Acclimation to humid heat lowers resting core temperature

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Buono, Michael J., Jay H. Heaney, and Katherine M. Canine. Acclimation to humid heat lowers resting core temperature. Am. J. Physiol. 274 (Regulatory Integrative Comp. Physiol. 43): R1295–R1299, 1998.—The purpose of this study was to test the hypothesis that a reduction in resting rectal temperature (Tre) is partially responsible for the attenuation in the rise of core temperature during heat exposure following acclimation to humid heat. Nine male volunteers completed 7 days of acclimation, performing 2 h of exercise per day in a hot, humid environment (35°C, 75% relative humidity). Mean (±SD) ending Tre significantly (P < 0.05) decreased from 38.9 ± 0.5°C on day 1 to 38.3 ± 0.4°C on day 7. Likewise, mean (±SD) resting Tre significantly (P < 0.05) decreased from 37.0 ± 0.3 to 36.7 ± 0.4°C. In fact, all nine men showed a decrease in resting Tre from day 1 to day 7, ranging from −0.1 to −0.5°C. In addition, resting Tre and ending Tre were significantly correlated (r = 0.68). However, the mean increases in Tre (ending Tre minus resting Tre) and heat storage that occurred on each of the 7 acclimation days were not significantly different. These results support the hypothesis that a reduction in resting Tre is partially responsible for the attenuation in ending Tre during heat exposure following short-term acclimation to humid heat.

METHODS

The subjects for this study were nine male volunteers with a mean (±SD) age, height, weight, percent body fat, and body surface area of 23 ± 2 yr, 178 ± 9 cm, 78.8 ± 8.1 kg, 15 ± 6%, and 1.96 ± 0.11 m², respectively. Signed informed consent was obtained before the start of data collection.

The subjects were a subsample of a larger study that examined heat tolerance in men vs. women. All of the women in the larger study were excluded from the subsample because it is well known that various phases of the menstrual cycle can significantly alter resting core temperature. Additionally, some of the men in the larger study were excluded because they missed one or more of the heat-acclimation sessions. Last, because of the known circadian rhythm in resting core temperature, men with both morning and afternoon heat-acclimation sessions were excluded.

The subjects reported to the laboratory for seven heat-acclimation sessions (within an 8-consecutive-day period) in the morning, after having refrained from exercise for at least 12 h. Furthermore, in addition to normal ad libitum daily fluid intake, they were instructed to drink one liter of water each night of the study before going to bed and another liter on awakening each morning. They were also given 0.25 liter of an electrolyte-glucose drink (Gatorade) on arrival to the laboratory each morning. The subjects gave a urine sample, and if they were dehydrated (specific gravity >1.028) they were required to drink an additional fluid. Next, a thermistor (Sheridan) was inserted 15 cm beyond the anal sphincter to measure Tre. Skin thermistors (Yellow Springs Instruments series 400) were taped to the right shoulder, chest, thigh, and calf. Mean skin temperature (Tsk) was calculated using the Ramanathan (17) formula. Finally, a Polar heart watch was used to measure heart rate (HR).

After being instrumented, the subjects rested in a seated position for ~30 min in a temperate environment (air temperature = 21–23°C), during which time data were collected on a computerized system which printed the values to the nearest 0.1°C each minute. A stable resting Tre was defined as five consecutive 1-min data points within 0.1°C. Resting Tre was calculated as the mean of the five consecutive values.

After resting data collection, each subject completed four 25-min exercise bouts with 5 min of seated rest between each in a hot, humid environment (35°C, 75% relative humidity, RH), wind speed = 0 miles/h). The exercise bouts consisted of treadmill walking at 1.34 m/s at a 3% grade or stationary cycling on a Monark ergometer at 75 W. Both modes of exercise produced absolute oxygen uptakes of ~1.2 l/min. Each subject completed two bouts of each mode of exercise, always finishing with treadmill walking. The subjects had a mandatory water intake of 0.25 liter every 30 min during each heat exposure. Water consumption over this require-
ment was allowed ad libitum. No subject lost more than 2% of their body weight during any heat exposure.

During the heat-acclimation sessions, HR, T<sub>re</sub>, and T<sub>sk</sub> data were collected each minute. The increase in T<sub>re</sub> (ΔT<sub>re</sub>) that occurred during each of the seven acclimation sessions was calculated by subtracting the resting T<sub>re</sub> from the T<sub>re</sub> at the end of the final exercise bout. ΔS, in watts per square meter, was calculated for each 2-h acclimation session using the formula

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\Delta S = 0.965 \times \text{body mass (kg)} \times (0.8 \times \Delta T_{re} + 0.2 \times \Delta T_{sk}) / \text{body surface area (m}^2\).
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Data obtained across the 7-day heat-acclimation period were statistically analyzed using repeated-measures ANOVA procedures. When significance was found with the ANOVA, a post hoc Tukey’s test was used to determine which means were different. The alpha level was set at P < 0.05.

RESULTS

The mean (±SD) resting and ending T<sub>re</sub> data collected on the 7 heat-acclimation days are presented in Fig. 1. As expected, during acclimation, the ending T<sub>re</sub> significantly (P < 0.05) decreased from 38.9 ± 0.5°C on day 1 to 38.3 ± 0.4°C on day 7. The change in ending T<sub>re</sub> between days 6 and 7 was not significant. Figure 1 also shows that the mean resting T<sub>re</sub> significantly decreased during acclimation from 37.0 ± 0.3 to 36.7 ± 0.4°C. In fact, all nine subjects showed a decrease in resting T<sub>re</sub> from day 1 to day 7, ranging from -0.1 to -0.5°C. In addition, resting T<sub>re</sub> and ending T<sub>re</sub> were significantly correlated (r = 0.68).

The mean ΔT<sub>re</sub> that occurred on each of the 7 acclimation days is presented in Fig. 2A. The ΔT<sub>re</sub> on day 1 was 1.9 ± 0.3°C and was 1.6 ± 0.5°C on day 7, a change not significantly (P > 0.05) different over days.

The mean ΔS for each acclimation day is shown in Fig. 2B. On day 1, the mean ΔS was 89 ± 15 W/m², whereas on day 7 it was 79 ± 23 W/m². The change in ΔS during acclimation was not significant (P > 0.05). Furthermore, mean (±SD) ending HR decreased significantly (P < 0.05) from 143 ± 16 to 129 ± 10 beats/min on days 1 and 7, respectively.

DISCUSSION

The purpose of this study was to test the hypothesis that a reduction in resting T<sub>re</sub> is partially responsible for the attenuation in ending T<sub>re</sub> during heat exposure following acclimation to humid heat. As can be seen in Fig. 1, the 7-day heat-acclimation protocol was successful, as evidenced by a significant 0.6°C decrease in ending T<sub>re</sub> from 38.9 to 38.3°C. The change in ending T<sub>re</sub>
between days 6 and 7 was not significant. The time course and magnitude of the decrease in ending $T_{re}$ and HR with heat acclimation are consistent with previous studies (5, 16, 20, 24). For example, Shvartz et al. (20) reported a 0.6°C decrease in ending $T_{re}$ following 8 days of heat acclimation. Thus the above findings suggest that our subjects successfully acclimated to the heat.

Interestingly, Fig. 1 also shows that our subjects had a significant 0.3°C decrease in resting $T_{re}$ following acclimation. Although this finding agrees with several other studies (10, 20, 24) that have anecdotally reported a reduction in resting $T_{re}$ with heat acclimation, to our knowledge this is the first study to statistically examine the effect of heat acclimation on resting $T_{re}$ using a controlled study design. Specifically, to obtain a stable resting $T_{re}$ during the acclimation period we controlled the following variables: 1) hydration level, 2) 12-h exercise abstinence, 3) gender of subjects, 4) time of day for data collection, and 5) room temperature. Furthermore, we instituted a criterion of requiring five consecutive 1-min $T_{re}$ values within 0.1°C to ensure that a stable resting $T_{re}$ was obtained on each of the acclimation days.

The agreement between the resting $T_{re}$ results of the current study and those of several older reports is remarkable. For example, over 40 years ago, Ladell (10) heat acclimated 17 men for 9 days in a hot, humid (38°C, 80% RH) environment. Mean resting $T_{re}$ decreased 0.3°C over the course of the study. Approximately 25 years ago, Wyndham et al. (24) heat acclimated men for nine successive days in warm air (32°C) that was fully saturated with water vapor (=100% RH). Although not specifically addressed in their original manuscript, tabular data show that mean resting $T_{re}$ fell from 37.4 to 37.0°C. More recently, Shvartz et al. (20) anecdotally reported that mean resting $T_{re}$ decreased 0.4°C following 8 days of heat acclimation. It must be remembered that in all of these studies, resting $T_{re}$ was not a primary dependent variable and thus control of potential confounding factors and statistical analysis was not performed. Even with these limitations, it is our opinion that the current results, combined with past findings, strongly suggest that heat acclimation has the potential to significantly reduce resting $T_{re}$ by 0.3–0.5°C. Such a conclusion supports Kenney’s observation that, “after acclimation, people seem to defend and maintain core temperature around a lower setpoint temperature” (23). Interestingly, this phenomenon does not appear to be exclusive to humans. Sato et al. (19) reported that resting $T_{re}$ decreased ~0.3°C following heat acclimation in male patas monkeys.

The most surprising finding of the current study was that humid heat acclimation did not significantly decrease either $\Delta T_{re}$ or $\Delta S$. These results are not without precedent in the literature. Ladell (10) reported that on the first day of humid heat acclimation the mean $\Delta T_{re}$ was 1.3°C whereas on the ninth, and final, day it was 1.4°C. Similarly, Garden et al. (5) heat acclimated nine men for 9 days in humid heat (37°C, 74% RH) via 2 h of treadmill walking. The mean $\Delta T_{re}$ on day 2 (day 1 data were not presented) was ~1.8°C, whereas it was 1.9°C on day 9. Finally, Shvartz et al. (22) heat acclimated two groups of subjects for 6 consecutive days. One group was exposed to humid (90% RH) heat while the other acclimated to dry (20% RH) heat. After heat acclimation, the physiological parameters obtained from both groups during a standardized heat-tolerance test were compared with a nonacclimated control group. The mean $\Delta S$ and ending $T_{re}$ were significantly ($P < 0.05$) reduced in the hot-dry acclimation group compared with the control group; however, they were not significantly different between the hot-humid acclimation group and the control group.

It is our opinion that the above findings support the hypothesis that a reduction in resting $T_{re}$ is partially responsible for the attenuation in ending $T_{re}$ following acclimation to humid heat. Previous studies (2, 8, 22) have clearly shown that acclimation to dry heat decreases $\Delta S$ via increased evaporative heat loss. However, the potential for improved evaporative cooling is significantly reduced in humid conditions (6, 8, 10, 22), particularly when the required evaporative cooling exceeds the maximal evaporative cooling capacity of the environment. For example, it has been shown that changes in sweat rate account for only 10% of the variability in mean body temperature during heat acclimation (20). Furthermore, convective and radiative heat loss is unchanged following acclimation to humid heat (6). Thus, by process of elimination, the only compensatory mechanism left to produce an attenuation of ending $T_{re}$ following acclimation to humid heat would be a lowering of resting $T_{re}$. The findings of the current study suggest that 50% of the reduction in ending $T_{re}$ is the result of a lowered resting $T_{re}$, and 50% is due to increased heat loss (i.e., decreased $S$). This agrees with the results of Shvartz et al. (22), who found that after endurance training approximately one-half of the decrease in exercise $T_{re}$ was attributable to a reduction in resting $T_{re}$.

The physiological benefits of having a lower resting $T_{re}$ may be twofold in nature. First, it has been shown (4, 6, 13, 18) that the thermoregulatory thresholds for the onset of sweating and cutaneous vasodilation are typically reduced by ~0.3–0.5°C following heat acclimation. Coincidentally, this magnitude of reduction is similar to that reported for resting $T_{re}$. In other words, it could be hypothesized that an absolute increase in $T_{re}$ over the resting value is needed to initiate sweating and cutaneous vasodilation. If so, then lowering resting $T_{re}$ should reduce the thresholds for these thermoregulatory effectors by a similar magnitude. Support for this hypothesis is found in the two studies (4, 20) that measured both resting $T_{re}$ and the threshold for the onset of sweating during heat acclimation. Neither of these studies, however, addresses the potential linkage between the reduction in resting $T_{re}$ and the onset of sweating. In the first study, Fox et al. (4) heat accli-
mated 20 young men under extremely humid conditions (using a hot water bath and vapor-barrier jacket). They found that mean resting core temperature significantly (P < 0.001) decreased by 0.19°C following acclimation. Similarly, the mean threshold for the onset of sweating was significantly (P < 0.001) reduced by 0.18°C. From their original data, we have calculated the correlation between the change in resting core temperature and the change in threshold for the onset of sweating. We obtained an r of 0.67 (P < 0.002), which supports the hypothesis that there is a coupling of resting $T_{re}$ with the sweating threshold during heat acclimation. More recently, Shvartz et al. (20) anecdotally reported that after 8 days of heat acclimation, mean resting $T_{re}$ fell by 0.40°C while the mean threshold for sweating decreased by 0.49°C. Last, Olschewski and Bruck (15) have shown that precooling subjects before exercise reduces both resting core temperature and the threshold for both sweating and cutaneous vasodilation by $\sim 0.2$–$0.3^\circ$C. Taken together, all of the above data support the concept that one of the benefits of a lower resting $T_{re}$ following heat acclimation may be lower thermoregulatory thresholds for sweating and cutaneous vasodilation. It is our opinion that further work on this interesting topic is certainly warranted in the future.

Second, the lower resting $T_{re}$ may simply allow an acclimated individual to exercise for a longer period of time in the heat before a critical temperature is reached (5). Specifically, precooling studies (1, 7, 11, 15) that treated subjects wearing chemical protective clothing. The views presented in this paper are those of the authors and do not reflect the official policy or position of the Department of the Navy, the Department of Defense, or the US Government. Address for reprint requests: M. J. Buono, San Diego State Univ., Dept. of Exercise and Nutritional Sciences, San Diego, CA 92182. Received 22 September 1997; accepted in final form 27 January 1998.

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