

THERMAL STRESS IN HELICOPTER PILOTS: EVALUATION OF TWO SURVIVAL SUITS USED DURING FLIGHT

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INTRODUCTION

On the Norwegian coastline, sea temperatures are low throughout the year, and the personnel operating Sea King rescue helicopters are required to wear survival suits during over-sea flights. Paradoxically, this may lead to a situation where the pilots are subject to heat stress during flight (1). Thermal stress may result in fatigue and impaired pilot performance, which may raise the risk of pilot error and reduce flight safety. The aim of this study was to evaluate the thermal stress experienced by pilots wearing survival suits during helicopter flights. We also wished to compare two different clothing ensembles currently in use by the helicopter personnel in the Norwegian Air Force.

MATERIALS AND METHODS

The two clothing ensembles used were a British Mark 10 Aircrew Survival suit of 2-layer ventyle (MK10, Beaufort, UK) and a 3-mm neoprene FCO Pilot Suit Type 330 (Finn Christian, Olsen, Norway). Under the suits the pilots wore an inner layer of long-legged/long-sleeved underwear (60% wool, 25% polyester, 15% polyamide). They also wore a whole-body coverall (100% wool) as a middle layer under the MK10 suit.

Experimental procedures. Six military helicopter pilots (age 29 ± 3 years, height 183.0 ± 5.8 cm, weight 89.3 ± 6.8 kg, relative fat% of 17.0 ± 3.7 and body surface 2.1 ± 0.1) volunteered for the study. Data were collected during 6 regular helicopter flights during the winter; 2 pilots flew each flight. Mean flight duration was 115 ± 11 min and took place in the morning. Each pilot flew on 2 consecutive days: once using the MK10 and once using the FCO clothing ensemble. The subjects were not permitted to eat or **drink** during the experiment.

Data collected. Nude body weight and clothing weight were measured before and after each flight in order to estimate total body sweat production (adjusted for respiratory and metabolic weight) and sweat accumulated in each individual clothing component. To evaluate the thermal status of the body during flight, skin and core temperatures were measured every minute using skin thermistors (EUS-U; Grant Instruments) at 4 sites (chest, arm, thigh and leg) and a rectal probe (REC-U; Grant Instruments). Mean skin temperatures (T_{sk}) were obtained using the formula of Ramanathan (2). Temperature data were recorded using a Squirrel 1021 data logger (Grant Instruments; UK). A questionnaire (3) was used to obtain information about subjective ratings of thermal comfort and

sensation before, during and after the flights. The pilots were also asked to answer a set of questions about degree of tiredness, mental ability and sensation of thirst. In order to estimate the energy costs of flight, values of oxygen consumption for each pilot were measured for a single 5 minute period during flight (Cortex MetaMax Portable Metabolic Test System). The pilots were also equipped with monitors (Polar Sports Tester), which measured heart rate continuously during the experiment. Environmental conditions (air temperature, relative humidity, wind and solar radiation) inside the helicopter were measured continuously using an Indoor Climate Analyzer T1213 (Brüel & Kjaer). Statistical analysis by ANOVA (repeated analysis of variance) was used to test for differences in temperatures and subjective ratings between the 2 suits and for the time dependent changes in temperatures throughout the experiment. Paired t-test was used to test the general difference in sweating rates and workloads between the 2 suits. Statistical significance was accepted at the 0.05 level, and results are presented as mean \pm SD.

RESULTS

Temperatures. Both survival suits produced a significant rise in T_{sk} over time reaching a plateau after about 50 min of flight (Fig. 1). T_{sk} rose from $33.3 \pm 0.3^\circ\text{C}$ to $35.2 \pm 0.5^\circ\text{C}$ when using the FCO suit and from $33.9 \pm 0.4^\circ\text{C}$ to $35.1 \pm 0.8^\circ\text{C}$ when using the MK10. There was no rise in core temperature for the subjects tested. There were no significant differences in skin and core temperatures between subjects wearing the 2 survival suits. The environmental data showed a relatively cool condition ($18.6 \pm 1.3^\circ\text{C}$) inside the Sea King helicopter cockpit.

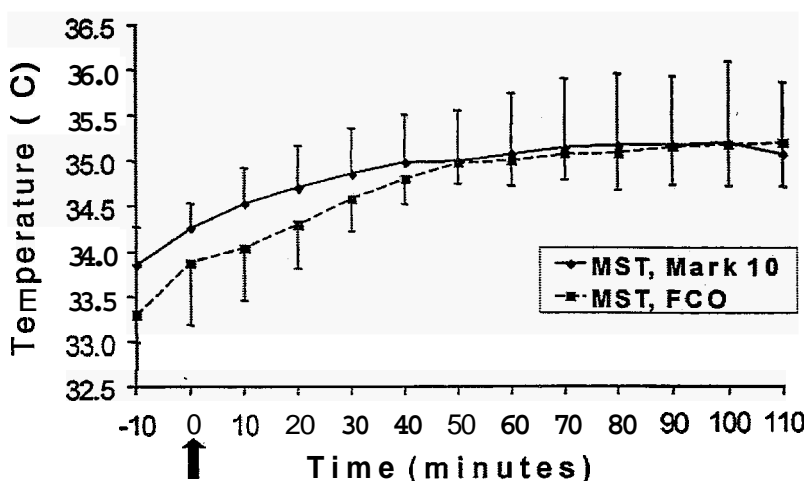


Figure 1. Mean skin temperatures ($n = 6$) using the MK10 immersion suit or the FCO immersion suit. Data are plotted for each 10-min interval, starting 10 min before take-off (-10 min). Up arrow on time axis indicates start of flight.

Subjective evaluation. Subjective sensations of warmth and thermal comfort did not differ between the 2 clothing ensembles. The pilots felt more uncomfortable during flight than before or after, and they preferred ambient temperature to be lower. The sensations of warmth and skin/clothing wetness were also higher during flight. The subjects reported that they were thirstier during flight, but there were no changes in the ratings of mental ability and tiredness.

Energy expenditure, sweat production, evaporation and accumulation. Energy expenditure during flight was equivalent to **43%** of maximal heart rate (81 ± 12 bpm, $88.8 \text{ W}\cdot\text{m}^{-2}$), and this resulted in an average sweat production of 591 ± 274 g and 364 ± 121 g while wearing the MK10 and FCO suits, respectively. Significantly more of the sweat produced accumulated in the FCO ensemble (**33.7%** of total sweat production) than in the MK10 ensemble (**20.5%**). However, evaporated sweat was significantly higher with the MK10 ensemble (**79.5%** of total sweat production) than with the FCO ensemble (**66.3%**). The distribution of accumulated sweat also differed between the 2 clothing ensembles. More sweat accumulated in the inner and middle layer of the underwear with the MK10, whereas more sweat accumulated into the outer garment with the FCO.

DISCUSSION

This study demonstrated that even under winter conditions, when cockpit temperature in the Sea King was relatively low, wearing survival suits caused a rise in T_{sk} , discomfort ratings and sweat production. Since flying requires very little physical effort, the survival suit that prevents heat loss through evaporation of sweat is the main cause of the rise in T_{sk} . Any change in the efficiency of sweat evaporation will be reflected in changes in other variables such as heart rate and core temperature that indicate the extent of the thermal stress. The lack of rise in heart rate and core temperature therefore suggests that the pilots were able to tolerate the rise in T_{sk} with minimal thermoregulatory strain.

The heat stress requirements for personal protective equipment according to the CEN/TC 122/JWG 9 standard (4) was followed in the present study. However, this standard does not take into consideration the special tasks that a pilot needs to perform, which require a high concentration level and rapid decision making. According to Hancock (5), a decrease in pilot performance is more closely associated with a feeling of thermal discomfort than with physiological strain. Even though the physiological thermoregulatory strain was well tolerated, we should not overlook the importance of thermal discomfort reflected in the subjective reports of the pilots during flight, but further investigation is needed to conclude whether this results in any performance deficit.

When the two clothing concepts are compared, there were **no** differences in the total heat load experienced by the pilots. Both concepts have different properties, each of which has its own advantages. The MK10 suit has the best evaporative efficiency and this is preferable as means of reducing the thermal stress. However, the higher insulation value of the MK10 caused higher total sweat production, and most of this sweat accumulated in the underwear. With the FCO suit, the sweat is transported to the outer layer and accumulates in the neoprene.

This may be an advantage in terms of thermal comfort during flight, because the further out in the garment that sweat accumulates, the less it affects the feeling of thermal discomfort. It is bound to be extremely difficult to avoid sweat accumulation in underwear when using survival suits, but in order to reduce the feeling of thermal discomfort, it is also important to consider the composition and construction of the underwear when selecting protective clothing for pilots.

Even a cool cockpit condition caused a T_{sk} over 35°C in pilots. Thus, selecting the right combination of underwear and survival suit represents an even higher challenge during summer flights when air temperatures and solar radiation is higher.

CONCLUSIONS

Wearing the MKIO or the FCO survival suits during winter flights caused a significant increase in T_{sk} , sweat accumulation and higher discomfort ratings in helicopter pilots. The pilots were able to tolerate the physiological thermal stress well, taking all of the physiological variables into account. There were no differences in the total thermal stress experienced by users of the two survival suits studied.

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