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TITLE

HEAT STRAIN WHILE WEARING THE CURRENT CANADIAN OR A NEW HOT-WEATHER FRENCH NBC PROTECTIVE CLOTHING ENSEMBLE

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ORIGINAL RESEARCH

Heat Strain While Wearing the Current Canadian or a New Hot-Weather French NBC Protective Clothing Ensemble

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Background: A new nuclear, biological and chemical (NBC) protective garment has been designed for use in hot environments. This NBC battle dress uniform (NBC-BDU) is intended to be worn over the skin or, at most, over underwear and an undershirt. It is unclear whether the documented reductions in heat strain associated with wearing this clothing configuration represent simply the removal of the combat clothing layer normally worn underneath a NBC protective overgarment or an improved heat transfer through the new NBC-BDU. ***Hypothesis:*** It was hypothesized that the removal of the combat clothing layer would produce a significant reduction in heat strain. As a result, it was also hypothesized that there would be no difference in heat strain between this new NBC-BDU and the current Canadian protective overgarment when the remaining clothing was standardized. ***Methods:*** There were 9 males who alternated 15 min of walking at 1.11 $m \cdot s^{-1}$ and 15 min of seated rest for a maximum of 4 h in a chamber set at 40°C, 30% relative humidity and a wind speed less than 0.1 $m \cdot s^{-1}$ while wearing underwear, an undershirt and the current Canadian protective overgarment either with (C+C) or without (C−C) combat clothing underneath and the new NBC-BDU worn over underwear and an undershirt. ***Results:*** All indices of heat strain which included tolerance time, sweat rates, sweat evaporation, T_{re}, T_{sk}, skin and garment vapor pressures, and heart rate indicated a significant improvement when the combat clothing was removed regardless of which NBC protective garment was worn. The new NBC-BDU was associated with a lower T_{re} after 2 h of exposure and lower skin and garment vapor pressures compared with the Canadian overgarment. Other indices of heat strain were not different between the NBC-BDU and C−C configurations. ***Conclusions:*** During light intermittent exercise when the rate of heat production is low, the removal of the combat clothing layer as part of the Canadian NBC protective ensemble is recommended to significantly reduce the heat strain.

THE HEAT STRAIN associated with wearing the military's current-issue nuclear, biological and chemical (NBC) protective clothing is well documented for many countries at different ambient temperatures, vapor pressures and metabolic rates (1,5,8,10,12,16,18). In very hot environments, the use of a thinner vapor protective clothing layer worn as an undergarment is one strategy that has been shown to be effective in reducing the heat strain involved with wearing the current protective overgarments (9,11,13). If operational conditions permit, another effective strategy is to remove the combat clothing layer worn underneath the protective overgarment. This practice will reduce the total insulative value of the protective clothing ensemble (7) and thus reduce the heat strain (9,11).

A new nuclear, biological and chemical protective battle dress uniform (NBC-BDU) has been designed specifically for use in hot environments (2). This 2-piece (jacket and trousers) protective uniform consists of an external cotton polyester layer and an internal layer of foam impregnated with charcoal. The NBC-BDU is intended to replace the standard battle dress clothing and is to be worn directly over the skin or, at most, over underwear and an undershirt. Etienne et al. (2) did report the insulative value of this garment measured on a static manikin and an effective wind velocity of 0.4 $m \cdot s^{-1}$ at 0.7 clo units which was similar to the value of 0.6 clo measured for their battle dress clothing. Vapor permeability was reduced however as indicated by the greater fluid loss during both laboratory and field trials while wearing the protective garment compared with the battle dress configuration. Total body weight loss at 35°C and 40% relative humidity following 45 min of walking at 4 $km \cdot h^{-1}$ and 40 min of seated rest was 0.8% while wearing the protective NBC-BDU compared with 0.6% while wearing the standard battle dress. The gradient between rectal and skin temperature was maintained above 2°C for both clothing configurations (2).

Documented differences in heat strain between the current Canadian protective ensemble and combat clothing during light exercise at temperatures between 30° and 40°C (10,12) are much greater than those reported by Etienne et al. (2). Thus this new protective NBC-BDU should reduce the heat strain associated with wearing the current Canadian NBC protective clothing ensemble which includes an overgarment worn over combat clothing and underwear. It is not clear, however, whether the reduction in heat strain would represent simply the removal of the combat clothing layer (9,11) or an additional component associated with an improved vapor permeability and/or a reduced insulative value of the

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new NBC-BDU itself. The purpose of the present study, therefore, was to compare the heat strain associated with wearing this new NBC-BDU with the current Canadian protective overgarment worn with or without the combat clothing layer. It was hypothesized that once the underlying clothing layers were standardized the heat strain would be similar regardless of whether this new garment or the current Canadian protective overgarment was worn.

METHODS

Subjects: Following approval from the Institute's human ethics committee, nine unacclimatized males volunteered to participate in the study. Mean values (±S.D.) for age, weight, height, body surface area and $\dot{V}O_{2max}$ were 32.7 ± 4.9 yr, 84.3 ± 12.2 kg, 1.81 ± 0.04 m, 2.04 ± 0.15 m^2 and 48.7 ± 4.5 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively. They were informed of all details of the experimental procedures and the associated risks and discomforts. After a medical examination to ensure that there were no medical contraindications to their participation in the experiment, each subject gave informed consent prior to the first day of data collection.

Determination of maximal aerobic power ($\dot{V}O_{2max}$): $\dot{V}O_{2max}$ was determined on a motor-driven treadmill using open-circuit spirometry before the series of experiments in the climatic chamber. Following 2 min of running at a self-selected pace, the treadmill grade was increased $1\% \cdot min^{-1}$ until subjects were running at a 10% grade. Treadmill speed was then increased 0.22 $m \cdot s^{-1}$ (0.8 $km \cdot h^{-1}$) each minute until the subject could no longer continue. $\dot{V}O_{2max}$ was defined as the highest $\dot{V}O_2$ observed during the incremental test. Heart rate (HR) was monitored throughout the incremental test from a telemetry unit (Polar Electro PE3000, Stamford, CT). The heart rate value recorded at the end of the exercise test was considered to be the individual's maximum.

Experimental Design

All subjects performed 3 experimental sessions in random order separated by a minimum of 3 d and a maximum of 7 d. The following items were worn during each trial: underwear or jogging shorts, cotton/polyester t-shirt, socks, jogging shoes, impermeable overboots and gloves, and C4 respirator. The 3 trials consisted of wearing these common items plus the Canadian 1-piece protective overgarment worn over lightweight cotton combat clothing (C+C) which is the current operational and highest level of protection available for the Canadian Forces, the Canadian overgarment worn over only the underwear and t-shirt (C−C, to indicate that the combat clothing was not worn) and the new 2-piece NBC-BDU worn over the underwear and t-shirt. The new protective overgarment is intended to be worn next to the skin or over underwear and a t-shirt. Combat clothing is not included as part of this operational clothing configuration. For the C−C configuration, there has been no indication that the extent of NBC protection is compromised with the removal of the combat clothing layer. All trials were conducted in the late winter and early spring months and performed at the same time of day for a given subject. Subjects were also asked to avoid alcohol on the day before and caffeine during the morning of each trial. Each session involved alternating 15 min of walking on a level treadmill at 1.11 $m \cdot s^{-1}$ (4.0 $km \cdot h^{-1}$) and 15 min of seated rest in the environmental chamber set at 40°C, 30% relative humidity and a wind speed less than 0.1 $m \cdot s^{-1}$. All trials continued for a maximum of 4 h or until rectal temperature (T_{re}) reached 39.3°C, heart rate remained at or above 95% of the individual's maximum for 3 min, nausea or dizziness precluded further exercise, the subject asked to be removed from the chamber, or the investigator removed the subject from the chamber. Subjects also performed a familiarization trial which involved wearing clothing configuration C+C, included all aspects of the experimental sessions and used the same criteria for termination of the trial. This session was performed 3–7 d prior to the first experimental condition.

Dressing and Weighing Procedures

Subject preparation, insertion of the rectal thermistor and placement of skin thermistors have been detailed previously (11,12). In addition, relative humidity capacitance sensors (Vaisala Sensor Systems, Woburn, MA) and thermistors were taped on the skin and the inner layer of the protective garment at the upper back, abdomen and upper thigh. The same sensor and thermistor were used to measure humidity and temperature at the same site for each trial for a given subject. These humidity sensors have an accuracy of ±3% and the linearity of response was verified for each sensor with saturated salt solutions of lithium chloride, sodium chloride and potassium sulphate to provide relative humidity measurements of 12%, 75% and 97%, respectively. Both nude and dressed weights were recorded prior to entry into the chamber. Upon entering the chamber, the subject's humidity sensors and thermistors, and skin and rectal thermistor monitoring cables were connected to a computerized data acquistion system (Hewlett-Packard 3497A control unit, 236-9000 computer and 2934A printer) and the exercise began. Mean values over 1-min periods for T_{re}, a 12-point weighted mean skin temperature ($\bar{T}_{sk}$) (19) and an unweighted average of skin and garment vapor pressure ($\overline{VP}_{sk}$ and $\overline{VP}_{G}$, respectively) were calculated, recorded and printed by the data acquisition system. HR was recorded every 5 min from the display on the telemetry receiver. Subjects were allowed the equivalent of 1 canteen (approximately 1 L) of water during the exposures. After the completion of each trial, dressed weight was recorded within 1 min after exit from the chamber and nude weight was recorded following a 5-min undress procedure.

Differences in nude and dressed weights before and after each trial were corrected for fluid intake and respiratory and metabolic weight loss (see below). The rate of sweat production was calculated as the difference between the corrected pre-trial and post-trial nude weights, divided by tolerance time which was defined as the difference in time between removal from and entry into the environmental chamber. Evaporative sweat loss was calculated from the differences in pre- and post-trial corrected dressed weights. The evaporative efficiency represented the evaporative sweat loss expressed as a percent-

TABLE I. TOLERANCE TIME, RATE OF SWEAT PRODUCTION, RATE OF SWEAT EVAPORATION, EFFICIENCY OF SWEAT EVAPORATION (WHICH IS THE RATIO OF SWEAT EVAPORATED TO SWEAT PRODUCED EXPRESSED AS A PERCENTAGE) AND THE AVERAGE METABOLIC RATE DURING ALTERNATING PERIODS OF TREADMILLL WALKING AND SEATED REST AT 40°C AND 30% RELATIVE HUMIDITY FOR THE CANADIAN NUCLEAR, BIOLOGICAL AND CHEMICAL (NBC) PROTECTIVE OVERGARMENT WORN WITH (C+C) OR WITHOUT (C−C) COMBAT CLOTHING AND THE NEW FRENCH NBC PROTECTIVE BATTLE DRESS UNIFORM (NBC-BDU).

	C+C	C−C	NBC-BDU
Tolerance time (min)	146.3 ± 27.8*	197.1 ± 34.3	202.8 ± 25.5
Rate of sweat production ($kg \cdot h^{-1}$)	0.91 ± 0.24*	0.68 ± 0.21	0.68 ± 0.17
Rate of sweat evaporation ($kg \cdot h^{-1}$)	0.28 ± 0.05*	0.34 ± 0.07	0.34 ± 0.04
Evaporative efficiency (%)	32.0 ± 8.0*	51.5 ± 11.0	52.1 ± 9.7
Average metabolic rate			
($L \cdot min^{-1}$)	0.74 ± 0.11	0.74 ± 0.10	0.73 ± 0.11
($W \cdot m^{-2}$)	127.5 ± 13.1	126.0 ± 13.4	125.7 ± 13.0

Values are means ± S.D. n = 9
* significantly different from the other clothing configurations

age relative to the total sweat produced. Sweat evaporation and evaporative efficiency calculations were not corrected for sweat drippage through the clothing or from the exhaust valve of the respirator. Sweat drippage through the C−C configuration became quite evident during the latter rest periods for several subjects. Sweat drippage through the exhaust valve of the respirator was common to all trials.

Gas exchange analyses: During each trial, open-circuit spirometry was used to determine expired minute ventilation ($\dot{V}_E$) and oxygen consumption ($\dot{V}O_2$) using a 2-min average obtained every 15 min. For all trials, an adaptor was attached to the respirator which allowed expired air to be collected. Respiratory water loss was calculated using the $\dot{V}O_2$ measured during the trial and the equation presented by Mitchell et al. (15). Metabolic weight loss was calculated from $\dot{V}O_2$ and the respiratory exchange ratio using the equation described by Snellen (17).

Statistical analyses: Data are presented as mean values and the standard deviation of the mean. A one-factor (trial) repeated measures ANOVA was used to evaluate any differences among the trials for sweat production, sweat evaporation, evaporative efficiency, average metabolic rate and tolerance time. A two-factor (trial and time) repeated measures ANOVA was performed for evaluating the changes in $\dot{V}O_2$, HR, T_{re}, $\bar{T}_{sk}$, $\overline{VP}_{sk}$ and $\overline{VP}_G$ during the exposures. When a significant F-ratio was obtained, a Newman-Keuls post-hoc analysis was used to isolate differences among treatment means. For all statistical analyses, the 0.05 level of significance was used.

RESULTS

Mean tolerance times, the rate of sweat evaporation and the evaporative efficiency of sweat from the clothing were decreased and sweat rates were increased for C+C compared with the other clothing configurations (**Table I**). There were no differences for these variables between the C−C and NBC-BDU clothing conditions. The metabolic rate averaged over the exercise and rest periods was not different among the trials (Table I). The metabolic rate also was not different among the clothing configurations during either the exercise (approximately $1 L \cdot min^{-1}$) or rest (approximately $0.4 L \cdot min^{-1}$) periods alone.

Fig. 1 presents the changes in heart rate throughout the trials for the 3 clothing configurations. After 60 min, heart rates were significantly higher for C+C compared with the other clothing conditions. There was no difference in the heart rate response between the C−C and NBC-BDU configuration.

The changes in $\bar{T}_{sk}$ and ΔT_{re} are presented in **Fig. 2 and 3**, respectively. After 60 min of exercise and exposure to the hot environment, $\bar{T}_{sk}$ was significantly elevated for C+C compared with the other two clothing configurations which were not different from each other. There was no difference in the initial T_{re} among the conditions which averaged 37.1 ± 0.2, 37.0 ± 0.2 and 37.1 ± 0.3°C for C+C, C−C and NBC-BDU, respectively. The use of a ΔT_{re} attempts to normalize small differences in T_{re} at the beginning of each trial for a given subject. The increase in ΔT_{re} for the C+C condition was significantly greater than NBC-BDU and C−C beyond 60 min and 70 min, respectively. Further, the increase in ΔT_{re} was significantly reduced beyond 2 h for NBC-BDU compared with the C−C configuration. Final T_{re} was not significantly different among the trials and averaged 39.0 ± 0.3, 39.0 ± 0.2 and 38.9 ± 0.3°C for C+C, C−C and NBC-BDU, respectively.

Fig. 4 and 5 document the changes in $\overline{VP}_{sk}$ and $\overline{VP}_G$,

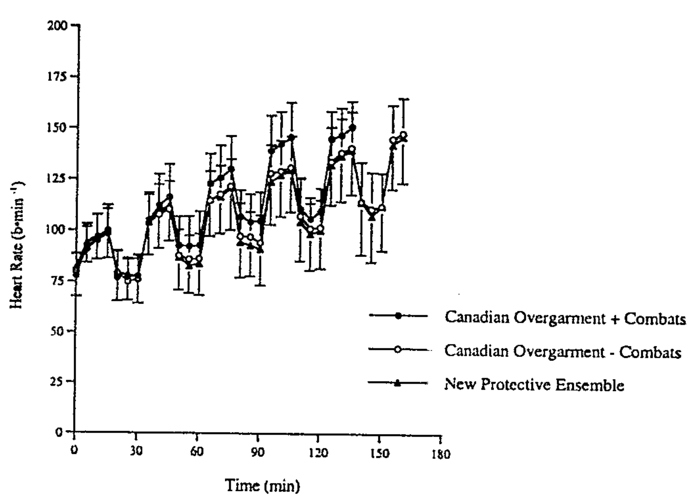

Fig. 1. Changes in heart rate during the alternating 15 min of treadmill walking and seated rest at 40°C and 30% relative humidity for the different clothing configurations. n = 9 except from 110–135 min for the closed circles where n = 7.

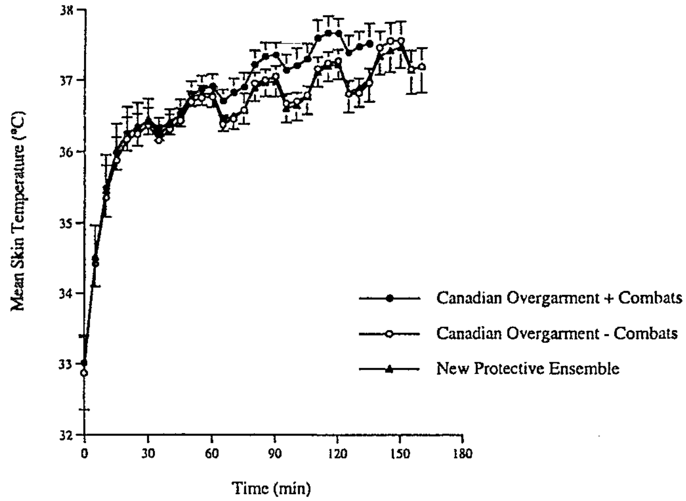

Fig. 2. Changes in mean skin temperature during the alternating 15 min of treadmill walking and seated rest at 40°C and 30% relative humidity for the different clothing configurations. n = 9 except from 110–135 min for the closed circles where n = 7.

respectively. There was a main effect of clothing for VP_{sk} which revealed a significant difference among the three configurations. After 105 min when data were available for all subjects, VP_{sk} was 40.6 ± 6.3, 39.6 ± 6.5 and 38.8 ± 6.3 mm Hg for C+C, C−C and NBC-BDU, respectively. There was no difference in VP_G among the clothing conditions after 105 min (n = 9) or 135 min (n = 7). A significantly lower VP_G was observed for NBC-BDU (32.9 ± 5.6 mm Hg) compared with C−C (34.4 ± 6.0 mm Hg) following a longer common exposure time of 160 min (n = 9).

Table II presents the end-point criteria for termination of the trials. It should be noted that 41% (or 11 of the 27 tests) were classified as "volition" which represents a request by the subject to end the session. For 8 of these 11 trials, T_{re} exceeded 38.9°C thus indicating that a substantial increase in body heat storage had occurred.

Calculations of the required evaporative cooling at the skin (E_{req}) and the environment's maximum evaporative cooling capacity (E_{max}) are shown in **Table III** for the C+C and C−C configurations. The ratio of E_{req} to E_{max} is used as an index of heat stress.

$E_{req} = M + (R+C) - (E_{resp} - C_{resp})$ in watts; M is the metabolic rate and R+C is the radiative and convective heat gain estimated as $(6.45/clo) \cdot A_D \cdot (\bar{T}_a - \bar{T}_{sk})$ (7) where 6.45 is the conversion value of 1 clo to resistance (0.155 $m^2 \cdot °C \cdot W^{-1}$), clo is the thermal insulation determined with the copper manikin at an effective wind velocity of 0.4 $m \cdot s^{-1}$, A_D is the Dubois surface area, T_a is the ambient temperature and $\bar{T}_{sk}$ is mean skin temperature. Evap-

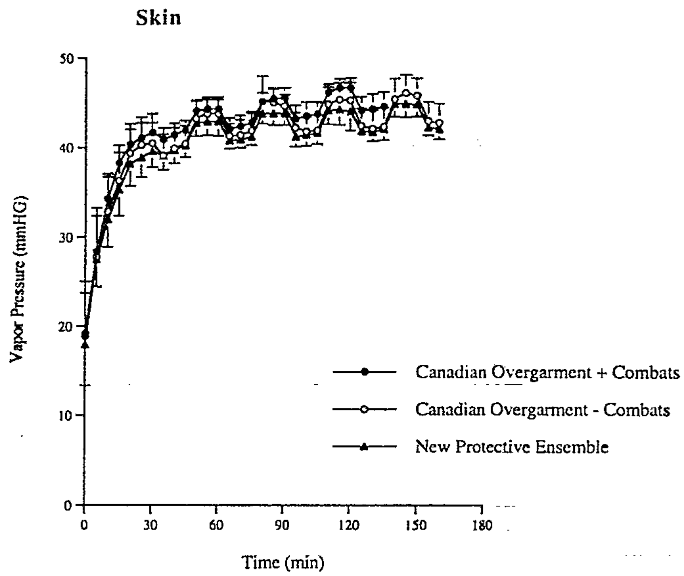

Fig. 4. Changes in vapor pressure measured on the skin during the alternating 15 min of treadmill walking and seated rest at 40°C and 30% relative humidity for the different clothing configurations. n = 9 except from 110–135 min for the closed circles where n = 7.

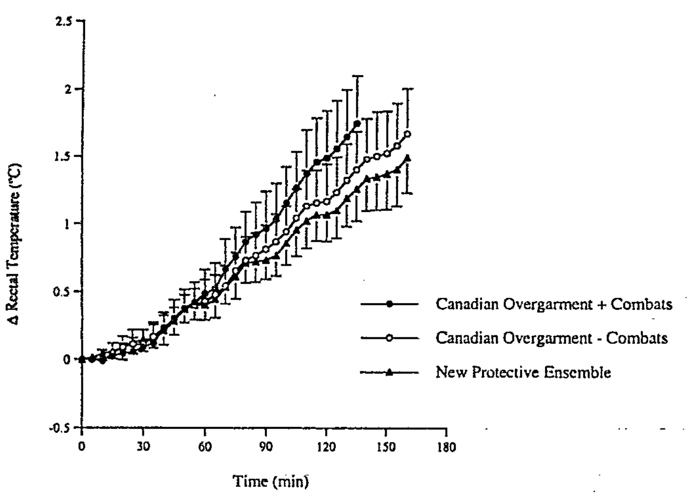

Fig. 3. Δ rectal temperature during the alternating 15 min of treadmill walking and seated rest at 40°C and 30% relative humidity for the different clothing configurations. n = 9 except from 110–135 min for the closed circles where n = 7.

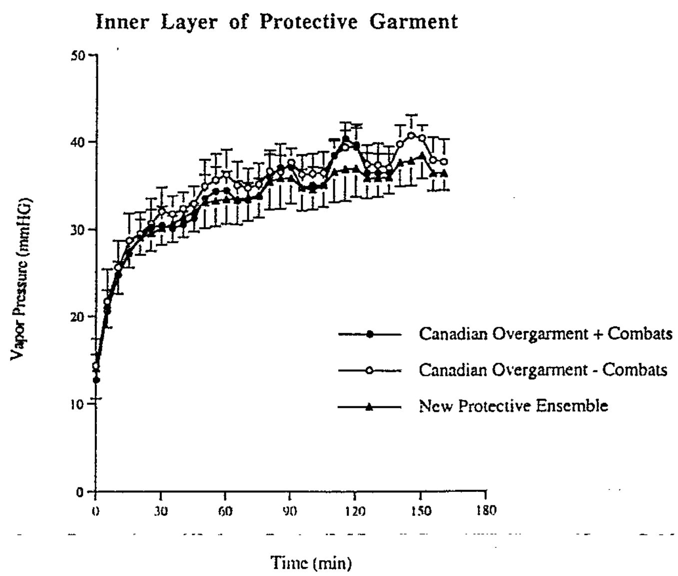

Fig. 5. Changes in vapor pressure measured on the inner layer of the protective overgarment during the alternating 15 min of treadmill walking and seated rest at 40°C and 30% relative humidity for the different clothing configurations. n = 9 except from 110–135 min for the closed circles where n = 7.

TABLE II. REASONS FOR TERMINATION OF THE TRIALS FOR THE CANADIAN NUCLEAR, BIOLOGICAL AND CHEMICAL (NBC) PROTECTIVE OVERGARMENT WORN WITH (C+C) OR WITHOUT (C−C) COMBAT CLOTHING AND THE NEW FRENCH NBC PROTECTIVE BATTLE DRESS UNIFORM (NBC-BDU).

Subject	C+C	C−C	NBC-BDU
1	T_{re}	volition	volition
2	T_{re}	nausea	nausea
3	volition	T_{re}	T_{re}
4	T_{re}	time	volition
5	T_{re}	time	time
6	heart rate	T_{re}	heart rate
7	volition	time	time
8	volition	volition	volition
9	volition	volition	volition

T_{re} represents 39.3°C, heart rate represents ≥95% of maximal heart rate, volition represents subject's request or experimenter's decision to end the trial, and time represents 240 min.

orative heat loss (E_{resp}) and convective heat gain through respiration (C_{resp}) was estimated at 15 W for both clothing configurations. E_{max} in watts was estimated as $(6.45 \cdot i_m \cdot clo^{-1}) \cdot 2.2 \cdot A_D \cdot (P_{sk} - P_a)$ (7) where i_m is the vapor permeability coefficient determined with a wetted manikin, 2.2 is the Lewis Relation coefficient (°C · mmHg^{-1}), P_{sk} is the saturated skin vapor pressure at $\bar{T}_{sk}$ and P_a is the ambient vapor pressure. $E_{req} \cdot E_{max}^{-1}$ is reduced for the C−C configuration indicating a reduction in heat strain with the removal of the combat clothing layer. However, since the value is greater than 1.0 both clothing configurations represent uncompensable heat strain.

DISCUSSION

The purpose of the present study was to compare the heat strain associated with wearing a new protective NBC-BDU designed for use in hot environments with the current Canadian protective overgarment under conditions which standardized the other clothing layers. The French NBC-BDU is designed as a stand-alone garment intended to replace the combat clothing. Thus to enable a meaningful comparison of the heat strain associated with wearing the NBC protective garments, the combat clothing layer was removed from the Canadian protective ensemble. The findings from this investigation have revealed a very significant reduction in heat strain associated with the removal of this clothing layer during light intermittent exercise. These findings are consistent with the results from earlier publications that involved both light and heavy exercise with a similar ambient temperature and vapor pressure but a smaller number of subjects (11) or involved comparisons with the U.S. protective overgarment during moderate exercise at 38°C, 30% relative humidity and wind speeds of 2.23 m · s^{-1} (9). Results from copper manikin tests at a wind velocity of 0.4 m · s^{-1} would also imply a reduction in the heat strain associated with removing the combat clothing layer (7). Thermal insulation values decreased from 2.35 clo for the current Canadian protective ensemble to 1.86 when the combat clothing was removed and the ratio of water vapor permeability to thermal insulation ($i_m \cdot clo^{-1}$) increased from 0.14 to 0.17, respectively (7). Under conditions where environmental temperatures are below $\bar{T}_{sk}$ these changes in clo and $i_m \cdot clo^{-1}$ would predict an increase in both convective and evaporative heat loss with the removal of the combat clothing layer (4). Under conditions where environmental temperature exceeds $\bar{T}_{sk}$, as was the case in the present study, the implications of the manikin testing are less obvious. The lower clo value and $\bar{T}_{sk}$ associated with removing the combat clothing would increase the convective heat gain. However, since the metabolic heat production was similar between trials and since this source of heat gain represented more than 90% of the total E_{req}, the increase in E_{req} for the C−C condition was estimated at less than 5%. In contrast, the 20% increase in $i_m \cdot clo^{-1}$ would favor a greater proportional increase in E_{max} and the ratio of E_{req} to E_{max} would indicate a reduction in the heat stress index following the removal of the combat clothing (see Table III). Therefore, the removal of the combat clothing prior to donning a protective overgarment and protective gloves, boots and respirator would be recommended for extended operations in hot environments if such a procedure were feasible in a military setting.

Similar predictive calculations of E_{req} and E_{max} were not possible between the C−C and NBC-BDU configurations since clo and $i_m \cdot clo^{-1}$ values derived from identical manikin testing procedures were not available. However, the present study has revealed that some indices of heat strain such as T_{re} and skin and garment vapor pressures are reduced when the new protective clothing was compared with the Canadian overgarment under conditions that standardized the additional clothing that was worn. In contrast, other indices such as tolerance time, heart rate, $\bar{T}_{sk}$, sweat rate and sweat evaporation from the clothing revealed no difference between the Canadian overgarment and the NBC-BDU. We have previously reported the potential problem of substantial subject variability associated with the dependent measure of tolerance time during submaximal exercise in a cool environment (14). Given that other criteria in addition to subject volition could influence tolerance time during this study (see Table II) and given the small differences in the other indices of heat strain that were observed, it perhaps should not be surprising that tolerance time was not different between the NBC-BDU and C−C clothing configuration. The use of sweat evaporation from the clothing as a dependent measure also is questionable considering the extent of the noticeable, and yet unmeasured, sweat drippage for the C−C condition. Finally, it must be remembered that the calculation of whole body sweat rates provides no information about the pattern of sweating throughout a given trial. It is well established that sweat

TABLE III. CALCULATION OF THE REQUIRED EVAPORATIVE COOLING AT THE SKIN (E_{req}) AND THE ENVIRONMENT'S MAXIMUM EVAPORATIVE POTENTIAL (E_{max}) FOR THE CANADIAN BIOLOGICAL AND CHEMICAL PROTECTIVE OVERGARMENT WORN WITH (C+C) OR WITHOUT (C−C) COMBAT CLOTHING.

	C+C	C−C
E_{req}	260.2	264.6
E_{max}	126.4	147.1
$E_{req} \cdot E_{max}^{-1}$	2.06	1.80

rates will decrease as skin wettedness increases during exposure to a hot and wet environment (3,6). Our measurement of skin vapor pressure revealed a difference in skin wettedness between the NBC-BDU and C−C conditions which could imply a difference in the extent of sweat suppression and pattern of sweating between trials. Although T_{sk} was similar between conditions, the skin and garment vapor pressures were reduced for the NBC-BDU trial implying a more effective evaporation of sweat from the skin and increased permeability of water vapor through the new overgarment. After 2 h of exposure this improved insensible heat transfer was reflected in a lower T_{re} (see Fig. 3). However, although this reduction in T_{re} was statistically significant the overall reduction in the physiological strain was minimal. In addition, the cardiovascular strain, as indicated by heart rate, did not reflect the greater evaporative heat loss while wearing the new garment. It must be emphasized that the differences in heat strain between the NBC-BDU and C−C conditions are far less than the impact of removing the combat clothing layer, by itself.

In a previous investigation which involved identical intermittent exercise periods and chamber conditions, C+C tolerance time was increased 82% when the overgarment was removed and a new vapor protective clothing layer was worn as an undergarment beneath the combat clothing layer (13). In the present study, tolerance time increased approximately 35–40% with the removal of the combat clothing (see Table I). The interpretation of these different relative improvements should be approached with caution since different groups of subjects were involved (although there was no difference in age, body surface area and $\dot{V}O_{2max}$ between groups) and tolerance time, as already mentioned, is not the most reliable dependent measure. Nevertheless the comparison implies that during light exercise equivalent to about 250 W the vapor protective clothing layer worn as an undergarment may provide more relief from the heat strain of wearing the current Canadian protective ensemble than the removal of the combat clothing layer. However, during moderate exercise approximating 425 W at 38°C and 30% relative humidity with a wind speed of 2.23 $m \cdot s^{-1}$ Levine et al. (9) observed no difference in the heat strain associated with wearing the current U.S. protective overgarment worn over underwear or a prototype protective undergarment worn beneath the battle dress clothing layer.

In summary, the present study has revealed that a significant reduction in heat strain during light intermittent exercise is associated with the removal of the combat clothing layer normally worn under nuclear, biological and chemical protective garments. The data have also shown that further reductions in heat strain are associated with wearing a new protective NBC-BDU but these additional changes are small in comparison to the effect of removing the combat clothing layer by itself.

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REFERENCES

1. Carter BJ, Cammermyer M. Emergence of real casualties during simulated chemical warfare training under high heat conditions. Mil Med 1985; 150:657–65.
2. Etienne S, Melin B, Pelicand JY, Charpenet A, Warmé-Janville B. Physiological effects of wearing light weight NBC battle dresses in hot environment. In: Frim J, Ducharme MB, Tikuisis P, eds. Proceeding of the Sixth International Conference on Environmental Ergonomics, Montebello, Canada. 1994; 30–1.
3. Fox RH, Goldsmith R, Hampton IFG, Hunt TJ. Heat acclimatization by controlled hyperthermia in hot-dry and hot-wet climates. J Appl Physiol 1967; 22:39–46.
4. Givoni B, Goldman RF. Predicting rectal temperature response to work, environment, and clothing. J Appl Physiol 1972; 32:812–22.
5. Goldman RF. Tolerance time for work in the heat when wearing CBR protective clothing. Mil Med 1963; 128:776–86.
6. Gonzalez RR, Pandolf KB, Gagge AP. Heat acclimation and decline in sweating during humidity transients. J Appl Physiol 1974; 36:419–25.
7. Gonzalez RR, Levell CA, Stroschein LA, Gonzalez JA, Pandolf KB. Copper manikin and heat strain model evaluations of chemical protective ensembles for the Technical Cooperation Program (TTCP). Natick, MA: U.S. Army Research Institute of Environmental Medicine, 1993; Technical Report No. 94-4.
8. Henane RJ, Bittel J, Viret R, Morino S. Thermal strain resulting from protective clothing of an armored vehicle crew in warm conditions. Aviat Space Environ Med 1979; 50:599–603.
9. Levine L, Quigley MD, Latzka WA, Cadarette BS, Kolka MA. Thermal strain in soldiers wearing a chemical protective undergarment: results from a laboratory study and a field study. Natick, MA: U.S. Army Research Institute of Environmental Medicine, 1993; Technical Report No. 2-93.
10. McLellan TM. Work performance at 40°C with Canadian Forces biological and chemical protective clothing. Aviat Space Environ Med 1993; 64:1094–100.
11. McLellan TM, Meunier P, Livingstone S. Influence of a new vapour protective clothing layer on physical work tolerance times at 40°C. Aviat Space Environ Med 1992; 63:107–13.
12. McLellan TM, Jacobs I, Bain JB. Influence of temperature and metabolic rate on work performance with Canadian Forces NBC clothing. Aviat Space Environ Med 1993; 64:587–94.
13. McLellan TM, Bell DG, Dix JK. Heat strain with combat clothing worn over a chemical defence (CD) vapor protective layer. Aviat Space Environ Med 1994; 65:757–63.
14. McLellan TM, Cheung SS, Jacobs I. Variability of time to exhaustion during submaximal exercise. Can J Appl Physiol 1995; 20:39–51.
15. Mitchell JW, Nadel ER, Stolwijk JAJ. Respiratory weight losses during exercise. J Appl Physiol 1972; 32:474–6.
16. Montain SJ, Sawka MN, Cadarette BS, Quigley MD, McKay JM. Physiological tolerance to uncompensable heat stress: effects of exercise intensity, protective clothing, and climate. J Appl Physiol 1994; 77:216–222.
17. Snellen JW. Mean body temperature and the control of thermal sweating. Acta Physiol Pharmacol Neerl 1966; 14:99–174.
18. Tilley RI, Standerwick JM, Long GJ. Performance of infantry soldiers wearing NBC clothing in hot/humid and hot/dry climates. Melbourne, Victoria: Materials Research Labs, 1981; MRL Report No. MRL-R-826.
19. Vallerand AL, Limmer R, Schmegner I. Computer acquisition and analysis of skin temperature and heat flow data from heat flux transducers. Comput Methods Prog Biomed 1989; 30:279–82.

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