TEMPERATURE AND HUMIDITY WITHIN THE CLOTHING MICROENVIRONMENT: DETERMINANTS OF HEAT STRAIN

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INTRODUCTION

For workers employed in occupations ranging from deep mining to aerospace industries, elevated environmental temperatures cannot be avoided as it is either impractical or impossible to remove all or part of the excessive heat from the workplace and the active worker. Quantification of the heat stress to which the worker is exposed has in the past been attempted through the development in heat stress indicies which are based primarily on measures of dry-bulb temperature, radiant temperature, relative humidity and velocity of the ambient air (1). Field studies in hot environments have demonstrated that there may be no universal index of heat stress which would predict the heat strain of workers for a wide range of conditions (2). The ineffectiveness of these indicies is to a large extent due to the variety of thermal protective clothing worn and the difficulty in quantifying overall garment heat and water vapour resistance with variations in fabric characteristics and garment design (vents and openings).

For a fully suited worker with only the head exposed, 93% of the body surface area will be exposed to the suit microenvironment, the volume of air above the surface of the skin but directly beneath the suit. A reduction in the transfer of both heat and water vapour due to the addition of clothing may result in a build up of heat and water vapour within the clothing microenvironment, the level of which will depend on the characteristics of the fabric and the design of the garment. The present study was designed to investigate the changes in the temperature and vapour pressure. of the microenvironment which may arise as a result of heat exposure when wearing a variety of thermal protective suits worn by helicopter personnel operating over Canadian coastal waters. The suits were designed to provide thermal protection in the case of emergency ditching but should not impair performance despite elevations in cockpit temperature.

METHODS

Before donning a suit, five physically active male university students were instrumented for measurement of rectal temperature (T_{re}), skin temperature (T_{sk}) and microenvironment temperature and relative humidity 8mm above the skin surface (T_{μ} and RH_{μ}) at three sites (upper arm, chest and thigh). In addition suits were instrumented for measurment of outer clothing temperature (T_{cl}). Subjects then donned a helicopter personnel suit over cotton thermal underwear and were seated in an environmental chamber. Chamber temperature was then increased from 20°C to 40°C over a period of 90 minutes and then held constant at 40°C for an additional 90 minutes (total duration of exposure was 180 minutes). Throughout the exposure chamber relative humidity was uncontrolled, decreasing from 50% to a final value of 28%.

The suits utilized in this study were constructed of Cotton Ventile (CV), Gore-Tex (GT), Nomex/Insulite (N/I) and Nomex/Neoprene (N/N). Both the CV and GT suits were of the dry-suit design with airtight seals at the ankles, wrists and neck such that the exchange of microenvironment air could only cccur through the fabric, which have reportedly low water vapour resistances. In contrast, the N/I and N/N suits were of the wet-suit design thus allowing some measure of ventilation through openings at the. ankles, wrists and neck. The N/I suit consisted of a 3-6mm insulite layer sandwiched between two layers of Nomex material throughout the entire garment, whereas the N/N suit consisted of a single layer Nomex coverall worn over a neoprene shorty wet-suit (arms and legs not covered by neoprene). During the exposure subjects wore leather gloves, wool socks and heavy leather boots.

RESULTS

Increased environmental heat load was accompanied by increases in the temperature of air within the microenvironment (Figure la). Average T_{μ} for all suits increased from 31.4°C to 35.9°C with no significant differences observed between suits. In contrast, microenvironment vapour pressure (VP_{μ}, calculated from T_{μ} and RH_{μ}) displayed trends that appeared to be dependant on the type of suit worn (Figure lb). Initial RH_{μ} and VP_{μ} values for the CV and GT suits were much lower than that of the N/I and N/N suits. Throughout the exposure the N/I and N/N consistently produced the highest VP_{μ}, achieving near saturation levels of 96.1 ± 1.5% and 97.7 ± 0.7% respectively. In contrast, the microenvironment air below the CV and GT suits achieved saturation levels of only 76.5 ±6.6% and 88.4 ± 4.1% respectively. One way analysis of variance showed no difference in RH_{μ} or VP_{μ}

between the N/I and N/N **suits** over the ***last*** 60 minutes of the exposure, whereas relative humidities **and** vapour **pressures within** the GT and CV **suits** were significantly lower ($p<0.05$).

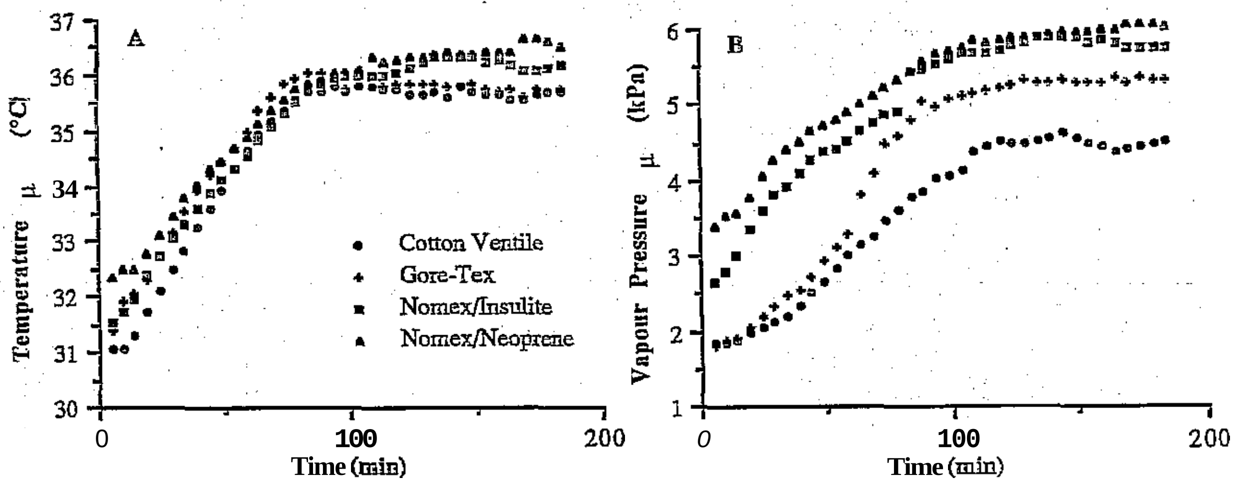

Figure 1: **A)** Microenvironment temperature (T_μ) and **B)** **vapour** pressure (VP_μ) **within** the **Cotton** Ventile, Gore-Tex, Nomex/Insulite **and** Nomex/Neoprene suits. **Data** are displayed **at 5** minute intervals.

Similar elevations in T_{sk} were observed in **subjects** for **all 4** suits tested throughout the exposure, whereas there were significantly greater increases in T_{re} (12°C) when subjects wore the N/I suit **as** compared to the CV **(0.29°C)**, GT **(0.23°C), and** N/N **(0.39°C) suits.**

CONCLUSIONS

Despite the differences in snit design and construction, the temperame within the microenvironment was **similar** for **all suits,** suggesting that the resistance of the fabric and garment to *dry* heat transfer plays little role in the thermal **status** of the wearer during hot **air** exposures of this magnitude. However, analysis of the component thermal gradients indicates **that** the temperature of the microenvironment air may be 1.0 **- 1.5°C** higher **than** that of the **skin** and outer layer of the suit **particularly during** transient increases in VP_μ. The liberation of heat observed in this smdy may **be attributed** to either condensation **or** absorption **(3).**

Most interesting in this study was the effect of snit design and construction on the microenvironment conditions. Although **suits** of the dry-suit design would limit the path of diffusion of water vapour to that of the fabric only, the dry-suits **utilized** in this study were both constructed of a water vapour permeable fabric **(Cotton and** Gore-Tex). ***As*** a result of its **high** vapour **permeability** the CV snit **tended** to maintain the lowest VP_μ throughout the duration of the exposure. Only the **N/I** suit, whose **Insulite** layer provides a water vapour barrier throughout d e whole **suit with** exception of the **neck,** wrists **and** ankles, demonstrated a **significant** elevation **in** rectal temperame **(1.2°C).** This is in contrast to the N/N suit which had similar VP_μ values as the N/I suit, however, the ΔT_{re} developed by the wearers of this suit was **minimal (0.39°C).** It **is assumed** that the areas of the body not covered by the neoprene in the N/N **suit (legs, arms** and head) were effective in permitting sufficient evaporative cooling to maintain body core temperature, **as** might be expected considering the lower water vapour resistance afforded by the Nomex fabric alone in these **areas.**

Since differing protective clothing assemblies will vary in their **properties** of insulation **and** water vapour permeability, **it** is proposed that assessment of conditions within the microenvironment of the suit may enhance predictions of heat strain **as** they reflect the true environment to which the **individual** is exposed

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