INFLUENCE OF AIR-PERMEABILITY OF NBC SUITS ON VAPOR RESISTANCE AND EVAPORATION OF SWEAT

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INTRODUCTION

It has been found that the suits for protection against Nuclear, Biological and Chemical Warfare (NBC), which are currently used in the Dutch army, are not suitable for hot climates. The heat strain of the wearer is too high and the body temperature rises quickly. Recently, a new NBC suit became available. While maintaining protection, this new suit has an outer layer with an increased air-permeability (0.73 ms at 200 Pa) compared with the current NBC suit (0.37 ms at 200 Pa). This should lead to an improved ventilation of the microclimate under the suit and therefore, lead to a decrease in vapor resistance. As a consequence there should be an increased possibility for the wearer to evaporate sweat, leading to increased tolerance times for working in the heat. To evaluate the expected benefits, we performed 2 studies comparing the current and new NBC suits with respect to the vapor resistance and the total heat strain to the wearer.

METHODS

Ventilation measurements. The vapor resistance was determined in a series of experiments on 3 subjects by determination of the ventilation of a tracer gas (Argon) at room temperature. The method has been described extensively by Lotens and Havenith (1,2). The subjects wore a harness of polyethylene tubes that blew air, enriched with 10% Argon, under the NBC suits. A similar harness was used to suck out air at the same rate. Both harnesses were connected to a pump that provided constant airflow. The concentrations of Argon in the airflow to the suit (Cin), coming out of the suit (Cout), and in the surrounding air (Cair) were measured with a mass spectrometer. From these concentrations the ventilation under the suit was calculated by:

$$(1) \qquad \text{Vent} = V'_{\text{pump}} \cdot \frac{(C_{\text{in}} - C_{\text{out}})}{(C_{\text{out}} - C_{\text{air}})} \qquad \left[\text{L} \cdot \text{min}^{-1}\right]$$

In which V'pump is airflow generated by the pump. To calculate the ventilation only, the relative differences of the concentrations are used; therefore, it was not necessary to calibrate the output signal of the mass spectrometer. From the ventilation (*Vent*) the vapor resistance can be calculated by:

$$(2) \qquad d = \frac{D_{\text{Ar}} \cdot A_{\text{D}} \cdot 60 \times 10^6}{\text{Vent}} \qquad [\text{mm}]$$

In which DAr is the diffusion constant of Argon, AD is the body surface area according to DuBois & DuBois (1916) and 60106 is a constant to transform the vapor resistance to mm air equivalent.

Protocol. The measurements were performed at room temperature on 3 young male subjects with average weight 79 kg and height 1.89 m. The harness was placed on top of the underwear and below the NBC suits. Data from 6 different conditions were obtained in random order: standing and walking (1.4 ms) on a treadmill in wind speeds of <0.1, 1.4 and 5 ms.

Heat strain experiments. Five young male subjects, with average weight 68 kg (1SD 7 kg) and height 1.83 m (1SD 0.05 m), participated in the study. The evaporation of sweat from the skin, rectal temperatures and dry heat flow were determined in a climate of 36 °C at 20% relative humidity. The subjects had to walk in this climate for 90 min at a speed of 1.4 ms in a wind of 5 ms. To determine the evaporation of sweat, we weighed the subjects, the clothing and both together before and after the session (90 min). The dry heat flow was estimated from solving the heat balance equation:

$$\text{(3)} \qquad DRY = M - W_{ext} - RESP - STO - EVAP \qquad [W]$$

The metabolism was determined from the oxygen consumption, the external work (W_{ext}) was zero, and the respiratory heat loss (RESP) was estimated with use of standard formulas (3). The heat storage (STO) was determined from the measured increase in rectal and skin temperatures, and the evaporative heat loss (EVAP) was determined from the measured weight loss, corrected for the loss of mass by respiration. The dry heat flow was calculated using equation (3). Finally, the heart rate was recorded every 15 s during the session.

Protocol. The subject, all clothes, and the subject with the clothes were weighed before the session. Every 15 min the subjects were weighed again and oxygen consumption was determined before, half way, and after the session. The subjects wore standard cotton underwear under the NBC suits. The suits were worn with gas mask, rubber gloves and with all cords and bandages closed.

RESULTS

Ventilation measurements. The results of the measurements are presented in Fig. 1. While standing still, the vapor resistance was slightly but significantly less (paired t-test, $P = 0.04$) for all wind conditions in the new NBC suit, compared with the current suit. While walking, there was only a significant difference between the current and new suit at the highest wind speed (5 ms). The values of the vapor resistance for the current and new suit in this condition were as follows, respectively: 8.4 mm and 3.9 mm (1SD :1 mm for both values).

Heat strain experiments. There was no difference in sweat production between the suits, but in the new NBC suit slightly more sweat evaporated. In Fig. 2, the

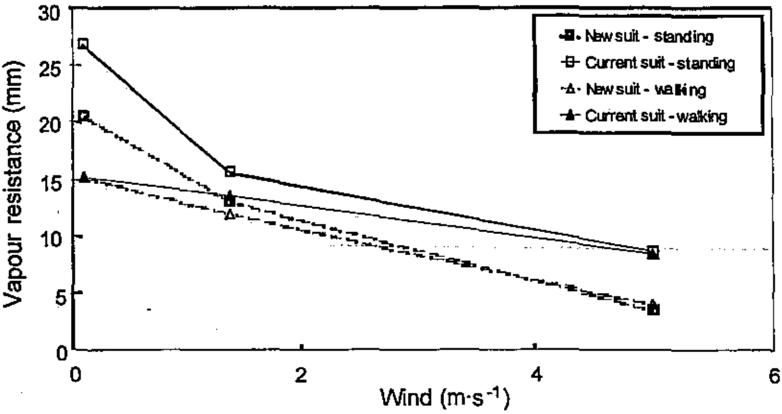

Figure 1. Vapour resistance (mm air equivalent) at three different wind speeds for the current suit (closed symbols) and the new NBC suit (open symbols). The data are the mean of three experiments and two sessions per experiment.

efficiency of sweat evaporation (sweat loss divided by sweat production) is presented. On average the efficiency of sweat evaporation was 5% (range 1% to 11%) higher in the new suit compared with the current NBC suit. The dry heat flow was on average larger in the new suit (-75 W) compared with the current suit (-49 W). The negative values indicated a dry heat gain of the subjects, caused by the air temperature being higher than the mean skin temperature (on average 35.3°C). There were no significant differences between the suits in rectal temperature, skin temperature, heart rate and all other relevant parameters in the heat balance before and after the experiment. (Wilcoxon signed rank sum test, $P > 0.05$). There was no difference in insulation between the 2 suits. The vapor resistance was slightly lower: on average 10.7 mm for the current suit and 9.9 mm for the new suit.

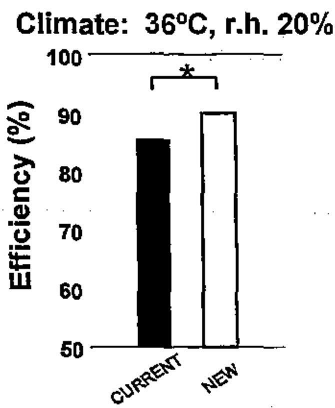

Figure 2. The efficiency (%) of sweat evaporation of both suits. The efficiency, defined as the ratio of evaporated sweat to the sweat produced, was significantly higher in the new suit than in the current suit (Wilcoxin signed rank sum test). The average difference was 5%

DISCUSSION

In a previous study we found a significant difference in rectal and skin temperatures when suits with different air permeabilities were used (4). These experiments were performed in the same climate (36°C), with the same walking speed and wind. In this previous study, the air-permeability of the outer layer was increased, but NBC protection was not maintained. In this study we compared the current NBC-protective suit with a new NBC-protective suit, having equal protection and an increased air-permeability.

It was found from the ventilation experiments that the vapor resistance of the new NBC suit, with a higher air-permeability, was up to 50% lower during walking on a treadmill at 1.4 ms with a wind speed of 5 ms. It was expected that such a difference would lead to reduced heat strain for the same conditions in the heat (36°C) because of the increased possibility to evaporate sweat, analogous to the previous experiments. However, the difference in sweat evaporation in the heat was on average only 5%. No significant difference was found in the rectal and skin temperatures and the heart rate between the 2 suits. The rectal temperatures at the end of the sessions were on average 38.2°C and 38.0°C in the current and new suit, respectively. We concluded that in this study the relatively small increase in rectal temperature from the neutral condition indicated that the heat strain under the conditions used was not very large. Significant differences between the suits are expected to occur only at more extreme conditions. Such conditions can be obtained by increasing the ambient temperature or by adding clothing (like a combat suit) under the NBC suit.

REFERENCES

1. Lotens, W.A. and Havenith G. 1988, Ventilation of rain wear determined by a tracer gas method, in Mekjavic, I.B., Bannister, B.W., Morrison J.B., (Eds.), *Environmental Ergonomics*. (London: Taylor & Francis) 162-176.
2. Havenith, G. and Lotens, W.A. 1990, Clothing ventilation, vapour resistance and permeability index: changes due to posture, movement and wind, *Ergonomics*, 33, 989-1005.
3. Fanger, O. 1970, *Thermal Comfort*. (New York: McGraw-Hill Book Company).
4. Havenith, G., Zeijl, A. and Wammes, L.J.A. 1998, Heat strain in NBC-protective clothing in relation to the air-permeability of the outer layer, Report TNO-HFRI: TM-98-A008 (In Dutch).