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HEAT STRAIN PRODUCED BY A 3 AIRCREW CHEMICAL DEFENCE ENSEMBLES UNDER HOT CONDITIONS: IMPROVEMENT WITH AN AIR-COOLING VEST

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HEAT STRAIN PRODUCED BY 3 AIRCREW CHEMICAL DEFENCE ENSEMBLES UNDER HOT CONDITIONS: IMPROVEMENT WITH AN AIR-COOLING VEST

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ABSTRACT: The heat strain produced by three different Canadian Forces chemical defence (CD) individual protection ensembles (IPE) was studied under simulated hot cockpit conditions with an air-cooling vest (AC) and with no cooling (NC). Seven healthy males were randomly subjected to six heat stress tests (37°C, 50% r.h., target of 150 min) using the helicopter IPE with AC-4 mask (H4), the helicopter IPE with AR-5 hood/respirator (H5), and the CF-18 fighter IPE (F) with AR-5 respirator and anti-G suit. Whatever the IPE, AC increased heat exposure time and total heat losses, and decreased the change in core ($\Delta T_{re}/h$) and whole body mean skin temperatures ($\Delta \overline{T}_{sk(WB)}/h$) ($P<0.05$). Differences within IPEs appeared restricted to the F-NC condition. F-NC produced a lower heat exposure time (vs H4-NC and H5-NC) and sweat evaporation rate (vs H4-NC), and a greater $\Delta \overline{T}_{sk(WB)}/h$ (vs H4-NC and H5-NC) and T_{re} at min 80 (vs H5-NC) ($P<0.05$). The results demonstrate that air cooling greatly enhances heat tolerance of subjects wearing any of the 3 CD IPEs tested. They also indicate that without cooling, both helicopter IPEs produce slightly better tolerance to heat than the fighter IPE, possibly an influence of the anti-G suit on evaporative cooling.

KEYWORDS: body temperatures, chemical defence, heat balance, heat loss, heat storage, protective clothing.

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The high insulation and low moisture permeability of chemical defence (CD) individual protection ensembles (IPE) are sources of growing concern, particularly with respect to the extent of the heat strain experienced by military aircrew (1, 2). Indeed, it is well known that cockpit temperatures can reach very high levels in modern aircraft and the interaction of such an environment with a difficult mission load and the wearing of a CD ensemble can produce an unacceptable level of heat strain (1, 2). The consequences can go from a reduced aircrew comfort to a reduced performance and loss of mission (1, 3-6).

The Canadian Forces (CF) are presently introducing three different CD IPE for aircrew. The CF-18 fighter IPE (F) includes a CSU-15P anti-G suit and an AR-5 respirator. The latter is a rubber hood for the head and neck, with a neck seal. The helicopter AR-5 IPE (H5) is similar to the F IPE but does not include the anti-G suit. However, it does include the helicopter rubber overboots. The third one is the helicopter AC-4 IPE (H4) which is identical to the H5, except that the AR-5 is replaced with a full face mask with a permeable suspension system (AC-4) instead of the sealed rubber hood. Whether these differences are important from a thermoregulatory point of view during heat stress is not known. It was therefore felt important to compare and quantify the physiological deterioration and changes in heat tolerance associated with wearing these CD IPE under simulated hot cockpit conditions. It was felt equally important to determine whether a DCIEM air-cooling vest prototype is similarly effective in enhancing heat tolerance amongst these clothing configurations tested under the same conditions. Cooling systems for aircrew have been studied for several years (6-9). However, the effectiveness of a DCIEM-developed air-cooling vest has not been tested with respect to different types of CF CD protective ensembles.

EXPERIMENTAL METHODS

Subjects

Seven healthy young male volunteers participated in the present study. A physician examined each subject and approved his participation in the study. The nature, purpose and possible risks of the experiment were explained to each subject before he gave his written consent to participate. The subjects knew that a test would be terminated: 1) if their rectal temperature (T_{re}) reached 39.0°C (or a 2°C rise), 2) if their heart rate was maintained for two min at 95% of their maximal level; 3) if a maximal subjective rating of thermal discomfort or perceived exertion were given (see below); 4) or when the subject himself requested that the test be aborted. The subjects were familiarised with the protocol, the clothing and the heat stress test (for 1 h) on a familiarisation visit, prior to any experimental testing. They were also asked to maintain their normal dietary habits. $\dot{V}O_{2max}$ was determined directly by the Bruce protocol, and body fat was assessed by the underwater weighing technique (10)

Protocol and CD Ensembles

Six heat exposures [three IPEs (F, H5, H4) with and without cooling (AC, NC)] were randomly performed one week apart by each subject. The target duration of each test was 150 min. The environmental conditions in the climatic chamber (37.0±0.5°C T_{db}, 50±5% r.h., and 42°C T_g at the helmet using an infrared light, negligible air flow) were considered representative of hot cockpit conditions. All subjects wore the following common items: cotton longjohns (the top was turtleneck style), semi-permeable charcoal impregnated CD foam liner, CD coverall, survival/flotation vest, DH-411 helmet, wool socks, CD socks, combat boots, and finally wool, rubber and leather gloves. The H4 and H5 configurations were thus identical except for the full face AC-4 mask or the AR-5 respirator. Similarly, the F configuration was identical to the H5 except that it included the CSU-15P anti-G suit, but excluded the helicopter rubber overboots.

Before dressing the subjects were instrumented with a rectal temperature thermistor (T_{re}, inserted 12 cm into the rectum), 12 skin thermistors for the assessment of mean skin temperature ($\overline{T}_{sk}$), and a heart rate recorder (Sport Tester, Polar Electro, Finland). Subjects then attempted the following protocol: 10 min walk on the treadmill (4 km/h, zero grade) to simulate the walk-out to the aircraft, 20 min rest (air cooling, if any, was applied after the simulated walk-out), followed by alternate periods of 10 min of exercise (50W of mechanical power output on an ergocycle) and 10 min rest, for a target of 150 min at a time-weighted metabolic rate of 240W. This protocol was selected to simulate periods of evasive flying manoeuvres and periods of straight flying (6). Nude and dressed body weights were measured (Setra scale, Los Angeles CA) before and after each test to respectively determine overall sweat rate and sweat evaporation rate, both corrected for respiratory water losses (11; no fluid intake during the tests). The evaporative efficiency index was calculated as the percent of sweat produced that had evaporated (6). Subjects were asked to subjectively rate every 5 min their thermal comfort (6) and perceived exertion (12). Oxygen consumption and carbon dioxide production (converted to STPD values) were measured for 3 min of every 10 min rest or exercise period using a Beckman Horizon Metabolic Cart (Beckman Anaheim CA). Analysers were regularly checked for proper calibration during the tests. Metabolic rate was calculated from the tables of Lusk, as described elsewhere (13). Preliminary tests had revealed some leakage of expired gases with both the AR-5 and the AC-4 masks. To counteract this problem, subjects were required to hold the AR-5 mask in place during metabolic measurements, and for the AC-4, they were required to lift the mask and use a mouthpiece for the collection of expired gases.

Air-Cooling Vest

The AC vest was worn over the permeable underwear top and thus directly under the CD liner. The AC system was an open-loop design which was comprised of a vest (0.25 m^2 surface) and an air chiller. The vest incorporated an inner spacer fabric design to ensure uniform distribution of cool air over the entire surface of the torso covered by the vest (6). Air was directed across the torso and close to the skin surface so that it acquired heat both by evaporation of sweat (E) and by convection (C_{vest}) and then vented at the periphery through the clothing to the surrounding environment. Flow and inlet temperature were maintained at 280 L/min, T_{db} 13°C and T_{dp} 8°C, respectively. The theoretical maximal dry convective cooling capacity of the vest (C_{vest}) was calculated as the product of air flow rate, density and specific heat, and the gradient between inlet temperature and an assumed skin temperature of 35°C, and amounted to 123W (6,14). The theoretical maximal evaporative cooling capacity was calculated as the product of the air flow rate, the latent heat of evaporation of water at 35°C and the gradient between moisture content of inlet air and air saturated at an assumed skin temperature of 35°C, and amounted to an E of 364W. Therefore, the theoretical total cooling capacity (C_{vest} + E) of that DCIEM air vest was 487W.

Thermophysiological Measurements and Heat Balance

All thermal data were averaged every min using a computer-controlled data acquisition system described in detail elsewhere (15). A standard 12 point system for the measurement of $\overline{T}_{sk}$ was used (10). However, because, the four standard torso sites were heavily influenced by the air vest during AC tests, they were deemed more representative of only the vest area covering the body (0.25 m^2, or 13% of the BSA) rather than the entire torso area (about 0.69m^2 or 35% of the BSA). Accordingly, $\overline{T}_{sk}$ for the vest and non-vest areas of the body ($\overline{T}_{sk(V)}$, and $\overline{T}_{sk(NV)}$ respectively) were calculated using modifications of the standard weighting factors, as before (6). Whole body $\overline{T}_{sk}$ [$\overline{T}_{sk(WB)}$] was then calculated as the area-weighted sum of $\overline{T}_{sk(V)}$ and $\overline{T}_{sk(NV)}$. Mean body temperature ($\overline{T}_b$) was calculated as $0.8T_{re}$ + $0.2\overline{T}_{sk(WB)}$ (16). Body heat storage was calculated according to conventional methods (10, 17). The dry heat exchange with the ambient environment by radiation and convection ($R{+}C_{amb}$ in watts) was assessed as follows (6, 18, 19):

$$R+C_{amb} = [BSA \cdot 6.45 \cdot (\overline{T}_{sk} - T_{amb})]/I \qquad (1)$$

where BSA is either the whole body or non-vest surface area (NC or AC configurations, respectively), 6.45 is a unit conversion factor from clo to SI units, I is the clothing insulation in clo units (2.5 and 2.7 clo for the helicopter and fighter IPE, respectively), $\overline{T}_{sk}$ is either the final $\overline{T}_{sk(WB)}$ or $\overline{T}_{sk(NV)}$ (for NC or AC, respectively) corresponding to the above-mentioned BSA, and T_{amb} is the ambient environmental temperature (37°C). Other heat losses, or the combination of E and C_{vest} (from AC vest) were lumped in one term (H_{ec}) that was calculated by resolving the heat balance equation (all values are in watts; conductive heat loss, K, was assumed negligible):

$$M - W - L - S - (R+C_{amb}) - E - C_{vest} = 0 \qquad (2), \quad \text{or}$$
$$H_{ec} = M - W - L - S - (R+C_{amb}) \qquad (3)$$

where M is the average rest and exercise metabolic rate, W is the average external work (20), L is the respiratory heat losses through evaporation and convection (8% of M) (21), S is the rate of heat storage and $R{+}C_{amb}$ is the dry heat exchange.

Statistics

The effects of cooling (NC and AC) and CD clothing (F, H5 and H4) were analysed using a two-way (2x3) analysis of variance with repeated measures (Biomedical Computer Programs, BMDP-89, Los Angeles CA). Dunnett's t-tests were used to locate significant differences between cells. Results are expressed as mean ± SEM.

RESULTS

The physical characteristics of the subjects were: 31±2 yr old, 1.80±0.01 m, 75±7 kg, 1.93±0.04 m^2 body surface area, 51±3 ml O_2/kg.min $\dot{V}O_{2max}$ and 12±1% body fat. Heat exposure time was affected by a main effect of air cooling as well as a main effect of CD clothing ($P<0.05$; Fig. 1). This is consistent, on the one hand, with the demonstration that each AC test produced a significantly longer heat exposure time than each NC test, and on the other hand, with the demonstration that both H5-NC and H4-NC exposure times were significantly longer than that of the F-NC test ($P<0.05$; Fig. 1).

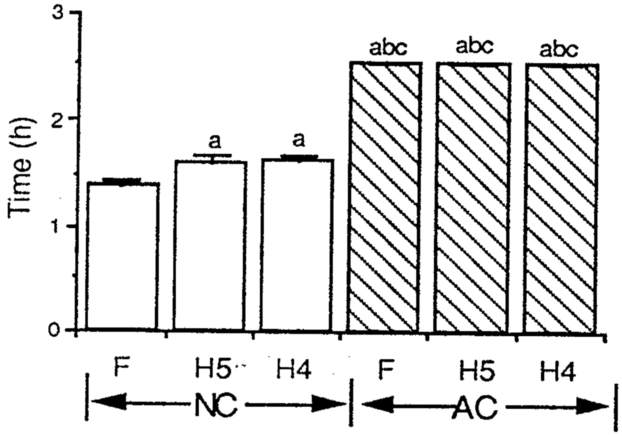

Fig. 1. Influence of Canadian Forces CD IPE (F, H5, H4) with and without air-cooling (AC, NC) on heat exposure time. All subjects were able to complete the 150 min test with AC. Significant differences from F-NC, H5-NC and H4-NC configuration are indicated by the letters a, b or c, respectively ($P<0.05$).

After 60 min in the chamber, there was already a main effect of air cooling ($P<0.01$) which reduced the T_{re} profile over time regardless of the IPE ($P<0.05$; Fig. 2). From min 60, subjects in all AC tests had indeed significantly lower T_{re} than in all other NC tests ($P<0.05$). In addition to the above main effect of air cooling, there was at min 80, an additional main effect of CD clothing on T_{re}. Post hoc tests revealed that this was restricted to the F-NC T_{re} which was significantly higher than H5-NC ($P<0.05$; Fig. 2). Relatively similar results were observed with the change (Δ) in T_{re}/h. Although a main effect of protective clothing was not significant, there was a main effect of air cooling ($P<0.001$) which markedly reduced all AC-induced increases in T_{re}/h (0.38±.06, 0.37±.05 and 0.42±.05°C/h for F, H5 and H4, respectively) in comparison to all NC tests (1.09±.04, 1.00±.05 and 1.06±.06°C/h for the F, H5 and H4, respectively; $P<0.05$).

In addition to the large changes in core temperature, final $\bar{T}_{sk(WB)}$ was significantly affected by a main effect of air cooling ($P<0.01$) which markedly reduced the rise observed in all NC tests (data not shown). This was accomplished by a large drop in $\bar{T}_{sk(V)}$ for AC (5.1±0.5 to 5.6±0.4°C vs an increase of 3.3±0.2 to 3.4±0.1°C with NC tests; $P<0.05$), which contributed to the smaller rise in

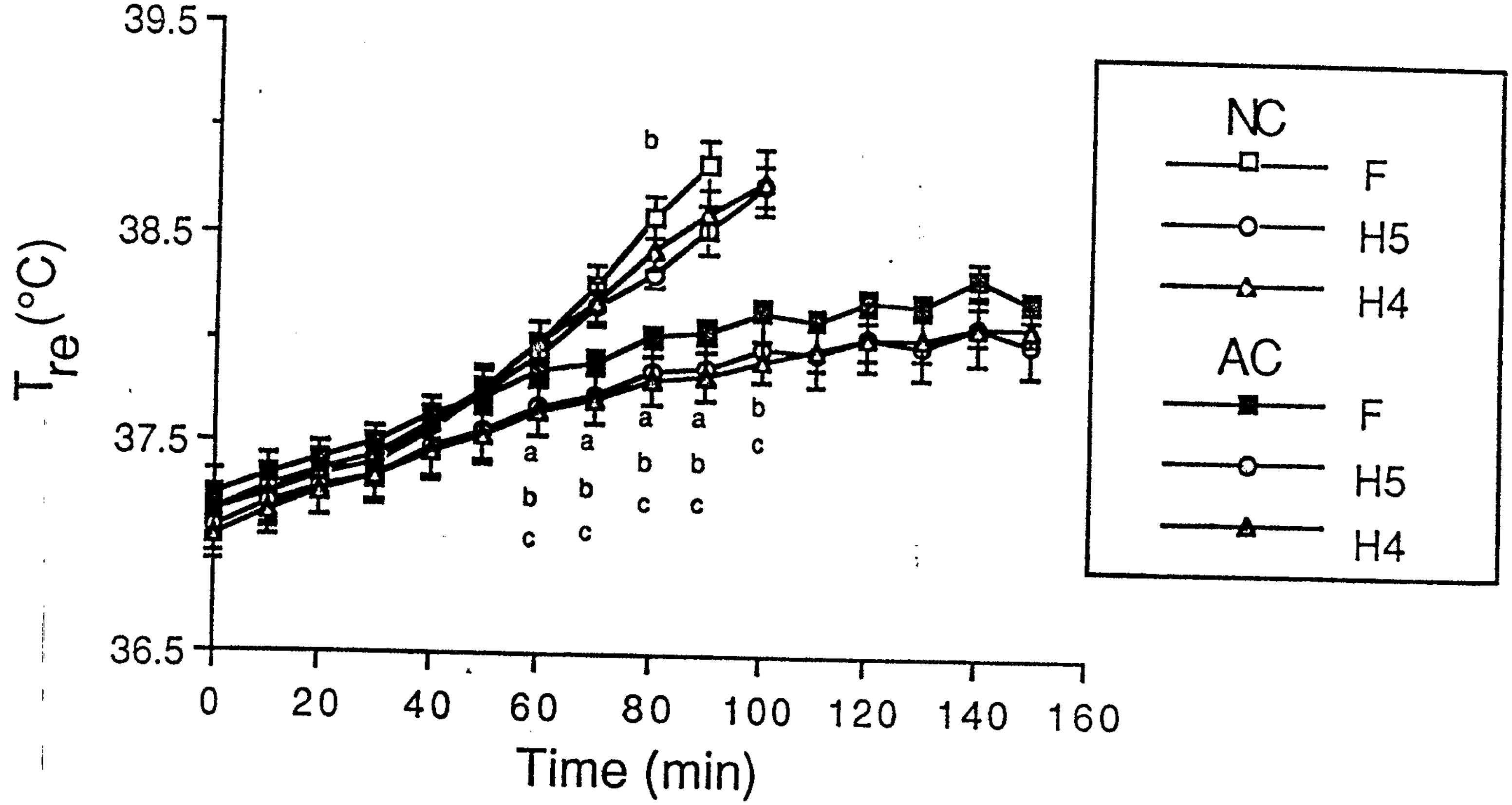

Fig. 2. Influence of protective clothing (F, H5, H4) and air cooling (AC, NC) on core temperature (T_{re}) profile over time. From min 60, all AC tests produced significantly lower T_{re} than all NC tests. Symbols for statistical significance are as in Fig. 1.

$\overline{T}_{sk(NV)}$ with AC (only 2.9±0.2 to 3.0±0.1°C vs 3.9±0.1 to 4.1±0.2°C for NC tests, $P<0.05$). It was also found that the $\Delta\overline{T}_{sk(WB)}/h$ (Fig. 3A) was not only altered by a main effect of air cooling but also by an interaction of effects ($P<0.01$), which indicated that the effect of protective clothing significantly changed with cooling. This was shown by the significantly greater increase in $\overline{T}_{sk(WB)}/h$ of the F-NC test in comparison to the other two NC tests, and in comparison to all three AC tests ($P<0.05$; Fig. 3A). In contrast, no differences were found within the three AC tests. Approximately similar results were observed with the rise in $\overline{T}_b/h$ (Fig. 3B). It was affected by main effects of air cooling and CD clothing. Indeed, Fig. 3B clearly shows that all three AC tests produced lower $\Delta\overline{T}_b/h$ in comparison to all 3 NC tests ($P<0.05$), while the F-NC configuration showed significantly greater $\Delta\overline{T}_b/h$ than that of the H5-NC test ($P<0.05$).

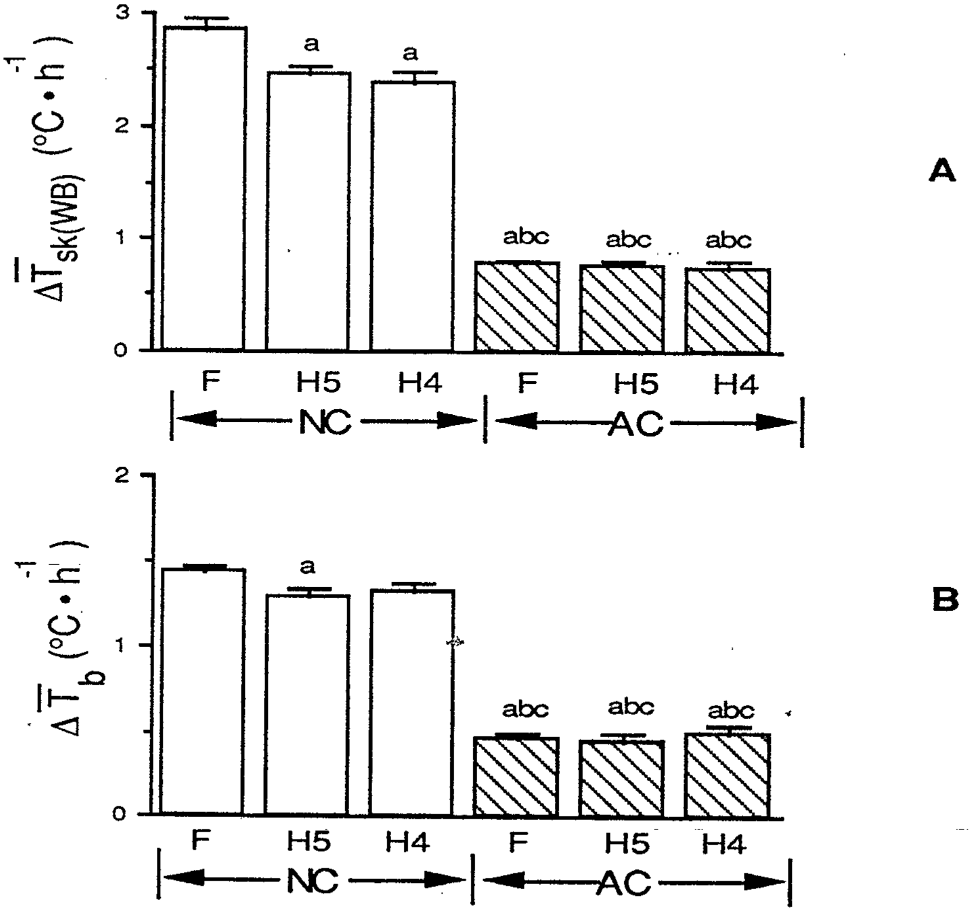

Fig. 3. Influence of protective clothing (F, H5, H4) and air cooling (AC, NC) on whole body mean skin temperature ($\Delta T_{sk(WB)}$ in °C/h; Fig. 3A) and mean body temperature (ΔT_b in °C/h; Fig. 3B). Symbols for differences are as in Fig. 1.

Fig. 4 describes the data on sweat production rate, sweat evaporation rate and evaporative efficiency index. Sweat rate was only affected by a main effect of air cooling ($P<0.001$), as the sweat production rate of subjects in all AC tests were significantly lower than that found in all NC tests (Fig. 4A). It should be mentioned that NC tests were associated with absolute sweat rates that were as high as 0.95-

1.00 kg/h, nearly twice that observed for AC. A different picture was found for the sweat evaporation rate. This parameter was affected by main effects of air cooling and CD clothing: all AC and the H4-NC tests produced sweat evaporation rates that were significantly greater that those of F-NC ($P<0.05$; Fig. 4B). The evaporative efficiency index data clearly shows the strong effect of air cooling since all AC test values were significantly greater that those of all NC tests ($P<0.05$; Fig. 4C).

Table 1 shows the heat balance data. There was no influence of the two treatments on M, W or L. However, there was a significant main effect of air cooling which

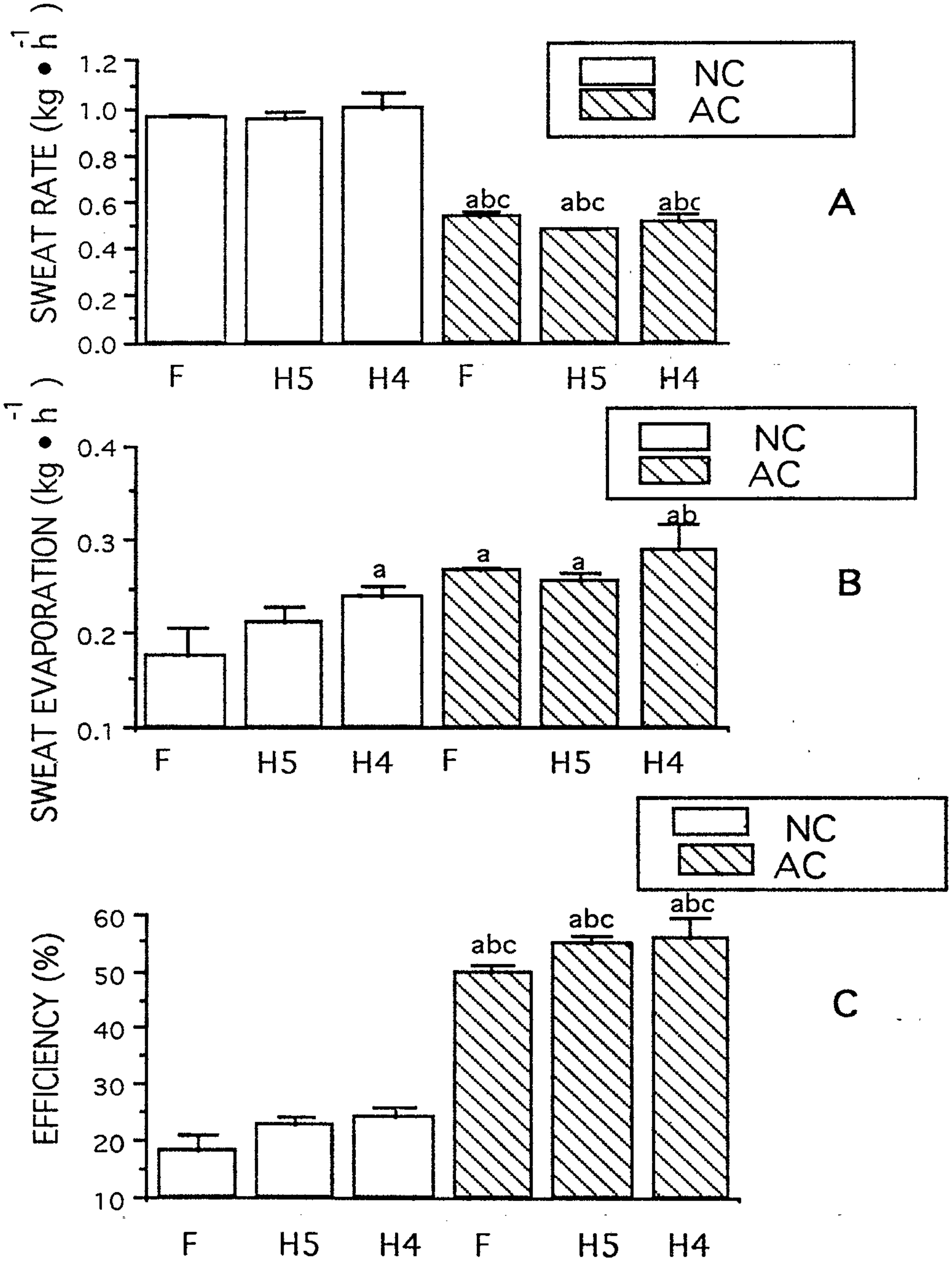

Fig. 4. Influence of protective clothing (F, H5, H4) and air cooling (AC, NC) on sweat rate (Fig. 4A), sweat evaporation rate (Fig. 4B) and evaporative efficiency index (Fig. 4C). Symbols for statistical differences are as in Fig. 1.

significantly reduced the body heat gain (S) and dry heat losses ($R+C_{amb}$), and significantly increased the combined E and C_{vest} heat losses (H_{ec}) ($P<0.05$). This was shown by the significantly lower S and $R+C_{amb}$ and the significantly greater H_{ec} of all AC tests in comparison to those of all NC tests ($P<0.05$). No significant differences between CD IPE were observed. Final rest/exercise heart rate and final ratings of thermal comfort and perceived exertion all showed the same pattern of response (data not shown), as all AC tests produced significantly lower results than each NC test. No significant differences between the three IPEs were observed.

TABLE 1- - INFLUENCE OF CD GARMENT AND AIR COOLING ON HEAT BALANCE

		M	W	L	S	$R+C_{amb}$	H_{ec}
NC	F	272 ±17	20.5 ±0	22 ±1	102 ±4	5 ±1	116 ±14
	H5	268 ±9	20.5 ±0	21 ±1	92 ±4	4 ±1	124 ±24
	H4	288 ±6	20.5 ±0	23 ±1	99 ±3	5 ±1	141 ±4
AC	F	260 ±8	20.5 ±0	21 ±1	21 abc ±4	0 abc ±0	182 abc ±10
	H5	257 ±12	20.5 ±0	21 ±1	21 abc ±3	-1 abc ±1	181 abc ±9
	H4	277 ±7	20.5 ±0	22 ±1	24 abc ±3	-1 abc ±1	197 abc ±6

Heat balance values during the heat stress test for the F, H5 and H4 CD IPE with NC or AC. M metabolic rate, W work rate, L respiratory heat losses, S heat gain, $R+C_{amb}$ whole body dry heat exchange with the environment, and H_{ec} other heat losses by evaporation (E) and convection (C_{vest} from AC only). All units are in watts. Symbols for statistical differences are as in Fig. 1.

DISCUSSION

The present results demonstrate that, during simulated hot cockpit conditions, a DCIEM air-cooling vest significantly enhances tolerance to heat of subjects wearing either the Canadian Forces H4 helicopter, H5 helicopter or F fighter chemical defence IPE. It was indeed observed that, regardless of the IPE, air cooling significantly increases heat exposure time, evaporative efficiency and total heat losses (Figs. 1 and 4; Table 1), and significantly decreases the rate of rise in body temperatures over time, sweat rate (Figs. 2-4), heart rate, thermal discomfort and perceived exertion (see Results). In addition, the results also show that under hot conditions without auxiliary cooling, subtle but possibly important differences were observed within the various IPEs.

Chemical Defence Ensembles: The H4-NC and H5-NC configurations produced longer heat exposure times and smaller rises in body temperatures than the F-IPE (Figs. 1-3). It is possible that these differences within protective clothing could be due mainly to the presence of the anti-G suit, which practically does not increase clothing insulation, but slightly reduces total and evaporative heat losses. The main difference between the H5 and F IPE was the CSU-15P anti-G suit in the latter.

While it is true that it adds to the total insulation of the garment, the effect is rather small (see Methods). It can be calculated that its slightly greater insulation could only decrease $R+C_{amb}$ by about 1 W. This is only possible because the gradient between skin and ambient temperatures is small. Since the anti-G suit includes an impermeable bladder over almost half of its area and since it fits close around the legs, it appears more likely that it inhibits the ventilation of the air layers that are usually found in loosely hanging pants, and thus reduces sweat evaporation and possibly evaporative heat loss in that particular body area. To ascertain whether E can be implicated in the lesser heat tolerance of the F-NC configuration, it is necessary to partition out the various avenues of heat loss (R, C, K, E).

The quantification of each avenue of heat loss in the NC mode is fairly easy: $R+C_{amb}$ is shown in Table 1, K is assumed negligible, and H_{ec}, a term representing the sum of E and C_{vest}, was estimated by resolving the heat balance equation (shown in Table 1). Of course, there was no C_{vest} component in H_{ec} during NC, therefore, that term only represents E, which amounted to 116, 124 and 141 W for the F, H5 and H4 configurations, respectively (Table 1). It is interesting to note that these 3 tests were also associated with a sweat evaporation rate of 0.173, 0.213 and 0.238 kg/h, respectively (Fig. 4B). Knowing the latent heat of vaporisation, these evaporation rates correspond to a potential E of 116, 143 and 160 W, again for the same F, H5 and H4 conditions, respectively. The ratio of estimated E (Table 1) divided by potential E (above) indicates that for both the H5 and H4 conditions, about 87% (124/143, 141/160) of the sweat evaporation would have occurred close to the skin level. It was surprising to note that the percentage was about 100% with the F-NC. The explanation of this higher result is still obscure. It could be ascribed to the fact that conductive heat loss (K; mainly to the aircraft seat) may not be negligible after all, particularly with the slightly warmer F-NC condition. It could also be due to slight inaccuracies in E or M during this particular test, which was the most stressful one (see Fig. 1). Nevertheless, individuals wearing CD gear may find it sweat permeable, but with the above exception of F-NC, they receive less than the full cooling benefit of sweat evaporation (6, 22). This would occur because as sweat is absorbed in the clothing, sweat evaporation occurs further away from the skin, diminishing skin cooling. Further studies are required to clarify the above and the contribution of body vs ambient heat to E. The predominant mechanism of heat loss in NC remains E (96-97% of total). However, it comes at the cost of a high sweat rate (0.95-1.00 kg/h; Fig. 4A) and dehydration (about 2%). Yet, only 18-22% of that sweat was evaporated (Fig. 4C). The present data are thus consistent with previous findings on the very low evaporative efficiency index observed with protective clothing in the heat (6), and extend them to different types of Canadian Forces CD IPE, with the lowest efficiency being observed with the F-NC condition (Fig. 4C). Although nonsignificant, it was found that both M and H_{ec} for H4 were slightly higher than for F and H5 conditions (Table 1). This could be related to the fact that subjects in H4 were required to raise their mask and hold a mouthpiece for the duration of each measurement. This procedure could have slightly altered M and E. Futures studies are required to clarify these small differences. It is also interesting to note that the type of respirator, in contrast with adding the anti-G suit, did not significantly affect exposure time or body temperatures (Figs. 1-3).

Auxiliary Air Cooling: In contrast to NC, all protective clothing differences that were previously observed without auxiliary cooling were dissipated with air cooling. The present prototype of the DCIEM air-cooling vest has a calculated maximal convective cooling capacity (C_{vest}) of 123W and a maximal E capacity of 364W, for a maximal theoretical cooling capacity of 487W. Since H_{ec}, the sum of C_{vest} and E, amounted to 182, 181 and 197 W for the F, H5 and H4 IPE, respectively, it is possible to estimate that the air-cooling system was operating at best, at about 37-40% of the maximal theoretical capacity shown above. This is consistent with previous data (6) and extends the efficacy of the DCIEM air vest to several different IPEs.

To better understand how the vest alters heat exchange, one has to analyse the proportion of heat loss through each avenue. As stated in Methods, there are two convective heat loss components in AC. One ($R+C_{amb}$) is related to the gradient from $\overline{T}_{sk(NV)}$ and the hot ambient conditions whereas the other (C_{vest}) is related to the gradient between $\overline{T}_{sk(V)}$ and the vest inlet temperature. Similarly, there are two E components, vest and nonvest . However, they could not be dissociated from one another, and strictly for the purpose of the present discussion, we have assumed that, in AC, nonvest E was low and that E was entirely due to the air vest. Using the same 87% of the maximal evaporative cooling potential of the sweat evaporation as in NC (H4-NC and H5-NC), the evaporation rates of 0.264, 0.254 and 0.288 kg/h of F, H5 and H4, respectively (Fig. 4) correspond to 154, 148 and 168 W of E. Comparing these values to H_{ec} (182, 181 and 197 W, respectively; Table 1) indicates that at best, E amounted to 85, 82 and 85% of the total heat loss for F-AC, H5-AC and H4-AC, respectively. C_{vest} was thus equal to only 28, 33 and 29 W, or 15, 18 and 15% of the total cooling in the same conditions, respectively. E would therefore be the major avenue of heat loss for AC. The proportion of E produced by the vest or the nonvest area of the body is not known. However, we do know from post hoc experiments that the cooling effect of the vest is not restricted to the vest area and that it spreads to a greater area (Vallerand and Michas, unpublished). It is important to point out that the present estimates of heat loss by E and C_{vest} are in agreement with the observed AC-induced low sweat rate and low heart rate, high sweat evaporation rate and evaporative efficiency index and reduced subjective discomfort and perceived exertion (Fig. 4 and Results).

This study confirms other findings which have shown that AC systems are an effective means to alleviate heat strain for aircrew, by providing less stressful conditions, resulting in a drier micro-environment (lower sweat rate and greater E) thereby increasing comfort (7, 23, 24). Answers to a simple questionnaire at the end of the study revealed that all subjects agreed that a cooling system was required to complete this strenuous test and that they experienced little heat stress with AC. It has been shown that aircrew performance can be reduced by a 1°C rise in T_{re} and that G-tolerance can be impaired by a 1-3% body weight dehydration (1, 2). The present 1.5°C increase in T_{re} and 2% dehydration (Figs. 2 and 4) with NC are certainly indicative of heat strain that is beyond acceptable limits for aircrew. The use of AC, under the present conditions, would therefore be recommended to prevent a reduction in aircrew thermal comfort, performance, G tolerance and safety.

To summarise, the results demonstrate that a DCIEM air-cooling vest markedly enhances heat tolerance of subjects wearing either the Canadian Forces fighter, helicopter H5 or helicopter H4 CD protective clothing under simulated hot cockpit conditions. The results also point out that without microclimate cooling, both helicopter ensembles are associated with slightly better tolerance to heat than the fighter ensemble, a difference that could be explained by the influence of the fighter anti-G suit on evaporative heat losses.

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