ADAPTATION TO HEAT: DIFFERENCES INDUCED BY ISOTHERMAL STRAIN FOLLOWING HEAT ACCLIMATION AND THERMONEUTRAL EXERCISE

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INTRODUCTION

Acclimatisation, in response to artificial heat exposure (acclimation) or endurance exercise which elevates body core temperature (T_c), induces physiological changes which reduce thermal strain during heat stress. While it is known that both techniques improve heat tolerance (4,6,8), few studies investigating differences in the acclimation response between such regimens have attempted to equate physiological strain. While cardiac frequency (f_c) has been matched in some studies, the prime stimulus for thermal adaptation is T_c. By equating T_c changes during acclimation, one can evaluate the role of thermoreception at the skin surface in the adaptation process. While it has long been held that an elevation in skin temperature is critical to acclimation, this hypothesis has not been adequately tested. This project sought to test such an hypothesis, using an isothermal strain (controlled hyperthermia) technique (after 2,3) to keep T_c constant across two separate acclimation protocols.

METHOD

Two groups of seven healthy males, matched for peak aerobic power ($\dot{V}_{O_2peak}$) and sum of six skinfolds, participated (1 hr per day for 10 consecutive days) in one of two acclimation conditions: (i) neutral physical training (NEUT: dry bulb 22.4 ±0.7°C, relative humidity (rh) 41.0 ±0.9%; aged 19.7 ±1.5 yr; $\bar{X}$ ±S.D.); or (ii) combined physical training and heat acclimation (HEAT: 38.2 ±0.7°C, rh 39.7 ±1.3%; aged 21.9 ±3.2 yr). Isothermal strain during each regimen was induced by rapidly elevating rectal temperature (T_{re}) to 1°C above resting level (cycling), then holding it constant by manipulating external work rate. Work performed during acclimation averaged 504.9 (±3.1) kJ, and 396.9 (±2.5) kJ, for the NEUT and HEAT conditions respectively. The respective T_{re}, mean skin temperatures and cardiac frequencies (f_c), averaged across time were: 37.6 ±0.10°C, 33.2 ±0.2°C, and 133.8 ±2.8 b.min^{-1}; and 37.7 ±0.1°C, 37.4 ±0.63°C, and 143.0 ±6.3 b.min^{-1} ($\bar{X}$ ±S.E.M.).

Subjects completed heat stress tests (39.8 ±0.1°C, rh 38.6 ±1.2%), before and after acclimation, consisting of: 20 min seated rest, 20 min cycling at 30% $\dot{V}_{O_2peak}$ (110.2 ±7.5 & 104.6 ±9.7 Watts, for NEUT & HEAT respectively), and 20 min cycling at 45% $\dot{V}_{O_2peak}$ (165.3 ±11.3 & 156.8 ±14.4 Watts, respectively; $\bar{X}$ ±S.D.). The following variables were measured during each test: T_c at the auditory canal (T_{ac}; zero gradient aural thermometry, London Hospital); local sweat rates at the forearm and forehead ($\dot{m}_{sw}$; capacitance hygrometry: Multi-site Sweat Monitor, Clinical Engineering, Sydney); forearm skin blood flow for the first 15 min of each test phase (SkBF; laser Doppler velocimetry: TSI Laserflo BPM^2, Vasamedics; $\lambda = 780$ nm, fibre separation of 0.5 mm, and expressed in voltage units); SkBF at the upper arm, head, back, chest and thigh (for the next 5 min); skin temperatures at 8 sites ($\bar{T}_{sk}$ (after 5); YSI EU mini-thermistors); f_c (Polar PE3000); thermal sensation and ratings of perceived exertion (RPE).

RESULTS

HEAT acclimation lowered T_{ac} and f_c for all phases of the second heat stress test ($p<0.05$). A similar change was observed for f_c ($p<0.05$), but not T_{ac}, following NEUT acclimation. Both groups reported a lower thermal sensation across all the three test phases following acclimation ($p<0.05$), but only the HEAT group experienced significantly lower perceived exertion across test phases ($p<0.05$).

Both conditions lowered the T_{ac} thresholds for sweating. HEAT pre-acclimation thresholds were: forehead 37.5°C (0.3; $\bar{X}$ ±S.E.M.), and forearm 37.6°C (±0.3); and post-acclimation thresholds were: forehead 36.9°C (±0.1), and forearm 37.0°C (±0.2). NEUT pre-acclimation thresholds were: forehead 37.3°C (±0.3), and forearm 37.3°C (±0.3); and the respective post-acclimation thresholds were 37.0°C (±0.1) and 37.0°C (±0.4). Similarly, both regimens elevated the gain of the sweat response ($\Delta\dot{m}_{sw}:\Delta T_{ac}$). Both these changes favoured the HEAT trained subjects, but neither between-group differences were significant ($p>0.05$).

During the first 40 min of the second test, forehead $\dot{m}_{sw}$ was equivalent to pre-acclimation levels for the HEAT acclimated subjects ($p>0.05$). During the final 20 min (45% $\dot{V}_{O_2peak}$), this group produced a significantly greater forehead $\dot{m}_{sw}$, relative to control ($p<0.05$). Since acclimation lowered T_{ac} across the second test in these

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subjects, this change reflects a more prolific sweat response over this time. In the NEUT group, the first 40 min of the second test elicited a significantly lower forehead $\dot{m}_{sw}$ ($p < 0.05$), while the response of the last 20 min was equivalent ($p > 0.05$). These data, in the presence of an unaltered T_{ac}, may indicate a more efficient sweating response in the NEUT subjects. Forearm $\dot{m}_{sw}$ increased in both groups throughout the two exercise periods in the second heat stress test ($p < 0.05$), reflecting a heightening of the distal sweat response. Since body mass changes were not different between groups, either before (HEAT 1.0 ±0.2 versus NEUT 0.9 ±0.2 kg; $p > 0.05$) or after acclimation (HEAT 0.9 ±0.3 versus NEUT 0.8 ±0.1 kg; $p > 0.05$), these changes in local $\dot{m}_{sw}$ probably reflect a redistribution of sweat production towards more distal sites.

Forearm SkBF did not display an acclimation effect in either condition ($p > 0.05$). The SkBF distribution pattern (between sites) was identical for each group, before and after acclimation, with the forehead receiving a greater blood flow across each of the three test phases. This trend became exaggerated with time and increments in T_{ac}, such that forehead SkBF exceeded blood flow at the other sites by a factor of two during the last 5 min of each heat stress test. Acclimation produced no significant affects on SkBF in the NEUT group ($p > 0.05$). However, of five intermittently measured sites in the HEAT acclimated subjects, there was a significant decrease in forehead SkBF during the final 20 min of the second test ($p < 0.05$).

CONCLUSION

The apparent preferential elevation of the sweating response at distal skin regions during acclimation is not a new observation. For example, Shvartz *et al.* (7) found that the $\dot{m}_{sw}$ of the limbs increased more than did torso $\dot{m}_{sw}$, when subjects were exposed to a combined heat and exercise acclimation regimen. This difference was attributed to a greater efficiency of evaporative cooling at the torso skin which, because of its greater vascularisation relative to the limbs, facilitated more rapid heat dissipation. However, neither our current multiple site data across all phases of the heat stress test, nor our previous work (1), support the view that torso SkBF is greater than limb SkBF. Furthermore, such an hypothesis implies an ability of the sudomotor system to modulate output according to core to skin heat exchange. It is possible that both skin regions received equivalent efferent flow following acclimation, but that local changes in skin temperature, gland sensitivity to neurotransmitter stimulation or some mechanical change in the skin prevented forehead $\dot{m}_{sw}$ from increasing in parallel with forearm $\dot{m}_{sw}$ during the second heat stress test.

On the basis of pre- versus post-acclimation differences in T_{au}, forehead $\dot{m}_{sw}$ and SkBF, and perceived exertion, the HEAT condition elicited a greater modification in acclimation state, even though central thermal strain was equated between experimental conditions. While the elevation in T_c is critical to acclimation, it appears necessary to expose subjects to an exogenous thermal stress to elicit optimal thermal adaptation. Peripheral thermoreceptors are thereby shown to play an integral role in both acute thermoregulatory responses, and in the acclimation process.

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