Use **of** Filtered Ambient Air to Reduce Heat Stress in NBC Protection Clothing

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INTRODUCTION

Army personnel who decontaminate both weapon systems and personnel have to wear completely tight protective suits (PS) including a gas-mask, rubber overboots and rubber gloves [1]. This results in three groups of stressors: a- thermoregulation is impeded by total water impermeability; b- physical workload of the job and the weight of the PS; c- additional stressors such as reduced vision, communication and manual dexterity as well as psychological and respiratory loads *[5,* 7, 9]. Several means of assisting heat dissipation from the body have already been studied. They include ice vests [2], microclimate cooling systems [7] and air conditioning by umbilical cords [3]. The present paper describes the effect of venting the German PS and the mask using filtered ambient air.

METHODS

Eight healthy informed consenting male volunteers whose anthropometric data are given in table I volunteered to participate after having signed an informed consent form. After a thorough medical examination they underwent VO_{2max} evaluation on a motor driven treadmill. During the investigations they wore the German NBC PS with or without ventilation. It consists of a two piece butyl-rubber suit with a over-lapping part rolled up around the waist as air seal, rubber overboots, rubber gloves, and the German NBC-protective mask. All subjects were experienced in wearing the ensemble and working in it. The ventilation, the effects of which were to be studied, is provided by a battery driven motor and fan carried in a pouch on the soldier's back. Ambient air is drawn through two standard filter canisters (120 l/min) and blown into the suit at two sites in the back at kidney height. Air leaves the suit via four outlet valves (opening pressure 8 cm H_2O) at both upper arms and legs. Approximately one third of the filtered air (depending on resistances) is guided into the face mask to provide breathing air at low resistance. For control conditions the subjects wore the German battle dress uniform (BDU) to which the weight of the PS (13,35 kg) was added using small sand bags.
Heart rate (chest leads, Sirecust 401A EKG monitor, Siemens) was monitored together with measurements of microclimate temperatures and humidities (Vaisala,

HMP 31 UT) at midscapular and midsternal areas as well as rectal **(YSI** 401D) and skin **(YSI** 409A) temperatures. The latter were averaged according to Ramanathan [8]. The outlet valve of the NBC-mask was connected to an open spirometric system (EOS, Jaeger, Würzburg) to measure V02 and VCO_2 **(STPD)**. Every five minutes during the experiments the subjective sensations of heat, sweat and overall stress were to be estimated by the subjects using a seven steps scale.
Ambient temperatures were set at 25°, 35° and 40°C, respectively, in random order. Ambient humidity varied since PS is watertight. The subjects marched on a motor driven treadmill at 5 km/h at zero incline for 45 min or until volitional exhaustion on four separate days, under four different conditions each (table **11).** The experiment was stopped at HR above 170 min^{-1}, rectal temperature above 38,0 "C or as other major complaints occurred. All data are given as means ± SE. The statistical probability was accepted at the .05 level using multivariate ANOVA and the one sided Students t-tests.

	Height	Weight	Age	BMI	BSA	BSA/Weight
	[cm]	[kg]	[y]	[kg/m²]	[m²]	[m²/g]
Mean	179,63	73,63	22,63	22,84	1,92	26,16
SE	± 1,88	± 1,52	± 0,90	± 0,50	± 0,03	± 0,28

RESULTS and DISCUSSION

Oxygen consumption during the VO_{2max} evaluation showed an almost ideal identity to the values predicted by the formula of Pandolf et al. [6] (y = 1.087x + .772 and y = 1.056x - .188). Thus it could be used to calculate the extra cost of wearing the PS. Oxygen consumption at rest (standing) was 5.4 ± 0.2 ml/min*kg (Mean ± SD). Wearing BDU plus weights in 25 °C augments VO_2 by 1 ml/kg*min, while wearing the **PS** at 25 °C unventilated, at 25 °C ventilated and 35 °C ventilated caused rises in VO_2 above predicted values by 3.2 ml/min*kg, 2.7 ml/min*kg, and 4.5 ml/min*kg, respectively.
Endurance times until volitional fatigue are given in table 11. Over all 75% of the experiments had to be ended early. At the lower temperatures the causes were respiratory difficulties and nausea, while at the higher temperatures heart rate ceiling (170 min^{-1}) led to a premature stop in 31% of the subjects. T_{rectal} remained constant for 15 min in all subjects, thereafter it rose almost linearly with time depending on $T_{ambient}$ (0.005 °C/min at control conditions and up to 0.032 °C/min at 35°C $T_{ambient}$).

Heart rate limit (170 min^{-1}) was reached in less than 25% of the tests thus the use of maximum heart rate as a criterion is difficult. Therefor the time until *HR* had risen to 140 min^{-1} (table 11) was calculated. Assuming a heart rate of 140 min^{-1} to be the limit for useful continuous work the ventilation of the PS expands the time for useful work by 20 min at 25 "C and by 5 min at 35 "C.
Volitional fatigue occured at heart rates higher than 140 min^{-1}, the beneficial effect of ventilation, however, at 35 "C is comparably short: ***id est*** **3** min (table II), while at 25 "C the subjects in the non-ventilated suit marched 7 min longer. The difference is rather small and physiologically insignificant. Thus the NBC PS cannot be used under high climatic stress conditions.

Table 11: Time to HR = 140 min^{-1} and to volitional fatigue (four subjects each, nt = condition not tested, statistically different (a) from **BDU**, (b) from no vent)

HR	Group	BDU	PS no vent	PS with vent
T ambient: 25 °C	I	> 45 min	22 min (a)	42 min (a,b)
T ambient: 30 °C	I	nt	nt	28 min
T ambient: 35 °C	II	36 min	15 min (a)	20 min (a)
T ambient: 40 °C	II	nt	nt	18 min
volitional fatigue				
T ambient: 25 °C	I	45 min	40 min	33 min (a)
T ambient: 30 °C	I	nt	nt	36 min
T ambient: 35 °C	II	45 min	23 min (a)	27 min (a)
T ambient: 40 °C	II	nt	nt	23 min

Subjectively perceived sensations of heat, sweat and exertion showed a clear cut difference between control and NBC-protective conditions as well as between $T_{ambient}$ < 35 "C and higher values. At high ambient heat differences in self perceived heat stress between the conditions were no longer observable.

CONCLUSIONS

Heart rate measurements and self perceived sensations of heat, sweating **and** exertion document a small effect of suit ventilation with ambient air in a completely tight NBC-protective garment under the condition of very high external workload.
Further steps will include training of crew in order to optimise their movements in the suit and additionally reduction of external work load or reorganisation of work/rest schedules, cooling of the ventilating air, and changes in air flow in the suit.

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