HAND IMMERSION AS A METHOD OF REDUCING HEAT STRAIN DURING REST PERIODS

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INTRODUCTION

Personnel wearing protective clothing often experience heat strain, are unable to cool during rest periods and subsequently overheat. Livingstone and Nolan[1] first demonstrated that personnel could be cooled by immersing the hands in cold water. The converse of this technique, using warm water hand immersion to rewarm hypothermic victims, was demonstrated by Vanggaard and Gjerloff[2]. They suggested that warming the skin dilated the arteriovenous anastomoses (AVAs) re-initiating peripheral perfusion. Blood heated during immersion returned to the core via superficial veins and thus the central tissues could be supplied directly with warmed blood; this change in blood flow was later demonstrated thermographically[3]. When the skin is warmed, either during hyperthermia[4] or warm water immersion[5], the constrictor tone of the periphery is reduced allowing greater perfusion. Furthermore when core temperature is raised the peripheral circulation actively dilates[6]. Thus cooling the peripheral blood during immersion presents a novel method of reducing core temperature. Previous studies have demonstrated the effectiveness of hand immersion in water at different temperatures[7,8,9]. Cooling powers measured in these studies have ranged between: 31-124 W[7]; 61-198 W[8], and; 113-334 W[9]. These cooling powers were associated with either attenuations in the rate of rise of rectal temperature (T_{rect}) as subjects exercised in the heat[7] or with reductions in aural temperature (T_{au}) at rates of: 0.62-1.10°C.hr^{-1} [8], and; 2.0-4.5°C.hr^{-1} [9], as subjects rested in the heat following exercise. Cooling powers[7,8,9] and the rates of reduction of T_{au}[8,9] were greater with lower water temperatures (in the range 10-30°C) or with a greater T_{au}[8] (in the range 37.5-38.5°C) at the start of hand immersion. The greater the gradient between T_{au} and water temperature the greater the amount of heat extracted during immersion. However, some of the differences between measured cooling powers may be due to methodological, clothing or physiological considerations: measuring[7] or estimating[8] cooling powers; the exercise status of the subjects, and; gloved *vs.* un-gloved hand immersion. The aim of this experiment was to measure heat exchange by calorimetry[7] and the reduction in T_{au} of hyperthermic subjects ($T_{au} \geq 38.5$°C), post exercise during un-gloved 20°C hand immersion.

METHOD

The study was approved by a local ethical committee. Six volunteer subjects were instrumented to measure T_{au} and skin temperatures (T_{sk}) and dressed in the Royal Navy (RN) firefighting ensemble: underpants, socks, Action Coverall (a double layered, cotton, anti-flash garment), Fearnought suit (a thick woollen garment), cotton anti-flash hood, mittens, boots, helmet and breathing apparatus. Each subject attempted three 30 minute exercise periods a day, on four separate days, as follows: 20 minutes in a hot environment (40°C dry bulb), followed by a further 10 minutes in a warm environment (30°C dry bulb) in order to simulate transit to the bottle changing point. Subjects then rested in this warm environment for 30 minutes following each exercise period with their outer clothing layer loosened (as firefighters would) either with their hands immersed for 20 minutes in 15 litres of 20°C water in a calorimeter, or rested without immersion (control). Exercise comprised stepping at a metabolic work rate previously shown to average 310 W (12 steps/min @ 22.5 cm). All subjects were asked to complete each exercise period unless T_{au} reached 39.0°C, heart rate exceeded (210-age) beats per minute, or they were unable or did not wish to continue, when they were stopped and rested either with or without hand immersion. An insulated container containing 15 litres of 20°C water was used as the calorimeter. Each subject stirred the water by moving their hands. A control calorimeter was used during each experiment to quantify any heat gain from the environment. Total heat loss from the hands was calculated as the product of the specific heat capacity of water, its mass and the difference in temperature rise between subject and control calorimeters. Analysis of variance was conducted to assess any differences between conditions.

RESULTS

The average reduction in T_{au} with hand immersion was 1.22 ± 0.39°C (mean ± s.d.) compared to 0.68 ± 0.30°C without, which was statistically significant ($P<0.01$). Furthermore there was a statistically significant difference ($P<0.05$) between cooling powers measured during the first and second immersion periods; 139 ± 20 W in the 1st, 167 ± 33 W in the 2nd. Cooling power during the third immersion period was similar to that in the second (169 ± 36.3 W). Average T_{au} at the start of each immersion period were 37.9 ± 0.03°C (1st), 38.4 ± 0.40°C (2nd) and 38.3 ± 0.47°C (3rd).

CONCLUSIONS

This study has shown that during hyperthermia heat is transferred from hands immersed in 20°C at a rate of between 140 to 170 W as measured by direct calorimetry. This heat loss resulted in greater reductions in T_{au} compared to the control condition without hand immersion. This shows that in a climate where personnel can lose heat passively, as indicated by the reduction in T_{au} during the control condition, hand immersion in 20°C water still provided an additional cooling benefit compared to the control.

In contrast, Livingstone and Nolan[7], although measuring heat transfer of up to 124±14 W, did not find corresponding reductions in T_{rect} during hand immersion with exercising subjects; during moderate exercise (455 W) the rate of increase of T_{rect} was attenuated whilst during light exercise (283 W) the rate of rise of T_{rect} actually increased, although this remains unexplained. In addition very little change was seen in T_{rect} during hand immersion following two hours of rest in the heat (35°C) without prior exercise even with reported cooling powers of between 32 to 99 W. However, this finding was likely considering that the maximum T_{rect} measured prior to hand immersion was only 37.3°C. Differences in the response time of aural *vs.* rectal temperature may account for some of these findings, however, the effect of exercise, increased metabolic heat production and redistributed blood supply, cannot be discounted.

Cooling powers measured by calorimetry in this study are lower than values reported previously in similar studies[8,9] where they were estimated from changes in body heat storage calculated from changes in core and skin temperatures[10,11]. Although the method of measuring or estimating cooling power may explain some of the difference, the effect of additional cooling has to be considered. The earlier studies[8,9] did not allow cooling other than by hand immersion. In this study subjects cooled through normal mechanisms in addition to hand immersion. The earlier studies[8,9] demonstrated the criticality of core temperature to cooling rates. A fall in core temperature by normal cooling methods would have reduced the gradient for heat transfer to the water and thus the cooling powers measured would have been reduced.

This study and others[8,9] have shown that hand immersion can be employed to effectively reduce T_{au} during rest periods after the cessation of exercise in the heat. This technique could extend safe exposure times for personnel either working in hot climates and/or wearing protective clothing.

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