NON-UNIFORM INSULATION IN IMMERSION PROTECTION CLOTHING: EFFECT ON BODY HEAT LOSS

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INTRODUCTION

Standards for the thermal insulation to be provided by immersion protective clothing specify a level of mean insulation derived from individual body segment conductance measurements from manikin tests. When this mean is used in conjunction with a model to derive predicted survival times in water, the accuracy of heat loss estimates relies on the assumption that the body has a uniform surface temperature. **As** this is not generally the case, errors in heat loss estimates may occur €or clothing with regional variation in thermal conductance. Previous studies have shown that insulation of the upper body is relatively more effective at retaining body heat than a similar amount of insulation over the lower body. In order to assess whether these findings are relevant to aircrew protective clothing, assemblies with undergarments having either uniform or lion-uniform insulation over the upper and lower body regions were tested on human subjects immersed in cold water. In order to compare results, estimates of heat loss were also measured using the same clothing assemblies tested on a manikin.

METHODS

Subjects were 6 males aged between 23 and 27 years and weighing between 62.4 and 78.7 (mean 71.2) kg. They comprised 2 groups, 'lean' and 'medium fat', based on mean weighted skinfold thickness for the 10th and 50th percentile levels as defined in an anthropometric survey of aircrew.

Clothing assemblies (A,B,C) with 3 different undergarments affording either uniform (A), high upper (B) or high lower (C) body insulation were tested. These comprised a long thermal protective undergarment (assembly **A),** 2 woollen pullovers (assembly B) and 2 pairs of acrilan pile drawers (assembly C). The overall immersed insulation of the **3** different undergarments, determined by manikin **ex**periments, were approximately the same (~0.6 clo). Additional garments common to all 3 assemblies were a long-sleeved cotton vest and long cotton drawers (worn under the extra undergarments), aircrew socks, a commercial one-piece dry immersion suit, a coverall, chest and leg anti-G garments proposed for aircrew for the new Eurofighter aircraft, lifejacket, neoprene mittens, helmet and boots.

Underclothing was weighed before and after immersion of the subject so that an estimate of any water leakage into the immersion suit could be made. After dressing the subject rested at the poolside for 30 minutes before entering the water with life-jacket inflated. A flotation angle of 45° was maintained by placing the subject's feet beneath a horizontal bar mounted across the pool. During the 2 hour (or less) immersion the water was at 8°C (range over all immersions, 8.0-8.5°C; mean 8.1°C) and did not vary more than 0.1°C for each immersion. The water was agitated by bubbling compressed air at 75 $l.min^{-1}$ through a distribution network secured to the floor of the pool. Air temperature above the pool over all immersions ranged from 15.2 to 17.6 (mean 16.3)°C and varied from 0.3 to 1.3 (mean 0.75)°C for each immersion.

Skin heat flow and temperature at 15 body sites and rectal temperature were measured at 1 minute intervals. Douglas bag expirate samples for the measurement of metabolic rate were taken ten minutes before, and at 15 minute intervals for 5 minutes during immersion.

RESULTS

A large amount of water leakage into assembly C occurred for 1 subject and was caused by a puncture in the rear of the neck seal causing wetting of the subject's back. For another subject, urine leakage into the immersion suit was known to occur with all three immersions. For the other 14 immersions water leakage ranged from 24-200 (mean 69) ml. Immersion times of less than 120 min occurred on three occasions; for one subject wearing assembly B after 93 min and for a second subject wearing assembly **A** after 60 min and assembly B after 95 min.

Analysis of variance was carried out on the data for metabolic rate, skin and rectal temperature and for heat flow. Average metabolic rate over the immersion period for assemblies A, B, and C were 112, 86 and 112 $W.m^{-2}$, respectively. Average metabolic rate while wearing assembly B was lower than for the other two assemblies ($p<0.05$). The change in rectal temperature during immersion ranged from +0.29 to -1.35 (mean -0.68) "C for assembly A, from -0.29 to -2.17 (mean -1.02) "C for assembly B and from -0.10 to -1.10 (mean -0.55) "C. Clothing assembly or body 'fatness' had no effect on the fall in rectal temperature during immersion.

Mean area-weighted skin temperatures of the upper and lower regions of the body were calculated using the temperatures recorded by the thermistor probes incorporated into the heat flow discs (Table 1). Data recorded at 15 minute intervals after initial immersion were used for analysis. The area weighting factors applied to each measurement site were based on area estimates of body segineiits according to Dubois. For the upper body area these were 0.77m^2 (10th percentile) and 0.83m^2 (50th percentile). For the lower body area these were 0.81m^2 (10th percentile) and 0.87m^2 (50th percentile). The upper body comprised hands, arms, chest, back, abdomen and 50% of the buttock area. The lower body comprised 50% of the buttock area, legs and feet. The head region was not included in any calculation. These combinations of segments were chosen to accord as far as possible with the delineation of insulation of the asymmetric clothing assemblies, B and C.

Table 1. Mean skin temperature (°C) and heat flow (watts) €or each clothing assembly and body area after 15 min immersion in water at 8°C

Assembly	Mean skin temperature (°C)			Heat flow (watts)		
	upper body	*lower body*	*whole body*	*upper body*	*lower body*	*whole body*
A	26.47	22.84	24.60	111	115	206
B	30.83	20.01	25.26	70	150	215
C	23.56	27.45	25.46	133	88	222
Mean	26.95	23.43	25.11	105	118	214

There was an effect of clothing assembly on the mean skin temperature for area-weighted regions of the upper and lower body regions and on heat flow in these two regions ($p<0.05$), though whole body mean skin temperature and heat flow did not differentiate between assemblies.

Regional heat flows equivalent to the body areas described above were derived from measurements on a thermal manikin (TIM3, Cord Group Ltd, Dartmouth, Canada) but corrected for the different mean temperature gradients across the clothing recorded during the actual subject exposures (Table 2). Heat flow measures derived for the manikin were higher than those estimated from heat flow disc measurements recorded during subject immersions.

Assembly	Heat flow (watts)		
	upper body	*lower body*	*whole body*
A	186	170	356
B	147	220	367
C	272	113	385
Mean	202	168	369

DISCUSSION

Previous studies involving both thermal modelling' and human experimentation' have shown that insulation of the upper body is relatively more effective at retaining body heat than a similar amount of insulation over the lower body. Though, in the present study, heat losses over the upper torso were less than those over the lower body, they were not significantly different. One possible explanation for this was the observed reduction in metabolic rate due to suppression of the stimulus for shivering when the upper body was insulated. Another possibility to account for differences between studies was related to the movement of subjects in the water giving rise to a variance in the regional hydrostatic compression of clothing and, hence, of clothing insulation levels. However, since this degree of variation is likely to occur in real immersion emergencies, it is considered that any difference found experimentally, would be of little practical significance at the levels of insulation and environmental conditions tested.

The disparity between heat flow estimates based on disc measurement and manikin tests may relate to an approximate 15% underreading with heat flow discs under the experimental conditions used in this study[3]. Additionally, there was greater compression-related reduction in clothing insulation with the manikin compared with subjects, particularly in the torso region, though the associated errors are not considered to have invalidated the regional comparisons of heat flow. Work to consider further the source of these discrepancies is required.

References

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