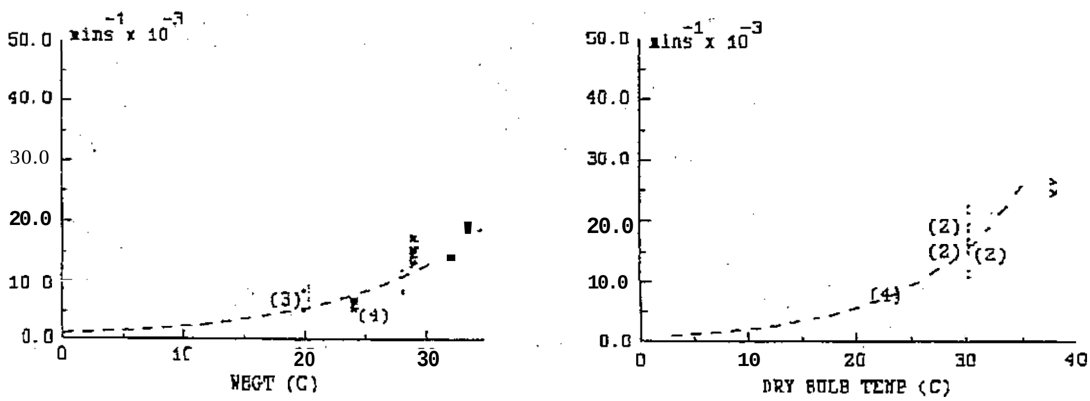
(P<0.01) slower compared to SEMI at WBGTs 20°C, 24°C and 28°C but not at WBGT 29°C. At WBGT 28°C all subjects demonstrated a slow continuous rise in TDB when at rest, more rapidly so after cessation of work. In addition, HR increased more rapidly (P<0.05) in IMP at WBGTs 20°C, 24°C and 28°C. At the end 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 t h e d gradient for conduction through higher TSK temperatures. This also necessitated an increase in HR to increase cardiac output to the cutaneous vessels'. 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 snit 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, an 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 ^{o}C) and whilst in the hot climate (WBGT 30.5 ^{o}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 rime 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 ^{o}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 temperahues 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** the 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 **°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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