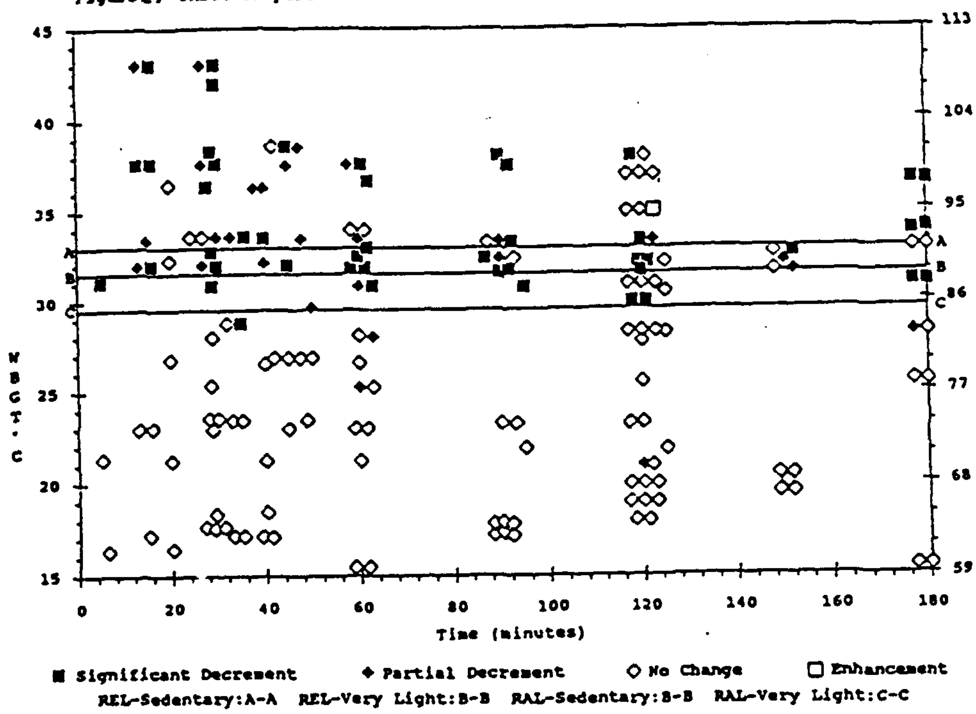


Figure 2. Onset of performance decrement for perceptual motor tasks in the heat.



HEAT STRESS: A COMPARISON OF SOME ESTIMATION METHODS

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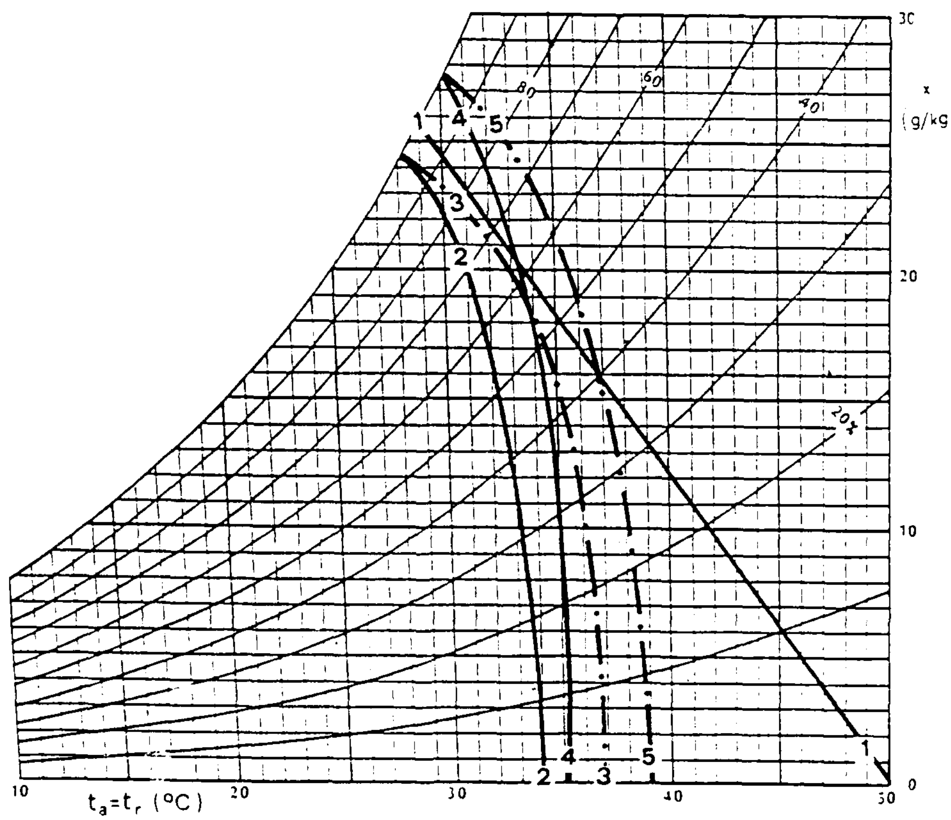
INTRODUCTION

METHOD

RESULTS and CONCLUSIONS



for a work period of eight hours. The diagram is relative to particular values of metabolic energy [illegible] air velocity, [illegible] clothing thermal resistance, I_{cl}, and clothing vapor permeation efficiency [illegible] in uniform environment (air temperature equal to mean radiant temperature) and to non-acclimatized subjects.

The diagram shows two interesting results:

- it is necessary to introduce the clothing vapor permeability in the estimation of thermal stress and, therefore, to increase available data, particularly for special protective clothings [8].
- the method based on WBGT index is not a safety method, as generally used and as [illegible] the ISO standard 7243 (9) (introduction, 5th paragraph).

A third result, not shown for the paper brevity, is that results obtained by methods based on HSI and ITS indices are quite similar to those obtained by the ISO standard 7933. This [illegible] thermal environment evaluation is easier by these methods than by ISO standard 7933.

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SKIN-CORE TEMPERATURE CONVERGENCE OFTEN WELL TOLERATED

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INTRODUCTION

When subjects must work while wearing impermeable clothing under hot conditions, mean skin temperature (Tsk) often approaches rectal temperature (Tre). Pandolf and Goldman reported in 1978 that in their subjects such convergence produced a state of near collapse even though neither Tre nor heart rate had reached limiting values; signs and symptoms included headache, dizziness, nausea, vomiting, malaise, inability to keep pace, hyperventilation, blurred vision and mental sluggishness (1). They concluded that convergence is an accurate guide to tolerance limits under conditions which minimize evaporative cooling. More recently, Goldman called convergence "the best physiological guide to heat limits" for workers in encapsulating garments and also states that a Tsk > 37° C should be cause for cessation of work in the heat (2).

The convergence paper is quoted in the literature in connection with widely differing experimental conditions. For instance, Smolander et al. discuss their results in terms of convergence when in fact there was a Tsk-Tre gradient of >1.0° C (3). Holmér mentions it in connection with diving experiments (4). The human use committee at NIOSH has evidently adopted convergence as a safety cut-off for experiments (5).

While the convergence-collapse concept is attractive in its simplicity, we cannot find any published validation of the phenomenon beyond the original paper, nor does it fit with experience in our laboratory. We report here on two recent protocols which often produced convergence, despite which subjects usually continued work until we stopped them at Tre=39° C.

METHODS

Data from two protocols were used. **Series A:** Nine subjects each participated in eight experiments wearing heavy, semi-permeable (chemical defense) clothing at Tdb = 22-38° C with work loads of 200, 350 or 500 W. **Series B:** Nine subjects each performed four experiments wearing impermeable clothing at Tdb = 29 and 38° C with a work load of 450 W.

Each subject was tested to establish individual treadmill VO2max and HRmax. Measurements during experiments included Tsk, Tre, HR, perceived exertion, and weight loss. Convergence was defined as Tsk rising to within 0.1° C of Tre. Convergence work time (CWT) was measured from the time convergence occurred until work was discontinued for any reason.

RESULTS

Convergence occurred in eight of the experimental conditions (Tdb = 29-38° C), involving 42 of the 60 runs under those conditions; Tsk rose to 37° C within the first 5-10 min of these experiments. In 29 convergence cases (64%) the subjects continued to work until Tre = 39° C and/or HR=HRmax with CWT=10-45 min; many could have continued longer. The remaining 13 experiments were terminated by the subjects at CWT=0-20 min due to extreme leg fatigue or inability to tolerate the inspiratory resistance of the full-face mask. No one collapsed or became ill.

Two examples of conditions which produced convergence are as follows. **Series A:** In Condition 7 (Tdb=35°, Twb=31°, Tbg=40° C, work=200 W), 7 of the 9 subjects experienced convergence at t=10-45 min and Tre=37.1-38.2° C, and all worked until Tre=39° C for CWT=15-45 min (mean 34 min). **Series B:** When subjects wore sealed, impermeable suits (with two levels of insulation) in a chamber at Tdb=38° C; 17 of 18 runs produced convergence at t=4-31 min and Tre=37.0-38.1° C, and 5 worked until Tre=39° C for CWT=15-35 min (mean=23 min).

DISCUSSION

Thermal balance can be maintained when Tsk≥Tre only by means of evaporative cooling. When clothing and/or high environmental humidity suppress evaporation, cutaneous circulation reaches very high levels. In theory this poses the threat that the subject might reach a cardiovascular limit in ability to meet the combined perfusion demands of the skin and the working muscles, but we observed no evidence of such a limitation. It appears that physiological tolerance was determined instead by body heat storage accompanied by increases in Tre and HR which eventually reach their physiological limiting values.

Our results fail to confirm that convergence of Tsk on Tre has any special significance. Neither did Tsk > 37° C cause any particular problem. Although subjects under these conditions were uncomfortable, they continued working until they reached classical physiological limits. Neither convergence nor high Tsk produced a change in the rate of rise in Tre or HR. In no case did a subject display the signs or symptoms of "imminent collapse" listed in the 1978 paper (1). It is unclear why Pandlolf and Goldman's subjects regularly reached symptomatic end-points at convergence when ours did not. Although their experiments involved higher ambient temperatures (Tdb=46-49° C), the work loads were lower (about 225 W), and the rates of rise in Tre and Tsk were similar in the two studies.

A recent paper unintentionally provides further evidence that convergence per se is not limiting (4). Divers wearing impermeable suits worked in water at Tw=38° C; their Tsk exceeded Tre for the entire 60-min experiment, which ended only when Tre reached 39° C or more. The work was repeated at Tw=42° C with similar results except that Tre reached 39° C sooner (34-42 min). If convergence had been viewed as a limit, these experiments could not have taken place.

The convergence concept is based on Tre, which is relatively slow in responding to external temperature changes and varies specifically with leg work. Under various conditions Tre may under- or over-estimate central venous temperature so that convergence of Tsk on Tre does not necessarily mean the absence of a core-skin temperature gradient.

CONCLUSIONS

Our analysis provides no support for the generalization that skin-core temperature convergence can accurately predict tolerance time for work in heat or has any unique effect on stress levels of subjects. The ability to work despite high skin temperatures appears to be a function of the rate of heat storage and the level of Tre, as well as subject fitness and motivation. Arbitrary termination of experiments based on either Tsk alone or convergence of Tsk on Tre may deprive investigators of valuable data and lead to erroneous generalizations regarding human tolerance for work in heat while wearing protective clothing.

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Physiological Strains in Hot-humid Conditions While Wearing Disposable Protective Clothing Commonly Used by the Asbestos Abatement Industry

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INTRODUCTION

Because of the asbestos exposure risk, the workers of asbestos abatement industry were advised to wear protective clothing. The utility of protective clothing is primarily determined by its efficiency and provided the extra physiological strain; especially the thermal stress on the wearer due to the clothing. The purpose of this study was to investigate workers' responses to work in the hot conditions while wearing the protective clothing commonly used by the asbestos abatement industry, and to evaluate the effects of resting in the cool environment between their work in the heat on physiological strains.

METHOD

Subjects were seven healthy male students, aged from 18 to 20 years. The protective clothing commonly used by the asbestos abatement industry - light, disposable coveralls with hoods and shoes covers (Tyvek 1422, Polyolefin) - were worn over shorts. Protective air masks were also worn.

Thermal conditions adopted in this study were as follows: (a) 35C°/ 85%RH (hot conditions), (b) 20°C/ 85%RH (cool conditions), and (c) worked in hot conditions and took a rest in cool conditions (hot/cool conditions). These hot conditions were adopted as simulated working environments for asbestos abatement industry in the summer season (1). Work was performed on a bicycle ergometer at a constant work level of 70 Watts. This work rate was also chosen to be the work load of the actual asbestos abatement work (1).

All testing sessions took place within the climate chambers. Each test continued for up to 100 min, with repeated work/rest intervals. The subjects rested for 11 minutes, and then took a ergometer work for 18 minutes. After that, they sat on a chair for 12 minutes. This work/rest schedule was repeated 3 times under the 3 environments. Under hot/cool conditions, the subjects took a rest in the next climate chamber which was set up at 20°C air temperature. The order of exposure to three thermal conditions was randomized for each of the subjects. Experiments were carried out during May.

Rectal temperature (Tre), skin temperatures at 5 sites were recorded by means of thermistors. Heart rate (HR) was obtained continuously from the electrocardiogram using chest leads. Total sweat production (SR) was estimated as the change in nude body weight, measured before and after the experiments. Discomfort sensation (5 points scale), thermal sensation (11 points scale), and rated perceived exertion (Borg's scale) were voted at before, during and after the exercises.

RESULTS

Under the hot conditions, two tests were terminated because of higher heart rate and higher rectal temperature over the critical values. Means of SR in hot and hot/cool conditions were 1252 and 1100 g, respectively, which were more than 4 times greater than in cool conditions (248 g).

Mean Tre responses were presented in Figure 1. The mean Tre under cool conditions did not change significantly through the experiments. Tre elevated gradually after the first work under both hot and hot/cool conditions. At the end of experiments, Tre increased, on average, by 1.2°C (range:0.95 - 1.63°C) under hot conditions. Although Tre increased in hot/cool conditions by 0.7°C (0.41 - 0.93°C), it was almost half of that in hot conditions.

Mean HR responses were presented in Figure 2. HR during work in hot conditions did not approach steady state levels in contrast to those in cool conditions. During 12-min rest periods, HR in hot conditions did not recover to near resting levels and remained high than those in cool conditions. Therefore, the increases in HR during work and in recovery with time were observed in hot conditions. Although HR during work in hot/cool conditions were higher than those in cool conditions, HR at pre-work was almost the same as that in cool conditions because of rapid recovery during rest periods.

Although, the degrees of discomfort sensations, thermal sensation, and perceived extortion became higher with time in both hot and hot/cool conditions, these were improved by resting in cool conditions. Especially the improvement of them were observed later in the experiment.

CONCLUSION

The great thermal stress was linked to work in protective clothing in hot environments. However, the physiological and psychological functions such as Tre, HR, SW, discomfort sensation and perceived exertion, etc., were dramatically improved by resting in the cool conditions between work in the heat. We propose the cooling space in the workplace of asbestos abatement industry to decrease thermal stress.

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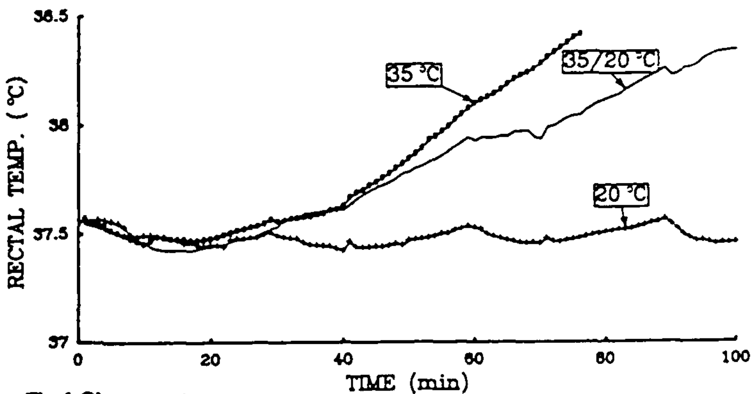

Fig.1 Changes in rectal temperature.

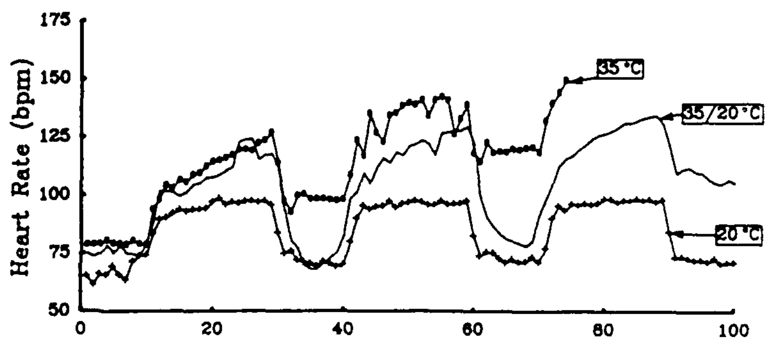

Fig.2 Changes in heart rate.

THERMAL PROPERTIES OF THE NORDIC CROSS-COUNTRY SKI ENSEMBLE IN WINDY AND CALM COLD

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INTRODUCTION

Skiing is affected by wind produced by the movement of the body through the air in addition to any external wind. In Nordic countries experienced skiers as well as touring skiers and even small children wear light, close-fitting clothing even in very cold weather, despite the fact that its thermal properties may be insufficient. It may reduce physical performance during dynamic exercise, and there may also be a risk of hypothermia (1).

The aim of this study was to compare body cooling of a subject dressed in a typical cross-country ski clothing ensemble during submaximal exercise in windy and calm cold.

METHOD

Five, physically trained men volunteered for the study (Table 1). The experiments were conducted in a climatic chamber under controlled cold (Ta -15°C) conditions with and without fan-generated turbulent wind (va 6 m/s and 0.3 m/s). The wind chill index was estimated as -30°C and -15°C. The subjects performed a 60-min submaximal work bout on a treadmill (10 km/h, incline 5°), in random order once in both of the test configuration. The cardiovascular workload was about 70-80 % of the maximum estimated by the heart rate. The subjects wore cotton pants, long underwear (polypropylen fishnet) and a hooded ski overall (lycra), gloves, head band (WO), socks, and training [illegible]s. Thermal insulation Icl was 0.6 clo. HR, rectal temperature (Tr) and skin temperatures [illegible] were monitored continuously. Tr was measured at a depth of 10 cm and skin thermistors were placed on the skin at nine sites. Sweat production was determined from the changes in body weight corrected for fluid intake and accounting for the amount of sweat absorbed into the clothing. The absorption of sweat by the clothing was assessed by weighing the garments before and after each exercise period. Subjective evaluations of perceived exertion (RPE), thermal sensations in general, and local discomfort votes were requested every 15 minutes.

Table I. Characteristics of the subjects

Age (yrs)	Height (cm)	Weight (kg)	Body Fat (%)	ADu (m^2)	$\dot{V}O2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)
19-28	175-180	63-76	9.7-10.9	177-191	47-72

RESULTS

No differences occurred in mean Tr between windy and calm conditions. Tr was 38.9°C at the end of exercise in both conditions. Final mean body temperature ($\bar{T}b$) were 2°C and mean skin temperature ($\bar{T}sk$) 5.5°C lower when the subjects exercised in wind (Figure 1). The skin temperatures for each of the body segments were lower in windy condition. The lowest individual local Tsk values were registered at the front of the body (chest 17.8, abdomen 11.1, thigh 13.5°C). In windless condition the local Tsk values did not fall under 20°C in any exposure. Windy condition resulted in a mean heat debt of 14.5 W/m^2, while in calm cold the heat accumulation was 16.2 W/m^2 (Figure 2).

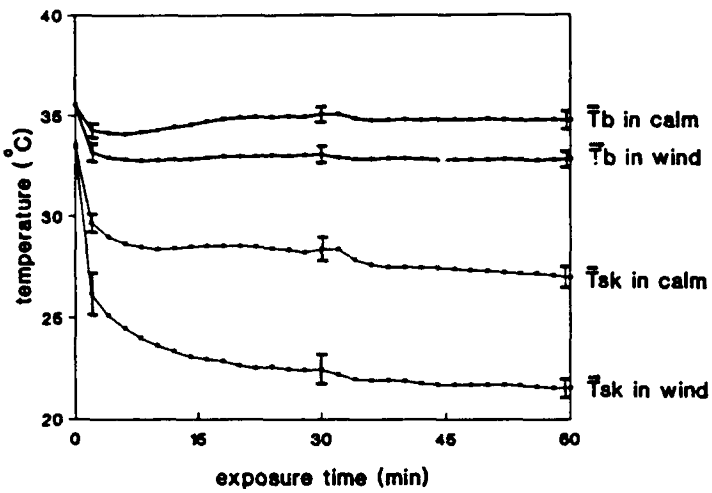

Fig. 1. Mean body and mean skin temperatures in windy and calm conditions (mean, ±SEM)

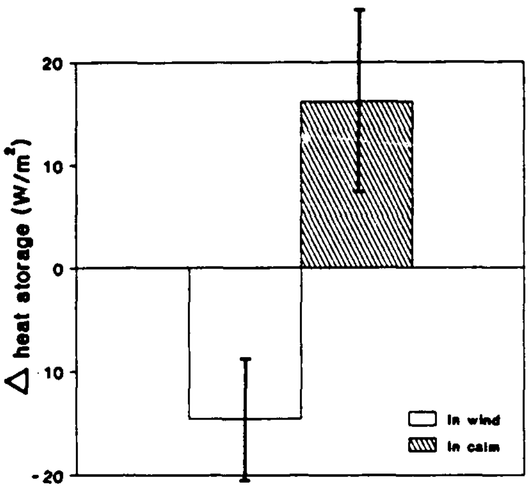

Fig. 2. The rate of change in heat storage (mean, ±SEM)

The average sweat production for windy condition was 685g and for windless condion 1044g. About 80 % of the produced sweat evaporated effectively in wind, and 60 % in calm, on average. The amount of sweat absorbed into the clothes was 125g (SEM±8.8) in wind, on average. The garments were moist and a moisture triangle appeard on the upper back. In calm cold 384g (SEM±54.5) of sweat was absorbed into the clothing, on average, and the wetness of the clothing was visible. Slight individual differences were found in the amounts of absorbed sweat in windy cold (range 91-144g). In calm condition the differences were notable (range 186-567g).

Both conditions were perceived equally strenuous, light at the beginning and hard at the end of exposure, on average. There was a tendency to grade windy cold as somewhat more uncomfortable. The final mean thermal comfort sensation was uncomfortable in wind and slightly comfortable in calm. The mean thermal sensation in general varied between slightly cool and cool in wind, while it was rated as slightly cool to warm in calm. Local thermal discomfort correlated with low skin temperatures. No one reported intolerable discomfort.

CONCLUSIONS

When the subjects exercised in a -15°C temperature without wind, the body heat created by the high metabolic demands of the exercise could compensate for the cooling effects of the environment. The thermal properties of the given ski clothing seems to be sufficient in calm and moderate cold, while they do not protect enough against body cooling and local cold injuries at -15°C with 6m/s wind. The negative value for heat storage suggests that the body was not in thermal equilibrium in spite of high Tr. This agrees with the drop in Tb and the low mean and local Tsk values. The temperature of working muscles may drop in long-lasting exercise to 35-36°C (2), which may reduce physical performance during prolonged exercise. The demands for a functional ski suit are the opposite; water vapour permeability and wind resistance of a light, aerodynamic bodysuit.

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INTERNATIONAL STANDARDS AND HUMAN PERFORMANCE II

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INTRODUCTION

ISO Standards concerned with the Ergonomics of the Thermal Environment collectively cover hot, moderate and cold environments and can be used in a complimentary way as the basis for a practical environmental ergonomics assessment. Although the standards and documents are most usefully used as a set, they have been published as individual documents. Olesen (1990) (in the present proceedings) has considered a number of ISO and other standards including those concerned with moderate and cold environments, clothing and measurement of the thermal environment. The present paper will consider assessment of hot environments, physiological measurements, estimates of metabolic heat production and contact with solid surfaces. This will 'complete the set' of standards as described above and will allow a discussion of a 'unified' practical approach, and the opportunity for standards in the future. For a more comprehensive description of ISO standards and the relationship between them the reader is referred to Parsons (1989).

HOT ENVIRONMENTS

The ISO philosophy for the assessment of hot environments is to use a simple 'fast' method for monitoring the environment, based on the Wet Bulb Globe Temperature (WBGT) index (ISO 7243 (1989)). If the WBGT values exceed the provided 'reference' values or a more detailed analysis is required then ISO 7933 (1989) provides an analytical method of assessment. This is based on a rational assessment of the environment involving the human heat balance equation, a calculation of sweat rate required in an environment to maintain heat balance and a comparison of what is required with what can be physiologically achieved. If what is required cannot be achieved over an eight hour day then allowable exposure times are calculated. Where an accurate response of individual subjects is required, for example, where subjects are exposed to extremely hot environments then ISO DIS 9886 (1989) describes methods for measuring and interpreting relevant physiological responses.

PHYSIOLOGICAL MEASUREMENTS

ISO DIS 9886 (1989) presents the principles, methods and interpretation of measurement of relevant human physiological responses to hot, moderate and cold environments. The standard can be used independently or to compliment the use of other standards. Four physiological measures are considered; body core temperature, skin temperature, heart rates and body mass loss. Comments are also provided on the technical requirements, relevance, convenience, annoyance to the subject and cost, of each of the physiological measurements.

METABOLIC HEAT PRODUCTION

All assessments of thermal environments require an estimate of metabolic heat produced by activity. ISO 8996 (1989) presents three types of methods for estimating metabolic heat production. The first is by use of tables, where estimates are provided based on a description of activity. These range from a general description (e.g. light, heavy etc.) to methods of summating components of tasks (e.g. basal metabolic rate + posture component + movement component etc.).

The second method is by the use of heart rate. The total heart rate is regarded as a sum of several components and in general is linearly related to the metabolic heat production for heart rates above 120 beats per minute. The third method is to calculate the metabolic heart production from measures of oxygen consumption, and carbon dioxide production during activity and recovery.

CONTACT WITH SOLID SURFACES

The ISO has recently become involved in the thermal sensation and degree of damage caused by contact between naked and covered skin and hot, moderate or cold solid surfaces. The work is in an exploratory stage with some information available for hot and moderate surface temperatures but little for cold. The European standards committee for Ergonomics, CEN TC 122 has produced a draft standard for contact with hot surfaces and ISO and CEN have set up a joint working party to 'harmonize' work.

ISO STANDARDS - AN INTEGRATED APPROACH

Each ISO standard and document has been produced (and revised) in a self contained form and each standard can be used independently of the others. For practical assessments the 'whole' is greater than the sum of the parts. An underlying philosophy exists however further consideration is required. Integrating all standards into one document (reducing repetition) and providing a software support system (ergonomically designed) would greatly aid the practitioner.

FUTURE STANDARDS

Interest in the production of International Standards has stimulated applied research and has contributed to knowledge of human responses to the thermal environment. Approaches to assessment however are similar to those used over twenty years ago. Developments in knowledge of human response and its application and in the utility of the digital computer should not be overlooked in the future where computer aided environmental design and assessment 'tools' will play a significant role.

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EVALUATION OF THE THERMAL ENVIRONMENT IN TRACTOR CABS

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INTRODUCTION

An optimal thermal climate in a vehicle is an important determinant factor for the driver's health, performance and comfort. A poor climate and its effects upon the driver may endanger traffic safety [4]. In the confined space of a tractor cab the thermal environment becomes very complex. Driver sits close to walls and windows. Glass windows are large and poorly insulated. Radiative heat exchange caused by cold or solar load may locally be excessive. HVAC–systems are normally powerful to compensate for poor insulation and considerable temperature gradients may build up. In addition, air velocities may be locally very high. The thermal impact on the driver is not easy to evaluate. Spot measurements are difficult to interprete and most climate indices only account for the average or whole body effect of the thermal load. This is not sufficient, since man may feel thermoneutral but still suffer severely from local thermal disturbances and asymmetries. Measurements with a thermal manikin yield a more complete, integrated and detailed picture of thermal effects [3, 6].

The purpose of the present investigation was to compare measurements with a thermal manikin with comfort votes obtained for a panel of subjects.

METHOD

A man-sized, sitting thermal manikin (AIMAN) was positioned in the driver's seat in a tractor cab, placed in a climatic chamber. Heat flow in W/m^2 from 15 different segments of the manikin surface was measured and controlled by a computerized system. Heat flow data were recalculated and expressed as EHT (equivalent homogeneous temperature), which serves as a standardized expression of the thermal load. EHT is the temperature of a room with air temperature=mean radiant temperature and air velocity <0.05 m/s, in which dry heat loss is the same as in the given environment. HVAC-system of the cab was controlled to provide three levels of internal cabin temperature (corresponding to 40, 48 and 56 W/m^2 of whole body dry heat loss from the manikin) and different types of vertical temperature gradients (warmer at head level, colder at head level and no difference between head and foot level).

Ten male subjects were exposed on consecutive days at random to the different types of climate for sessions of 1 hours duration. Thermal votes according to the Bedford 7–point scale were obtained after 30 and 60 min for the whole body and for the same 19 body segments as the manikin. The mean thermal vote (MTV) was calculated for the ten subjects.

Experiments with subjects and manikin were carried out during winter (-20 °C) and summer conditions (30 °C with solar load and 35 °C without solar load). A total of 20 climatic conditions were investigated.

RESULTS AND DISCUSSION

Linear regression equations were calculated for all segments for MTV as function of EHT. Data for summer and winter conditions were analyzed separately. Correlation coefficients for whole body MTV were 0.92 and 0.91, respectively. Corresponding coefficients for individual segments were high and varied between 0.63–0.98. Usually, the lowest correlations were obtained for segments, that were only marginally affected by thermal factors. This was particularly true for parts of the body in contact with the seat (lumbar back and buttocks). For these segments very small or no differences in EHT and MTV were recorded.

In figure 1 are depicted mean thermal votes of subjects for the different climatic conditions in relation to equivalent homogeneous temperature (EHT) calculated on the basis of measurements of heat loss with the thermal manikin. Data are given for the whole body during both summer and winter conditions and for the right and left arm during winter conditions, respectively. Regression lines are drawn for the data plots.

Sensitivity to local thermal influences was higher for legs and feet, than for arms and hands. Uncovered parts like face and hands were subjected to great variations in local heat exchange, but were not particularly sensitive. Sensitivity to whole body thermal effects was the same for winter and summer conditions. However, at the same EHT–value subjects voted warmer in the winter due to warmer clothing (higher insulation value).

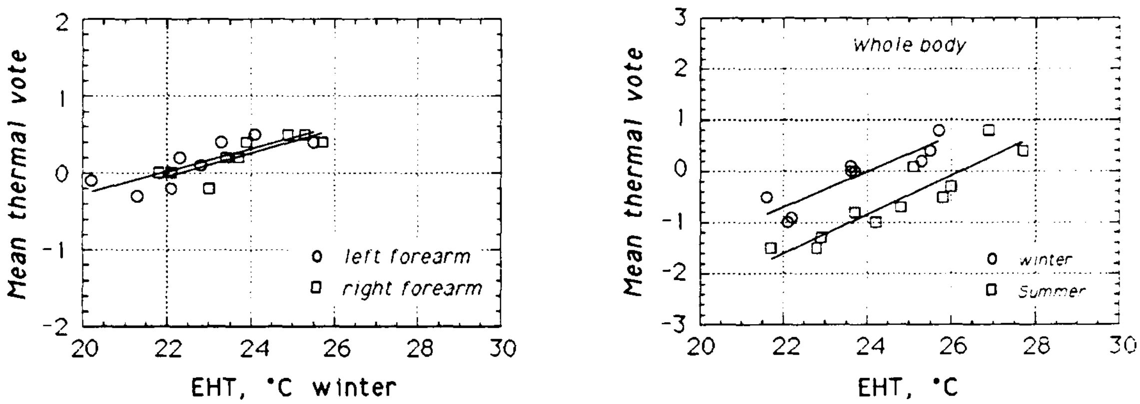

Figure 1. Regression lines for mean thermal votes of subjects and the equivalent homogeneous temperature (EHT) calculated on the basis of manikin measurements for whole body and forearms, respectively.

On the basis of the regression lines obtained and exemplified in Figure 1, it is possible to specify a lowest and a highest EHT–value for each body segment, corresponding to a defined level of acceptance (MTV). A MTV–value between ±0.5 on the 7–point scale has been proposed as criteria for acceptable ("comfortable") indoor climate conditions [1, 2]. Wyon et al. [5] proposed for the more complex vehicle climate a value of ±0,8 to be more realistic and practical. This value would then correspond to approximately 80% of a group of people being satisfied with the thermal conditions. The set of temperature intervals (EHT–intervals) so obtained may serve as a guide-line for the evaluation of vehicle climate and for the development and improvement of HVAC–systems.

CONCLUSIONS

Measurements of local climate disturbances with a man–sized thermal manikin are well correlated with the thermal sensation experienced by subjects exposed to the same conditions.

Criteria for acceptable climatic conditions can be defined in terms of quantities measured with the manikin.

The manikin method represent a quick, accurate and reproducible technique for reliable and cost–effective assessment of many of the complex details of the climate in a vehicle and their integrated effects on humans.

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HUMAN TOLERANCE TO WORK IN HEAT WITH SEMI-PERMEABLE CLOTHING: VALIDATION OF PREDICTIONS

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INTRODUCTION

Protective clothing is commonly used to prevent worker contamination with toxic industrial chemicals, pesticides, asbestos or radioactive substances. The military services use analogous clothing to protect personnel from agents which might be used in chemical warfare. Unfortunately, such clothing slows heat dissipation from the body by inhibiting both convective air exchange and the evaporation of sweat. The need to protect workers from undue heat stress has led to the wide use of Wet Bulb Globe Temperature (WBGT) as an index of environmental heat load. However, WBGT was developed for conventional clothing (shirt and trousers), and must be modified when protective ensembles are worn. The Texas Model developed by Dr. Wissler (1,2) was used in an earlier parametric analysis of work, air temperature and humidity for persons wearing USAF chemical defense (CD) clothing. Results indicated that WBGT tended to over-emphasize the effects of external humidity and sunlight, and that a better index of environmental heat load was the "Discomfort Index" where DI = 0.5 Tdb + 0.5 Twb. The main objectives of this study were: A) To compare the output of the Texas Model with the data obtained from human experiments with CD clothing, and B) To examine the validity of the DI as a predictor of environmental heat stress.

METHODS

DI values of 20, 30 and 33°C were selected and combined with various work loads to produce eight experimental conditions representing a range of heat stress levels (see table). The DI's of 20 and 30 were each produced by two combinations of Tdb and Twb to test the validity of the 50/50 weighting of these variables. In addition, these DI's were also used with different work loads to examine the interaction between external and internal heat load for persons wearing protective clothing.

Condition	Discomfort Index	Work Load (Watts)	Tdb (°C)	Twb (°C)	Tbg (°C)	Vapor Pressure (Torr)	Predicted Tolerance Times (min)	Experimental Tolerance Times (min)
C.1	20	541	22	18	27	14.0	∞	97.4 ± 8.6
C.2	20	541	28	12	33	3.0	∞	103.3 ± 16.0
C.3	30	393	32	28	37	26.5	90	65.7 ± 5.5
C.4	30	541	32	28	37	26.5	49	52.2 ± 6.3
C.5	30	541	40	20	45	7.5	54	58.9 ± 5.0
C.6	30	738	32	28	37	26.5	33	34.5 ± 5.6
C.7	33	393	35	31	40	32.0	59	57.7 ± 3.8
C.8	33	738	35	31	40	32.0	29	32.1 ± 3.9

Nine healthy male subjects agreed to participate in this study and signed a statement of informed consent. The physical characteristics were (mean ± SD): age 35.1 ± 9.9 years; weight 73.9 ± 11.6 kg and height 174.3 ± 8.7 cm. Subject's peak aerobic capacity (VO2 Max) and corresponding heart rate (HRmax) were determined using a progressive treadmill test. The mean values were: VO2 Max 45.5 ± 3.5 ml O2/Kg body weight and HRmax 190 ± 12 bpm.

Subjects reported at 08:00 h on each testing day and were instrumented with skin thermistors, a rectal probe and ECG electrodes. They wore tee-shirt, military fatigue shirt and trousers, and a chemical defense overgarment consisting of charcoal-impregnated jacket and trousers. Subjects wore their own tennis shoes, cotton gloves with rubber overgloves, a vapor-impermeable hood, and a chemical defense mask with the filter canister removed to reduce inspiratory resistance. The thermal insulation value of the outfit was about 2.4 clo. Each subject was tested under all eight experimental conditions in randomized order at a rate of 1-2 experiments per month. Subjects walked continuously on the treadmill at the pre-determined workload (low, moderate or high) until they reached a Tre=39.0°C or were unwilling to continue. Thermal tolerance time (TTT) was defined as the time required to reach Tre=39°C. Rectal and skin temperatures and HR were recorded at 30-s intervals during the experiments.

The eight experimental conditions were divided into subsets for analysis of the various factors affecting TTT. Comparison of conditions 1 vs. 2 and 4 vs. 5 allowed the evaluation of environmental heat load effects in order to assess the validity of the Discomfort Index. Conditions 3, 4 & 6 allowed examination of workload effects in a single hot, humid environment. Conditions 7 & 8 used low and high workloads in a hotter, humid environment.

Group means were calculated for: TTT, final Tmsk, final HR, SR, ER, percent of sweat evaporated (E) and change in body weight (ΔBW). Group means for each variable were analyzed among the eight conditions using a two-way analysis of variance. When significant F values were found, a Duncan's Multiple Range Test was used to test for significant differences at the $p < 0.05$ level.

RESULTS

Predicted TTTs obtained from the Texas Model were compared with the mean TTTs obtained during the experiments (see table). Overall, the model provided a good estimate of TTT. The model's predictions on TTT under conditions 4,5,6,7 & 8 were within 2 to 5 min of experimental TTTs. Exposure times (both predicted & experimental) under these conditions were limited to less than 1 h due to the severe net heat load that resulted from metabolic generation of heat and environmental heat stress. Under C.1 & C.2 the model showed that with an elapsed time of 175 min Tre equilibrated at 38.8°C, resulting on an "infinite" TTT. Under C.3 the model predicted a TTT = 90 min, while the mean experimental TTT was 65.7 min. We can speculate that under C.1 and C.2 the model predicted an unimpaired sweat evaporation mechanism (through the clothing), that resulted in greater skin cooling and led the to the attainment of a thermal equilibrium. It is possible that during exposure to either mild ambient conditions (C.1 & C.2) or to a low workload (C.3), the model's estimates of heat transfer to the environment appear to be higher compared to what can be expected due to clothing characteristics (insulation, water vapor permeability). However, this error in overestimation of body cooling through the various clothing layers should not be attributed entirely to the model. An accurate measurement of heat transfer in complex clothing systems (multi-layer) is a very difficult task. This task becomes even more difficult when a human body has to be considered an integral element of such a determination. This difficulty is due in part to technical limitations in the static copper manikin generally used to determine the heat transfer characteristics of clothing. Limitations associated with the use of such a manikin include: 1) Changes in sweat rates (local and total), evaporation rates and distribution patterns observed on humans are difficult to reproduce, 2) Effects of body motion on heat transfer through the clothing cannot be reproduced. Therefore, static copper manikins measurements of clothing characteristics do not adequately represent heat exchange from the moving, sweating human body to the environment. However, data used in the specification of the thermal transfer characteristics of clothing for input to the Model came from static copper manikins, which explains some of the conflicting results previously discussed. This problems with the static manikin have led to the development of a new generation of dynamic manikins intended to reproduce human movements and to simulate regional sweat rates and distribution patterns. Data from studies using this new type of manikins will be necessary to refine the representation of heat transfer through complex clothing systems in the Texas Model.

The validity of the Discomfort Index for the assessment of heat stress tolerance can be evaluated by looking at the results from comparing C.1 (humid) vs. C.2 (dry), and C.4 (humid) vs. C.5 (dry). Experimental TTT's under these two sets of conditions indicate that ambient heat stress under each set was physiologically equivalent. Furthermore, C.6 and C.8 had similar, but not the same DI's (30 and 33); however, they also showed the same tolerance times. These results indicate that the Discomfort Index is useful for a general assessment of the physiological impact of exposure to ambient heat stress under similar clothing conditions. This index could be specially useful applied to conditions where individuals are required to wear semi-permeable or impermeable clothing. On the other hand, this index should not be used to assess heat stress while wearing different types of clothing, even if the 50-50 weighting of Tdb and Twb is the same for these conditions.

CONCLUSIONS

The model showed an adequate accuracy in predicting heat tolerance for highly stressful conditions, which represent various combinations of work, heat and humidity. The model had difficulties to predict the physiological impact of semi-permeable clothing during exposure to a low workload or to mild environments (humid & dry). Under these conditions, the model seemed to overestimate the body's capacity to transfer heat to the environment through the clothing layers. In this respect, input data for the model could be improved by incorporating new data on the heat transfer coefficients through different clothing layers using a dynamic manikin. In addition, this studies could also provide additional data on the magnitude of indirect (convective) vs. direct (conductive) skin cooling which results from the evaporation of sweat from the clothing. Our results also indicate that the use of the Discomfort Index as a predictor of heat stress is useful when individuals are wearing similar protective clothing that isolates them from the environment partially or completely.

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THE ROLE OF THE MOISTURE/VAPOUR BARRIER IN THE RETENTION OF METABOLIC HEAT DURING FIRE FIGHTING

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INTRODUCTION

Fire fighting is unquestionably a hazardous occupation for which highly specialized protective clothing is required. A recent development in firefighter turnout gear is "bunker clothing" consisting of high cut trousers and an overcoat. Compared with the standard "pitch coat" and rubber hip boots, the bunker clothing provides higher levels of hazard protection for the firefighter, but it also impedes the dissipation of metabolic heat.

Much of this impediment comes directly from the insulative nature of the clothing in its capacity to reduce conductive, convective, and radiative heat transfer. A portion of it may, however, arise from the moisture/vapour barrier included in the new clothing. This component is intended to shield the firefighter from steam and hazardous chemical vapours, and to help keep him dry (a vapour barrier is also a liquid barrier). It interferes, however, with metabolic heat dissipation by reducing evaporation of sweat from the body. With conduction, convection, and radiation often being avenues of heat gain for the body during fire fighting, evaporation remains the only natural mechanism for passively cooling the body.

A recent development in barrier materials was the introduction of "breathable" fabric coatings, such as expanded polytetraflouroethylene (PTFE) with the trade name "Gore-tex®". These coatings are claimed to be permeable to water vapour while still providing a barrier to liquid water. Such properties would seem to identify coated fabrics as the ideal materials for moisture barriers in turnout clothing, since they should minimize heat strain while still providing hazard protection.

This paper reports some of the findings of a large study that examined the role of the moisture/vapour barrier in the retention of metabolic heat in firefighters. Vapour impermeable barriers, vapour permeable barriers, and partial coverage barriers of both types were included. A portion of the study involved extensive laboratory trials in which firefighters performed simulated fire fighting tasks under carefully controlled environmental and physical work conditions. These laboratory trials were followed by a field trial in which actual fire fighting tasks including exposure to flames were carried out.

METHODS

The turnout clothing consisted of 3 different outer shells (WOOL, COTTON, and NOMEX), 5 barriers (FULL-NEOPRENE, FULL-GORETEX, PARTIAL-NEOPRENE, PARTIAL-GORETEX, and NONE), and 2 thermal liners (WOOL and NOMEX) tested in a 3 X 5 X 2 factorial design in the laboratory. These bunker suits were specially designed for the study so that all elements were interchangeable. Apart from the colour of the outer shell, subjects were not aware of the barrier/liner combination being worn. In addition, subjects wore long sleeved cotton turtle-neck undershirts, cotton long-johns, wool socks, Nomex® coveralls, leather gloves, rubber boots, a helmet, and a breathing apparatus with a face mask and air tank.

Two environmental chamber conditions were evaluated. Condition HOT involved 8 subjects working for 30 min at a dry bulb temperature (T_{db}) of 30°C, relative humidity (RH) 50%, while condition VERY HOT involved 3 subjects working for 70 min (two 30-min sessions with a 10-min rest period in the chamber) at T_{db} = 35°C, RH = 45%. The field trial was conducted with 6 subjects over a 5-day period during which ambient conditions were remarkably consistent, with sunshine every day and afternoon highs of T_{db} in the range 25 - 30°C.

The simulated fire fighting tasks used in the laboratory phase of the study consisted of 3 work stations: treadmill walking at 4.5 km/h; bench stepping on 2 standard 8-in steps at 60 steps/min; and carrying 20 kg boxes a distance of 2 m across the room at a rate of 6 transports/min (four boxes were unstacked, transported, and restacked one at a time during this task, thereby forcing the subjects to bend as well as lift and carry). Each activity was conducted for 9.5 min, with 0.5 min between activities for station rotation and a total work cycle time of 30 min. Fire fighting tasks during the field trial consisted of the following activities: walking, 5 min; hose work, 5 min; ladder climbing and chopping, 8 min; rest, 12 min; casualty search and rescue, 10 min; and fire tending, 10 min. Total activity time was 50 min, with the air tank replaced during the rest period.

The physiological parameters recorded and analyzed during the study were final mean skin temperature (FMST), delta mean skin temperature (DMST), final rectal temperature (FTRE), delta rectal temperature (DTRE), heart rate (HR), fluid loss (FLOSS), percent dehydration (%DEHY), fluid evaporated (FEVAP), air consumption (AIRCONSUM), and subjective thermal comfort (COMFORT). In the laboratory, data were recorded with a computerized data acquisition system while during the field trial portable solid state data loggers (Vitalog PMS-8) were used. The HOT laboratory data were analysed via analysis of variance (AOV) for repeated measures, but the other results could only be analysed by inspection and comparison with condition HOT due to reduced subject numbers.

RESULTS

AOV showed a statistically significant main effect of BARRIER for 8 of the 10 parameters examined. By comparison, main effects SHELL and LINER had only 1 instance of statistical significance each. A marginally significant interaction was noted between SHELL and BARRIER for parameter DMST, suggesting that the rise in skin temperature may depend slightly upon the specific combination shell and barrier used. BARRIER had an extremely significant effect ($p < 0.0000$) on parameters FMST, DMST, and FEVAP, indicating that the composition or extent of the barrier used in the clothing profoundly affects moisture evaporation from the clothed body (fluid evaporation was 25% greater with FULL-GORETEX than with FULL-NEOPRENE, and 55% greater with NONE). Post-hoc LSD tests showed that the FULL-NEOPRENE barrier clearly imposed the greatest thermal stress on the body while the FULL-GORETEX barrier was often grouped with the partial barriers or no-barrier configuration.

The absolute levels of thermal physiological strain achieved during condition HOT were not overly severe, although most subjects appeared very exhausted after the exposure. The highest mean FTRE recorded was 37.8°C, HR was generally between 140 - 150 bpm, and FLOSS was 0.5 - 0.6 kg over 30 min. This could have been due to the relatively short duration of the exposure. Indeed, during condition VERY HOT which lasted just over twice as long, much higher levels of strain were observed (FTRE exceeded 38.5°C; HR was between 160 - 170 bpm; FLOSS exceeded 1.7 kg over 70 min), and virtually all significant differences seen during condition HOT were amplified. Of particular note is the fact that whereas all subjects completed all exposures during condition HOT, several subjects were unable to complete 70 min of work during condition VERY HOT, and barrier FULL-NEOPRENE resulted in the shortest exposure times. The field trial results were extremely comparable and supported all of the results obtained in the laboratory.

CONCLUSIONS

This study demonstrated under a broad range of both simulated and realistic fire fighting conditions that a full vapour barrier of a material such as neoprene leads to significantly higher levels of thermal physiological strain than a vapour permeable barrier of a material like Gore-tex®. The vapour permeable barrier appears to provide its beneficial action by permitting evaporation of sweat from the body, hence increased metabolic heat dissipation, as manifested in higher sweat evaporation rates, lower skin and deep body temperatures, and lower heart rates. Not to be forgotten is the subjective data that showed neoprene to be the least desirable barrier material from a thermal comfort perspective.

The design criteria for firefighter turnout clothing to provide a high degree of hazard protection concomitantly with a high metabolic heat dissipation capability are essentially in conflict. Clearly, the optimum design of turnout clothing must be a compromise between these disparate requirements. The advent of vapour permeable moisture barriers is a significant step forward in achieving this objective.

REMOVAL OF METABOLIC HEAT BY INTERMITTENT AND CONTINUOUS PERSONAL CONDITIONING

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INTRODUCTION

Heat extraction characteristics of personal liquid conditioning garments (LCGs) have generally been derived from experiments with resting, or mildly exercising subjects exposed to hot environments. There is little, or no information concerning heat extraction capability where the heat source is predominantly metabolic. Similarly, studies of the ergonomic aspects of LCGs have tended to concentrate on the sedentary subject. The major difficulty for the ambulatory user is the need to be tethered to a fixed supply, with subsequent restriction of movement. Provision of a portable conditioning unit overcomes this difficulty but may reduce load carriage capability of the user, and impose further ergonomic problems. One potential solution could be to provide cooling during the rest periods of a work/rest routine. We have set out to determine the heat extraction capacity of a liquid cooled vest (LCV) when worn by intermittently exercising subjects in a thermoneutral environment. Further, to compare work tolerance of these subjects when personal conditioning is provided either continuously, or during rest only.

METHOD

Six fit male volunteer subjects took part in the study, mean age was 26.5 yrs, height 177.8 cm, weight 77.6 Kg and treadmill specific peak oxygen uptake 4.09 l/min. With ethical committee approval each subject attempted three 90 minute intermittent work routines (20 mins work/10 mins rest) in a thermoneutral environment (T_{air} 22°C). At least 48 hours separated each exposure. Work consisted of walking on an inclined treadmill (2%) at 4.5 Km/hr with the addition of carrying a box (40cm x 24cm x 22cm) weighing 16 Kg for 30 seconds in every minute. Mean (± standard deviation) oxygen uptake for the task was 1.93 ± 0.32 l/min. Rest was undertaken in the standing posture, during which time subjects were encouraged to drink freely.

For all experiments subjects wore highly insulative chemical protective clothing, including gloves and respirator and an LCV. This garment, worn next to the skin, covered the torso and upper arm, approximately 20% of total body surface area and has been described in detail by Richardson and co-workers (1988). Cooling was supplied either continuously, during rest, or not at all; the fluid inlet temperature was 20°C, flow rate 1.0 l/min.

Core temperature was measured by thermistors in either auditory canal (T_{ac}), with skin temperature measured at 4 sites, chest, back, upper arm and thigh. Heart rate was visually displayed on an oscilloscope from a 3 lead ecg system and was recorded every 15 seconds. Nude body weight losses and fluid intakes were recorded. Subjective Ratings of Perceived Exertion (RPE; Borg 1970) and subjective assessment of thermal comfort, based on a method adapted from Corlett & Bishop (1976) were recorded at the end of each work and rest period respectively. Heat extraction of the LCV was calculated from the temperature difference between the vest inlet and outlet temperatures, mass flow and specific heat of the coolant. Subject withdrawal criteria and, hence, tolerance times were heart rate exceeding 180 bpm, T_{ac} exceeding 38.5°C, or subjective distress. Results were analysed using Analysis of Variance and Newman - Keul, or Freidman's non-parametric test where appropriate.

RESULTS

Mean heat extractions by the LCV were 34.5 (± 5.8) watts during intermittent cooling and 29.5 (± 3.5) watts during continual cooling. There was a clear decline in heat extraction with time during rest, whereas with continual cooling heat extraction remained relatively constant throughout.

Mean tolerance times were, no cooling 47.2 (± 11.1) min; intermittent cooling 61.3 (± 23.9 min); and continual cooling 85.3 (± 11.4) min; significantly more ($P<0.01$) than for the other two conditions. Subject withdrawal was invariably due to heart rate exceeding 180 bpm. Between condition comparisons of core and skin temperature and heart rate could not be made because of withdrawal of subjects after the first work period. However, at the time of the first subject withdrawal (40 minutes) the highest core and skin temperatures and heart rate were observed in the no-cooling case, the lowest in the continuous cooling condition. Body weight loss was significantly less following continuous cooling, (16.7g/min; $P<0.05$), compared to the other two conditions (26g/min) but with no significant differences in fluid intake (10ml/min for all conditions).

Cooling, in either condition had no significant effect on RPE, the overall rating being "somewhat hard work" at the end of the first work period. Subjective ratings of thermal comfort at the end of the first rest period were close to thermal neutrality for both cooling conditions, and with votes significantly higher ($P<0.05$) for no cooling.

DISCUSSION

Vest heat extractions were considerably less than the reported 150 watts (Richardson et al 1988), or calculated metabolic heat extraction of 69 watts (Hayes et al 1986). Both workers used a similar LCV to that employed in this study. The discrepancy between these sets of findings and the present study may be explained in terms of differing environmental heat loads and clothing physical characteristics. Subject posture and exercise form may also have been contributory factors. Nevertheless, even the small rate of heat extraction achieved with continuous cooling was sufficient to allow the subjects to work twice as long as when not cooled. It should also be noted that in 3 subjects tolerance time was increased by intermittent cooling. Further studies are required to examine the possibility of work tolerance in protective clothing being increased by intermittent cooling.

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CHAIN SAW TROUSERS AND PROTECTION STANDARDS
EFFECT ON METABOLIC WORK, HEAT PRODUCTION, COMFORT AND SAFETY

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INTRODUCTION

A survey carried out by the Health and Safety Executive (HSE - Edinburgh) concluded that an analysis of 119 chain saw injuries revealed the need for greater protection to the face, head, neck, hands and arms and, in particular, for all-round protection of the legs. The evidence for increased leg protection indicated that 46% of injuries occurred on the legs, with 11% of these on the upper leg back and 15% on the lower leg back. Although the severity of the individual accidents was not reported, 93% needed hospital treatment with the individuals having an average of 28 days absence from work. By comparison details of Forestry Commission (FC) injuries since 1980 show a somewhat lower proportion of injuries to the backs of the legs (upper = 4%, lower = 14%). Neither the HSE nor the FC data demonstrate the comparative potential risk to the fronts and backs of the legs, because the injuries have been reduced by the provision of protection, more often to the fronts than the backs. German data, however, in respect to chain saw accidents in forestry work give details of all cuts - i.e. cuts to the protective material as well as to the legs themselves. On the basis of these data, where no protection is provided, 95% of the risk of chain saw injury to the legs of forest workers is to the fronts and only 5% to the backs. It would be logical therefore to take into consideration the distribution of the risk when deciding about the distribution of protection to be provided.

Cuts (11.4%) are certainly not the most frequent injury sustained in forestry harvesting work. The sprains/strains (51.8%), bruises (14.0%), dislocations (0.9%) and fractures (7.9%) which make up the majority have two main causes - lifting and falling. Falls are unavoidable particularly on conifer clear fell sites with the inevitable mass of debris hampering movement; but they need to be reduced to the unavoidable minimum. Anything which further hampers movement has to be thoroughly justified. Consequently the Forestry Commission commissioned the Ergonomics Unit at the Polytechnic of Wales to investigate and compare the physiological, subjective and safety effects on forest workers of wearing chain saw trousers with full protection all round the legs up to the waist at the front and to the crotch at the back, and of wearing the current FC trousers with protection restricted to the front and extending up to a level 10cm. above the crotch.

METHOD

Analysis of chain saw users identified three areas of work - felling and shedding trees and movement of the whole body around the work site area. The latter exercise, being more crucial to the effect of wearing padded trousers, was subsequently adopted for simulation of work in the laboratory. In the investigation 6 FC workers walked over a stepped and spring-gated apparatus with simulated ground conditions of a harvesting site for 20 minutes. Heart rate, sweat rate, aural, mean skin, thigh and calf temperatures were measured before (10 mins),during (20 mins) and after each experiment together with the number of times they struck the gates. The wearers' subjective opinions were recorded using a questionnaire. All the first three variables were also combined into a "physiological stress value" (Zakay et al, 1982) and experiments were undertaken in a climatic enclosure (20° ± 1°; 55% ± 5% Relative Humidity) (Cuff et al,1983).

RESULTS

Heart rate, aural, mean skin, calf and thigh temperatures rose steadily as exercise commenced, reflecting the gradual elevation in thermal strain. There was a noticeable elevation in thigh, calf and hence mean skin temperature of subjects wearing the semi-padded and fully-padded trousers throughout the experiment. The physiological stress value, showed that the wearing of fully-padded trousers carried a significant increase in strain compared with both normal and semi-padded trousers.

Table 1
Statistical Comparison between the Physiological Stress Value whilst wearing the Variable Trouser Condition

Trouser Condition		
Normal v Semi-padded	Normal v Fully-padded	Semi-padded v Fully-padded
t = 1.0104 p = -	t = 2.9360 p = <0.05	t = 3.1340 p = <0.05
n = 8	n = 8	n = 6

The sweat rate contributed most to the strain experienced by the wearers.

Subjective assessment of the trousers significantly showed that the fully-padded trousers were least preferred in that they were perceived to have the worse fit, were distinctly heavier, damper, warmer, more uncomfortable and more restrictive to movement. The frequency of gate errors, which represents trips and falls during actual work, validated this perception. A greater number of errors was experienced by wearers of fully-padded trousers (50.0) compared to semi-padded (15.67) and unpadded trousers (6.40).

CONCLUSIONS

The investigations produced clear physiological and subjective evidence that the wearing of fully-padded trousers would be detrimental to the health, safety and performance responses of forest workers. Introduction of protection to the backs of the legs greatly increases the risk of trips and falls and does not justify the reduced risk of cuts by only 5%. As a result of the work, adaption of fully-padded trousers by the British Standards Institution was subsequently not imposed. Implications for European Standards will follow the BSI decision.

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STATUS AND PROBLEMS OF WORK AT COLD STORAGE IN JAPAN

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Cold storages are the popular working place of artifical cold environments in Japan. The factory number of cold storages increases and the capacity becomes bigger with year. Worker in cold storage wears cold-protective clothing. Nevertheless body temperature of worker drops. thermal sensation becomes severe and task performance becomes worse. There are near 4.000 cold storages in Japan by reports of Assoc. Refring. Warehouse and Asssoc. Refrig. Ind. and about 80 percent storages of them are kept at a temperature below -20℃. The capacity became recently bigger and the average capacity of a factory is near 6.000m`. The total stock in commercial cold storages increased year by year: 12.5 million ton in 1987. The chief items of the stock in storage were marine products. livestock products. frozen food and agricultural products. The cold storages at -50 or -60℃ are used for storage of Tuna for Sashimi in Japan. Although cold exposure time in one entrance into the cold storage is shorter. physiological load of the worker is severe.

To investigate the work environments and working conditions. the several surveys with questionnaires were done to cold storages. We made the survey with mailing questionnaire in this year to the cold storage which had over 3.000m` capacity a factory. The mailing number was about 1.700 and valid rate of answer was 31 percent. The worker number was 50 and below in 90 percent of the factories. There are the methods of loading and unloading by folk lift. handling and/or automatic machine system; about 80. 30 and a few percent respectively. There were the resting room in over 90 percent of the factories. which were heated in all season or winter season.

The most popular total time in cold storages was less than 30 min. in a day at a temperature -40℃ and below and between 2 and 4 hours at a temperature -39 to -20℃. The most popular frequency of entrance into cold storage was between 10 and 19 times in a day at -20℃ and below cold storages. The most popular work time in one entrance into cold storage was less than 5 min. and shorter at a temperature -40℃ and below and between 5 and 9 min. and between 10 and 29 min. at a temperature -39 to -20℃. These status are difference with the kind of jobs or temperature level in cold storage.

Cold-protective clothing is important to worker in cold storage, which is to prevent general cooling of the body, i.e., to maintain body temperature, and local cooling of peripheral body parts, especially the hands and feet. Great individual variations in energy expenditure existed, and therefore different needs for clothing insulation existed. The clothing supplied by the company were heavy insulating vest, shoes, trousers, gloves, helmet, and so on.

Cold is regarded by the workers in this kind of work as one of the main causes of accidents, illness and different types of complaints. Working in cold storage is sever especially at -40℃ and below cold storages. Workers in cold storage complain more frequent in summer than in winter, because there are big temperature difference between the inside and outside of cold storage in summer. Workers in cold storage would be laid aside by lumbago, bronchitis, neuralgia and so on. Incidence of lumbago was near 60 percent at -40℃ and below cold storage.

Although cold exposure time per one entrance in cold storage worker usually short: almost less than 5 minutes, and the workers entered frequently to the cold storage, the peripheral parts of the body become gradually cold. Working group in ISO is proposing IREQ (Required Clothing Insulation) as an analytical index of cold stress. ACGIH made the threshold limiting values for work done in cold environments. But, at -43℃ and below ambient temperature and no noticeable wind, work should cease except in the case of an emergency.

There are cold storage workers under even more sever working conditions than this. We have to propose a certain threshold limiting values for these workers in sever cold and the worker for longer time in the mild cold environments.

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INDOOR THERMAL STRESS IN ANTARCTICA

by W A Freeland

ARMY PERSONNEL RESEARCH ESTABLISHMENT

INTRODUCTION

It has been argued that life in Antarctica is associated with little or no cold stress. This was based on man spending only 9-15 % of his time outdoors[1,2], whilst experiencing indoor air temperatures similar to those in temperate climates[3]. An indoor temperature of 15°C +/- 2°C has been described as acceptable and satisfactory[4] while at Australian Antarctic stations, air temperatures of 18°C were recorded, suggesting little cold stress[3].

The British Antarctic Surveys' southern most base, Halley Bay, is located 1280 kms from the South Pole on a floating ice shelf 175 metres thick. The base was constructed of Armco steel tubing inside which was found the living and working accommodation. Originally built on the surface the base gradually became submerged as snow accumulated around it.In 1978 it was buried to a depth of 10 metres. Entrance and egress was via vertical shafts which were extended regularly as more snow accumulated. The temperatures described above applied to stations constructed on terra firma where the indoor thermal environment had no effect on the life expectancy of the base construction. However at Halley Bay, surrounded by ice, strict control of the indoor temperature was essential to prolong the useful life of the structure and prevent subsidence.

The aim of this study was to examine the indoor thermal environment at Halley Bay.

METHOD

A biometeorological record was compiled from the daily synoptic observations made by the scientists. Indoor temperatures were recorded using a Comark Electronic Thermometer and Cu-Ni thermocouples. The thermocouples were enclosed in clear plastic tubes, open at each end, to dampen the effects of air movement. These were attached to a wooden pole 208 cm long and positioned at 2.5 cm, 30.5 cm, 61.0 cm, 91.4 cm, 122.0 cm, 152.4 cm, 183.0 cm and 203.2 cm above floor level. Measurements were made at 39 work stations on 24 occasions between Mar - Dec 1978. A thermograph, temperature range + 5°C to - 40°C, was positioned in a commonly traversed Armco corridor linking the dormitory and living block, near the latrine.

RESULTS

The outside temperatures ranged from + 2.7°C to - 47.7°C with a maximum monthly mean of - 5.2°C and a minimum monthly mean of - 28.7°C. The annual mean wind speed was 15.9 knots. It was observed that as the wind speed increased so did the temperature and vice versa. The sun set in mid April rising again in August giving 2 months total darkness and 2 months twilight.

The mean office temperature was 11.9°C (maximum 24.9°C and minimum - 8.8°C). The mean workshop temperature was 4.1°C (maximum 22.0°C and minimum - 24.4°C, both in the generator shed). The mean internal corridor temperature was 6.0°C (maximum 19.2°C and minimum - 17.1°C). The Armco corridor temperatures (ie. those corridors linking the buildings under the ice) were; mean of - 3.4°C with a minimum of -23.3°C and maximum of 9.5°C. The mean temperature in the washroom was 15.5°C with a maximum of 34.7°C and a minimum of - 6.5°C while the drying room had a mean of 14.6°C(maximum 35.1°C and minimum - 6.1°C). The minimum temperature in the latrine was - 21.1°C and in the toilet -9.6°C; fortunately gastro-enteritis was not a problem. On each test occasion a minimum temperature sub-zero was recorded in the workshops, corridors, Armco corridors, washroom and drying room. The coldest temperatures were invariably at the lowest levels although stratification was in evidence. The results from the thermograph were ; 100 % of the time was spent sub - zero; 53.2 % of the time was below - 10°C ; 6.6 % of the time below - 20°C and 1.6 % of the time below - 25°C. A large thermal gradient existed across the complex both vertically, due to stratification, and horizontally. A man working indoors might walk from the surgery, with a mean temperature of 15.7°C, towards the kitchen and experience a temperature fluctuation of 47.3°C; leave and walk to the garage with a range of 44.4°C move on to the toilet an experience a range of 49.3°.

CONCLUSIONS

Scientists in Antarctica are exposed to little cold stress while living and working at bases constructed on terra firma. However where man lives a troglodytic existance submerged beneath the surface of a floating ice shelf, constraints on the internal thermal environment are necessary. In these circumstances it must be concluded that scientists at Halley Bay do not live and work in temperate surroundings but are exposed daily, indoors, to marked cold stress.

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ROLE OF PERSONAL PROTECTIVE EQUIPMENT IN FIRE FIGHTERS' ACCIDENTS

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INTRODUCTION

Protectors enable fire fighters to work more effectively and closer to a dangerous place, but they may also have side effects (1). They may make the work heavier and awkward (2,3,4), or degradation of their properties may deacrease their protective performance (5,6). In the accident sequence, the role of personal protective equipment is also twofold. Personal protective equipment may contribute to the release of the hazardous energy or may have some other effect that contributes to the accident by means of side effects. The energy released can injure to the fireman if he neglects the use of protective equipment or if the equipment provides insufficient protection.

Some earlier studies have assessed the role of personal protective equipment in fire fighters' accidents (7,8,9). Most of these accidents were associated with the use of SCBA.

The aim of this study was to:
- evaluate the function of protective clothing and other personal protective equipment during accidents,
- examine the needs for developing and improving of protective clothing and other protective equipment, and
- judge fire fighters' readiness to use protective equipment correctly.

MATERIAL AND METHOD

The accident material studied comprises the reports of Finnish fire fighters' accidents filed with Finnish insurance companies in 1980-1985, and which led to at least three days of absence from work (N=801); also included were the fatal and serious accidents recorded since 1977 (N=27).

The relevance of personal protective equipment was first evaluated from the reports. Reports where personal protective equipment were considered to be relevant in the accident sequence were classified into three categories: 1) no personal protective equipment was used in the situation, 2) the protection performance of personal protective equipment was insufficient, but they may have had an alleviating effect, and 3) personal protective equipment seemed to have been a factor contributing to the accident situation by means of side effects.

RESULTS AND CONCLUSIONS

About half (N=396) of the accidents occurred during fire fighting and rescue situations when fire fighters were wearing turnout equipment. Personal protective equipment was evaluated to have been relevant in 59 % of those accidents.

In about one-third of the accidents that occured in alarm situations, the injuries - mostly burns - would have been less severe if the injured person had been protected better by protective clothing and other protective equipment. Most injuries of this type could have been prevented or alleviated by improving the protection given by the protective clothing to the upper parts of the body and to the hands.

Protectors were evaluated to have been a contributing factor most commonly in slipping and tripping accidents, accounting for 23 % of the accidents in alarm situations and in 17 % of the station accidents. Lighter and more flexible protective shoes and, especially in tasks at the station, shoes with better friction properties would reduce the number of such accidents.

In the course of eleven years, from 1977 to 1988, six firemen died, five at the scene of fires. Two victims neglected the use of SCBA in reported serious accidents, the use of SCBA involved problems in three cases, and the protection performance of clothing was insufficient in accidents leading severe burns. The reports on serious accidents show that there is a need for more training to control risk-taking behavior and to ensure that the use of personal protective equipment is standard procedure occuring at a subconscious level in every situation. Changes in regulations are also needed to guarantee sufficient protection.

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PHYSIOLOGICAL RESPONSES DURING ASBESTOS REMOVAL WORK - A FIELD STUDY

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INTRODUCTION

The removal of asbestos-containing building materials requires the use of dust-repelling protective clothing and a respirator. Lightweight disposable suits are the most common types of protective clothing in use.

The removal of asbestos is physical work, which may sometimes be carried out in warm environments (e.g. boiler rooms). Very few studies have been performed to quantify the physiological responses to actual asbestos removal work (1).

The purpose of this study was to evaluate the metabolic and thermal strain during asbestos removal work in real work situations while wearing protective clothing and a respirator.

METHODS

Eight asbestos workers served as subjects. The field measurements were done in the morning between 7 and 12 at randomly chosen days. The asbestos removal work was always carried out in an area which was isolated with plastic sheeting. Air temperature and relative humidity were recorded. The main work postures and the work tasks were also observed minute by minute throughout the whole work period.

During the work the men wore either permeable or impermeable protective whole-body suits with a full-face or half face respirator mask. In addition, they wore gloves and shoes and, under the protective suit, short underpants and socks.

During the work the heart rate (HR) was continuously measured and recorded every minute by a telemetric system. Oxygen consumption ($\dot{V}O_2$) at work was estimated from the individual $\dot{V}O_2$ and HR relationships determined on the bicycle ergometer in the laboratory. Rectal temperature and skin temperatures measured on the chest and upper back were recorded every minute with portable Vitalog-system. The sweat rate was determined by weighing the subjects nude before and after the work period. Perceived exertion, thermal sensation, thermal comfort and skin wettedness were rated by the subjects with standardized scales.

RESULTS

The work time observed averaged (± SD) 178 ± 51 min at the asbestos removal sites. The work included approximately a 15-min rest pause during every hour. The tasks were mainly stripping the asbestos insulation off from the pipes and boilers in underground corridors, in boiler rooms or in office rooms. The air temperature varied from 19 to 37 °C and relative humidity from 21 to 50%. The asbestos removal work was done for 73% of the observed work time in a standing position. The arms were elevated over shoulder level for 35% of the work time.

The mean HR was 113 ± 20 beats min^{-1}. The estimated $\dot{V}O_2$ values ranged from 0.9 to 1.9 l min^{-1} and the peak rectal temperatures averaged 37.7 ± 0.3 °C. During the work the mean of two skin temperatures increased 2.2 and 2.0 °C for the impermeable and permeable clothing, respectively. The sweat rate varied from 162 to 583 g h^{-1}.

The overall ratings of perceived exertion ranged from 'light' to 'fairly heavy', the thermal sensation from 'neutral' to 'warm' and thermal comfort form 'neutral' to 'unpleasant'. The skin wettedness varied from 'almost dry' to 'very wet'.

CONCLUSIONS

The asbestos-containing materials were removed from building structures mainly with handtools ie. knives, saws, steelbrushes and less commonly with motorized machines. With the exception of one work place the environmental conditions were thermoneutral ie. between 23 - 25 °C. Although the work places were randomly selected, very few warm or hot work situations were found. Possibly hot working places do not represent a high proportion of the asbestos work, because often the heating units are shut off during the work.

Poor work postures were common during the removal work of asbestos. The high location of the pipes often required working on the scaffolding or ladder. Arms were frequently elevated over the shoulder level.

The mean estimated $\dot{V}O_2$ associated with the relative aerobic strain of 27 - 60% of the $\dot{V}O_2max$. On average, the asbestos removal work could be classified as moderately heavy dynamic work, including some heavy work phases. According to the analysis of work postures and environmental conditions the increases in HR and thermal responses seemed to be primarily due to the poor static work postures and the muscle work of upper body (2,3). In this study HR and skin temperatures were lower than those reported for steam tunnel asbestos workers (1). Under the examined environmental conditions the used protective clothing did not seem to add the heat strain. The subjective ratings were quite similar in both types of the suits, considering the different work loads and air temperatures. It can be stated that the heat strain was not excessive, because most of the work situations occured in thermoneutral conditions and the rest pause for 10 - 15 min every hour decreased the physiological strain during work. Improvements in work methods and tools are needed to reduce metabolic and postural strain during the asbestos removal work.

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PHYSIOLOGICAL AND SUBJECTIVE RESPONSES TO WORK IN ASBESTOS PROTECTIVE SUITS

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INTRODUCTION

Work with asbestos products on site is rather heavy and performed in tiresome working postures, often in narrow and warm spaces. Since the work has to be done in full personal protective equipment; i.e. overall and ventilation mask, there is a great risk that the thermal balance can not be maintained [3, 5]. In a previous study [4] the physiological and thermal strain was monitored during asbestos work in the field. The present study was undertaken as a complement with an aim to determine, during controlled climate and working conditions, the effect of different types of protective suits on the heat balance and to calculate their permeability. This paper, however, only gives a summarized view of some physiological and subjective data.

METHOD

Subjects

Four healthy males volunteered for the study after their informed consent had been obtained. All subjects where familiarized with the measurement procedures before entering the experiments. The subjects had an (Mean±SD) age of 36±8 years, a weight of 70±7 kg and a height of 1.76±0.07 m.

Clothing

The subjects were dressed in shorts, socks, and sneakers for one condition (No PS) and in combination with each of the suits for the other conditions. The suits were made of Gore-Tex® (GT), Mölnlycke polypropylene (PP) and Tyvek® (TYV). Every suit except the GT was taken new to each experiment, and was taped close to the leg down at the ankles.

Climate

Three types of protective suits for asbestos removal work were tested in climatic chamber experiments at two ambient temperature conditions, 24.9±0.6 and 35.7±0.7 °C. The relative humidity and air velocity were 50±12, 26±3 % and 0.3±0.1 m/s.

Measurements

The subjects performed each experiment at the same time of the day to avoid circadian variations in body temperature. The preparation of the subjects did take about 20 minutes and was done in a antechamber with an air temperature of 22°C and a relative humidity of 40%. Thermistors for skin temperature measurements (Fenwall, UUA32J3) were taped on 8 locations. Core temperature was measured with a thermistor (YSI 401) inserted 8 cm beyond the anal spincter. Four humidity sensors were used (Two Vaisala HMP-113 Y and two General Eastern 850) placed on the right thigh, trunk, back and right arm to measure the relative humidity near the skin. The heart rate was measured with a chest electrode belt and a recording unit (Sport Tester PE3000). Potentiometers were used to set subjective ratings (work, temperature, sweating and comfort). The total weight loss due to evaporation was measured with a scale (Mettler KC240) under the ergometer (Siemens 380B).

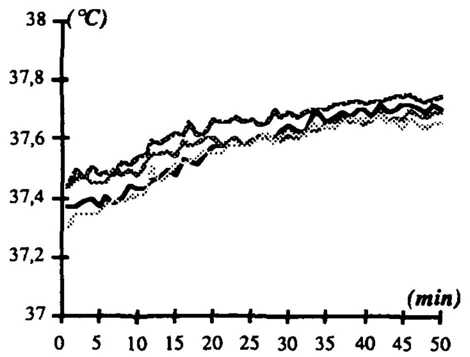
Procedures

Four subjects performed 50 min of bicycle exercise at 90 W. All temperatures, humidities, heart rate, subjective ratings and weight loss were collected by a computer (IBM AT) every minute during the experiment and stored for analysis. Each piece of clothing was weighed (Sartorius 1403MP) before and immediately after the experiment when removed from the subject. The only dripping possible, from the face, was wiped of with a towel stored in a bag and the weight difference was calculated. Oxygen uptake (VO^2, RQ) was measured, between minute 20 and 30, with an oxygen uptake system (Ametek OCM-1); calibration was checked before each experiment. The subjects worked without a breathing apparatus in order to facilitate oxygen uptake measurements and sensor placement.

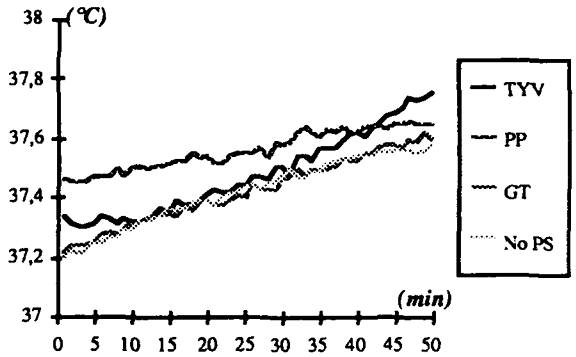
RESULTS

In the 25°C experiments the subjects reached thermal ·'ance after approximately 35 minutes and the rectal temperature showed only marginal differences between the different suits (see diagram below). In 35°C, on the other hand, the subjects were not able to reach and maintain steady state, and the rectal temperature curves had a steeper gradient, especially at the end of the experiment.

Rectal temperature, 25 °C

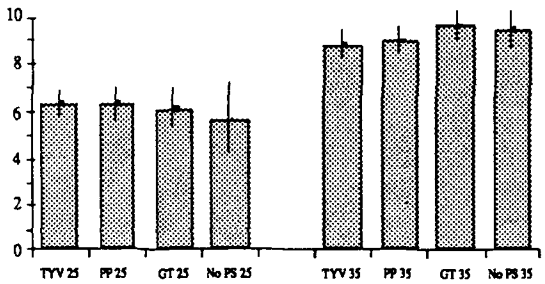


Rectal temperature, 35 °C

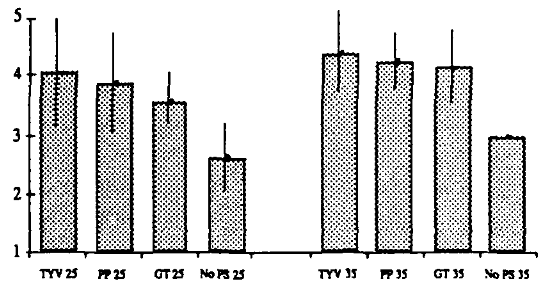


As shown in the diagram below the weightloss due to evaporation was fairly constant between the suits within the two conditions. Apparently sufficient amount of sweat evaporated and passed through the suits in all conditions, despite differences in permeability of fabrics. However the evaporative part of the heat exchange could be maintained only at the cost of a higher water vapour pressure (wettedness) inside the less permeable suits.

Weightloss minute 32-50 (g/min)



Subjective ratings sweatting



The subjective ratings of sweat sensation were reported on a 5-point scale [1] (How does your skin feel? (1) Dry, (2) Sweat onset, (3) Damp, (4) Wet, (5) Soaking wet). The diagram above show that the subjects also experienced the increase in skin wettedness. The subjective ratings were clearly correlated (r^2=0,952) with the variation in skin wettedness.

CONCLUSIONS

At 25 °C responses differed very little between suits. At 35 °C TYV resulted in higher physiological strain than for PP and GT, caused by a greater impedance to vapour permeation. The results indicate differences between the suits, that may be of little importance at normal room temperature, but becomes significant under conditions of heat stress, especially under longer working periods and at higher workloads. The use of a breathing apparatus could also in some cases further increase the physiological strain and the personal discomfort.

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Gross Partitional Thermal Balance With Protective Clothing

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INTRODUCTION

The precise quantification of thermal flux via different routes of energy exchange between man and his environment is more difficult to accomplish with the wear of individual garmentry (1). Although *static*, bench-level evaluations may be made with a variety of techniques to estimate the rates of heat transfer and water vapor flux across the fabric(s), when configured and worn as an ensemble the combined routes of energy transfer become much more dynamic. This phenomenon is commonly attributed to non-uniform fabric/body-surface spacing, the number and type of ensemble closures, combined with the "pumping" effect due to the kinematic action of body movement (2). Conventional heat balance equations may therefore not accomodate a number of these additional factors (3). Several investigators have empirically derived mathematical factors which attempt to explain these complicated relationships (1,3). However, laboratory observations have consistently demonstrated lower rates of heat storage than predicted during the active wear of chemical protective ensembles (4). The present analysis was therefore undertaken to further explore the specific partioning of heat flux and energy balance during the active wear of a highly impermeable protective ensemble.

METHODS

The laboratory observations were conducted in an environmental chamber at T_{wbgt} 31°C while subjects (n=9) walked on an inclined treadmill at 1.34 m/sec at a 3-6% grade which elicited approximately 40% of each subject's VO_2 max. The subjects wore a one-piece butyl rubber suit (TAP) clo=2.05, i_m/clo=.04, over a lightweight shirt and trousers. A protective mask and hood were also worn. Physiological responses of core temperature (T_{re}), heart rate (HR) and skin temperature at four sites (forearm, calf, chest, and thigh) were monitored continuously and recorded every five minutes while subjects exercised until reaching tolerance limits of T_{re} = 39.0, HR > 185 bpm or volitional fatigue. Microclimate suit temperature and relative humidity were also recorded. Nude and clothed, pre and post experiment body weights were used to calculate sweat production and evaporation (EVAP). Thus, the EVAP term would also account for respiratory water loss. Heat storage (S) was calculated as follows:

$$S = 0.83 \text{ kcal/kg/°C} \times (\text{kg body wt}) \times [\, 0.8\ \Delta\ \text{Tre} + 0.2\ \Delta\ \text{Tsk}]$$

Heat balance was either calculated using standard equations (1,3) from physiological measures of the folowing: metabolic rate obtained during the experiment (MR), evaporative loss (EVAP), and heat storage (S) <u>or</u> predicted with an integrative physiological computer model (5). Radiative and convective (R+C) heat loss was mathematically deduced and not obtained empirically.

RESULTS

All results are expressed as Kcal/30 minutes.

Trial //	S	=	Ω (MR)	- (R+C)	- EVAP
TAP	***108***	=	.95 (*210*)	- 30	***- 62***
TAP (model)	203	=	.80 (*210*)	+ 35	- 0

* Estimated Values   **** Measured Values***

Ω = 1-(work efficiency)   MR = energy consumption/30 min

CONCLUSION

These results clearly identify differences between the observed heat balance *in vivo* and those predicted from the model. Differences in total heat production will result from the use of various estimated work efficiencies, i.e. values of either 5% or 20% were used for transformation of metabolic energy to physical work. However, the specific efficiency value (Ω =.80) used here in the computer model, tended to attenuate the potential difference between the two estimates of S. Partial explanations to account for some of the above discrepancies between observed and modelled values include: 1) potential failure of the model to account for the energy required to raise the temperature of the suit (S_{suit}), calculated using the specific heat and the weight of the suit as ~28 kcal 2) the model represents EVAP as 0 for the TAP, while empirically determined EVAP likely overestimates EVAP due to drippage of sweat which was not accounted for. This, coupled with the fact that not all sweat is evaporated at the skin (garment sweat thru) (6), suggests the actual term is somewhere between 0 and 62 Kcal.

Depending on the amount of heat loss which can be attributed to either EVAP or S_{suit}, the remaining delta between laboratory and modelled values for heat storage might then be attributed to the removal of heat by the pumping action of the body in motion. Thus, this air turnover would need to remove as much as 95 kcal over the duration of the experiment. Using measured values of external air temperature and temperature inside the suit, along with the specific heat capacity of air, this would necessarily equate to an air exchange of approximately 960 cf or 32 cfm: a maximal air turnover rate that is highly unlikely. Therefore, the range of observed and modelled values (Kcal/30min) for the TAP suit might be expressed as:

S	(R+C)	EVAP	S_{suit}	$S_{air\ exchange}$
108 to 203	-30 to 35	0 to -62	0 to -28	0 to -95

Despite advances in the mathematical description of heat exchange between sedentary clothed man and the environment, there are still many important practical factors regarding the thermal properties of clothing which remain to be more precisely quantified during human performance trials (3). The preliminary analysis described above suggests the need for more definitive techniques in measuring the key variables involved in heat balance *in vivo*. Independent validaton studies must then be undertaken in order to better resolve certain estimates of physiological thermal flux and energy balance between robust mathematical models of heat storage and laboratory observatons.

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A COMPARISON OF IMPERMEABLE AND SEMI-PERMEABLE NBC SUITS IN A RANGE OF ENVIRONMENTS

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INTRODUCTION

In order to afford the fullest possible NBC protection an impervious suit is clearly a simple and effective solution which has the additional advantages of low weight and compactness. The disadvantage of this type of garment lies with its impermeability to sweat evaporation, a highly efficient heat loss mechanism. However, the environmental limitations of wearing this type of garment (IMP) compared to a semi-permeable (SEMI) suit, whilst performing light to moderate work are unexplored.

METHODS

Several climates were used for this study:

WBGT degC	DRY degC	WET degC	RH %	Amb. Vap. Press. kPa
10	13	9	60	0.9
20	24	18	50	1.7
24	30	22	50	2.1
28	38	24	30	2.0
29	30	28	86	3.7

Five or 6 subjects were used in each experiment aged 21–43 years and unacclimatised to the heat. The SEMI and IMP suits were worn with underpants, cotton work dress, boots and S10 respirators. Heart rate (HR) was monitored from a 3–lead ECG (Siemens Telecust). Aural temperature (TDB) was monitored continuously to 0.05°C by means of insulated thermistors and recorded every 2.5 minutes (SQ1200 Grant Instruments) together with mean skin temperature (TSK) from skin thermistors at 4 sites[1]. Sweat production (SP) and evaporation (SE) rates were calculated from changes in body weight corrected for fluid intake (water, ad. lib. via the drinking tube of the respirator).

Subjects were seated whilst baseline measurements were taken and then commenced stepping, up to a height of 22.5 cm at a rate of 12 complete steps/min. (approximately 310 J/sec)[2]. Subjects continued until their TDB reached 38.5°C when they were allowed to rest until TDB fell to 38.0°C. This cycle was repeated to a maximum of 3 hours work/rest. Subjects who did not achieve a rise to 38.5°C worked continuously for 3 hours unless they requested a rest for which 15 minutes was permitted.

RESULTS

Univariate analysis of variance (ANOVA) has been performed to assess for differences between the 2 suits based on a linear additive model including the main effects for 'suit', 'WBGT index' and the interaction between these 2 factors. At the WBGT 10°C level TSK was significantly ($P<0.05$) lower in the IMP but all 6 subjects completed 3 hours of work in both suits at this temperature. Of the remaining 4 WBGT levels, maximum times were achieved only in the SEMI suit: 3 subjects at WBGT 20°C and 1 at WBGT 24°C. Subjects wearing the SEMI worked for longer ($P<0.05$) at WBGTs 24°C and 28°C. At WBGT 29°C the differential between work times for IMP and SEMI was small. At WBGT 20°C 2 subjects showed no difference between IMP and SEMI (180 minutes) whilst 3 others achieved at least 40% extra work in SEMI compared to IMP. The times to the first stop (column 1) and total work time (column 2, max 180 mins) are given below.

WBGT deg	No.Subs (max)	IMP (mins) Min		Median		Max		SEMI (mins) Min		Median		Max	
20	6	35	110	85	123	104	147	50	114	180	180	180	180
24	5	40	52	59	60	99	118	79	149	143	165	180	180
28	6	20	20	31	31	41	41	63	76	81	113	128	155
29	5	40	40	53	53	65	65	41	57	61	65	77	77

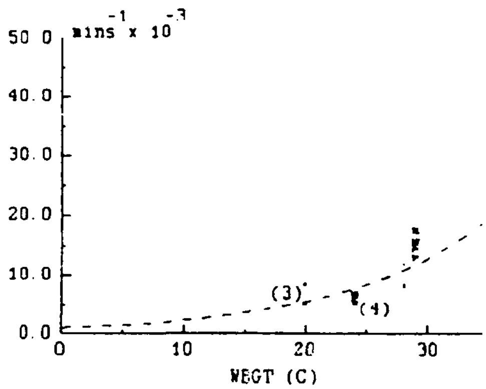
TDB increased at a faster ($P<0.01$) rate in IMP at all WBGT levels and cooling rates were significantly

(P<0.01) slower compared to SEMI at WBGTs 20°C, 24°C and 28°C but not at WBGT 29°C. At WBGT 28°C all subjects demonstrated a slow continuous rise in TDB when at rest, more rapidly so after cessation of work. In addition, HR increased more rapidly (P<0.05) in IMP at WBGTs 20°C, 24°C and 28°C. At the end of the first work period the TSK was higher (P<0.01) with IMP at all WBGT levels examined. SP was greater (P<0.01) in the IMP suit but only at WBGT 28°C whilst rates of SE were lower (P<0.01) for IMP compared to SEMI at all WBGT levels.

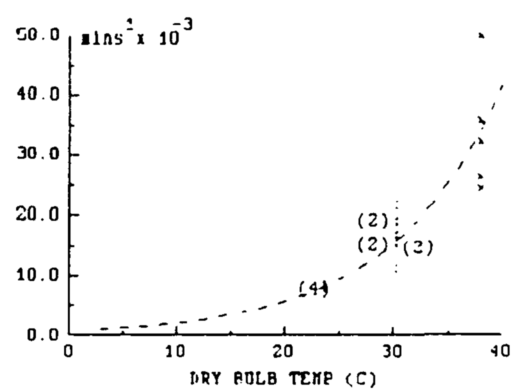
CONCLUSIONS

From the above series of experiments it is clear that for a WBGT of 10°C the IMP suit presented no additional physiological burden compared to the SEMI. At the higher WBGTs the reduced rate of SE increased the body temperature by reducing evaporative heat losses and the thermal gradient for conduction through higher TSK temperatures. This also necessitated an increase in HR to increase cardiac output to the cutaneous vessels[3]. The overall effect of these mechanisms is to reduce the work output of the subject wearing the IMP suit through heat

Inverse of Work Time against WBGT Temperature for the two Suit Assemblies



SEMI Suit



IMP Suit

exhaustion. It can be seen that work time in the IMP suit is limited by the dry bulb temperature. The results here would indicate that using a work/rest schedule in the IMP suit, work times of 2 hours and 1 hour are possible over a 3 hour period at dry bulb temperatures below 24°C and 30°C respectively. It is estimated that the 'safe' dry bulb temperature limit below which work is unlikely to be limited by the demands of thermoregulation is approximately 20°C. This compares to the 22.2°C reported elsewhere for men wearing NBC beneath impermeable waterproofs[4].

The steady increase in TDB at WBGT 28°C in the IMP suit suggests that the body cannot attain thermal equilbrium under these circumstances. As the major determinant of thermal load in the IMP suit is the dry bulb then the results for WBGT 24°C and WBGT 29°C should be similar. However, on close examination it was apparent that many of the measures indicated a more severe thermal stress at the higher WBGT level, perhaps due to reduced respiratory heat loss in the higher ambient vapour pressure. The results from the 29°C environment also show that the gradient for SE, although reduced, still allowed a substantial degree of evaporative cooling.

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COMBAT BODY ARMOUR FOR THE FLEET PHYSIOLOGICAL AND HUMAN FACTORS ASSESSMENTS

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INTRODUCTION

A new lighter (2.5kg) Combat Body Armour (CBA) has been developed by the Stores and Clothing Research & Development Establishment to replace the existing British Army 'flak-jacket'. It consists of a protective inner of 'Kevlar' inside a sleeveless collarless cotton cover with adjustable straps and a velcro front fastener. Several prototype garments were trialled (1,2) and improvements made to increase its flexibility. To give effective fragmentation protection the CBA should be the correct fit and be compatible with other protective garments; the added weight, bulk and thermal insulation might reduce mobility and increase the thermoregulatory burden on the wearer particularly in hot climates. Furthermore, any tendency to reduce sweat evaporation may prove problematic in extreme cold conditions. To assess these possible penalties and the suitability of the CBA for RN upper deck crew the latest prototype (MKII) was evaluated in a series of physiological and human factors studies.

METHODS

Three upper deck tasks were repeatedly timed to measure speed of access and egress to and from confined work spaces of 6-8 men wearing, or not wearing, CBA over an Action Coverall and Foul Weather Clothing (AC/FWC). A further three loading/unloading tasks were also timed to assess the limitations to body movement or posture of the CBA. Teams of 3-4 subjects repeated the tasks dressed as above. The experimental design was balanced for order effects in all but 2 of the above trials. Comfort and mobility were accessed by subject questionnaire at the completion of each trial.

Eight volunteers wore AC or AC/NBC (NBC Nuclear, Biological and Chemical suit with respirator) with and without CBA in a temperate climate (wet bulb globe thermometer - WBGT index 27 $^{\circ}$C) and whilst in the hot climate (WBGT 30.5 $^{\circ}$C), but wearing the CBA over the AC or No8s/NBC (No8s - Standard working dress). Subjects performed light to moderate work (stepping exercise, 310 W approximately) for a maximum work time of 85 minutes. Physiological measurements were made of aural temperature (T_{aur}) and mean skin temperature (T_{skin}) from thermistors, heart rate (HR) by ECG telemetry, and sweat production/evaporation calculated from differences in body weights and clothing weights. Expired gas was sampled and analyzed to calculate energy expenditure. Subjective measures of thermal comfort were also recorded from a continuous scale.

Similar measurements were made in a physiological assessment of the CBA in a cold environment (- 5 $^{\circ}$C). Eight subjects wore 4 different assemblies; AC/FWC, AC/FWC+CBA, NBC and NBC+CBA and each performed 60 minutes of exercise (450 W approximately) before resting for a further 60 minutes. In addition the skin temperatures of the extremities were recorded at the left index finger and both great toes.

RESULTS

Access and loading task times were assessed by a linear model incorporating constants for subjects, occasions and CBA. Entry and exit times for 2 of the tasks (into the Seacat Director and out of the 40/60 Aimer) were significantly slower ($P<0.01$) but ease of access was not affected in the other tasks, indeed only one instance of snagging was recorded in some 168 entries and exists. The degree of discomfort reported by subjects when wearing CBA was unaltered with the exception of movement to and from the Helicopter Weapon Mountings. Weapon and ammunition loading tests yielded only one significant result, this being the increased time to load the 40/60 ammunition if wearing CBA. However, CBA wear generally (but not significantly) increased the overall time requirement of the loading tasks.

A linear additive model of main effects for subject, clothing and session was assessed for temperate and hot climates independently by analysis of variance. No significant increase in energy expenditure was found by adding CBA to any clothing assembly.

In the temperate climate all subjects completed the maximum work time (85 mins) in AC irrespective of CBA and there was a small (not significant) reduction in work time in NBA if CBA was worn (71.5 and 62.6 mins respectively). T_{aur} was significantly elevated by the CBA in both assemblies which yielded higher maximum temperatures.

In the hot climate subjects completed the entire work in AC and AC+CBA, but CBA reduced work significantly when worn with No8s/NBC (59.6 to 45.7 mins). In this climate HR and T_{aur} rose significantly faster to a higher maximum value if wearing CBA and yielded significantly higher subjective ratings of tiredness, thermal discomfort and dampness as time progressed. Sweat production was elevated ($P<0.05$) by the CBA, but the garment did not reduce evaporation rates significantly.

In the cold study differences between clothing assemblies were assessed by an analysis of variance. CBA had remarkably little effect on the above measures of thermal strain with the exception of slightly higher chest (not significant) and toe ($P<0.1$) temperatures when worn over the other assemblies and a higher level of thermal comfort if wearing NBC+CBA compared to NBC alone. However, a number of subjects were withdrawn from the chamber when their peripheral temperatures fell below the prescribed safety limit for this study.

CONCLUSIONS

The small but significant increases in access times and ammunition loading times reported above need to be considered in relation to the overall time evolution of the task; thus the average increase in time (10-13 %) when wearing CBA had only a minimal effect on the time to complete the total task and should not be given any appreciable weighting. Similarly the reduction in comfort with CBA was minimal and occurred only during extensive body movement. Because of the importance of correct size and fit, data from a recent INM anthropometric data base (age weighted for peronnel at sea) were used to estimate the size roll requirements. It was observed that the provision of 8 different sizes according to chest circumference and height would permit a correct fit for 95 % of men.

On comparing CBA and non-CBa conditions in the temperate climate, it was observed that the full permissible work time was achieved by all subjects, but physiological indices indicated a progressive increase in thermal burden and cardiovascular strain with CBA. Increases in thermal strain were more dramatic in a AC/NBC clothing and the addition of CBA made a further small but significant impact. In the hot climate findings for the AC and AC+CBA were similar to those results in the temperate climate, whereas the No8s/NBC assembly caused a significant decrement in work time which was further reduced by 25 % with the addition of CBA. The CBA did not pose any significant physiological penalties if worn with other protective clothing at - 5 ^{o}C.

Taken together, the results from the above series of trials have established that this latest design of CBA is much improved and would indicate that the penalties incurred by its use are outweighed by the desire for improved fragmentation protection.

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HEAT STRAIN AND EFFECT OF PASSIVE MICROCLIMATE COOLING

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INTRODUCTION

Throughout the years numerous studies have addressed the effects of high heat on human performance in military working environments: aviation (1,2), land-based operations (3,4), and wearing chemical defense ensemble (5,6). Most recently, concerns have been expressed by Fleet Commanders for U. S. Navy personnel conducting shipboard operations in the Persian Gulf. The Navy's presence in the Gulf has involved a variety of ship types; many of them World War II model, steam and diesel powered vessels. Aboard these ships a number of job are tasks exposed to high heat without the benefit of work space cooling. One in particular is the Engine/Fire Room watch stander. During a previous study in the Persian Gulf, shipboard engine room temperatures had been recorded in the range of 32°C to 71°C (7). Because of operational necessity, workers in this type of environment may also be required to work many hours and repeated shifts during the day. Unlike industry, the Navy's working environment is not always able to be readily changed by appropriate engineering methods such as, provision of air conditioning or structural isolation. However, Navy guidelines for watch standing stay times (8) and/or provision of individual protective countermeasures have been implemented to assist maintenance of safety, performance, and health. The most recent countermeasure has been the introduction of a microclimate cooling system (passive ice vest) (9). The passive ice vest, called the Steele Vest, manufactured by Steele Incorporated, is made of cotton canvas, and contains six frozen thermostrips sewn in horizontally thinsulate insulated pockets, three in front and three in back. The vest is recommended to be worn over a T-shirt and working shirt to prevent excessive skin chilling and reddening by direct contact.

METHOD

In order to confirm the effectiveness of the ice vest to retard the physiological strain commonly associated with high heat environments, a field study was conducted during shipboard operations in the Persian Gulf during the summer of 1989 (June-August). Sixteen Engine/Fire Room (ER/FR) personnel (x age = 26.0 +/- 7.3 years) serving on two U. S. Navy ships (one steam and one diesel-powered) volunteered to participate. Subjects were evaluated in a with and without cooling vest condition during separate four-hour ER/FR watch periods. Data collection watch periods were restricted to one watch per day, and in order to reduce circadian influences, were at the same time each day. All subjects had been aboard their ship, and had stood similar watch periods for more than two weeks; therefore, were considered to have acquired heat acclimatization. During watch, the frozen thermostrips were replaced at two hours in order to maintain the vest's cooling effect. The metabolic workload of the ER/FR job task was determined by investigator observation to be light and most likely not exceeding 200-250 watts. Performance measures taken included levels of anxiety and fatigue (measured by questionnaire), heart rate (HR), rectal temperature (Tre), mean weighted skin temperature (Twsk), dehydration, and grip strength.

RESULTS

Ambient conditions within the ER/FR during this study were: Mean Dry Bulb temperature = 39.7°C, range = 34.2 to 42.7°C; Mean Relative Humidity = 56.4%, range = 50.0 to 67.5%; Mean Partial Vapor Pressure (PVP) = 30.5 mmHg, range = 26.0 to 37.0 mmHg. Anxiety increased during the watch period for subjects without an ice vest and decreased with an ice vest, although these changes were not statistically significant. During the watch, fatigue increased for subjects when not wearing an ice vest, $t = 2.75$, $p = .015$. Over time on watch, HR increased in relation to heatload. After two hours, subjects wearing an ice vest began to demonstrate a reduced cardiac strain response so by hour four of the watch, mean HR was 97 bpm without an ice vest and 84 bpm with. PVP proved to have the highest correlation with HR response. At PVP > 29 mmHg mean HR was significantly reduced in the vest condition, $F = 10.11$, $p = .034$. Twsk was reduced, $F = 38.3$, $p = .003$, however, Tre did not significantly change during the watch or between vest/no vest conditions. Dehydration as measured by urine specific gravity, osmolarity, and reduced sodium excretion demonstrated opposite effects following watch in the vest condition. Hematocrit did not markedly change between pre to post watch in either vest condition, yet grip strength, as a measure of total body strength, decreased significantly in the no vest condition, $p > .05$.

CONCLUSIONS

Due to the nature of today's U. S. Navy shipboard working environment and climate regions of operations, the safety, health, and job performance of the ship's crew may be compromised. Current operational guidelines describing authorized stay times in high heat working environments would seem to be appropriate to protect the individual for a given watch period. However, when these guidelines can not be adhered to due to operational reality, e.g., General Quarters, mechanical breakdown, reduced manning, emergency response, etc., supplemental countermeasures must be utilized. Additionally, when individuals are required to work in conditions of high heat and humidity without protection over repeated periods of time, concerns include questions about chronic (long term) health effect. Provision of a supporting countermeasure such as a passive cooling vest may retard or prevent such adverse effects.

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AIR TEMPERATURES REQUIRED FOR COMFORT IN FIGHTER AIRCRAFT

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INTRODUCTION

Modern fighter aircraft capable of low-level, high speed flight can produce severe thermal loads on aircrew. In addition, the protective clothing worn by aircrew is both highly insulative and relatively impermeable to water vapour with the result that dissipation of metabolic heat is difficult. Thermal comfort is known to affect aircrew performance (1,2) and therefore it is necessary to specify the cockpit temperature at which comfort will be maintained. This poster describes a method of determining the required cockpit temperature, the results of experiments to validate this model, and discusses the effects on comfort of temperatures in excess of the required temperature for comfort.

METHOD

The Subjective Temperature (T_{sub}) (3) required for thermal comfort can be predicted using an empirical equation derived by McIntyre (4), based on the work of Fanger (5), and is a function of clothing insulation and metabolic rate. Subjective comfort has traditionally been assessed using a 7 point scale (Figure 1) where the comfort range is generally taken as the centre 3 points on the scale. The T_{sub} for a neutral comfort vote can be shown to be 25.6°C which, using the McIntyre equation, will be required for a metabolic rate of 55.5W.m^{-2} and clothing with an insulation of 0.6clo. Similarly, it can be shown that at a T_{sub} of 30°C, 50% of subjects will vote greater than 5 on the scale in Figure 1 and thus will be uncomfortably warm (5). This upper limit of comfort can be predicted by simple modification of the equation. In addition, if T_{sub} is redefined in terms of ambient and radiant temperatures (T_{rad}) and air velocity, the effects of radiant heat loads and cockpit air movement can be included in the equation (4). Finally, the equation can be extended to calculate the likely T_{rad} for various climatic conditions and to include the effect of aerodynamic heating during high speed flight. The model developed in this way was used to predict the temperatures required for thermal comfort (T_{comf}) and for the upper limit of thermal comfort, for aircrew wearing flying clothing of different insulations, at a range of ambient temperatures, during different phases of flight and with varying solar radiation intensities.

The temperatures predicted by this model were validated in a series of experiments conducted in a climatic chamber capable of accurate simulation of the thermal conditions in an aircraft cockpit. Two different clothing assemblies were worn (2.45clo and 3.02clo) by 4 subjects who were exposed for 2 hours to the comfort temperature (T_{comf}) and 5°C above T_{comf} for the clothing worn. The values for clothing insulation were obtained using a thermal manikin. In a second experiment a further 4 subjects were exposed to 10°C and 15°C above comfort temperature wearing clothing of 2.45clo insulation. Rectal (T_{re}) and skin temperatures (T_{sk}) at 4 sites were measured throughout each exposure and sweat loss estimated by nude weighing before and after the experiments. During the exposures subjects repeated a cycle of 5 minutes rest followed by 10 minutes lower limb exercise which consisted of raising and lowering a 10kg mass every 2s. Metabolic rate was measured by indirect calorimetry during the last 5 minutes of the exercise periods. At the end of each of the 8 exercise periods subjects were asked to record their impressions of thermal sensation on the seven point scale shown in Figure 1. These comfort votes were compared with the predicted mean vote (PMV) calculated using the equation derived by Fanger (5).

RESULTS

The required air temperatures for comfort ranged from as low as -1.0°C for aircrew wearing summer chemical defence flying clothing operating at low level Mach 0.9 on a summer day with bright sunshine, to 11°C whilst taxying on a cool day wearing the same clothing. Required temperatures for the upper limit of comfort were approximately 4°C higher.

The data from the validation experiments showed that in all cases subjects' T_{re} rose by no more than 0.3°C from the starting value. Mean T_{sk} was between 34.1°C and 34.8°C at T_{comf}, between 35°C and 35.5°C at 5°C above T_{comf} and rose to a maximum of 35.7°C at the 2 highest temperatures. Mean subject weight loss over the 2 hour exposures ranged from 0.27% to 0.97% of body weight.

Figure 1 shows the mean votes for the 4 subjects over the second hour of exposure at each temperature for the 2 clothing assemblies. The mean vote at 5°C, T_{comf} for a 2.45clo assembly, was not significantly different from a neutral comfort vote. 5°C above T_{comf} produced a mean vote of 5 which may be considered to be the upper limit of comfort. Temperatures higher than this produced votes indicating thermal discomfort, although there was no significant difference between the votes at 15°C and those at 20°C. When the subjects wore the more insulative clothing assembly, the mean votes during the second hour of exposure at both the predicted T_{comf} and 5°C higher

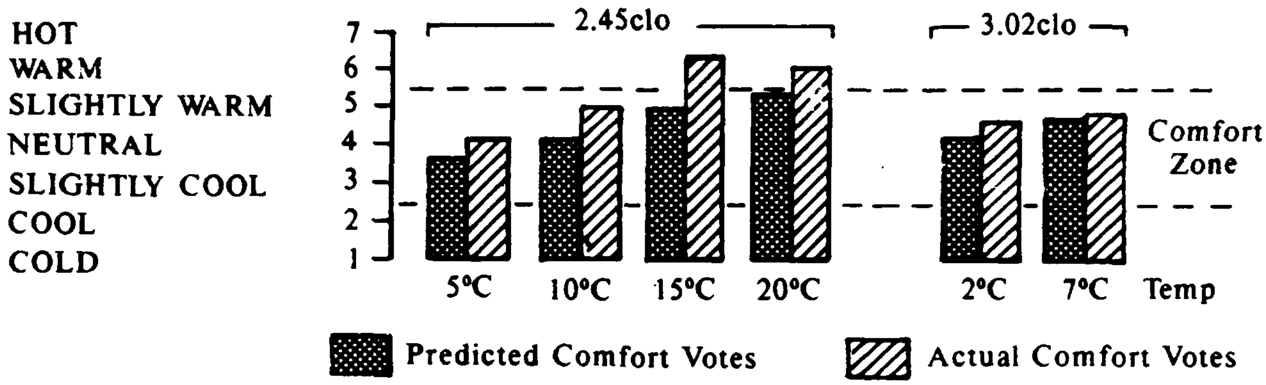

FIGURE 1

were within the upper limit of thermal comfort. The mean vote for each subject showed no correlation with nude weight loss, mean T_{sk}, or change in T_{re}. There was, however, a correlation between metabolic rate and comfort vote during exposures at the 2 highest temperatures ($r^2=0.56$; $p<0.05$). The PMV calculated for the conditions employed in the validation was not well correlated with the actual comfort votes cast by the subjects: in every case the PMV underestimated the actual vote although the difference was generally less than one point on the scale of comfort (Figure 1).

DISCUSSION

The climatic chamber experiments show that, even at the highest temperature in this study, there was no evidence of serious physiological thermal strain. Nevertheless, at temperatures 10°C or more above T_{comf} the subjects were suffering thermal discomfort. There was no correlation between the subjective impression of comfort and any of the physiological measures except metabolic rate which was positively correlated with comfort vote. This is, perhaps, not surprising since, given the highly insulative clothing which was worn, the discomfort is principally due to the rate of internal heat production.

The data show that the simple model predicts T_{comf} and the temperature for the upper limit of comfort reliably. However, it is not capable of giving any indication of subjective comfort beyond that limit. Prediction of comfort using the PMV equation derived by Fanger would be one method of assessing the effects of cockpit temperature in excess of those required for comfort although the equation as originally developed only dealt with clothing insulations up to 1.5clo. PMVs calculated for the conditions employed in this study tended to underestimate the actual votes probably because of the high level of insulation being worn and the effect on sweat evaporation of the impermeable nature of the clothing.

This study confirms that highly insulative and impermeable flying clothing will require cockpit temperatures which cannot readily be achieved in current military aircraft. Conditioning systems could only provide these temperatures at the expense of engine power, range and payload. A more efficient method of ensuring aircrew comfort would be to condition the micro-environment under the flying clothing.

CONCLUSIONS

The model predicts values for T_{comf} which are valid. The cockpit temperatures required are lower than those which can be achieved in most military aircraft and, therefore, micro-environment conditioning will be necessary to maintain comfort and performance.

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MANIKIN TECHNIQUES AND THERMAL COMFORT CRITERIA IN HEATED INTERIORS

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INTRODUCTION

A major aim of buildings is to protect us from unpleasant outdoor climate. Man stays inside buildings most of his life and this environment becomes a significant factor affecting his general health. From the point of view of building construction and heating systems, the quality of the indoor climate must be satisfying to human physiological requirements, as well as subjective sensations. Therefore, suitable heating systems should be designed and operated to maintain acceptable levels of thermal comfort in interiors [5]. Requirements for indoor thermal comfort result from the physiological and hygienic conditions of the occupants. Thermal comfort criteria in heated interiors of dwellings must be met by adjusting the physical properties of the building construction and by the performance of the heating system.

THERMAL COMFORT CRITERIA IN HEATED INTERIORS OF DWELLINGS

Thermal comfort criteria in heated interiors of dwellings are affected by the following thermal properties: thermal resistance and thermal capacity of structures, thermal reception of floors, thermal stability of rooms, water condensation on structures, and air infiltration through structures. Heating systems are designed after specification of the thermal envelop has been completed. Then the criterion for their design becomes some ambient temperature; i.e., a globe temperature or an operative temperature. However, thermal comfort of heated interiors must be guaranteed not only by setting optimal parameters (globe temperature, horizontal and vertical temperature gradients, surface temperature of the floor, thermal radiant intensity, relative air humidity and air velocity), but also by giving admissible values and their ranges [3].

THERMAL MANIKIN TECHNIQUE

Although the principle of thermal manikins is well known, there are significant differences between actual types and, therefore, the "EIT-MAN" (ETI-Hungarian Institute for Building Science) version is briefly described. The "ETI-MAN" thermal manikin is a sophisticated measuring instrument consisting of the thermal body, and a controlling and data acquisition system with two microprocessors and a computer for higher level evaluation of measured data. The manikin body is a full-scale male plastic model. Neglecting here the description of construction details, it has to be mentioned that the manikin body is divided into 18 segments in the sitting position and 16 in the standing position.

The principle of the thermal manikin involves measuring the supplied electric heating power necessary to maintain the temperatures of individual body segments at prescribed values with high accuracy. The following quantities are measured by the data acquisition system: deviation of the average temperature at the segment from the prescribed value, heat transfer per unit area through the segment surface, thermal resistance between the segment surface and the ambient air expressed in clo, and finally the ambient temperature sensed by the segment [4].

EXPERIMENTAL MEASUREMENT

The aim of the experimental measurement is to deterine the following quantities in a room heated by different convective, radiant, and combined heating methods [2]: a. the relation between the convective and radiant heat flow to the human subject, b. the ratio of convective and radiant components in the mathematical expression of the operative temperature, c. the global thermal states at different places and points.

The listed quantities were measured using the thermal manikin in the microclimatic laboratory, where typical heated interiors of dwellings were simulated. Two basic measurements were made at 4 different points (A-in the corner, B-in front of a window, C-in the middle of the room, and D-in the front of the outside wall) when: a. the surface temperatures of all walls and the indoor air temperature were kept at 18, 20, or 22 C, and b. surface temperatures were maintained at Fanger's optimal value of 22,5C.

RESULTS

From the point of view of place (A, B, C, or D), there is a great thermal comfort difference between pairs of points A,B, and C,D. A convective heating system characterized by a radiator placed in front of the window was not suitable, especially at points C,D, where a so called cold radiant heat flow was observed. A floor heating system was found to be the most acceptable for an occupied zone, i.e. in the middle of heated interiors, while in front of outside walls with windows, thermal comfort was compromised. A ceiling radiant heating system is not suitable for this application, especially for points A,B, where a significant cold radiant heat flow was recorded. A wall radiant heating system guarantees the best thermal state in front of the outside windows and provides acceptable thermal comfort in other places as well. A combined heating system (basic floor heating with radiators) was acceptable in all places of heated interiors.

CONCLUSIONS

It can be claimed that according to the described experimental evaluation of heated interiors of dwellings from the point of thermal comfort criteria: a. Subjects preferred radiant heating over convective heating, b. The coeficient for mean radiant temperature in the mathematical expression of the operative temperature must be greater than the coeficient for the indoor air temperature, c. Global thermal comfort from the aspect of heat exchange between the human body and heated interiors is best for combined and wall radiant heating systems.

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A FIELD EVALUATION OF THERMAL STRESS FOR ESTIMATION OF STRAIN IN INDUSTRY

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INTRODUCTION

Selection of suitable individuals for work in hot environmental conditions has often been a challenge to the practicing managers of industries in India. Use of a simple physiological parameter to assess an individual's capacity for work in hot environments is explored in this paper. Studies available for Indian conditions on this aspect pertain to laboratory conditions (Sen Gupta, et al, 1977; Dutta and Ganguly, 1975) which are difficult to translate to field conditions. The complexity of such problems requires relationships and formulas to be established for easy evaluation of strain without hampering either the production process or the routine activities of the employees. The present study is an attempt to obtain a relationship of heart rate with thermal stress in field conditions.

METHOD

The study was carried out in two textile industries and a steel plant, which together employ 33,000 individuals. Heat stress was evaluated in terms of WBGT from the readings of air temperature, humidity, wind velocity and radiation. Heart rates of individuals were recorded during rest, work and recovery. Work heart rates were recorded after 5 min, 2 hrs, 4 hrs, and just before the end of the shift, and the average was computed. Data for a total of 188 individuals were collected.

RESULTS

Average heart rates at the end of 4 hours have been used in the analysis. Data from both types of industries have been pooled in this analysis. Relationships of heart rate (dependent variable) with age and WBGT on the one hand (independent variables) and with body surface area and WBGT on the other were established. Separate sets of regression equations were developed. They are:

(i) $Y= -6.94 + 0.49\ X1 + 3.45\ X2$ ($R=0.59$) were Y is the heart rate in bpm; X1 represents age; and X2 represents WBGT in degrees C.

(ii) $Y=2.08 - 2.43\ X1 + 3.81\ X2$ ($R=0.61$) where Y is the heart rate in bpm; X1, represents BSA in square meters; and X2 represents WBGT in degrees C.

CONCLUSIONS

The physiological strain amongst individuals has been found to be beyond the premissible limit for safe work proposed by Sen Sara et al, (1985). The incremental heart rate per C of WBGT increase has been found to be 3 bpm. The heart rate increased on the average from 88 to 118 bpm for a rise of WBGT index by 10 C, and the working heart rate varied between 110 and 143 bpm. This increase in heart rate exceeds the observations of increase of 7-10 bpm/10 C rise while carrying a load under dry ambient temperature of 20-45 C (Kamon and Belding, 1971). The present observations are quite close to the study data collected for harvest workers in South Eastern America where the heart rate was found to increase by 42.5 to 69.2% when the WBGT index ranged from 20 to 30.4 C. The difference between our observations and that above is due to the variation in physical characteristics of subjects. Also the present finding of increase in heart rate is yet more than what was predicted by Meese et al. (1984); i.e., 1 bpm/C above 25 C. Kenney (1986) suggests a physical limit of PL (min) = 83 - 0.53 (HR 5 P), and this in conjunction with the nomogram set can be used for determining the working time limit for individual workers.

Estimation of the physiological cost of work to determine the physical working capacity may satisfy the task of assessing the fitness of an individual. However, the inherent difficulties of the technique being laborious, time consuming, and restricting the freedom of movement of workers associated with its estimation in field situations, discounts its choice as a suitable technique. Heart rate, which fairly reflects the severity of work of an individual, by virtue of its established relationship with energy expenditure, can be a viable alternative under the circumstances. Two nomograms presented on the next page can be used as a tool in the hands of practising managers to overcome the above difficulties, while, at the same time, presenting a fairly good picture of the strain imposed.

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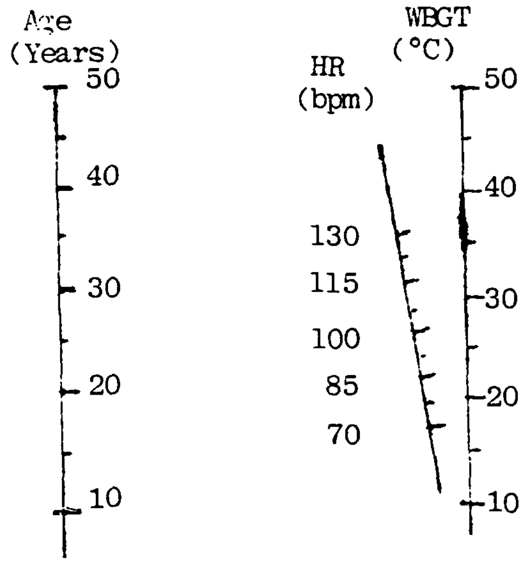
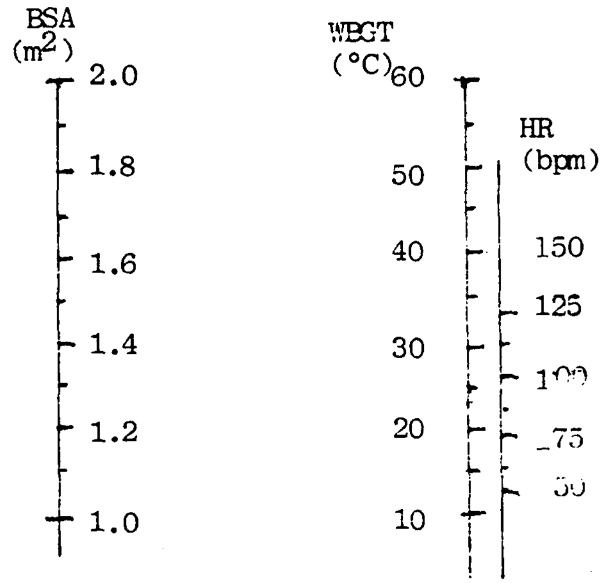


Estimation of Heart Rate after
4 Hours of Work from Age

Fig. 1



Estimation of Heart Rate after 4 hours
of Work from Body Surface Area and
WBGT

Fig. 2

BODY COOLING CONCEPT IN CONJUNCTION WITH CHEMICAL PROTECTION SUITS

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Performing work or rescue under hazardous conditions requires the use of special body protection equipment including breathing apparatus and chemical protection suits. Unfortunately, wearing such equipment adds weight and restricts movement, visual field, ability to communicate, and manual dexterity. Moreover, it inhibits evaporation of sweat, thereby, creating a humid micro-environment as part of the sweat is absorbed in the garment. All of this leads to increased cost of preforming a task, which adds to the heat stress problem.

Effective body cooling equipment can alleviate the stress problem. This paper describes three different personal cooling systems, which have been developed and tested for used with the breathing apparatus and chemical protection suits.

1. Air ventilation system. A network of hoses attached to the inside of the chemical protection suit supplies fresh dry air to the entire surface of the body. Two different systems have been designed and tested. The SU 120 supplies breathing air and ventilation air from an external air line at a rate of 120 liters per minute. The SU 30 supplies ventilation air from a breathing equipment (e. g., CABA) with a maximum flow rate of 30 liters per minute.

   Results show that the principal advantage of ventilating the suit is that it allows sweat to evaporate, which helps the body to loose heat without employing a sensible cooling system. The disadvantage of the SU 120 ventilation system is that it restricts movement due to the air line connection. That is not a problem with the SU 30 system, but it suffers from a relatively low ventilation rate and short duration time.

   In spite of these disadvantages, these systems do offer the advantages of increased comfort of the test subjects and prolonged time available for work while wearing the chemical protective suit compared to the maximum work time without ventilation.

2. Water-ice vest. This system was also tested as a personal cooling device for use under a chemical protection suit. Test results indicate that relatively effective body cooling with the water-ice vest could be achieved only when the subject wears a closed circuit oxygen breathing apparatus having a duration time of 60 to 90 minutes.

3. Oil cooled tube suit. A system for providing whole body cooling with a circulating chilled oil as the cooling medium and dry ice as the cooling source has been developed and tested. Incorporated into the whole body cooling garment is approximately 100 meters of tubing through which a special cooling oil circulates. The tube suit is connected to a dry ice cooled heat exchanger which is carried in the back pack. The principal disadvantage of this system is the total weight of the system, especially when it is worn under a chemical protective suit. Nevertheless, a system has been developed which provides body cooling for more that 60 minutes.

EFFECTS AND LIMITS OF PARTIAL BODY COOLING FOR WORK IN HOT-DRY CLIMATES

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Increasingly stressful ambient climates, changed working tasks, and higher demands on the working conditions require application of air conditioning measures at many workplaces. In that regard, clothing garments are gaining greater importance for technological and economic reasons. The severe climate in hot dry salt works ($T > 40\ ^{o}C$ and $\phi < 30\ \%$) has provided motivation for intensive and thorough field tests, in addition to tests in climate chambers, with different cooling garments (water/ice and dry ice vests, liquid cooled vests and helmets, and vortex tube cooled vests).

During these tests, the principal points of interest have been the technical design of the cooling garment and the relief they provide from thermal stress for two conditions: (1) during work of several hours duration (application period < 3 hours, T of 40 to 55 ^{o}C, $\phi < 30\ \%$, and BEU < 300 Watts), and (2) for short-term operation of the mine rescue corps (application period < 2 hours, T of 40 to 60 ^{o}C, $\phi < 30\ \%$, and BEU < 300 Watts.

The principal test results are:

- For all conditions tested, the application of partial body cooling results in significant stress reduction (pulse frequency, temperature of the interior of the body, and sweat rate).
- A liquid-cooled helmet/vest combination provided the largest stress reduction and the greatest wearing comfort for normal work in a hot workplace.
- Water/ice filled vests are the most suitable cooling garments for use in industrial workplaces that require the employees to have freedom of movement.
- Air conditioned protective clothing provides no real alternative for air conditioning at industrial workplaces due to extensive technical requirements and the low efficiency of such systems.

The following notable limits and marginal conditions are applicable to use of partial body cooling in hot dry environmental conditions:

- With respect to stress reduction, there are climatic upper and lower limits of effectiveness for partial body cooling systems.
- When using ice vests, the lower the thermal-work stress the larger the psychological reservations of wearers.
- Cooling only the head during longer periods of work in hot places ($T > 50\ ^{o}C$ and $\phi < 30\ \%$) results in false control of thermoregulation.
- The application of cooling garments during operation of the mine rescue corps is strongly influenced by the physical condition of the men.
- Extension of the work period during mine rescue operations in extreme environmental conditions causes new problems (inspiratory conditions and cooling) for self-contained breathing apparatus.

PHYSIOLOGICAL AND PATHOPHYSIOLOGICAL ASPECTS OF PARTIAL BODY COOLING GARMENTS UNDER HEAT STRESS

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The use of cooling garments reduces efficiently thermal and cardiovascular strain in a hot working environment.Individual personal cooling however may not be seen as a substitute for technical climate control.It rather serves under very hot working conditions as a supportive measure or prevents unreasonable heat stress.In any case those working under extreme thermal conditions should be required to make use of their own ability to increase their tolerance to heat through heat acclimation(1) or their physical endurance capacity(2).

Our own four hour investigations using water-ice cooling vests with 17 physically trained and 14 untrained male subjects on a treadmill (3 km/hr , 1°increase corresponding to a 300 watt consumption of energy at a room temperature of 40°C and a 45% rel. humidity) demonstrated an on-the-average significantly less increase in rectal temperature and heart rate than in similar experiments without cooling vests (figure 1).For subjects with lower physical endurance capacity wearing a cooling vest the differences in physiological relief were 0.5(±0.08)Kelvin in rectal temperature and 23(±5)beats per minute in heart rate. In trained subjects the differences were 0.44(±0.15)Kelvin in rectal temperature and 15(±4)beats per minute in heart rate.

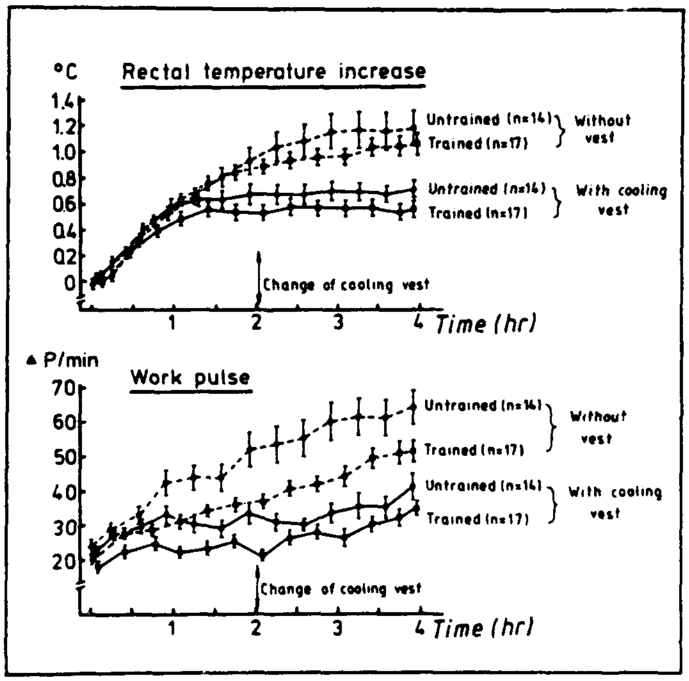

Fig. 1:Physiological strain during 4 hr heat work of 17 physical endurance trained and 14 untrained male subjects (unused to heat)wearing water-ice cooling vests, and control test. Brackets =standard error.

A basic question arising from these experiments is the following: does cooling of the chest by means of cooling vests lead to certain health risks such as the common cold? This issue was further borne out by measurements of the mucous membrane temperature of the pharynx by infrared methodology which were performed on 4 male subjects under conditions of 23°C and 40°C room temperature (figure 2). No change in pharynx temperature was observed under 45 minutes passive heat exposure as well as when walking on a treadmill at 40°C. To a distinct decrease of mucous membrane as well as rectal temperature led passive exposure at 23°C room temperature. At 40°C room temperature rectal temperature of the subjects also showed a slight increase. In conclusion there seems to be no general health risk wearing a cooling vest under passive heat exposure as well as heat work.

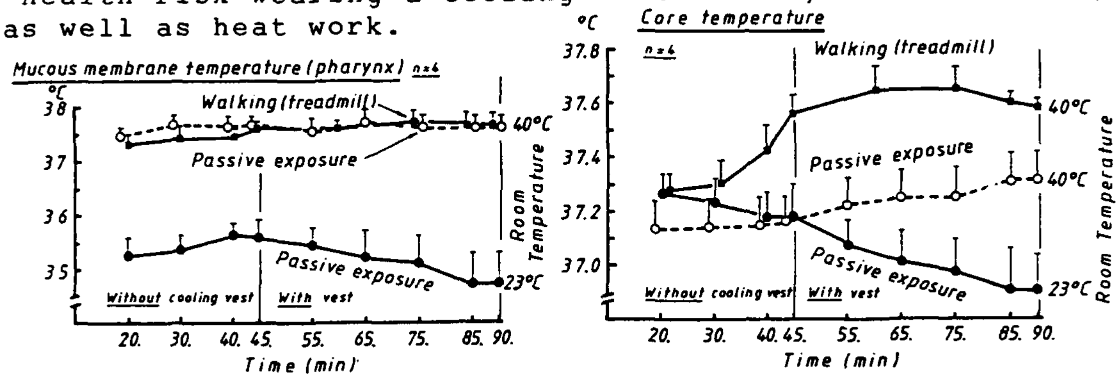

Fig. 2: Average mucous membrane (pharynx) and core temperature during normal and hot room temperature of 4 subjects wearing a water-ice cooling vest. Brackets =standard error.

The use of cooling vests offers the chance to expose also subjects with disturbances of their thermoregulatory system more safely to extreme heat. Taking a Finnish sauna bath spinally injured patients have greater internal heat storage than able-bodied subjects because of their insensate parts of the body (3). In our own experiments 8 para-and quadroplegic patients took a 15 minute sauna bath in a supine position at 85°C dry temperature and 5-10% rel. humidity with and without wearing a water-ice cooling vest (figure 3). Increase of core temperature and heart rate at the end of the heat exposure were clearly smaller when wearing a cooling vest than without its use.

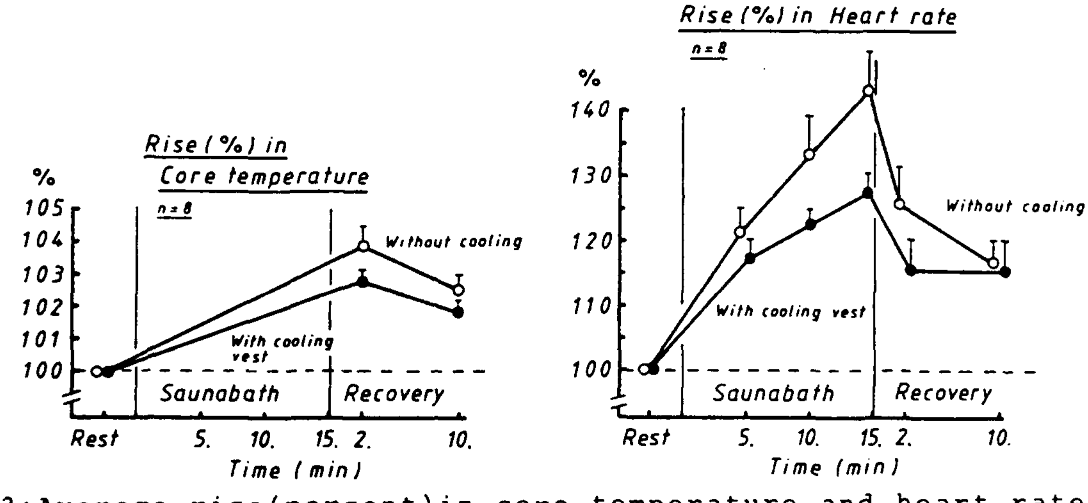

Fig. 3: Average rise (percent) in core temperature and heart rate of 8 spinally injured subjects taking a 15 min Finnish sauna bath, with and without wearing a cooling vest. Brackets =standard error.

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EFFECT OF HEAD COOLING ON MAN DURING LIGHT EXERCISE IN A HOT ENVIRONMENT

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INTRODUCTION

The head is an excellent site for removing body heat (Nunneley *et al.*, 1971) and has been investigated as a region for artificial cooling. Several studies have shown that head cooling leads to an improvement in thermal comfort under the heat stress(Nunneley *et al.*, 1971; Brown and Williams, 1982; Nunneley *et al.*, 1982), but have investigated limited physiological responses, such as body temperature, heart rate, and weight loss.

We have previously studied the effects of head cooling on several physiological functions of man at rest under the condition of ambient temperature (Ta=40 °C) and relative humidity (RH=50 %) , and during moderate exercise (40 %$\dot{V}o_2$max) under the condition of 30°C/50 % (Katsuura *et al.*, 1989), and during moderate exercise (40 %$\dot{V}o_2$max) under the condition of 40°C/50 %. Results showed that head cooling may inhibit sweating and cutaneous blood flow of man at rest and during moderate exercise in hot environments.

In this study, the effects of head cooling on physiological responses were further investigated when subjects exercised lightly in a hot environment.

METHODS

Six male students, aged 22-24 yrs, volunteered for this study. They sat on a chair in a semi-reclining position for 120 min under three thermal conditions:

(1)Ta=40°C, RH=50% with water cooled cap (water inlet temperature Twi=10 °C) [HC10]

(2)Ta=40°C, RH=50% with water cooled cap (Twi=15°C) [HC15]

(3)Ta=40°C, RH=50% without head cooling [NC]

The water cooled cap was constructed as an open network of Tygon tubing(Fig. 1). The 10 tubes involved a total length of approximately 394 cm. The cool water flowed at a rate of 1000 ml/min.

Head cooling started 30 min after the subject wearing only shorts entered a climatic chamber. The subject exercised on a bicycle ergometer for 45 min after 45 min resting. A work level was kept at 20 %$\dot{V}o_2$max. Following exercise, the subject took a rest for 30 min.

Oxygen uptake ($\dot{V}o_2$), heart rate (HR), rectal temperature (Tre), forearm blood flow (FBF), skin temperature, sweat rate (SR) at chest region , weight loss were measured on each occasion. Thermal comfort and thermal sensation were also estimated.

RESULTS AND DISCUSSION

The heat removal ($\dot{H}$) from subject's head under the HC15 and HC10 conditions were stabilized after 30 min of head cooling, and were approximately 1.8 kcal/min in HC15 and 3.0 kcal/min in HC10(Fig. 2).

Whereas $\dot{V}o_2$ did not change significantly due to head cooling, HR tended to decrease in HC10. An increase in Tre (ΔTre) with head cooling was lower than that without head cooling. There was no difference in ΔTre between HC10 and HC15 while the water inlet temperature were different under these conditions(Fig.3).

From the regression equation of FBF on Tre, the adjusted means of FBF under each condition were calculated. The adjusted means of FBF under head cooling conditions were significantly lower than that in NC(Fig.4). These results may be associated with lower hypothalamus temperature due to head cooling for a given Tre. Head cooling may inhibit sweating. The adjusted mean of SR calculated from the equation of SR on Tre was significantly lower in HC10 than those in HC15 and NC(Fig. 5). Weight loss was significantly lower in HC10 than that in NC. Both head and body thermal comfort improved with head

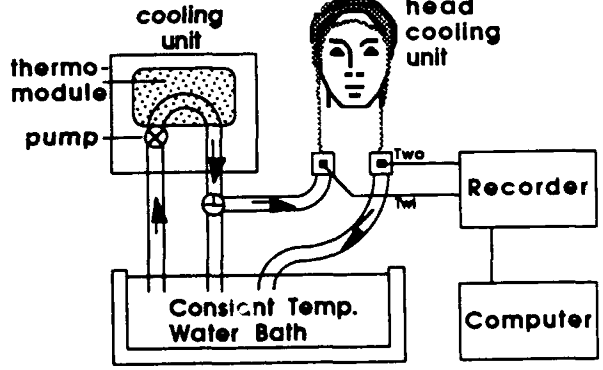

Fig. 1. Head cooling system

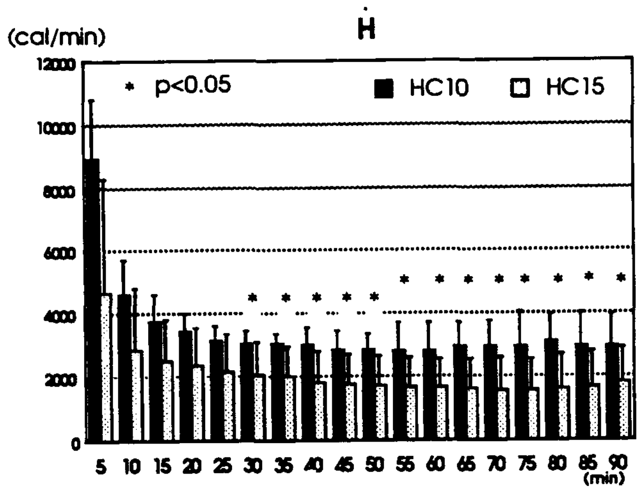

Fig. 2. Heat removal (H) from subject's head under the HC10 and HC15 conditions. Values are means ± SD.

cooling.

In our previous study(Katsuura *et al.*, 1989), it was found that ΔTre rose prominently when subjects exercised moderately with head cooling in a 30°C environment. It was due partly to inhibition of effective sweat rate with head cooling. In the present study, however, such a negative effect of head cooling was not observed. Thus, head cooling is an effective means for man during light exercise to alleviate heat strain in a hot environment.

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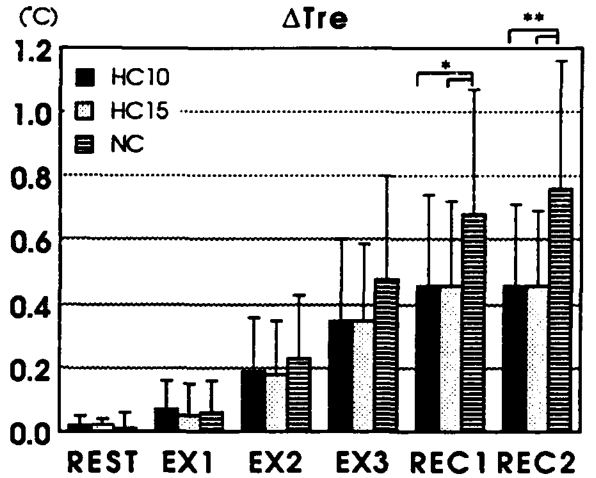

Fig. 3. Increase in Tre (ΔTre) under the HC10, HC15, and NC conditions. Values are means ± SD. *P<0.05; **P<0.01.

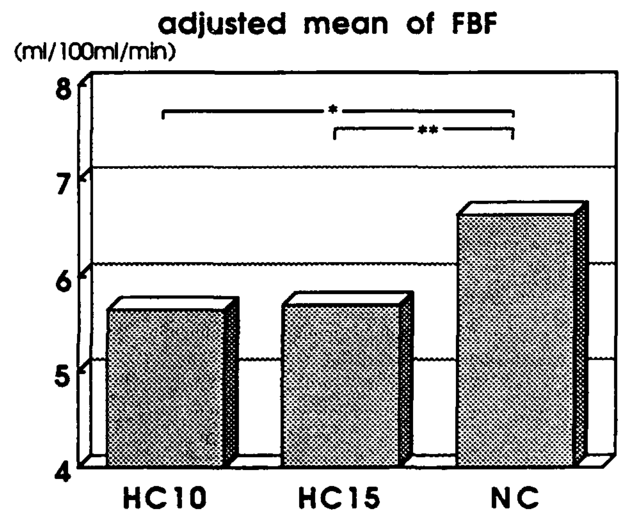

Fig. 4. Adjusted means of forearm blood flow (FBF) under the HC10, HC15, and NC conditions. *P<0.05; **P<0.01.

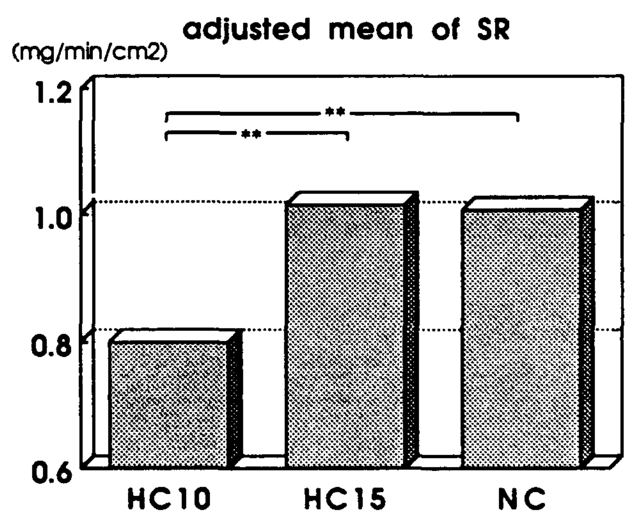

Fig. 5. Adjusted means of sweat rate (SR) under the HC10, HC15, and NC conditions. *P<0.05; **P<0.01.

A Light Weight Ambient Air Cooling Unit for Use in Hazardous Environments

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INTRODUCTION

Thermal stress to personnel as a result of working in a warm and contaminated environment is a critical problem in industry and the military. While performing under such stressful conditions an individual must wear a protective garment such as the military chemical defense ensemble (CDE) which features high thermal insulation and low moisture permeability. In the past years, various personal microclimate cooling systems have been developed and studied which remove stored heat, and therefore reduce body core and skin temperatures (1,2). Since man-mounted cooling units have the disadvantage of increased weight carriage and modest physiological cooling capacity, the concept of intermittent, microclimate cooling only during rest periods has been investigated (3). Use of either air or liquid, upper-body cooling during rest periods extended work times, lessened the associated physiological stress, and improved personal comfort when compared with uncooled control trials. However, even when cumulative heat storage was prevented, general physical fatigue was still more progressive than when no CDE was worn (4). In an attempt to further improve this concept, we conceived a strategy implementing continuous air cooling with the added wear of a filtered air blower. With this approach, ambient air ventilation is added during work while conditioned air is delivered during rest periods. This paper describes the development and testing of this continuous cooling approach.

METHODS

System Description: In the current study, a prototype ambient air cooling unit was designed and fabricated at the USAF School of Aerospace Medicine. This unit is composed of a DC vacuum blower, battery set, air plenum, control panel, 3 Army C-2 filters, and supporting frame. This compact "beltpack" unit (~ 3.8 Kg) provides 340 liters per minute (L/m) filtered ambient air through a U.S. Army developed air vest (5): 280 L/m to the body and 60 L/m to the face. The unit may be used independently or in conjunction with a chilled air cooling system.

Human Testing: The seven subjects used for this series of tests were military volunteers. The physical task employed for all test batteries in this study consisted of walking at 4.8 km/h at 3-6 % grade, which elicited approximately 40% of each subject's VO_2 max. Subjects performed either intermittent or continuous exercise in a thermally controlled chamber under warm conditions (32°C, 40% RH) until reaching limits of T_{re}= 39.0°C, HR= 180 bpm, or volitional fatigue. For intermittent work, three experimental conditions were employed with each subject serving as his own control: 1) no personal cooling during work or rest, (no cooling, NC), 2) conditioned air cooling during rest periods (intermittent cooling, IC), and 3) conditioned air cooling during rest plus ambient air ventilation during work (continuous cooling, CC). Four cycles of 40 minutes work (450 watts) and 20 minutes rest were attempted at each condition. The 510 L/m of 20° C conditioned air (85 L/m to the face) was delivered to subjects during rest periods in both the CC and IC trials. In a second set of experiments during continuous work, subjects walked on the treadmill with either: 1) no personal cooling (NC), or 2) ambient air ventilation (AV) until reaching one of the termination criteria specified above.

Data Analysis: Preliminary statistical analysis applying a 3-way ANOVA was conducted using physiological data and ratings from Thermal Comfort and Rated Perceived Exertion including all conditions, and a second 3-way ANOVA was accomplished to specifically compare IC and CC using paired data from these conditions only. Rates of sweat production, and evaporation were analyzed using a 2-way ANOVA. Significance was accepted at the P= .05 level for all tests.

RESULTS

During the intermittent work scenario where subjects attempted four hours of work-rest cycles, all seven subjects completed at least 80 minutes in the NC trial. Initial analysis of these data indicated that individuals receiving cooling performed significantly better both physiologically and perceptually than in the NC condition. Since four of the subjects completed at least 140 minutes work in IC and CC conditions, an additional statistical analysis was conducted up to this point for IC and CC only. This analysis indicated that the increase in rectal temperature and mean skin temperature observed over the first three work periods was significantly greater during IC than CC. Although there were no differences in heart rate during the work cycles, the average heart rate during rest cycles with CC was significantly lower than for IC. Sweat production rates (SP) were significantly lower for CC and IC than for NC, while the rate for CC was also lower than for IC. Additionally, the sweat evaporation rate for CC was higher than for IC and NC. Therefore, the percentage of sweat evaporated during the CC condition was also significantly greater than for IC or NC.

Use of ambient air ventilation (AV) during 50 minutes of continuous work, resulted in significantly less increase in heat storage. Mean skin temperatures were observed to be significantly higher in the no cooling (NC) scenario. AV also had a significant effect on lowering thermal comfort ratings (TC), which was evident even at the 10 minute point. Sweat production rates (SP) were not different for AV and NC. However, there was a significant difference in sweat evaporation (SP) and percent of sweat evaporation.

DISCUSSION

All cooling scenarios (AV,IC,CC) decreased thermal strain as compared to no cooling trials. Significant differences between continuous cooling and intermittent cooling were observed in the following physiological measures: skin temperature, heat storage, and sweat evaporation efficiency. The 3.8 kg load experienced by subjects when carrying the ambient air cooling unit during work periods might have counteracted some of the expected physiological and psychological benefits from ambient air ventilation. However, since only four subjects completed at least 140 minutes of intermittent work, limited data were analyzed. These data may not be adequate to reflect truly significant physiological effects. It is necessary that additional subjects finish four work-rest cycles with continuous air cooling to more accurately evaluate the full effect of CC. Further reduction in weight of the ambient air cooling unit and optimization of work-rest cycle length would possibly amplify the efficacy of the application of ambient air ventilation. Additionally, the filtered ambient air gained heat from the motor and control panel, increasing inlet air temperature approximately 2-3° C. Therefore, skin temperature and the resulting thermal perception may have also been increased. Another possible improvement may be to increase the air volume to 560 L/m to the body, 140 L/m to the face since most subjects commented that air flow to the face was marginal during work.

CONCLUSION

This beltpack, ambient air cooling system has been shown to reduce thermal stress during work when wearing the military CDE. Further improvements would support the main objective of ambient air ventilation which is to maximize the reduction of thermal stress for individuals working in a warm environment while wearing protective garments. The positive air pressure which results from the system may also decrease breathing resistance and increase protection from toxic substances. Consequently, mission effectiveness during a chemical warfare or industrial decontamination scenarios should be enhanced.

ACKNOWLEDGEMENT

We would like to note the critical technical suggestions provided by Dr. A.L. Allen, USA Natick RD&E center IPD/LSSD, regarding the choice of blower and battery hardware.

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HUMAN PERFORMANCE ASPECTS OF NEW DRAFT EUROPEAN STANDARDS FOR LIFEJACKETS AND PERSONAL FLOTATION DEVICES

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INTRODUCTION

Scientific efforts to develop good lifejackets and other devices to aid flotation started during the Second World War, and included the pioneer studies of Macintosh and Pask[1]. Most countries, and some international organisations (such as IMO), have adopted their own detailed performance standards, many of which have led to demonstrable reductions in the incidence of fatal immersion events. For some years, attempts to reach agreement on an International Standard under the auspices of ISO have struggled with reconciliation between strongly held and opposing views. However, the EEC Council Directive recently published[2] forced the countries of the EEC and, by association, those of EFTA to develop and agree a set of standards which will be legally binding within Europe from 1993 onwards.

In a period of less than six months, a working group of experts from many of the member states of the EEC and EFTA was required to produce draft standards which would satisfy all requirements for lifejackets and buoyancy aids (or personal flotation devices) excepting for those circumstances in which IMO approved items are required, and those in which FAA or CAA legislation is effective. These encompass many offshore workers, those employed to work on or near water in other circumstances, and the ever-increasing number of leisure users in powered and sailing craft. This paper discusses some aspects of these standards, and considers what developments they may lead to in the future.

STANDARDS

It was agreed that no single standard could satisfy the needs of every user, and four different ones have survived into publication as draft European Standards[3]. Although these are categorised by the buoyancy level provided, there are many other differences between them, and various national terminologies are free to use whatever descriptors are most appropriate. There is no intention that performance is directly dependent on buoyancy alone, rather that buoyancies are an easily measurable means of classification. Minimum levels for adults have been set at 275, 150, 100 and 50 N, which are intended to cover, respectively, offshore use when counter buoyancy is present or loads are carried, general offshore use, inshore use in relatively calm waters, and circumstances where the user is a swimmer and help is immediately to hand.

The aim with the three higher levels is to provide sufficient buoyancy positioned in such a way that an incapacitated wearer is kept with his airways clear of the water, so increasing the likelihood of his rescue alive. After much discussion, it was agreed that a measurement of freeboard between mouth and water surface would be included, although the height set as a minimum, 80 mm, is clearly not that which is desired. This was because of a number of reports that such measurements can be difficult to achieve reliably in test houses[4], so making it possible that good devices would be failed. On the other hand, tests of self-righting have been retained in the two highest buoyancy categories, and using a less stringent test for the 100 N standard too. These latter considerations have been made more important as the result of recent publications[5,6] which have highlighted the possible adverse interactions between buoyant devices and air trapped within immersion suits, which may act as counterbuoyancy.

Counter to these tendencies to produce large, high performance lifejackets was the experience of the Nordic countries[7], which indicated that the cheaper, simpler, and above all more comfortable the lifejacket, the more likely it was to be worn and used, and thus the greater the reduction in immersion casualties. There are also situations in which the use of highly buoyant devices may prevent escape from a capsized dinghy or other vessel, so it was agreed that even those buoyancy aids with relatively little buoyancy should not be excluded from standardisation, and that other devices should be made more attractive to the wearer.

Another area of controversy has been the requirement for display of retro-reflective tape. In the past it had been argued successfully that the great majority of users would not be likely to be immersed during darkness or poor visibility, and that the additional cost of such tape would deter the prospective purchaser, but increasing amounts of retro-reflective tape will be required for all devices from the 100 N standard upwards. Lights and other location aids are the subject of a separate document (which also provides standards for multi-chamber buoyancy systems, safety harness and line compatibility, splash screens, and industrial protection)[3]. The standards also prescribe series of minimum buoyancy levels for devices for children, when appropriate, although it has been agreed that evidence as to what is necessary is sadly lacking. Finally, great attention has been paid to the labelling of lifejackets and buoyancy aids, in order to ensure that no matter who uses them, they can be well informed about their use and limitations.

DISCUSSION

Although it is many years since the pioneering work of Macintosh and Pask[1], remarkably little scientific work had been carried out until the recent studies suggesting that there may be problems when lifejackets are worn in conjunction with immersion protective garments[5,6]. At present, there is no simple performance test which can be carried out with good reproducibility in all test houses, to ascertain whether or not a suit and jacket combination is safe. Efforts to do so are to be encouraged, and any resulting test should be included in future revisions to these standards.

Another area in which there has been very little work is that of the buoyancy and other performance indicators for devices for children. As body proportions and density of children of different ages are quite unlike those of adults, it could be suggested that the current guessed extrapolations are erroneous, but in the absence of any good evidence, it is not possible to set different values. Work on this is urgently required.

Labelling of many other safety items is now being carried out using pictograms and other clear non-verbal means. The CEN Working Group has been unable to devise clear pictograms which are suitable for indicating the subtle differences between the different performance standards, but would like to be able to use some. Further work and the input of ergonomics research would be valuable.

If the whole of Europe is to adopt and enforce these standards – one of the provisions of the directive[2] is that it will be illegal to produce or sell items which do not comply with them – then there is also a need to base more international standards, such as those which ISO must eventually produce, on them. This does present an unusually difficult situation, in that previously, ISO has been in advance of CEN, and it has been easy for CEN to adopt an existing ISO standard. With regard to lifejackets, the process must be reversed, which could cause conflicts with non-CEN nations. However, it is hoped that the latter may see in these draft European standards very close parallels to their existing national ones, and that compromise may be reached.

Finally, it would be only logical if the existing international standards maintained by the IMO, and the FAA and CAA, could be incorporated in some way too. Those responsible for the European Standards believe that they have created good standards which will result in major safety improvements, and will be beneficial to both users and manufacturers. It would be even better if the world could move away from the many dozens of often conflicting national standards to a simple, functional and universal system.

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ABBREVIATIONS

CAA – Civil Aviation Authority; CEN – European Standards Committee (EEC); EEC – European Economic Community; EFTA – European Free Trade Association; FAA – Federal Aviation Authority (USA); IMO – International Maritime Organisation; ISO – International Standards Organisation.

THE DEVELOPMENT OF AN

INSULATED LIFERAFT FOR POLAR CONDITIONS

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Regulations formulated by international regulatory bodies are normally developed to meet a common acceptable standard and in many instances, do not fully address the requirements for vessels operating in extreme conditions. It is the responsibility of national regulatory agencies to develop specific regulations that address their country's unique requirements. Accordingly, The Canadian Coast Guard has been carrying out research and development in the Arctic Region in order to attempt to formulate a required Arctic Survival life saving equipment pack for vessels in extreme cold environments.

This paper describes work sponsored by the Canadian Coast Guard and carried out by The CORD Group Limited. The work involved the design, analysis, construction and laboratory testing of a prototype liferaft which can function as part of the envisioned life saving equipment pack.

The design phase of the work consisted of needs analysis, design objectives formulation with constraints, the development of design criteria, the creation of design solution alternatives and finally a design specification. Of the design objectives, the most important were:

- The liferaft must provide thermal protection of personnel from hypothermia by maintaining their bodies in thermal equilibrium; and

- The liferaft must maintain an interior atmosphere of acceptable composition.

The constraints included the use of a Dunlop-Beaufort ten-man, navy, twin arch liferaft, compliance with Canadian Coast Guard standards, the existence of 20 km/hr winds, personal insulation of 2.69 Clo with 3 Clo sleeping bags and physiological criteria of the occupants.

Concurrent with design, baseline tests were carried out on the standard (uninsulated) raft for evaluation of the 'insulated' design to assist in the development of design specifications and to use in the development of mathematical models during the analysis phase. Parameters measured were air infiltration, heat transfer through the envelope and internal air temperatures. These parameters were measured as functions of wind velocity and direction and the number and positions (sitting or lying) of raft occupants.

The design and construction phases culminated in the production of an insulated raft by the modification of the standard one. The design consists of replacing the double-walled canopy with a manually inflated double canopy with two (2) layers of 8 oz. Polarguard batting plus a layer of metallized Mylar between the two (2) shells. A skirt of similar design was added inside the liferaft against the buoyancy tubes or side walls. The floor was replaced with a new manually inflated floor using the same design as the canopy and sidewall skirt except the shell materials and stitching between the shells were stronger because of the higher air pressure required to keep the floor rigid with occupants sitting or lying on the floor. In addition, one door was eliminated and replaced with a 10" vent with adjustable closure, an insulated plug was provided for the remaining door and a removable vestibule was provided to fit over the boarding ramp to provide a double entrance way. Finally, a Nomex removable liner was added to provide some internal fire retardancy and to absorb condensation.

The laboratory testing phase continued with the test protocol used for the baseline tests of the uninsulated liferaft being repeated on the modified insulated liferaft. The results showed a marked improvement of the insulated liferaft in controlling infiltration and envelope heat loss except for the floor directly under the occupants. The insulation in this area actually showed poorer insulation than that for the uninsulated raft.

This can be explained when one considers the fact that both the uninsulated and insulated raft floors are inflatable and that a slow leak in the insulated floor allowed it to deflate and so become very thin under the occupants.

The analysis phase of the work involved the use of mathematical modelling to characterize the heat transfer through the raft envelope, the physiological performance of the occupants and the air quality of the raft atmosphere. A detailed steady state analysis of heat transfer and air quality was done using a spreadsheet and a dynamic analysis including all three mechanisms was done by Dr. Eugene Wissler of the University of Texas at Austin.

The results show that an insulated raft is indeed a benefit and that proper design of the floor is important to maintain an acceptable level of insulation. However, an increased level of personal insulation is still required. Auxiliary heating should also be considered.

ERGONOMIC AND HUMAN FACTORS ANALYSIS OF RAM PARACHUTE RIPCORD/HANDLE SYSTEMS

PART I: TORSO POSITION

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INTRODUCTION

Parachute ripcord/handle positioning on the parachute harness in both military and civilian ram parachute assemblies have not formerly been subject to a comprehensive ergonomic and human factor analysis. Some studies have analyzed strength requirements and release capabilities of ripcords/handles for certain populations, however to date little work is available defining torso position based on an ergonomic and human factor analysis[1-2]. A study of this nature is important. Parachute ripcords/handles are used to deploy main parachutes, 'cut-away' a malfunctioning parachute, and deploy the reserve parachute. These procedures require precise hand-arm-eye coordinated movements which are executed in a freefall and stressful environments. In the military setting this situation is magnified due to the added problems of equipment weight and bulk, clothing bulk, gloves, and in certain circumstances life support systems.

This study conducted an ergonomic and human factors analysis of ripcord/handle system positioning on the harness of conventional present day military ram air parachute assemblies. Specifically, vertical and horizontal positioning on the harness was studied to define arm movements required to activate the system and to identify the optimal positioning to ensure ease of grasp, excessibility, visibility and biomechanical advantage. In Part I of the study, the main deployment handle was analyzed. This is located on the right riser of the harness.

METHODS

The primary method of analysis was based on a biomechanical computer model that was designed to simulate the upper arm movements around the ripcord/handle along the front right of the torso. The model used a geotrigometric solution solving for elbow angle, and posterior shoulder rotations necessary to reach and grasp the ripcord/handle without flexing the wrist. Fixed variables in the model were based on a three dimensional input which included shoulder declination, position of the ripcord on the torso, and the protrusion of the ripcord beyond the side of the torso. The model is based on the 95th centile arm length with component segments calculated from regression models from US Army male anthropometric data[3]. Three dimensional graphic surfaces were generated to describe the output and the define the associations between the output variables. The model was run in iterative sequences mapping out contours of elbow angle required to reach and activate the ripcord/handle. The model assumed a properly fitted and adjusted harness.

RESULTS

Military ram air parachute assemblies show poor ergonomic and human factor design of the ripcord/handle system positioning. Ripcord/handles are placed in positions that require extreme elbow flexion and posterior shoulder rotation with wrist flexion to acquire and activate the system. Military parachutists are therefore forced to use awkward arm movements and positions to activate the parachute. The biomechancial model also defined and quantified the required arm movements. This showed that ripcords and handles are commonly too high (headward) up on the front of the chest. The model demonstrated by lowering the ripcord/handle downward (towards the waist) on the front of the chest, the angles at the elbow, posterior shoulder rotation, and wrist flexion could be optimized thus ensuring a less awkward ripcord/handle operation.

It was found that the ideal position for a ripcord/handle is dependent on the individuals arm length, torso length, clothing bulk, and chest depth. The ideal location for the ripcord can be identified using an anthropometric land mark, the olecranon. This is used by placing a 90 degree flexed elbow against the side of the body in the vertical plane and using the olecranon to mark the mid-point of the ripcord/handle position on the side of the torso. Here the ripcord/handle should be placed on the riser of the harness.

CONCLUSION

The governing principles underlying the placement of ripcord/handle systems on the parachute harnesses is visibility, accessibility, ease of grasp, and force to activate. All of these criteria are improved by keeping the positioning low rather than high on the torso. This analysis has begun to formalise and define parameters of upper arm movement that will provide parachute designers with guidelines to make ripcord/handle systems with better ergonomic and human factor design.

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Characteristics of visual responses viewing at VDTs

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INTRODUCTION:

The authors have developed three-dimensional Optometer (TDO) which can measure major three basic ocular functions - eye movement, accommodation and iris area - while watching real visual targets. The TDO was applied to measure visual responses of three young subjects working at VDTs.

METHOD

Equipment: The TDO system is shown in Fig. 1. The second box from the left depicts a modified auto refractometer (NIDEC, AR3-SV4) to measure accommodation. The left box contains a light relay system which directs infrared light emitted from the AR3-SV4 into a pupil perpendicularly, irrespective of the angular eye position. The feature is obtained by moving two galvano-mirrors in the box according to eye movements. On the right side, there is an eye monitor, a controller of the galvano-mirrors, a calculator to determine the area of the iris and a microcomputer to control the timing of measurement.

Precision and cutoff frequency in measuring accommodation and iris response are the same as for commercially sold devices ($\pm$ 0.25D, $\pm$ 2% ; 4.7Hz, 6.4Hz, respectively), and those of eye movement are $\pm$ 0.5° and 4.7Hz, respectively. Visual angles allowed are 40° horizontally and 30° vertically (-25° ~ +5°).

Subjects: Three emmetropic youth (2 females O.R. age 23, B.S. age 21 and a male K.H. age 19) were used as subjects. They demonstrated visual acuity of 1.0 or more without correction and accommodative power of 7.7, 4.6 and 7.2 diopters, respectively. The dominant eye, which was the right eye for all the subjects, was measured.

Task: The subjects were required to search specified 2 digits numbers out of 19*14 displayed random numbers on a CRT as shown in Fig. 2. The search time was consecutive 60 minutes without a break. Accommodation, eye direction and iris area were measured every 10 minutes while the subjects were continuing the task.

Results:

Fig. 3-4 show the visual responses (left) before the VDT work and (right) after 1 hour work of subjects OR and BS. Lines (A) are accommodation responses, lines (X) are horizontal eye movement (left eye position is shown in upper side deviation in the figures), lines (Y) are vertical eye movement and lines (I) are pupil diameter. Vertical division means 1 diopter change of accommodation, 5 degrees of eye movement and 1 mm pupil diameter change.

The most remarkable and prominent feature of the visual responses as shown for examples in the Fig. 3-4 is that the amount of fluctuation in the accommodative responses tend to increase by the prolonged usage of VDTs.

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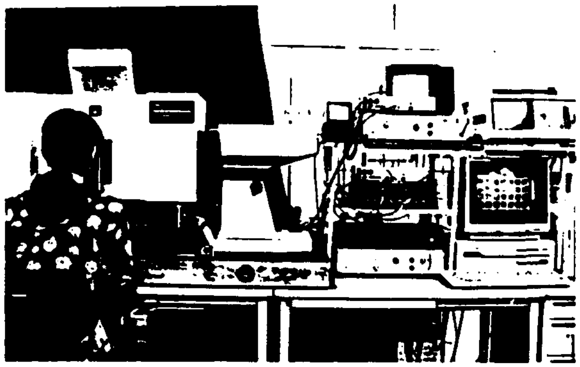

Fig.1 The TDO system which can measure accommodation, eye movement and iris diameter simultaneously while Subjects are shifting eye position freely.

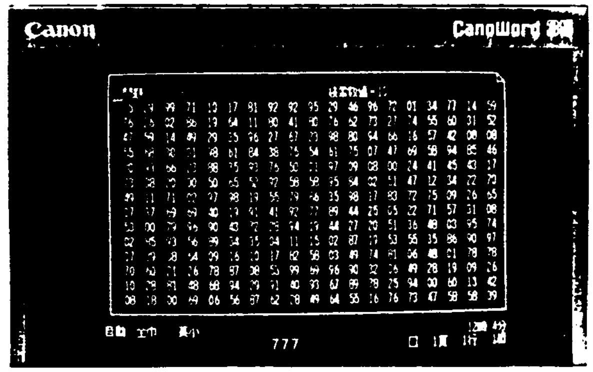

Fig.2 The display used. It shows 2 digits random numbers (19*14). Subjects are required to search a specified number.

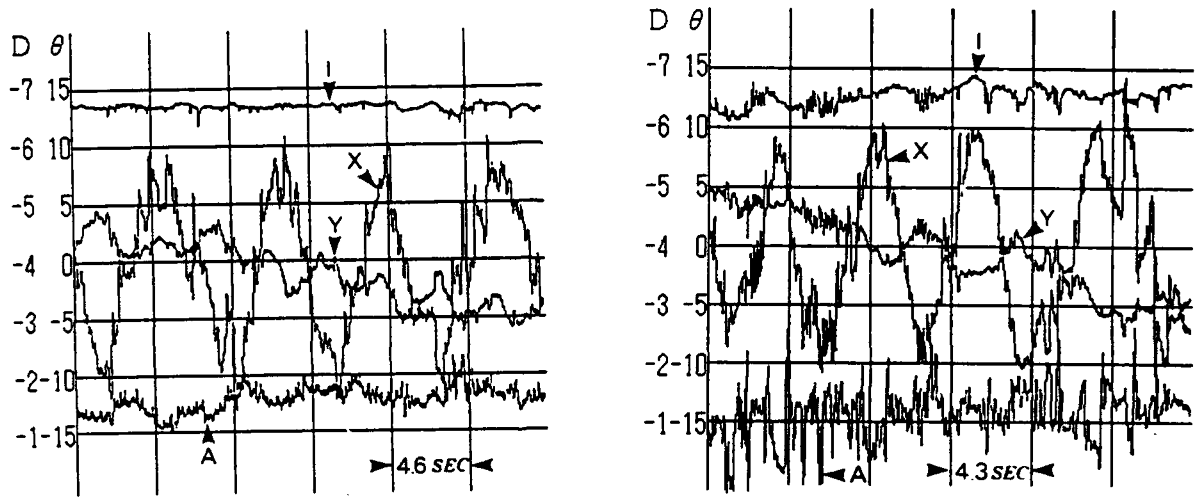

Fig.3 Response of subject OR. Left is a response before the VDT work and the right is a response after an hour of the VDT work. The response curves are accommodation (A), horizontal eye position (X), vertical eye position (Y) and pupil diameter (I), respectively. Horizontal divisions are 1 diopter of change in accommodation, 5 degrees of eye position and 1 mm change of iris diameter, respectively.

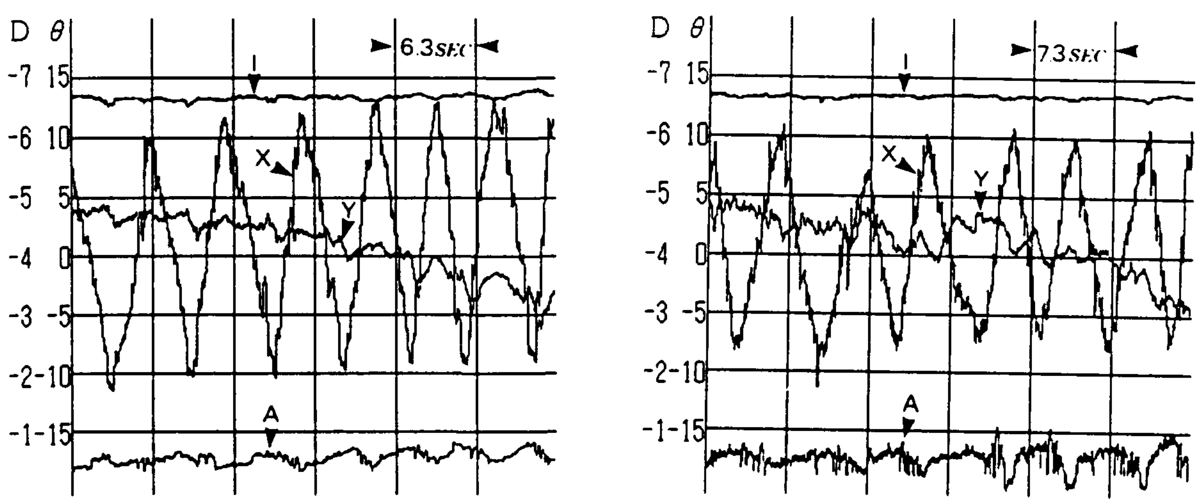

Fig.4 Response of subject BS. Left is an response before the VDT work and the right is the response after an hour of the VDT work. The mean of symbols and vertical division are the same as in Fig.3.

<u>COLD-WATER SURVIVAL</u>

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Cold-water survival is dependent on avoidance of both drowning and hypothermia and upon the many factors related to these risks (1,2):

1. The ability to swim
2. The ability to keep one's head out of water (even without flotation aids)
3. The ability to avoid panic
4. The sea-state
5. The availability and type of personal flotation device
6. The availability of a life raft
7. The availability of other floating objects to increase one's buoyancy (e.g. a capsized boat, etc.)
8. The water temperature
9. The physical characteristics of the survivor
10. The type of protective clothing worn against immersion hypothermia
11. The behavior of the survivor in the water
12. The availability of signalling devices (e.g. whistles, flares, strobe-lights, [illegible] and mirrors)
13. The proximity of rescue personnel

Drowning is the most immediate survival problem following water entry. To maintain airway freeboard and to avoid drowning, a survivor must possess the physical skills and psychological aptitude to combat the effects of wave action. Although a personal flotation device assists in maintenance of airway freeboard, waves can still submerge a survivor's head, even in moderate sea-states (3). A survivor can reduce his risk of drowning in rough seas by increasing effective airway freeboard by partially exiting the water (e.g., clinging to an overturned vessel or other debris floating in the water), or by climbing totally out of the water into a life raft or onto a capsized vessel. In both these environments, the survivor may still have to cope with the effects of cold wind, spray, and waves.

Sudden immersion in cold water is accompanied by cardiorespiratory reflexes which can potentiate the risk of drowning. The abrupt release of sympathetic catecholamines potentiates the risk of incapacitating cardiac dysrhythmias in susceptible individuals or of myocardial infarction or cerebrovascular accident in persons with arterial disease or hypertension (4). Sudden immersion in cold water initiates a reflex gasp and hyperventilation (5), which significantly shorten breath-holding time. This reflex can have severe consequences for survivors attempting an underwater egress from a submerged vehicle, capsized vessel or aircraft, or for survivors simply trying to maintain airway freeboard in rough water.

If a victim of cold-water immersion can avoid drowning during the initial few minutes following water entry, then prevention of hypothermia becomes an important problem. Survival time in cold water, based on the pathophysiological effects of decreasing core temperature, is not a precise calculation. The large individual variation among survivors in morphology and [illegible] of health and fitness, combined with many exogenous variables affecting cooling rate (e.g., clothing, water temperature, sea-state, flotation, and behavior) preclude exact survival time predictions. However, sufficient experimental data and case-history findings exist to [illegible] generalizations. At a core temperature of 34 C, there is a significant deleterious effect on manual dexterity and "useful function" in cold water (6,7). If a survivor is trying to [illegible] rough seas, this level of dysfunction may potentiate drowning. At a core temperature of

30 C, unconsciousness is probable (8). Even if a survivor is wearing a self-righting flotation device, designed to maintain airway freeboard in an unconscious person, drowning is probable at this core temperature in all but the calmest sea-states. Finally, at a core temperature of 25 C, cardiac arrest is probable. Of these three temperatures, 30 C is the most practical for defining limits of survival in cold water.

For immersion hypothermia, the most important variables affecting cooling rates are:

1. Water temperature
2. Survivor's percentage body fat
3. Type of protective clothing worn by the survivor
4. Sea-state
5. Survivor's behavior in the water
6. Amount of the survivor's body immersed in the water

A large number of studies over the past few decades have evaluated the relationship of different types of protective clothing to heat loss and cooling rates (9,10). Nearly all of these have been conducted in calm water or laboratory settings. Most have shown that in calm water, intact, "dry" insulated garments provide better protection than do "wet" insulated garments; and well-insulated garments provide significantly better protection than do poorly insulated garments. In rough seas, a survivor's cooling rate may be affected by swimming to maintain airway freeboard, passive body movements caused by waves, flushing of cold water through "wet" suits, and leakage of cold water into "dry" suits. Recent studies have demonstrated: 1) significantly faster cooling rates for human volunteers wearing "wet" protective garments in rough water or moving water than for persons in calm water (11); 2) higher energy expenditure and faster cooling rates for subjects in a wave-tank than for subjects in calm water (12).

All of the above factors make survival times in cold water highly variable: as short as a few minutes for drowning victims to many days for well-protected survivors with adequate buoyancy.

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HUMAN INITIAL RESPONSES TO IMMERSION IN COLD WATER: EFFECT OF WATER TEMPERATURE AND PRIOR HYPERVENTILATION

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INTRODUCTION

The initial responses to immersion in cold water include an "inspiratory gasp," hyperventilation, tachycardia, peripheral vasoconstriction and hypertension [1,2,3]. These responses represent a significant threat to individuals who are immersed in cold water by choice or as a result of an accident. For individuals with pre-existing hypertension or coronary heart disease the cardiovascular responses may be particularly hazardous. For healthy individuals it is the respiratory responses which represent the major threat by preventing the conscious control of breathing at a time when it is most needed.

It is likely that the initial responses to immersion in cold water are responsible for the majority of the 400-1000 open water immersion deaths which occur in the U.K. each year [4]. Despite the obvious importance of these responses they have received little detailed investigation: the relationship between water temperature and the responses is still, for example, a matter for debate[2,5,6].

The aim of the present investigation was to examine the initial physiological responses of human subjects to immersion in water at three different temperatures, chosen to represent the range of U.K. mean coastal water temperatures. The influence of hyperventilation before immersion on the respiratory response observed during immersion was also examined, in an attempt to obtaining some insight into the mechanisms which initiate and modify this response.

METHOD

The experimental protocol was approved by a local ethical committee prior to subject recruitment. Eight naked subjects performed head-out immersions of two minutes duration into stirred water at 5, 10 and 15°C, and into 10°C after one minute of voluntary hyperventilation during which the end-tidal concentration of carbon dioxide was lowered to 3%. A repeated measures Latin Square experimental design was employed in which the subjects were all exposed to each of the four conditions once, with at least a week left between successive immersions.

Following a 10 minute pre-immersion period in thermoneutral air the subjects were immersed at $0.18\ m.s^{-1}$ into the cold water. During each experiment respiratory (respiratory frequency, tidal volume, expiratory/inspiratory volume and oxygen consumption), cardiac (heart rate) and thermal (chest skin temperature) responses were recorded. A week after their last immersion the maximum breath-hold time of subjects was determined at rest in air. The data obtained were examined using an analysis of variance technique and Sheffes method of multiple comparisons.

RESULTS

The chest skin temperature of subjects fell at a faster rate and was lower on immersion in water at 5 compared to 10°C ($P<0.05$), and on immersion in 10 compared to 15°C ($P<0.05$). Despite this, analysis of the respiratory and cardiac data collected during consecutive 10 s periods showed that differences between the variables recorded on immersion in water at 5 and 10°C were due to the duration of the responses evoked, rather than their magnitude during the first 20 seconds. The exception to this was the tidal volume of subjects which was higher on immersion in water at 15°C than 5 or 10°C.

Hyperventilation before immersion in water at 10°C did not attenuate the respiratory responses seen on immersion and the minute ventilations of subjects during the first and second minutes of immersion were significantly ($P<0.01$) negatively correlated with maximum breath-hold time in air.

CONCLUSIONS

The results suggest that the respiratory drive evoked during the first seconds of immersion is more closely reflected in the rate rather than the depth of breathing at this time. It is therefore concluded that during the first critical seconds of immersion, water at a temperature of 10°C can represent as great a threat as water at 5°C and, in water at 10°C, the respiratory component of this threat is not influenced by the biochemical alterations associated with prior hyperventilation.

The inverse relationship identified between the maximum breath- hold time of subjects in air and their ventilatory response to immersion may be due to the differing capacities of subjects to consciously suppress ventilatory drive, from whatever stimulus: mechanical, chemical or thermal. This implies a conscious component in the habituation of the respiratory responses to immersion and has implications for the selection and training of those at high risk of immersion in cold water.

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THE DYNAMIC BEHAVIOUR OF THE FLOATING SURVIVOR IN SEA WAVES AND ITS EFFECTS ON AIRWAY PROTECTION

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INTRODUCTION

Lifejackets are worn to provide protection from drowning. Their performance is specified in terms of mouth freeboard, flotation angle, self-righting, and stability in tests that are usually conducted in calm water, the assumption being that this performance is related to the protection provided in waves. Dynamic tests are difficult to perform. Real sea waves do not provide a reliably reproducible environment and the danger of drowning for the human subject wearing a poorly performing lifejacket is very real! Limited wave simulation is possible in large tanks, but these are expensive and do not abolish the risk of drowning for the subject. In any case, the measure of the degree of protection provided will be very subjective and influenced by the subject's reaction to the wave insult. Marine manikins have been developed that remove some of these difficulties and these can be fitted with devices to measure the protection provided by immersion protective clothing assemblies. This paper describes experiments which demonstrate how the protection provided by a lifejacket as measured by a simple assessment of static freeboard may not reflect the performance in waves. The method was extended to demonstrate how well a marine manikin simulated the flotation characteristics of relaxed human subjects. Finally, a device to measure the protection provided by a lifejacket was calibrated using a breathing dummy head.

METHOD

Two immersion-suited subjects (nude weight 67kg & 110kg) and a nude water-filled fabric manikin (wt 106kg) were subjected, for a range of flotation angles of 0-90^{o}, to vertical impulsive displacements in an immersion pool (6x2.5x3m) while wearing regular military lifejackets. Their subsequent transient motion was recorded digitally at a 32Hz frame rate using an image array camera system together with helmet-borne LED markers arranged to detect both rotational and translatory displacements. The static buoyancy/immersion characteristic of the lifejacket was also determined. Similar impulse and static measurements were made on 4 subjects (nude weights 63, 75, 78, 85kg) and two commercial marine manikins (RAMM1, RAMM2; RGIT OSC, Aberdeen, UK) (nude weight 72kg) to determine whether the manikin dynamic behaviour adequately simulates that of relaxed humans. Tests were conducted with subjects and manikins both nude and attired in lifejacket/protective clothing combinations commonly used by UK offshore operators.

Motion recordings, employing instrumentation similar to that above, were made of 3 human subjects and RAMM2 floating in simulated sea waves of fetch 7km (576m^2 wave tank), in accordance with the Joint North Sea Wave Project (JONWSAP) power spectrum (1). Data from a 4 LED helmet-mounted array were collected as the untethered subjects, wearing various lifejacket/immersion suit combinations, floated through the camera view field (time window = 30s).

In a parallel study the performance of a mouth-mounted splash detector system, which has been used with RAMM to assess the protection capabilities of immersion/flotation clothing (2), was compared with that of an RAF IAM system of different design (3). Both devices were mounted on an artificially ventilated dummy head which accurately modelled the human upper airways and were immersed in simulated waves of varying severity. Water volumes inhaled by the dummy during 5 minute intervals were recorded, together with response frequency and duration of the two splash detectors.

RESULTS

Post-impulse motion data from subjects and fabric manikin were analysed to distinguish the vertical linear (z) and rotational components. Rotation was generally less than 14^{o} and contributed little to vertical motion of the mouth. Using a second order model, exponentially damped sine waves were fitted to the invariably oscillatory z component data and mean values for damping ratio and natural frequency were derived. Damping ratios and natural frequencies were in the ranges 0.054-0.230 and 0.49-0.8Hz, respectively. The manikin exhibited the lowest damping, perhaps due to absence of clothing, while resonant frequency increased with flotation angle (possibly due to increased body flexion at a near horizontal attitude). Idealised frequency response plots were produced in order to predict the effect on mouth freeboard of motion in sea waves. These showed peak magnification factors ranging from 2.5 to 9.5, depending on damping. An expression was derived relating minimum freeboard to avoid mouth immersion with steady state frequency response parameters, and it was shown that there was sufficient energy in typical sea waves around the measured natural frequencies to cause transient mouth immersion when the static freeboard is 0.11m.

A similar analysis of the RAMM/human subject comparison data showed that for both humans and RAMM manikins the natural frequency and damping ratio were greater ($p<0.05$) for the dressed condition, consistent with increased stiffness and drag. For the dressed condition, human natural frequencies were proportional to the reciprocal of the square root of the subject's mass ($p<0.01$), and the natural frequencies of the manikins were within the range of the human values. For the undressed case, the manikins' natural frequencies were slightly lower than those of the humans. Small differences in damping ratio for humans and manikins were also determined for both dressed and undressed conditions.

For the simulated sea wave trial analysis, power spectral densities were estimated from the z data. Attention was concentrated on 20 frequencies between 0.31Hz and 1.5Hz since most of the power in the responses was concentrated in this band, as was that of the JONSWAP waves. Small but significant differences between the power in human subject and RAMM2 motions were determined at frequencies near 1.0Hz. Differences in response power of both manikin and humans when wearing 3 lifejacket/immersion suit combinations were clearly shown in the range 0.56Hz to 0.81Hz.

Analysis of splash detector signals showed that for the IAM device (4 probes spanning the mouth) the best correlate with inhaled water volume up to 500ml was the percentage duration of a logical-AND sensor signal combination ($R^2=0.985$). For the RAMM system (2 bilateral probes) the best correlation obtained from mean event rate ($R^2=0.981$). This difference in performance is in part attributable to the greater responsivity of the IAM device. The results indicate that on average 41 splashes or a total splash duration of 1.5s will cause inhalation of 200ml of water, which can cause drowning (4).

DISCUSSION

Despite the limitations of the simple linear model (eg, non-rigidity and nonlinear buoyancy-displacement characteristics of the floating bodies), the results suggest that the impulse method is useful in predicting real wave behaviour, which is borne out by the simulated wave measurements, since both techniques showed small differences between human and manikin responses. The initial study provides evidence that a more horizontal flotation attitude improves the dynamic freeboard, in that damping and resonant frequency are increased; other methods of achieving this end may be investigated with the impulse test.

The RAMM splash detector investigation showed that it provided a reliable prediction of airway protection and agreed well with the performance of an independently designed system.

CONCLUSIONS

Current lifejacket design, while addressing such aspects as wearability, stability, self-righting, spray protection and freeboard, should also take account of the dynamic behaviour of the wearer in waves, which may be modified, for instance, by other clothing. Impulse testing in a small immersion pool together with splash measurements in real sea waves, using a marine manikin as the test vehicle, affords a safe technique of assessing these additional performance factors important for airway protection in waves.

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SIMULATION OF ROUGH SEAS IN A WATER IMMERSION FACILITY: PART II - COMPARISON OF LABORATORY TO FIELD DATA

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INTRODUCTION. To examine the effects of rough compared to calm seas on human thermal responses to cold water immersion, two unique field evaluations were previously conducted by the U.S. Coast Guard (1, 2). Testing was conducted in a river in the Northwestern U.S., when water temperatures averaged 6-11°C. In these studies, body cooling rates with wet suit garments were 1.5 to 2.0 times faster in rough compared to calm seas. To simulate the cooling effect of rough seas in the laboratory, the Navy Clothing and Textile Research Facility has evaluated a number of techniques utilizing compressed air and water surface current to create turbulence in a water immersion tank. Initial work was conducted on a thermal manikin to compare eight methods of water agitation for their effectiveness in reducing the thermal insulation (clo) of an anti-exposure garment. A diffuse compressed air methodology was found to be both effective in reducing thermal insulation and practical for routine laboratory use. To evaluate the validity of this technique, human testing was then conducted both in the laboratory and during a rough seas field evaluation.

METHODS. Eight male subjects (age, 25 yr; ht, 175 cm; wt, 68 kg; body surface area, 1.8 m^2; body fat as determined by hydrostatic weighing, 12%) underwent a total of nine, 90-minute cold water immersions. Three immersions were conducted in an Atlantic Ocean inlet, with the subjects wearing a) a closed-cell foam jacket with beaver tail (loosely-fitted, wet suit concept), b) a closed-cell foam coverall (also loosely-fitted, wet suit concept), and c) the coverall over a tightly-fitted, shorty wet suit. Both water and air temperatures averaged 10°C; wind averaged 4 m/s wind. The subjects were tethered via a safety harness to a nearby pier. A Coast Guard vessel was used to create a 1.2-m breaking wave over the subjects approximately once every 50-60 seconds. Following the field testing, the same subjects participated in six immersions in the laboratory immersion tank. The environmental conditions measured during the field testing were duplicated in the laboratory. To create water turbulence, compressed air was released from lines located at the bottom of the pool. During the six laboratory immersions, the amount of compressed air and the subject's position in the water were varied. Two garments - the beaver-tail jacket and the coverall - were evaluated. For both field and laboratory evaluations, exposures were terminated when rectal temperature decreased to 35°C or the subject or medical monitor requested termination because of severe cold discomfort.

RESULTS. Field Testing. After the first 20 minutes of water immersion, the decrease in rectal temperature was greater with both the jacket and the coverall than with the coverall/shorty wet suit combination ($p<0.05$). By 40 minutes of immersion, the decrease in rectal temperature with the jacket was also greater than with the coverall ($p<0.05$). The decrease in rectal temperature after 50 minutes averaged 0.6, 1.3, and 1.9°C with the coverall plus shorty wet suit, coverall, and jacket, respectively. (Note: Because of the significantly reduced tolerance time when the jacket was worn, physiological responses for all three ensembles were statistically analyzed only up until 50 minutes of exposure.)

Laboratory Testing. During the first hour of water immersion, there were no significant differences in the rectal temperature response between the coverall and the jacket ($p>0.05$). From 70 minutes on, the decrease in temperature was greater with the jacket than with the coverall ($p<0.05$). After 90 minutes, the decrease in temperature averaged 1.2°C with the coverall and 1.6°C with the jacket. Comparison of Field and Laboratory Data. With one exception, the methods used to simulate rough seas in the laboratory resulted in slower body cooling rates than those obtained during field testing. When the beaver-tail jacket was worn, the decrease in rectal temperature after 60 minutes of immersion averaged 1.1°C in the laboratory compared to 2.6°C in the field. When the coverall was worn, the decrease in rectal temperature after 80 minutes averaged 1.0°C in the laboratory and 1.9°C in the field. The one laboratory technique which reproduced the field results utilized the maximum amount of compressed air and created a geyser effect about the subject's head. Because this technique caused an unacceptable risk of water aspiration, it was not considered feasible for continued use.

RESULTS OF FURTHER TESTING. Modifications were made to the rough sea simulator and further thermal manikin and human testing was conducted. The modified methodology combined compressed air with a water surface current. The cooling rates that resulted using this technique, however, were generally lower than desired. In addition, duplicate tests demonstrated that reproducibility of the data was poor. When the test with the coverall was repeated, the decrease in rectal temperature after 50 minutes of immersion averaged only 0.6°C, compared to 1.3°C for the previous immersion. It was hypothesized that the subjects learned after the first exposure to reduce the flushing of water through the neck seal by holding the back of their necks more tightly against the life jacket.

CONCLUSIONS. While using water surface current and/or compressed air to agitate the water in a laboratory immersion tank results in a faster cooling rate than calm water testing, these techniques may not duplicate the cooling effects of actual rough seas. This may be because actual waves cause a greater degree of flushing of water through the garments' seals and/or a greater heat loss from the head. To simulate the cooling effect of actual waves and currents, a laboratory technique which involves periodically dunking the subject may be required.

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PHYSIOLOGICAL ASSESSMENT OF THE RNZ AIR FORCE CONSTANT WEAR IMMERSION GARMENT

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INTRODUCTION

The Royal New Zealand Air Force (RNZAF) has developed a Gortex® non-insulated, constant wear immersion suit (CWIS), with integral booties, for use by strike and rotary wing aircrews. Assessment of such thermal garments may be conducted using modelling or physiological testing. While testing human subjects is controversial, the complete interaction between the environment, the CWIS and the wearer may best be obtained using human immersions. This is exemplified when water ingress is considered. Since ingress critically affects dry-suit insulation, both modelling and calm water tests may fail to adequately reflect the result of realistic stresses upon water seal integrity. The purpose of this project was to evaluate the thermal performance of the CWIS using human subjects during both laboratory and open sea trials.

METHODS

Six subjects were immersed to neck level in a 2 m^3 tank. Water temperature was controlled at 4.99 ±0.13°C. Subjects wore each of two clothing ensembles representing minimal and maximal undergarment configurations: (i) long cotton underwear, one pair of woollen socks, non-integral gloves, and CWIS; and (ii) long cotton, long and short woollen underwear (9 mm pile), two pairs of woollen socks, non-integral gloves, and CWIS. The same subjects were immersed in open ocean (13.89 ±0.69°C, sea state 0-2, Beaufort wind 0-4) wearing undergarment configuration (ii) without the second pair of socks and with boots, coverall, Mk12 parachute harness/lifejacket, G-trousers, and helmet.

Rectal and 10 skin temperatures were monitored with thermistor probes (Thermonetics) and stored using a Grant Squirrel datalogger (1200 Series), while heart rate was recorded using a Sportester (PE3000R). These data were sampled at fifteen second intervals. Water temperature was monitored 30 cm anterior to the subject. Skinfolds were recorded at the skin temperature sites in addition to the chest, suprailiac, and calf. Expired gases were collected using Douglas bags (laboratory trials only) and subsequently analysed for O_2 and CO_2 content. Whole body thermal sensation, and total and regional discomfort were monitored. Garment and body insulations were derived (except for field trials). Trials were terminated either by volitional withdrawal, T_{re} = 35°C, local skin temperature less than 7°C for three minutes, or elapsed time (3 hr laboratory trials, and 2 hr ocean trials). Hotellings T_2 statistic was used to evaluate differences between ensembles, while polynomial regression analysis (half-interval method) was used to predict time to hypothermia (T_{re} = 35°C) and time of useful consciousness (T_{re} = 34°C).

RESULTS AND DISCUSSION

All laboratory trials, except one, were prematurely terminated due to: T_{re} less than 35°C in both trials (subject 4); T_{toe} less than 7°C twice in subjects 1, 3, 5, 6; and extreme thermal discomfort in ensemble (i) for *subject 2, who completed* 3 *hr in ensemble (ii).* Subjects 2 and 5 completed the sea trails while subjects 1, 4 and

6 became hypothermic and subject 3 was withdrawn for non-thermal safety reasons. Subjects 3, 5 and 6 stabilized T_{re} above 35°C, therefore no statistics are shown in Table 1. Water ingress was minimal in the laboratory, but was estimated to exceed 3 litres in 4 subjects in the sea.

Mean body tissue insulation was 0.058 (±0.025) °C.W $^{-1}$.m^2 for both ensembles at 15 min, and 0.061 (±0.008) and 0.069 (±0.023) °C.W $^{-1}$.m^2 for ensemble (i) and (ii) at 42.5 min (respectively). On average, the woollen undergarments increased clothing insulation by factor of about 3.5, with respective mean garment insulation at 42.5 min being 0.035 (±0.002) and 0.130 (±0.030) °C.W $^{-1}$.m^2. Metabolic heat production, was four-fold higher than at 15 min for ensemble (i) and two-fold higher for ensemble (ii).

Table 1: Test durations, and predicted time to hypothermia and time of useful consciousness (minutes (±SD)).

Condition	Test duration	Time to hypothermia	Time of useful consciousness
Lab (i)	58.3 (10.2)*	70.6 (19.3)*	86.6 (19.5)*
Lab (ii)	141.7 (25.4)	200.8 (50.0)	269.2 (77.9)
Sea	109.0 (15.0)	97.4 (9.4)	118.8 (7.8)

* Difference between Lab (i) and (ii) significant for $\alpha = 0.05$.

Chest temperature displayed between-subject variation that corresponded with survival time estimation. Similarly, skinfold thickness correlations with rectal cooling were consistently higher for local sites (lateral chest, medial chest, front thigh, triceps) than for the sum of ten skinfolds. It was not surprising that the predicted time of useful consciousness (laboratory) was considerably lower than might be predicted using body fat approximations for the 10th percentile (Nunneley et al. 1985). While localized skinfold thickness appeared a good indicator of rectal cooling rate, the poor association between skinfold thickness (measured by calipers) and total body subcutaneous fat restricts its use as a general predictor of survival time.

Sea trials confirmed that thermal protection was degraded by wave-induced water ingress, serving to further reduce predicted survival times (Table 1). Half of our subjects may have lost useful consciousness by about 4.5 hr, yet RNZAF aircrew are expected to survive for 12 hr before being recovered from an open sea ditching. The thermoregulatory responses of these subjects was inadequate to provide thermal homeostasis above 35°C. It is recommended that the water seals undergo modification to minimize leakage, particularly at the neck, and that aircrew be exposed to cold stress tests to identify crew in whom thermoregulatory responses are not conducive to survival during extended immersions. Such crew could then be provided with CWIS modifications and undergarments to enhance survival.

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EFFECTS OF THERMAL PROTECTIVE AID ON BODY COOLING IN COLD AND WINDY WEATHER

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INTRODUCTION

The fact that hypothermia is a major lethal risk, besides drowning, for a victim of maritime hazards while immersed in water is well accepted. However, it may still be a serious problem after the victim has managed to enter a lifeboat or craft, especially if his clothes are wet. The international regulations of SOLAS-74 from November 1984 introduce the requirements for *life-saving appliances* (1). A passenger ship shall carry for each lifeboat on the ship a thermal protective aid for every person to be accommodated and not provided with an immersion suit. There are no specific tests for the thermal protective qualities of thermal protective aids. It should only be demonstrated by the fabric test that the material has a thermal conductivity of not more than 0.25 W/(mK) and a thermal aid shall be so constructed that when used to enclose a person, it shall reduce both the convective and evaporative heat loss from the wearer's body. However, the information about the effects of any thermal protective aid on body cooling and potential survival time in accidental cold exposure is scanty.

The objective of the study was to evaluate the effects of a thermal aid, approved for survival crafts in Finland, on body cooling in cold and windy conditions.

METHOD

A mummy-shaped thermal aid (TA), made of wind- and waterproof non-woven olefin fabric, TYVEK, with a metallized, heat reflective inside was selected for testing and studied in conjunction with standard test clothing (C) with a thermal insulation I_{cl} of 1 clo.

Four medically screened men and two women volunteered (Table I) as subjects after being fully informed of the experimental protocol and associated risks. The experiments were conducted in a climatic chamber according to the principles of the Declaration of Helsinki, which governs ethical human experimentation. Each subject was studied in random order once in each of the test configurations i.e., Cdry+TA, Cwet+TA, Cdry, and Cwet at an air temperature of -14°C (±0.5°C) with a turbulent air velocity of 6 to 10 m/s. Two subjects were exposed simultaneously and they were instructed to sit as still as possible on a thin disposable paper blanket placed on the floor of the chamber. The exposure time was 2 hours, except for the control trial Cwet, which was scheduled for 1 hour. The minimun time interval between the trials for a given subject was one week in order to minimize the acclimation effect.

The continuous monitoring included ECG, heart rate, rectal temperature (Tr) at a depth of 10 cm, and skin temperatures (Tsk) at nine sites. Subjective evaluations of thermal sensation and comfort as well as perceived exertion (RPE) were requested every 30 minutes. The termination criteria were Tr 35°C, any Tsk <10°C for more than 30 min, severe muscle cramps, irregularities in cardiac function, the subject's own request, and the supervisor's decision.

Table I. Characteristics of the subjects

Sex	N	Age (yrs)	Height (cm)	Weight (kg)	A_{Du} (m^2)	Body Fat (%)	$\dot{V}O_2$ ($ml \cdot kg^{-1} min^{-1}$)
Female	2	14-39	164-166	54-63	1.58-1.66	22.0-25.0	39.6-46.5
Male	4	34-49	168-187	57-78	1.66-2.03	9.6-12.9	47.7-63.0

RESULTS

None of the exposures was terminated prematurely. The lowest individual Tr value of 35.5°C was registered in a trial of Cwet. In this particular case *after drop* during the recovery resulted in a Tr drop to 34.6°C. The mean drop in Tr was 0.65°C for Cwet, 0.35°C for Cwet+TA, 0.30°C for Cdry, and 0.15°C for Cdry+TA during the first 60 min. In 2 hours Tr decreased 1°C in Cwet+TA, 0.9°C in Cdry, and 0.6°C in Cdry+TA on average.

The mean skin temperature ($\bar{T}sk$) decreased by 7.0°C in Cwet, 4.0°C in Cwet+TA, 3.5°C in Cdry and 2.0°C in Cdry+TA on average during the first hour, and the changes in 2 hours were 6.7°C for Cwet+TA, 4.0°C for Cdry, and 3.0°C for Cdry+TA. The lowest skin temperatures were measured in the extremities, even as low as 3 to 4°C for the toes at the end of exposure. In Cwet and Cdry also the Tsk of the upper arm, thigh and calf fell rapidly to about 15 to 20°C. The Tsk for the lower back, shoulder, and abdomen was more affected by postural temperature regulation (cramped sitting and leaning on each others).

Mean body temperature ($\bar{T}b$) drop was about the same for Cdry and Cwet+TA in two hours (3.9°C) and for Cwet (3.8°C) in one hour. In Cdry $\bar{T}b$ decreased slower, 2.9°C in 2 hours (Fig. 1). The greatest heat loss (Wm^{-2}) in first 60 minutes on average was measured for Cwet, in which the individual responses differed the most. The individual rates of change in heat storage varied from 67 to 236 Wm^{-2}. Also in Cdry mean body heat loss was greater (107 WM^{-2}) than in Cwet+TA and in Cdry+TA, which resulted in about the same (80 Wm^{-2}) heat loss on average.

There were no differences between Cdry and Cwet+TA in the average ratings of thermal sensations. Both conditions were perceived *slightly cool* at the beginning and *cold* at the end of exposure. Cdry+TA was perceived the warmest and least uncomfortable condition. Individual variation in thermal votes was great, but all the subjects rated Cwet as the coldest and the most uncomfortable condition. In a few Cwet trials some subjects reported their condition as *intolerable* at the end of the exposures.

Cdry+TA was perceived the least strenuous condition on average (Fig. 2). Cdry and Cwet+TA were rated more strenuous, but the differenses in mean votes for those two conditions were small. Violent shivering and painful feelings of cold resulted in the perception of Cwet to be the most strenous condition.

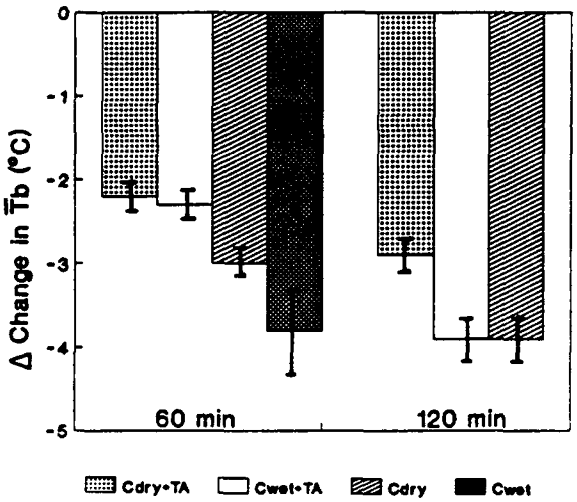

Fig. 1. Mean body temperature change in 60 and 120 minutes (X±SEM)

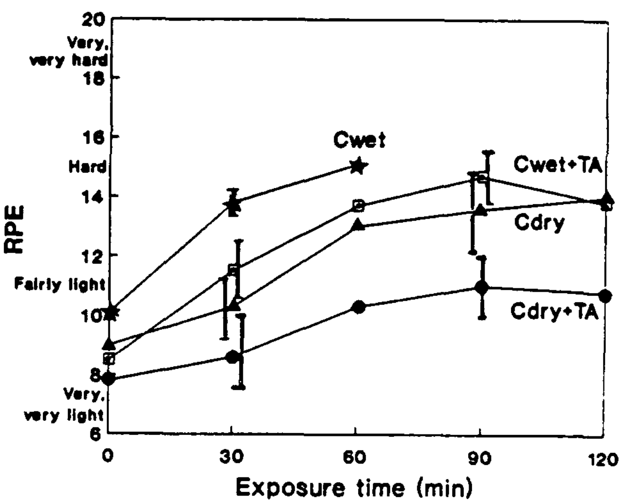

Fig. 2. Repeated perceived exertion (RPE) for each test configurations (X±SEM).

CONCLUSIONS

The results indicate that the wind- and waterproof thermal protective aid with a heat reflective inside is not sufficient to maintain the thermal balance of a lightly clad victim in cold and windy conditions. However, it provides protection which could extend survival time significantly in accidental exposure to cold and windy weather. The protective effects are most notable for persons in wet clothes.

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