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Laboratory-based Evaluation of the Protection Provided Against Cold Water by Two Helicopter Passenger Suits

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Summary
The thermal protection provided by two helicopter passenger immersion suits was evaluated. Suit A was a standard 'dry' suit and suit B was a 'dry' suit with inherent insulation provided by inflation of the outer shell of the suit. During four hour immersions in water at 4°C with simulated rain, wind and waves, suit B provided significantly ($p < 0.01$) better protection against the long-term effects of immersion than suit A. The skin and core temperature of subjects fell at slower rates over the immersion period when they wore suit B, they shivered less, had lower heart rates and were more comfortable in this suit. The problems of testing and selecting appropriate immersion suits are discussed and it is concluded that tests of immersion suits should be as realistic as possible and, when this is so, 'dry' suits with inherent insulation which is unaffected by leakage are likely to perform better in cold water than those without such insulation.

Introduction

Garments designed to protect individuals from the hazards associated with immersion in cold water are now frequently used by groups within the military and oil industry as well as by a large number of individuals participating in water-based leisure activities. These 'survival suits' can be classified into three different types: 'wet' suits have high levels of inherent insulation and which should allow only a small volume of water to enter between the skin-suit interface; 'dry' suits which have little inherent insulation and provide protection by keeping the insulation worn beneath them dry; 'dry' suits with inherent insulation which should keep the wearer dry, as well as provide insulation, for example, by the use of highly insulative material such as foam neoprene in the construction of the suit, or by providing insulative linings to be worn under otherwise normal 'dry' suits.

The greater demand for such garments has resulted in a proliferation of different makes of suit. With this increase has come a requirement for those responsible for the procurement of such equipment to be able to make choices between suits and to be confident that the suit they choose will fulfil the requirements they have of it. Of the numerous performance criteria which should be investigated when considering a helicopter passenger immersion suit, the thermal protection it provides the wearer in cold water is amongst the most important. Another important, yet often conflicting, consideration is the discomfort caused by a suit when it is worn in warm air.

The relative merits of the different types of immersion suit, particularly wet versus dry suits, have been discussed by several authors[1,2]. It is the 'dry' immersion suit without inherent insulation which, primarily on the basis of laboratory-based tests, has become the popular choice; it is regarded as less cumbersome and uncomfortable to wear in air than either a wet suit or a dry suit with inherent insulation, while providing good protection against cold water. The possibility remains, however, that this choice may be in error, due to the unrealistically benign nature of many laboratory-based evaluations.

In the present investigation the thermal protection provided by a helicopter passenger immersion 'dry' suit without inherent insulation is compared with that provided by a suit, the inherent insulation of which is only provided when required. The performances of the suits, and the validity of laboratory-based tests of such suits are discussed.

Methods

The experiment received ethical committee approval before subject recruitment. Ten healthy male volunteers acted as subjects for the experiment. Before undertaking the experiment each was given a medical examination, was fully informed about the experiment and gave witnessed informed consent to participate[3]. The subjects attempted to complete two 4 hour immersions into stirred water at 4°C wearing a different helicopter passenger immersion suit for each immersion. A cross-over, within subject, repeated measures experimental design was followed. At least one week was left between successive immersions and the two immersions of each subject were undertaken at a corresponding time of day.

Suit A

Suit A is a 'dry' suit constructed from a composite fabric incorporating a Gortex membrane and Nomex outer, with rubber 'push through' wrist seals and a waterproof neck to groin metallic neoprene backed zip fastener. A strip of foam neoprene inside a rubber collar constitutes the neck seal when closed by the zip. The hood is constructed from the same material as the rest of the suit and includes a thin foam neoprene partial face seal. Two 3-fingered mitts are provided with the suit, they are constructed from 4 mm neoprene and have a 12.5 mm gauntlet which can be tightened at the forearm by elastic and fastened by Velcro. The gloves are normally stowed beneath flaps at each elbow. The suit is provided in 8 sizes. A life-jacket (RFD Type 102 Mk 2BA) was worn with the suit. This is inflated by a 26 g CO_2 cylinder fired manually by a toggle located at the bottom of the jacket. The life-jacket incorporates a splash guard, normally folded and secured by Velcro at the top of the jacket.

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Suit B

Suit B is a 'dry' inflatable suit constructed from two layers of polyester nylon with an interlayer of 'Tuftane'. The outside of the suit has a flame retardant 'lick-wipe' treatment and the inside of the suit has a heavy duty flame retardant coating. The suit incorporates a full neoprene face seal and loose fitting neoprene wrist seals which can be secured with Velcro when required. The suit is secured at the front by a chin to groin waterproof plastic zip; constructed from circular wound nylon on a polyurethane tape base. The suit is provided in 3 sizes. A self-righting bag is attached to the front of the suit on the right-hand side, this is constructed from polyester nylon and has an internal volume of 23 litres. It is inflated by a single 45 g CO_2 cylinder fired manually by pulling a toggle located at the bottom of the bag. The suit is inflated by two 45 g CO_2 cylinders fired manually by a single toggle located on the left-hand side of the suit. The suit includes an adjustable splash guard stowed beneath a flap on the left side of the suit over the abdomen. The same flap also covers the suit-inflating CO_2 cylinders. When required the splash guard can be removed from beneath the flap, placed over the head and secured to a metal D-ring positioned at the groin. The gloves provided with suit A were also used with suit B, where they were stowed beneath a flap on the left thigh.

The following clothing was worn beneath both immersion suits: swimming trunks, short-sleeved cotton vest, woollen socks, polyester/cotton long-sleeved shirt and long trousers, and a polyester/cotton pullover.

Experimental Procedure

Only one subject was immersed at a time. The subjects ate a light breakfast before attending the laboratory. On arrival at the laboratory they were given a calibrated gastro-intestinal radio temperature pill (Remote Control Systems Ltd, London) to swallow. They then rested for two hours in thermoneutral temperatures to allow the pill to equilibrate and leave the stomach. The subjects did not eat, drink or smoke during this period and the position of the pill was regularly checked with the receiving apparatus. Towards the end of the two hour pre-immersion period the subjects changed into swimming trunks, had the physiological monitoring equipment attached to them and were dressed in the appropriate clothing assembly. The subjects were allowed to try the immersion suits on until they found the size which provided them with the best fit.

Pre-immersion the subjects rested in an upright, seated posture over the immersion tank for 20 minutes whilst baseline data were collected. They were retained in their chair by a cross-lap seat belt. Just before being immersed the subjects secured their suits; this involved zipping-up suit A, and zipping-up and securing the wrist seals of suit B. They adopted a standardized 'crash' position; holding the seat belt buckle with their left hand and the base of the chair with their right hand. The subjects were then lowered at 0.2 ms until they were just totally submerged in the cold water. As they were lowered the subjects took a slightly larger than normal inspiration as the water crossed their chin and attempted to hold this breath for a 15 second period of submersion. After 15 seconds the chair on which the subjects were sitting was raised until the water level corresponded with the top of the shoulders. The subjects then released the seat belt and inflated their life-jacket whilst the chair was removed from the water. When suit B was worn it was inflated immediately after the self-righting bag.

The subjects were loosely tethered in the centre of the pool; after three minutes of immersion a wave maker was started which produced 1 Hz, 15 cm waves for the rest of the immersion. As soon as the waves had started the subjects donned their splash guard and gloves and then attempted to complete the 4 hour immersion. They were sprayed with 9 litres of 4°C water every 15 minutes and a 6 knot wind, moving across the water from the feet to head of the subjects, was maintained throughout each immersion. The level of inflation of the life-jacket, self-righting bag and suit B could be manually adjusted by the wearer at anytime.

Subjects were removed from the water according to the following criteria: subject request; core temperature below 35°C; a skin temperature of 6°C at anytime or 8°C for more than 30 minutes; the appearance of any undesirable alteration in the ECG; decision of the independent Medical Officer or Project Officer. Following the immersion the subjects were lifted from the water in a reclining position, undressed and rewarmed in water at 40°C.

Variables Monitored

The subjects went on to a mouthpiece and wore a nose-clip for 5 minutes of the pre-immersion period, for the first three minutes of immersion and for the last 5 minutes of each 30 minutes of immersion. Respiratory tubing attached to the mouthpiece allowed expired air to be collected. During each experiment the following variables were monitored.

GRIP STRENGTH

The left and right hand grip strength of subjects was measured without a mitt just before and just after immersion using a digital hand grip dynamometer (Medical Research MIE grip tester).

CLOTHED WEIGHT AND WATER LEAKAGE

The weight of the underclothing and clothed weight of subjects was measured just before and after immersion, the weight of any loose water within the suit was also measured post-immersion. The increase in the weight of the underclothing plus the weight of any loose water in the suit was recorded as water leakage.

HEART RATE

Obtained from a 3-lead electrocardiogram (ECG, Tektronic 408 monitor) which was recorded continuously on a pen recorder (Gould Series 2600S). The ECG electrodes were attached to the skin by waterproof adhesive tape.

BREATH-HOLD TIME

A Fleish head (PK Morgan No. 2) was placed on the inspiratory side of the respiratory tubing, the output of this was integrated (PK Morgan integrator unit) and recorded continuously on the pen recorder allowing breath-hold time to be calculated.

OXYGEN CONSUMPTION (VO_2)

Assessed by open circuit spirometry where expired air was collected in Douglas bags and analysed for oxygen and carbon dioxide concentrations (PK Morgan 500D

& 801D analysers). The volume of air expired was measured by evacuating the Douglas bags through a dry gas meter (Harvard) which gave a digital read-out of volume to 0.1 litre. Douglas bags were collected for 5 minutes during the pre-immersion period, for the first 3 minutes of immersion and for the last 3 minutes of each 30 minute period of immersion.

CORE TEMPERATURE

Monitored continuously and recorded pre-immersion and every 15 minutes during immersion using: a rectal thermistor (Grants CM probe) inserted 15 cm beyond the anal sphincter and connected to a data logger (Grants Squirrel meter logger) and a gastro-intestinal radio temperature pill and receiver (Remote Control Systems Ltd, London).

SKIN TEMPERATURE

Monitored continuously using skin thermistors (Grants EU probes), attached to the skin by single pieces of waterproof adhesive tape and recorded on the data logger pre-immersion, every 5 seconds for the first minute of immersion and then every fifteenth minute of immersion. Skin temperature was recorded at the following standardized sites: centre forehead; back of neck; chest; forearm; back of hand; abdomen; mid-right buttock; right heel. These sites were primarily chosen to give an indication of the sites of water leakage into the suits.

CARBON DIOXIDE LEVEL BENEATH SPLASH GUARDS

Assessed every 15 minutes during immersion by the analysis for carbon dioxide (Beckman LB2 analyser) of a continuous air sample taken from just above the mouth of the subjects.

SUBJECTIVE EVALUATION

Recorded pre-immersion and every fifteenth minute of immersion using a sliding scale (14 increments unseen by subjects) which ranged from 'extremely comfortable' to 'extremely uncomfortable'. The time taken to don the splash guard and gloves in water was recorded. Water and air temperature were measured 30 cm below and 30 cm above the surface of the water using thermistors (Grants EU probes).

The leads from the electrodes and thermistors exited the immersion suits through a watertight cable gland positioned on the shoulder of the suits. This ensured that the seals of the suits were not compromised. All experimental equipment was calibrated in a standard scientific manner before and after experimentation.

Statistical Techniques

The data obtained during the first 45 minutes of immersion were analysed as this was the longest period during which all subjects were immersed in both suits. In addition, for some variables, comparisons between the immersions of each subject in suits A and B were made: at the end of the respective immersions and at the end of the immersion in suit A and after an equivalent period of time had elapsed during the immersion of each subject in suit B.

The statistical significance of the main 'effects' of suits, sequence of wearing suits, time (where applicable), interactions of clothing and time, and sequence and time were assessed using analysis of variance techniques. The thermal comfort data were standardized by converting it into percentages; an angular transformation was performed on the data to satisfy statistical assumptions of the analysis of variance.

Calculations

Mean skin temperature ($\bar{T}sk$, °C) was calculated by an unweighted division of the 8 skin temperatures recorded.

The average 'survival time' (ST) of subjects in each of the clothing assemblies was estimated from the following calculation: $ST = (T_{t1} - 30/r) + tT_{t1}$, where 30 = lowest average core temperature (°C) compatible with life; T_{t1} = core temperature (°C) 30 minutes from the end of each subjects' immersion; r = rate of change of temperature (°C/h) during the last 30 minutes of immersion; tT_{t1} = time (min) to T_{t1}.

Results

Unless stated otherwise all results are quoted at the 1 per cent level of significance ($p < 0.01$) for a subject number of 10. The physical characteristics of each subject are shown in *Table I*. The average weight of subjects just before immersion was 82.4 kg in suit A and 83.3 kg in suit B. The mean (s.d.) water temperature was 4.1 (0.4)°C during the experiments with suit A and 4.1 (0.3)°C during the experiments with suit B. The respective air temperatures were: suit A, 14.3 (0.4)°C and suit B, 14.6 (0.4)°C.

The subjects were attempting to complete 240 minutes of immersion in each of the suits. The immersion times of each subject and reasons for leaving the water are shown in *Table II*. The immersion times recorded in suit B were longer than those recorded in suit A. The most

Table I. Subject characteristics

Subject	Age (years)	Height (cm)	Weight (kg)	Fat (%)*	Suit size A	Suit size B
1	35	187	76	16.5	6	L
2	31	165	73	19.5	2	S
3	22	177	73	15.1	2	M
4	24	174	80	14.5	2	M
5	32	174	64	10.8	1	S
6	23	185	84	13.1	6	L
7	23	187	87	14.8	7	L
8	31	174	86	22.6	4	M
9	23	186	90	16.7	6	L
10	21	182	67	10.8	6	M

* % Fat calculated from skinfold thickness measured at four sites using callipers[20].

Table II. Immersion times (min) and reasons for terminating the immersions of each subject in both suits. CT = low core temperature; ST = low skin temperature; SR = subject request

Subject	Suit A		Suit B	
1	78	CT	240	
2	90	SR	240	
3	76	SR	190	SR
4	50	SR	125	SR
5	46	ST	190	SR
6	90	ST	240	
7	50	SR	155	SR
8	75	SR	95	SR
9	100	SR	180	SR
10	60	ST	240	
Mean	71.5		189.5	

common reason for terminating the immersions was subject request and the most common causes of such requests were thermal discomfort associated with groin, abdominal and lower back stiffness. The mean thermal comfort scores recorded during the first 45 minutes of the immersions are shown in *Table III*. In both suits the thermal comfort of subjects fell during the course of the immersions. Subjects remained more comfortable however, when wearing suit B. During the pre-immersion period there was no significant difference in the thermal comfort recorded in each suit.

The statistical analyses of the core temperature data obtained from the rectal thermistor and gastro-intestinal temperature pill produced similar results. During the first 30 minutes of immersion the core temperature of subjects fell significantly in both suits. The fall observed in suit A did not differ from that observed in suit B. By the 45th minute of immersion the rectal temperature recorded in suit B was higher than that recorded in suit A (*Fig.* 1), although gastro-intestinal temperature did not differ by a significant amount at this time. When the rates of fall of core temperature over the last 30 minutes of immersion were examined, core temperature was found to be falling at a faster mean rate in suit A (1.65°C/h) than in suit B (0.22°C/h). The resulting calculated average survival time for subjects in suit A is 4 hours 47 minutes compared with 30 hours 28 minutes for suit B.

The alterations in mean skin temperature over the first 45 minutes of immersion are shown in *Fig.* 2. The $\bar{T}sk$ was higher pre-immersion when suit B was worn. On immersion $\bar{T}sk$ fell in both suits, but at a faster rate when suit A was worn. This resulted in $\bar{T}sk$ being higher in suit B at all times. The average skin temperatures recorded at each thermistor site during the first 45 minutes of immersion are shown in *Table IV*. During the first 30 seconds, and with the exception of the head and

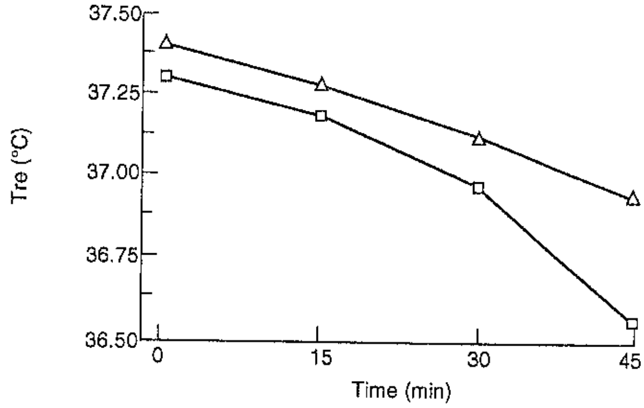

Fig. 1. Mean rectal temperatures (°C) just before and during the first 45 minutes of immersion (n = 10). □ = suit A; △ = suit B.

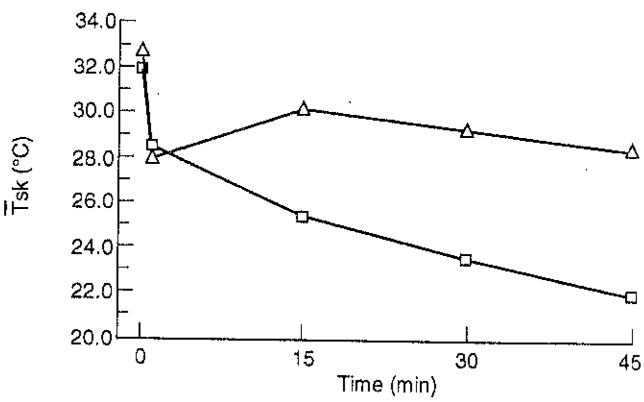

Fig. 2. Mean skin temperatures (°C) just before and during the first 45 minutes of immersion (n = 10). □ = suit A; △ = suit B.

hand skin temperature sites which were not covered at this time, the greatest fall in skin temperature in either suit occurred at the forearm when suit B was worn. In this suit, 4 subjects had at least a 10°C reduction in forearm skin temperature during the first 30 seconds of immersion, another 4 had at least a 5°C fall. The mean water leakage was calculated at 1.32 litres in suit A (71.5 min of immersion) and 2.2 litres in suit B (189.5 min of immersion).

There was no significant difference between the suits with regard to the heart rate recorded before immersion

Table III. Mean thermal comfort scores during the first 45 minutes of immersion (n = 10)

Time (min)	Suit *A*	*B*
Pre	11.3	11.6
15	5.5	9.4
30	3.0	8.2
45	1.1	6.8

Table IV. Skin temperature (°C) at each site before and during the first 45 minutes of immersion (n = 10)

Suit/Time	*Head*	*Neck*	*Chest*	*Arm*	*Hand*	*Abdomen*	*Buttock*	*Heel*
Pre								
Suit A	31.6	35.3	35.2	33.1	27.7	35.3	29.5	27.9
Suit B	32.0	36.0	35.8	32.6	29.7	36.2	31.2	28.5
30 sec								
Suit A	21.0	35.3	35.1	32.2	14.3	35.0	27.9	26.2
Suit B	20.2	36.0	35.6	25.2	13.7	35.9	30.2	26.9
1 min								
Suit A	24.4	34.8	35.0	31.6	15.8	34.8	26.7	25.2
Suit B	23.9	35.8	35.6	23.7	14.7	34.2	29.1	26.5
15 min								
Suit A	28.4	27.6	30.6	26.4	21.9	30.9	17.4	20.6
Suit B	30.5	34.7	35.1	28.5	24.4	34.7	28.5	25.4
30 min								
Suit A	29.3	25.6	28.0	24.3	20.1	29.5	15.1	17.3
Suit B	30.4	33.8	35.1	26.5	22.2	34.6	28.3	24.0
45 min								
Suit A	29.7	24.3	26.7	22.5	18.3	28.4	12.7	14.7
Suit B	29.6	32.9	34.7	25.4	21.0	34.3	27.6	22.9

or during minutes 1 or 15 of immersion. Heart rate was higher after 30 minutes (suit A: 81 beats/min; suit B: 67 beats/min) and 45 minutes (suit A: 80 beats/min; suit B: 62 beats/min) of immersion when suit A was worn.

All of the subjects were able to hold their breath for the required 15 second period of submersion when wearing both clothing assemblies. No significant differences were found before or during the first three minutes of immersion in the oxygen consumptions recorded with each of the suits. During the immersion period the subjects shivered when wearing both suits but shivering was reported to start later and was less intense when suit B was worn. The mean oxygen consumptions recorded during the experiments are shown in *Fig.* 3. The average of the maximum oxygen consumption recorded for each subject in suit A (1.138 litres/min) was found to be greater than the maximum recorded in suit B (0.724 litres/min).

The average times to don the splash guards provided with the suits were: 23.5 s in suit A and 28.3 s in suit B; these times were not found to differ significantly. Inspired CO_2 levels beneath the splash guards did not rise above 1.1 per cent in either suit assembly at any time, and averaged 0.56 per cent in suit A and 0.36 per cent in suit B. The average time to don the gloves was 109.4 s in suit A and 111.0 s in suit B; these times were not found to differ significantly. Grip strength decreased in both suits following immersion, but the decrease observed with suit B (189.5 min of immersion) was greater than that seen when suit A (71.5 min of immersion) was worn. Immersion reduced right hand grip strength by 19.8 per cent in suit A and 28.3 per cent in suit B. The corresponding reductions in the left hand were: suit A, 18 per cent; suit B, 20.5 per cent.

Discussion

The thermal data collected during the short pre-immersion period suggest that the subjects were slightly warmer in air when wearing suit B. This was not reflected however, in any differences between suits in the thermal comfort of subjects at this time. Thus, the problem of wearer discomfort in air, which is normally associated with dry suits with inherent insulation, may have been largely avoided in suit B because the insulation is only provided when required. This was subsequently confirmed during 3 hour resting exposures in air at 30°C, with 60 per cent relative humidity and 1.5 ms^{-1} of air movement[4].

The results obtained in the water demonstrate that suit B provided significantly better protection against the long-term effects of immersion than suit A. The skin and core temperatures of subjects fell at slower rates over the immersion period when they wore suit B and, as a consequence, they shivered less, had lower heart rates, felt more comfortable and remained immersed for longer when wearing this suit. Evidence of the effect of the extra insulation provided by suit B can be seen in *Fig.* 2 which shows that mean skin temperature increased in suit B when it was inflated. By contrast, mean skin temperature fell throughout the immersions when suit A was worn.

The survival time calculations give a further indication of the greater level of protection provided by suit B. However, the limitations and assumptions associated with the calculation make it more useful for comparative than definitive purposes. It is assumed in the calculation, for example, that the lowest core temperature compatible with life is 30°C, in reality this temperature will vary greatly between individuals and will also depend on the performance of the life-jacket and splash guard worn by the immersed individual[5]. A limitation of the calculation is the reliance it places on extrapolation; it is assumed that the rate of cooling established during the last 30 minutes of immersion will remain the same until death. This takes no account of factors such as the cessation of shivering due to fatigue or the inhibition of muscle metabolism at low core temperatures.

In addition, it is possible that following an initial fall in core temperature a new 'steady state' can be achieved by subjects in which core temperature is stabilized due to an increase in heat production from shivering and a decreased gradient for heat loss resulting from a lower core temperature[6]. The clothing worn may be critical in determining when, or whether, a victim manages to stabilise core temperature; if this does not provide adequate levels of insulation then the heat produced by shivering will be lost and, therefore, be unable to contribute to the thermal balance of the individual.

When suit B was worn six of the subjects showed an initial fall in core temperature followed by stabilization for the rest of the period of immersion. As an example, the core and skin temperatures of one of these subjects is shown in *Fig.* 4. During the last two hours of immersion the core temperature of this subject did not fall significantly when he wore suit B, instead it increased and decreased as he began and ceased shivering. None

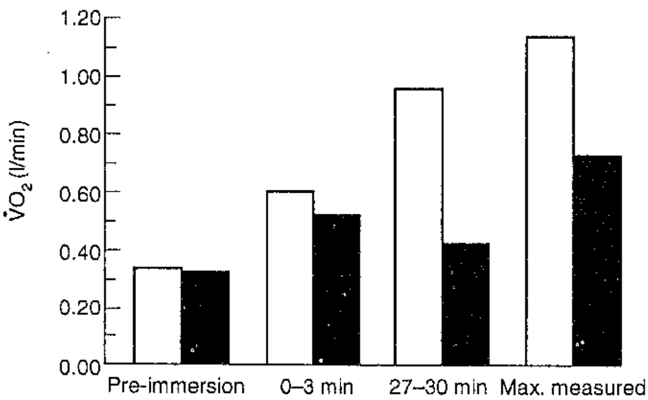

Fig. 3. Mean oxygen consumption (litres/min) before and during immersion (n = 10). □ = suit A; ■ = suit B.

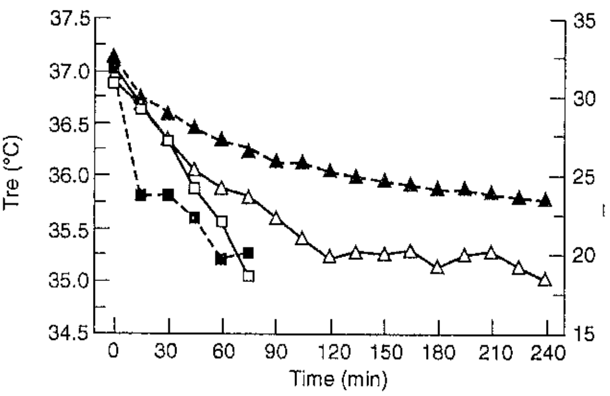

Fig. 4. Mean skin ($\bar{T}sk$) and rectal (Tre) temperatures (°C) of Subject 1 just before and during immersion (n = 1). □ = Tre suit A; ■ = $\bar{T}sk$ suit A; △ = Tre suit B; ▲ = $\bar{T}sk$ suit B.

of the subjects in the present experiment were able to stabilize core temperature when wearing suit A.

A further limitation of survival time calculations is that they are usually based on data obtained from laboratory tests. These are unlikely to recreate the stresses placed upon a suit in adverse conditions during a real emergency and will therefore tend to overestimate survival time. This limitation could be reduced if laboratory tests were made more realistic than many of those which have been previously employed and suggested[7-9]. For example, the survival time calculated for subjects in suit A during the present investigation (4 h 47 min) was somewhat shorter than the 6 h 48 min obtained for the same suit in an earlier, less arduous, evaluation[10]. The major difference between the two studies was the introduction of wind, periodic spraying, waves and initial submersion in the present investigation, plus the requirement to don the splash guard and gloves in the water. Such factors can have a deleterious effect on the performance of 'dry' suits without waterproof inherent insulation, primarily by increasing water leakage[11] and thereby reducing the insulation provided by the clothing worn beneath the suit[12,13].

Even in relatively innocuous tests of 'dry' suits, water leakage appears to be the norm rather than the exception[14,15], this is despite the efforts of investigators to ensure that subjects are correctly dressed before immersion. In the real situation, the problem of leakage may not only be compounded by waves, wind and so on, but also by wearers not securing the seals of their suit prior to immersion, either due to a lack of time[2] or a reluctance to experience the discomfort in air which can result from such actions.

Individuals with the responsibility for selecting immersion suits should be aware of the over-estimations of performance which can result from laboratory evaluations of immersion suits; in particular the greater leakages which can be expected in the real situation. Such knowledge will not only enable the individual to reassess the absolute level of performance which can be expected from a suit, but it may also influence the type of suit selected. 'Dry' suits which depend upon dry underclothing for the majority of their insulation, as well as those with inherent insulation which is not waterproof, are likely to be more adversely affected by increased levels of water leakage than suits, such as suit B, whose inherent insulation is unaffected by water ingress. This is supported by the findings of the present investigation in which the greater performance observed in suit B occurred despite greater levels of underclothing wetting.

When considering the protection provided by an immersion suit against the potentially hazardous responses associated with immersion in cold water, it is essential that all such responses are considered and not just those associated with a fall in core temperature. In particular, the protection offered against the initial responses to immersion should be examined[16]. These responses, which include a significant reduction in maximum breath-hold time and a sudden increase in the workload of the heart[17,18] are initiated by a rapid decrease in skin temperature[19]. This should be avoided, therefore, if these responses are to be minimized.

Tipton & Vincent[10] have examined the protection provided against the initial responses by suit A. The heart rate and oxygen consumption results of the current investigation suggest that the initial protection provided by suit B is not significantly different from that provided by suit A. In the present investigation, both suits enabled the subjects to breath-hold for the required 15 second period of submersion. Previous work[10,16] suggests, however, that some form of emergency breathing equipment would be required if all individuals are to achieve underwater survival times much in excess of 25 seconds.

It is concluded that when immersion suits are being evaluated in cold water, the test employed should examine all of the hazardous responses associated with such immersion. Tests should be as realistic as possible, so as to minimize the discrepancy between the laboratory-based assessment of the protection provided by a suit and the level of protection it might provide in a real accident. When more arduous tests are employed, water leakage into suits tends to increase; under such circumstances 'dry' suits with inherent insulation which is unaffected by leakage are likely to perform better than those without such insulation.

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