CONTROL OF THE TEMPERATURE OF A COOLING GARMENT BY TEE SUBJECT

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INTRODUCTION

Body cooling with a water perfused suit can reduce heat stress during work in a hot environment. The objective results are a lower heart rate, a reduction of sweating, decreased heat storage and a higher comfort level (1,2,3). But how can the temperature be controlled? In our experiments, the subject himself was able to control the inlet temperature T_{WI} of the suit. We supposed that the subjective thermal sensation would be the controlled variable and wanted therefore to study the differences between the individual control strategies. Another point of interest was the question whether the human controller is able to learn. Furthermore we wanted to see whether the results are optimal in terms of technical control.

METHODS

Three young and healthy male subjects wore a water perfused suit while exercising on a cycle ergometer in a climatic chamber. Ambient temperature was 35°C at 40% relative humidity. The procedure was always the same, 30 minutes rest before and after a 75 minute long exercise load at a 75 Watt level. At the start of an experiment inlet temperature $T_{,}$ was fixed at 32°C. In order to choose T_{WI}, an unscaled potentiometer was placed near to the subjects. Evaluation of their subjective thermal sensation was possible by means of a nine step turn switch :

Discomfort : very hot, hot, warm,
Comfort : slightly warm, neutral, slightly cool
Discomfort : cool, cold, very cold

Thermal state was obtained by measuring two core and ten skin temperatures. All data were sampled minutely by an MC 68000 based microcomputer system. The subjects TV and VS took part four times, one experiment per week, subject JG only twice with a three weeks interval between the sessions.

RESULTS

The experiments confirmed the supposition that thermal comfort was the controlled variable. Votes showing discomfort involved changes of the snit temperature in the opposite direction. All subjects followed different control strategies. JG solved the problem with small, successive changes of the inlet temperature not only at rest but also during the change to exercise. He felt comfortable for 94% of the experimental time. The repetition of the experiment showed a cruder control strategy but the number of comfortable votes remained constant. TV always accepted the selected temperature in the resting period. When undergoing the change from rest to exercise, he lowered the temperature in not more than three steps. His comfort level increased steadily with each experiment from 60% to 94%. The most interesting behaviour was shown by the subject VS. The suit temperature always oscillated (+/- 3°C) around a mean value. In none of the experiments was it possible for him to adjust T_{WI} to a constant level, neither in rest nor during exercise. It seemed that in terms of control theory, the control loop with VS as controller was instable. Due to the great temperature changes evoked by him, his thermal feeling always alternated between the extreme ends of the comfort scale. He started with a poor 45% comfortable votes in the first experiment and finished with 79% in the last. The suit temperatures selected during the exercise period were as as different as the control strategies. (Tab. 1)

	JG1	JG2	TV1	TV2	TV3	TV4	VS1	VS2	VS3	VS4
$T_{WI,mean}$	22.8	18.8	18.6	18.6	12.6	20.2	24.2	27.2	26.2	26.7
dT_c	0.38	0.73	0.64	0.80	0.77	0.79	0.37	0.24	0.22	0.31
COMFORT	94	95	61	87	94	95	45	70	56	79

Tab. 1 Mean snit temperature $T_{WI,mean}$ and max. rise in core temperature dT_c during exercise.(in °C)
Comfort is the total amount of comfortable votes for the whole experiment in % of all votes

By means of the measured subjective comfort values, one can state that the human controller is able to learn.

It is a well-known fact that core temperature increases to a higher level during exercise (4). Looking at the values listed above, one can see that the higher increases in T_C coincide with the lower $T_{Wt,mean}$. The reason for this might be due to the fact that the controller wishes to compensate his hot core with a cool skin in order to limit the rise of the body temperature. The comparison between TV and VS shows that slight cooling for VS evokes a smaller rise in T, than strong cooling for TV. Perhaps TV causes vasoconstriction in the skin and therefore heat removal is impeded, with the result of a higher T_C. This earlier reported fact of overcooling (5) is especially evident at work onset and has been observed in other research at our laboratory. The rather different temperatures, both $T_{Wt,mean}$ and dT_C, in JG's experiments seem to support that supposition.

CONCLUSIONS

On the basis of these results it is assumed that there are individual strategies to control the snit temperature. According to the increase of the subjective thermal comfort one can state that all subjects showed the capability to learn from earlier experiences. Yet the differences in the chosen suit temperatures are great and no relationship exists at all. The results also point out that the human controller is not optimal:

The oscillatory behaviour of the controller VS is contrary to the important d e in control theory that energy demand must be minimized. Frequent changes between heating and cooling need more energy than adjusting the suit temperature to the mean value. This fact may be important in real situations when energy ressources are limited. But the energetical aspect of damping such oscillations is of less importance than the decreased comfort level of the subject, expressed in the alternating comfort votes from both ends of the scale.

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