

THE ALLEVIATION OF HEAT STRAIN USING WATER-PERFUSED FOREARM CUFFS

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INTRODUCTION

A number of air-, liquid- or ice-cooled clothing systems are used to alleviate heat strain when thermoregulation is impaired by protective clothing; these have been widely studied (1-3). Hand immersion in cool water, first described by Livingstone(4), is one method of reducing heat strain. We have measured cooling rates from 200 to 400 W for this technique (5), greater than those for the previously listed methods. In a direct comparison, hand immersion in 20°C water has been shown to cool resting personnel at a faster rate than ice vests (6). An advantage of the other cooling methods is that they can be used while working, whereas hand immersion greatly reduces both mobility and the use of the hands, although foot immersion has also been used successfully. If hand immersion could be undertaken during exercise, then cooling efficiency in working personnel might be enhanced. Thus, a technique that allows or equates with hand immersion, but which does not hinder work, might provide further benefits in the management of heat strain. Water-perfused cuffs that can be worn around the forearm were designed and produced jointly by the INM and the UK Defence Clothing and Textiles Agency. The cuffs were constructed in 2 layers (neoprene outer; metallic, plastic foil inner) through which chilled water could be circulated. The aim of the study was to assess the efficiency of the cuffs at reducing heat strain during exercise and recovery. It was hypothesized that the cuffs would attenuate the rate of rise of heat strain during exercise and provide similar cooling to hand immersion during rest.

METHOD

The protocol was approved by the Ministry of Defence (Navy) Personnel Research Ethical Committee. Ten male volunteers aged between 21 and 32 years were recruited after obtaining their informed consent and following a medical examination. The subjects exercised ($\dot{V}O_2 = 0.99 \pm 0.17(\text{SD}) \text{ L}\cdot\text{min}^{-1}$), wearing Royal Navy firefighting clothing (including gloves and anti-flash hood) in the heat ($40 \pm 0.2^\circ\text{C}$ db, $28.8 \pm 0.4^\circ\text{C}$ wb, wbg $32.2 \pm 0.3^\circ\text{C}$) on 5 occasions. The exercise consisted of stepping on and off a 22.5 cm box at a rate of 12 complete steps per min until core temperature reached 38.5°C . This was followed by 40 min of seated rest in the same environment. There were 5 experimental conditions: control (Con); hand immersion during rest (Han); large cuff worn during exercise (Lcx); large cuff worn during rest (Lcr) and small cuff worn during rest

(Scr). The cooling water temperature was $11.9 \pm 0.8^\circ\text{C}$ during the Lcx condition and $14.8 \pm 1.4^\circ\text{C}$ during the Lcr, Scr and Han conditions. A balanced randomized order design was used. Insulated auditory canal (T_{ac}), rectal (T_{rec}) and mean skin (T_{sk}) temperature (7) and heart rate (HR) were monitored continuously and recorded every minute. Mean body temperature (T_b) and rate of change of heat storage (S) were also calculated (8,9). Water was provided at room temperature to drink ad libitum. Variables were analyzed across conditions using ANOVA.

RESULTS

All but one of the subjects completed the work periods. One subject was stopped due to a high HR before T_{ac} reached 38.5°C on 2 occasions (Han & Lcx). All subjects completed the full rest period in each condition except subject 4 who requested removal 25 min into the rest period (Con). The mean work time until $T_{ac} = 38.5^\circ\text{C}$ was 34 ± 9 min (range 28 to 40 min) for Con and 47 ± 14 min (range 26 to 68 min) ($P < 0.01$) during Lcx. The mean rate of increase of T_{ac} during work was lower during Lcx ($2.1 \pm 0.5^\circ\text{C}\cdot\text{h}^{-1}$ compared to Con $3.0 \pm 0.5^\circ\text{C}\cdot\text{h}^{-1}$; $P < 0.01$) as shown in Figure 1. There were no differences in the rates of rise of T_{rec} .

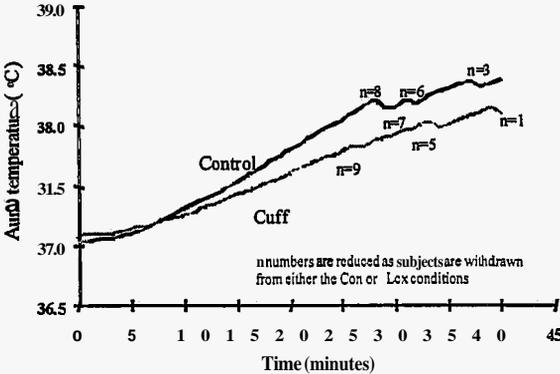


Figure 1. Mean T_{ac} of subjects exercising in the heat and the effect of water perfused cuffs. (n = 10)

During rest, mean T_{ac} and T_{rec} were reduced earlier and by the greatest amount during Han compared to the other 4 conditions, and the difference remained throughout the rest period. After 10 min of rest, the fall in mean T_{ac} in the Han was $0.8 \pm 0.24^\circ\text{C}$, while the next largest change was only $0.2 \pm 0.14^\circ\text{C}$ for Scr and Lcx ($P < 0.05$) and $0.1 \pm 0.08^\circ\text{C}$ in the Con and Lcr. After 40 min of rest, the reductions in mean T_{ac} in the Han ($1.5 \pm 0.05^\circ\text{C}$), Lcr ($0.7 \pm 0.05^\circ\text{C}$), Lcx ($0.7 \pm 0.10^\circ\text{C}$) and Scr ($0.6 \pm 0.05^\circ\text{C}$) were greater than in the Con condition ($0.3 \pm 0.08^\circ\text{C}$) ($P < 0.05$). These are shown in Figure 2.

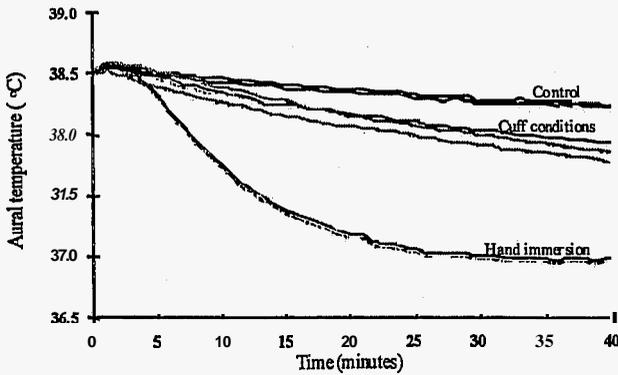


Figure 2. Mean T_{ac} of post-exercised subjects resting in the heat, and the effect of water-perfused cuffs ($n = 10$).

The differences in T_{rec} were similar, although the changes were slower. After 20 min of rest, the fall in mean T_{rec} was $0.3 \pm 0.11^\circ\text{C}$, while in all other conditions, T_{rec} had continued to rise. After 40 min only the Han ($0.7 \pm 0.17^\circ\text{C}$) condition resulted in a reduction in mean T_{rec} compared to the control ($0.1 \pm 0.18^\circ\text{C}$) ($P < 0.05$).

During work, S was attenuated in the Lcx compared to the Con, by a mean rate of $65 \pm 28 \text{ W}$ ($P < 0.05$). During rest, mean S was greatest in the Han ($-324 \pm 32 \text{ W}$) ($P < 0.01$) compared to the Lcx ($-83 \pm 10 \text{ W}$), Lcr ($-88 \pm 7 \text{ W}$) and Scr ($-80 \pm 8 \text{ W}$) conditions, which were in turn greater than the Con ($-28 \pm 11 \text{ W}$) ($P < 0.05$).

The rate of increase of HR during work was not significantly different between the Con (100 , range 52 to $156 \text{ bpm}\cdot\text{hr}^{-1}$) and Lcx conditions (84 , range 49 to $115 \text{ bpm}\cdot\text{hr}^{-1}$). After 40 min of rest, HR was significantly lower in the Han ($93 \pm 6 \text{ bpm}$) compared to all other conditions; the cuff conditions Lcx ($115 \pm 4 \text{ bpm}$), Lcr ($105 \pm 4 \text{ bpm}$) and Scr ($106 \pm 4 \text{ bpm}$) being intermediate to the Con ($120 \pm 4 \text{ bpm}$) and the Han and not significantly different from either.

CONCLUSIONS

During exercise, the large cuffs attenuated the rate of increase in heat storage (S) and extended safe working time by 38% confirming our first hypothesis. S , when wearing any of three types of ice vests, was between -17 and -33 W when measured under identical conditions (6). These values represent only 25 to 50% of that measured for the cuffs, despite the fact that the ice vests have a greater surface area than the cuffs and are colder (frozen at -18°C), and the cuffs do not provide direct skin contact. S , when a liquid-cooled torso vest was worn, has been recalculated from the published data (10) using the same equations as here to be approximately -178 W , although it should be remembered that the torso cooling surface area was 0.5 m^2 compared to the cuffs of only 0.065 m^2 .

During rest, the same pattern is seen with the cuffs reducing T_b at a rate (S) between 33 to 87% greater than that measured for ice vests during similar conditions (6). However, the cuffs were much less capable at extracting heat than direct hand immersion (thereby rejecting our second hypothesis); this remains the recommended method of reducing heat strain if subjects can utilize the technique. It is suggested that the differences in the efficiencies of extremity vs. torso cooling must be due to differences in the peripheral circulation. The perfusion rate of which determines heat extraction. In **summary**, cooling the forearms represents an effective method of attenuating heat strain during exercise. However, hand immersion remains a more effective method of cooling in those that are able to rest.

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