SKIN-CORE TEMPERATURE CONVERGENCE OFTEN WELL TOLERATED

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INTRODUCTION

When subjects must work while wearing impermeable clothing under hot conditions, mean skin temperature (Tsk) often approaches rectal temperature (Tre). Pandolf and Goldman reported in 1978 that in their subjects such convergence produced a state of near collapse even though neither Tre nor heart rate had reached limiting values; signs and symptoms included headache, dizziness, nausea, vomiting, malaise, inability to keep pace, hyperventilation, blurred vision and mental sluggishness (1). They concluded that convergence is an accurate guide to tolerance limits under conditions which minimize evaporative cooling. More recently, Goldman called convergence "the best physiological guide to heat limits" for workers in encapsulating garments and also states that a Tsk > 37° C should be cause for cessation of work in the heat (2).

The convergence paper is quoted in the literature in connection with widely differing experimental conditions. For instance, Smolander et al. discuss their results in terms of convergence when in fact there was a Tsk-Tre gradient of >1.0° C (3). Holmér mentions it in connection with diving experiments (4). The human use committee at NIOSH has evidently adopted convergence as a safety cut-off for experiments (5).

While the convergence-collapse concept is attractive in its simplicity, we cannot find any published validation of the phenomenon beyond the original paper, nor does it fit with experience in our laboratory. We report here on two recent protocols which often produced convergence, despite which subjects usually continued work until we stopped them at Tre=39° C.

METHODS

Data from two protocols were used. **Series A:** Nine subjects each participated in eight experiments wearing heavy, semi-permeable (chemical defense) clothing at Tdb = 22-38° C with work loads of 200, 350 or 500 W. **Series B:** Nine subjects each performed four experiments wearing impermeable clothing at Tdb = 29 and 38° C with a work load of 450 W.

Each subject was tested to establish individual treadmill VO2max and HRmax. Measurements during experiments included Tsk, Tre, HR, perceived exertion, and weight loss. Convergence was defined as Tsk rising to within 0.1° C of Tre. Convergence work time (CWT) was measured from the time convergence occurred until work was discontinued for any reason.

RESULTS

Convergence occurred in eight of the experimental conditions (Tdb = 29-38° C), involving 42 of the 60 runs under those conditions; Tsk rose to 37° C within the first 5-10 min of these experiments. In 29 convergence cases (64%) the subjects continued to work until Tre = 39° C and/or HR=HRmax with CWT=10-45 min; many could have continued longer. The remaining 13 experiments were terminated by the subjects at CWT=0-20 min due to extreme leg fatigue or inability to tolerate the inspiratory resistance of the full-face mask. No one collapsed or became ill.

Two examples of conditions which produced convergence are as follows. **Series A:** In Condition 7 (Tdb=35°, Twb=31°, Tbg=40° C, work=200 W), 7 of the 9 subjects experienced convergence at t=10-45 min and Tre=37.1-38.2° C, and all worked until Tre=39° C for CWT=15-45 min (mean 34 min). **Series B:** When subjects wore sealed, impermeable suits (with two levels of insulation) in a chamber at Tdb=38° C; 17 of 18 runs produced convergence at t=4-31 min and Tre=37.0-38.1° C, and 5 worked until Tre=39° C for CWT=15-35 min (mean=23 min).

DISCUSSION

Thermal balance can be maintained when Tsk≥Tre only by means of evaporative cooling. When clothing and/or high environmental humidity suppress evaporation, cutaneous circulation reaches very high levels. In theory this poses the threat that the subject might reach a cardiovascular limit in ability to meet the combined perfusion demands of the skin and the working muscles, but we observed no evidence of such a limitation. It appears that physiological tolerance was determined instead by body heat storage accompanied by increases in Tre and HR which eventually reach their physiological limiting values.

Our results fail to confirm that convergence of Tsk on Tre has any special significance. Neither did Tsk > 37° C cause any particular problem. Although subjects under these conditions were uncomfortable, they continued working until they reached classical physiological limits. Neither convergence nor high Tsk produced a change in the rate of rise in Tre or HR. In no case did a subject display the signs or symptoms of "imminent collapse" listed in the 1978 paper (1). It is unclear why Pandolf and Goldman's subjects regularly reached symptomatic end-points at convergence when ours did not. Although their experiments involved higher ambient temperatures (Tdb=46-49° C), the work loads were lower (about 225 W), and the rates of rise in Tre and Tsk were similar in the two studies.

A recent paper unintentionally provides further evidence that convergence per se is not limiting (4). Divers wearing impermeable suits worked in water at Tw=38° C; their Tsk exceeded Tre for the entire 60-min experiment, which ended only when Tre reached 39° C or more. The work was repeated at Tw=42° C with similar results except that Tre reached 39° C sooner (34-42 min). If convergence had been viewed as a limit, these experiments could not have taken place.

The convergence concept is based on Tre, which is relatively slow in responding to external temperature changes and varies specifically with leg work. Under various conditions Tre may under- or over-estimate central venous temperature so that convergence of Tsk on Tre does not necessarily mean the absence of a core-skin temperature gradient.

CONCLUSIONS

Our analysis provides no support for the generalization that skin-core temperature convergence can accurately predict tolerance time for work in heat or has any unique effect on stress levels of subjects. The ability to work despite high skin temperatures appears to be a function of the rate of heat storage and the level of Tre, as well as subject fitness and motivation. Arbitrary termination of experiments based on either Tsk alone or convergence of Tsk on Tre may deprive investigators of valuable data and lead to erroneous generalizations regarding human tolerance for work in heat while wearing protective clothing.

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