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ORIGINAL ARTICLE

Lowering of resting core temperature during acclimation is influenced by exercise stimulus

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Abstract The decrease in resting core temperature (T_{co}) and its relation to the reduced physiological strain during heat acclimation was analysed with rectal temperature data measured in three groups of eight semi-nude persons (6 males, 2 females) who were acclimated for 15 consecutive days to dry, humid and radiant heat, respectively, with equivalent WBGT (33.5°C), by performing 2-h treadmill work. A fourth group followed the same protocol for 12 days in a neutral climate. After acclimation, both resting T_{co}, prior to heat exposure, and final T_{co}, measured at the end of work, were significantly reduced. The reduction in final T_{co} increased with decreasing ambient water vapour pressure and was higher for the data pooled over the heat conditions (0.46 ± 0.31°C) than in the neutral climate (0.21 ± 0.25°C), whereas resting T_{co} declined similarly in the heat (0.20 ± 0.25°C) and the neutral environment (0.17 ± 0.23°C). The lowering of resting and final T_{co} after heat acclimation showed a significant correlation ($r = 0.67$) and regression analysis showed that 37% of the average reduction in final T_{co} was attributable to the lowering of resting T_{co}. The same analysis was applied after extending the database by short-term series of clothed persons (17 females, 16 males) acclimated at 29.5 and 31.5°C WBGT for 5 days. A significant correlation was found between the lowering of resting and final T_{co} ($r = 0.57$) that did not depend on climatic conditions and gender, although the reduction in resting T_{co} was significantly smaller for females (0.06 ± 0.22°C) than for males (0.21 ± 0.23°C). It is concluded that the lowering of resting core temperature contributes to the reduced physiological strain during heat acclimation. Similar effects under neutral conditions point to the exercise stimulus as a probable explanation.

Keywords Acclimation · Heat stress · Exercise · Resting core temperature · Rectal temperature · Gender

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Introduction

Repetitive exposure to heat usually results in the adaptation of the organism to the climatic and working conditions, leading to a decrease of physiological strain (acclimation). Depending on climatic conditions and work intensity, heart rate and body temperature will decrease during repeated heat exposures, whereas sweat rates will increase (e.g. Aoyagi et al. 1997). If a person is exposed to uncompensable heat stress, the final level of core temperature also depends on its initial value (Givoni and Goldman 1972; Gonzalez et al. 1997; Selkirk and McLellan 2001; Fig. 1B in Nielsen et al. 1993). Some acclimation studies (Table 1) showed that during the adaptation process body core temperature decreases so that it is lowered already during the resting periods preceding the successive heat exposures. The reported reduction of resting core temperature given in Table 1 ranged between 0.2 and 0.8°C, which might be

Table 1 Examples of lowered resting T_{co} during acclimation as reported in the literature

Reference	No. of subjects	Duration of acclimation	T_{co} type[a]	Decrease of resting T_{co} (°C)	*P* value
Wyndham et al. (1954)	13 accl. versus 10 nonaccl. each	8 days	T_{re}	0.65	Not given
Fox et al. (1963)	20	12–24 days	T_{or}	0.19	<0.001
Höfler (1966) (natural tropical climate, Abeokuta, Nigeria)	1	11 weeks	T_{or}	0.83 a.m. 0.87 p.m.	<0.001 <0.001
Höfler et al. (1969)	1	1–3 versus 26–35 day	T_{or}	0.9	<0.001
Shvartz et al. (1974)	5	12 days	T_{re}	0.2	<0.05
Kobayashi et al. (1980)	5	9 days	T_{re}	0.4	<0.05
Orenstein et al. (1984)[b]	10 CF 10	8 days	T_{re}	0.2 0.4	<0.05 <0.05
Cotter et al. (1997)	8	6 days	T_{ac}	0.2	<0.05
Buono et al. (1998)	9	7 days	T_{re}	0.3	<0.05
Cheung and McLellan (1998)	7 medium fit 8 highly fit	2 weeks	T_{re}	0.17 0.11	Not given
Shido et al. (1999)	6	10 days	T_{re}	0.09 a.m. 0.19 p.m.	NS NS
Patterson et al. (2004)	11	3 weeks	T_{oe}	0.20 (day 8) 0.32 (day 22)	<0.05 <0.05
Schütte and Kampmann (2005)	5	4 weeks	T_{re}	up to 0.37	NS

[a] T_{co} measured as—T_{re}, rectal; T_{or}, oral; T_{oe}, oesophageal; T_{ac}, auditory canal temperature

[b] Ten patients with cystic fibrosis (CF) and ten normal controls

influenced by different acclimation protocols and climatic conditions.

Therefore it could be expected that the reduction of resting core temperature contributes to the decrease of core temperature during acclimation. On the other hand, there are heterogeneous results reported in the literature as, e.g. Gonzalez et al. 1997, who did not find the decrease of resting core temperature in one of three samples analysed. All in all this justifies further investigation of the change of resting core temperature and its relation to the beneficial effects of acclimation.

The aim of the present study is thus to quantify the influence of the lowering of resting core temperature on the reduced core temperature at the end of an exposure during acclimation to heat with different characteristics. For that purpose, a re-analysis of data from controlled laboratory experiments in a climatic chamber (Griefahn 1997) was accomplished. These experiments were originally conducted in order to demonstrate that people experiencing acclimation to heat with a certain characteristic (e.g. hot–dry or with radiant heat load) gain the same benefit in terms of reduction of thermoregulatory and cardiac strain for another type of heat stress (e.g. warm–humid), which is equivalent in terms of WGBT. The development of resting core temperature has not been considered so far. The database is enlarged by unpublished data of a second experiment comprising short term acclimation series of 5 days' duration where approximately the same proportion of males and females participated, thus allowing the investigation of a possible modifying effect of gender. The available data have the advantage that it is possible to compare three different types of heat stress, namely hot–dry, warm–humid and radiation in relation to a thermal neutral condition.

Methods

The analysis is based on the registration of core temperature (T_{co}) data measured in the rectum 10 cm beyond the anal sphincter with a flexible thermistor probe (YSI 401, Yellow Springs, USA) during two experimental studies of acclimation, which had been approved by *IfADo*'s Ethics Committee and to which all participants had given their consent after they were informed about the study objectives and the methods. As the procedure and measurements are reported in detail by Griefahn (1997), they are only briefly reviewed here together with a description of the available data and the applied analyses.

Experiment 1

Three series were carried out in 15 consecutive days at equivalent heat stress in terms of WBGT (33.5 ± 0.1°C), but with different characteristics: warm–humid [air (T_a) and mean radiant temperature (T_r) 37.0°C, wet-bulb temperature (T_{wb}) 32.0°C, air velocity (v_a) 0.3 ms^{-1}], hot–dry ($T_a = T_r = 50.0$°C, $T_{wb} = 26.5$°C, $v_a = 0.3$ ms^{-1}) and radiation ($T_a = 25.0$°C, $T_r = 90.8$°C, $T_{wb} = 16.2$°C, $v_a = 0.5$ ms^{-1}).

One additional series took place in 12 days in a neutral environment ($T_a = T_r = 25.0$°C, $T_{wb} = 19.5$°C, $v_a = 0.3$ ms^{-1}). In each series, 8 semi-nude (0.1 clo) subjects (2 women , 6 men) participated daily in a 2.5-h session. They started with a resting period sitting for 10 min in a comfortable chair at 22°C, then moved into the climatic chamber, where they rested for another 10 min and then completed 4 periods (25 min plus 3 min break) of walking at 4 km/h on the level on a treadmill (cf. Fig. 1). The characteristics of the females were (AM ± SD) age 27.9 ± 3.4 years, body height 1.63 ± 0.04 m, body mass 61.8 ± 4.4 kg, body surface area 1.67 ± 0.07 m^2, and those of the males 23.7 ± 2.6 years, 1.80 ± 0.06 m, 73.6 ± 5.6 kg, 1.93 ± 0.10 m^2.

Experiment 2

In the second experiment the same protocol was followed as before, but each series lasted only for 5 days and the participants wore a cotton coverall (0.6 clo). Two levels of heat stress in terms of WBGT were realised with three different characteristics, all with $v_a = 0.5$ ms^{-1}: WBGT = 29.5°C [warm–humid ($T_a = T_r = 32.7$°C, $T_{wb} = 28.1$°C), hot–dry ($T_a = T_r = 44.0$°C, $T_{wb} = 23.0$°C) and radiation ($T_a = 25.0$°C, $T_r = 72.9$°C, $T_{wb} = 16.3$°C)] and WBGT= 31.5°C [warm–humid ($T_a = T_r = 34.9$°C, $T_{wb} = 30.0$°C), hot–dry ($T_a = T_r = 47.0$°C, $T_{wb} = 24.5$°C) and radiation ($T_a = 25.0$°C, $T_r = 80.8$°C, $T_{wb} = 16.3$°C)]. In total, 33 acclimation series were carried out, 17 with women (23.5 ± 2.4 years, 1.67 ± 0.07 m, 59.1 ± 4.9 kg, 1.67 ± 0.09 m^2) and 16 with men (23.8 ± 3.2 years, 1.82 ± 0.07 m, 78.3 ± 11.8 kg, 1.99 ± 0.16 m^2).

Data analysis and statistics

The differences in the course of resting T_{co} (at end of first resting period) and final T_{co} (mean of last work period) were tested by repeated-measures ANOVA calculated with linear mixed models assuming an autoregressive covariance structure for the time factor, with multiple comparison adjustment according to Tukey–Kramer for post hoc tests of all pairwise differences between climates and according to Dunnet–Hsu for differences over experimental days with the final day as a control (Littell et al. 1996). The same ANOVA model was applied to the lowering of final and resting T_{co} due to acclimation, whereby the lowering of T_{co} was calculated as the difference of the actual values from the values at the first day in each case. Regression analysis and ANCOVA were applied to predict the lowering of final T_{co} after acclimation by that of resting T_{co} while considering the modifying effects of the different climates and of gender. T tests were used to test for differences between females and males concerning the lowering of T_{co}.

Results

Data from experiment 1 (15 days)

Figure 1 presents an example of an individual showing a lowering of T_{co} during acclimation to dry heat not only at the end of the work period, but also for the resting values before the start of heat exposure.

The results of the ANOVA given in Table 2 confirm the lowering of the final values of T_{co} during the acclimation procedure and the influence of the climate (Griefahn 1997). Post hoc tests revealed that the effects of the different types of heat stress did not differ significantly from one another but differed significantly from those of the neutral condition. For the resting values a significant lowering of T_{co} during the series showed up without a specific influence of climate. Post hoc tests showed that starting with the second day the resting values did not differ significantly from those at the last day, whereas final T_{co} did not change significantly after day 5.

The attenuation in physiological strain during acclimation is illustrated by Fig. 2 for final T_{co} together with the corresponding change in resting T_{co}. The resting T_{co} decreased by about 0.2°C in a similar way for each of the four series and without significant alterations after day 2, as shown by the results of the ANOVA in Table 3. However, for the final T_{co} the attenuation effect appeared to increase from the neutral to the warm–humid, hot–dry and radiant heat stress conditions. This was proved by the ANOVA (Table 3) with post hoc tests showing a significant differ-

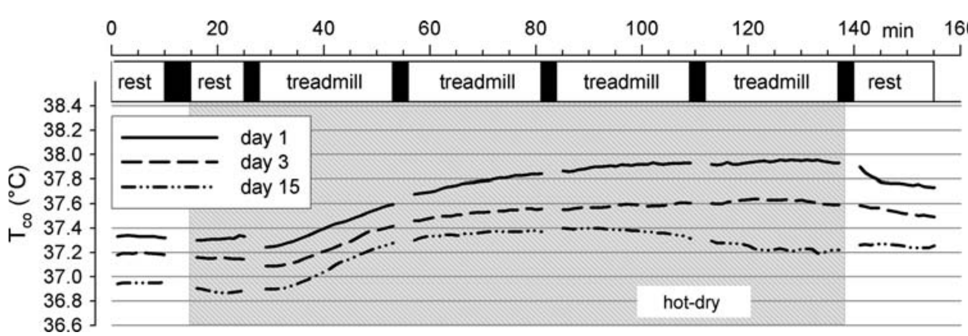


Fig. 1 Change in time response of T_{co} of a person during acclimation to dry heat. The *grey* shaded area indicates heat exposure time. T_a was 22°C in the first and final resting periods

Table 2 ANOVA results for the development of resting and final T_{co} over the first 12 days in four climates of experiment 1

Effect	Resting T_{co}				Final T_{co}			
	df_1	df_2	F	P	df_1	df_2	F	P
Day	11	308	3.22	0.0004	11	308	6.52	<0.0001
Climate	3	28	0.87	0.4666	3	28	13.43	<0.0001
Day × climate	33	308	0.68	0.9135	33	308	1.19	0.2208

Nominator and denominator degrees of freedom (df_1, df_2), F and P values

Table 3 ANOVA results for the development of the change in resting and final T_{co} from day 2–12 in four climates of experiment 1

Effect	Change in resting T_{co}				Change in final T_{co}			
	df_1	df_2	F	P	df_1	df_2	F	P
Day	10	280	1.12	0.3435	10	280	2.21	0.0174
Climate	3	28	0.52	0.6717	3	28	3.40	0.0313
Day × climate	30	280	0.72	0.8572	30	280	1.17	0.2503

Nominator and denominator degrees of freedom (df_1, df_2), F and P values

ence for the radiant heat condition not only compared to the neutral, but also to the warm–humid condition. The significant difference between radiant and warm humid condition could be observed here in contrast to the analysis of the absolute values presented in Table 2 because the starting values of the acclimation series were adjusted to zero in each case by the calculation of difference values.

For the reduction of heat strain at the end of the acclimation series, calculated as averaged changes of days 14 and 15 (cf. Griefahn 1997) a significant correlation ($r = 0.67$, $P = 0.0004$) between the lowering of resting and final T_{co} values showed up (Fig. 3). An ANCOVA predicting the lowering of final T_{co} from that of resting T_{co} and including the type of heat stress as additional factor had shown a non-significant ($P > 0.05$) interaction term, meaning that the regression slopes did not differ significantly between the three warm climates, thus justifying the analysis of the pooled data presented in Fig. 3. The linear equation predicting the change in final T_{co} (y) from the change in resting T_{co} (x) was $y = -0.29 + 0.84 \times x$ as obtained by ordinary least-squares regression, which was very similar to the results ($y = -0.30 + 0.76 \times x$) from a robust regression procedure (Huber 1973), indicating that the estimates had not been biased by extreme observations.

Averaged over the three heat stress conditions, resting T_{co} was lowered by 0.20 ± 0.25°C whereas the final T_{co} was reduced by 0.46 ± 0.31°C at the end of the acclimation

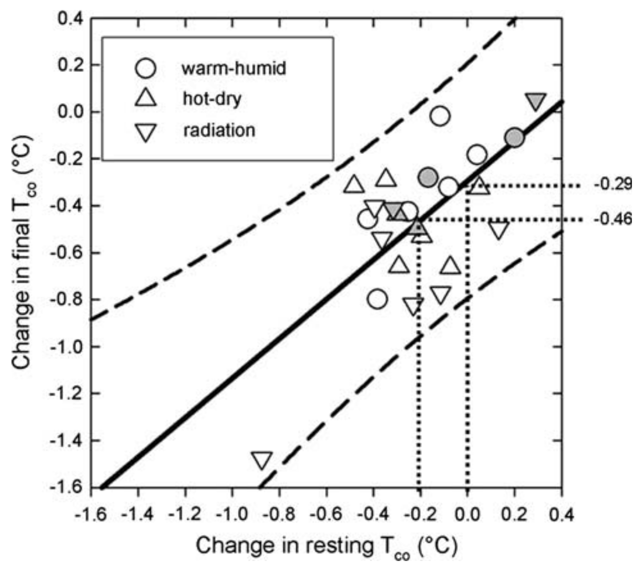
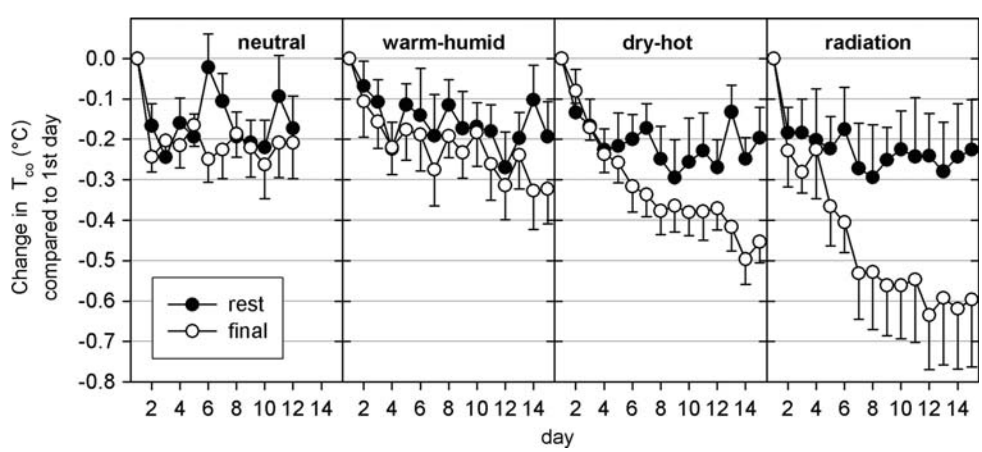


Fig. 3 Regression line with 95% prediction limits (*dashed curves*) for changes in resting and final T_{co} after acclimation to heat with equivalent WBGT. *Dotted lines* mark the change in final T_{co} on average (−0.46°C) and at zero change in resting T_{co} (−0.29°C). Data on females are *grey* shaded

procedure (Fig. 3). The decrease of the final values without lowering of the resting T_{co} (0°C) calculated from the regression line in Fig. 3 amounted to 0.29°C. Thus the component of the averaged effect of heat acclimation on final T_{co} that

Fig. 2 Change in resting and final T_{co} (AM ± SE) during acclimation to different climates



was attributable to lowering resting T_{co} could be calculated as 0.46°C − 0.29°C = 0.17°C corresponding to 37% of the effect size.

Short-term acclimation data (5 days)

Figure 3 revealed a high inter-individual variability with some persons, especially females, showing a less-pronounced decrease or even an increase of resting as well as of final T_{co} during heat acclimation. This aspect is studied more deeply in Fig. 4 combining the data after 5 days of heat acclimation from all available 22 series with females (1 series was excluded because of missing resting T_{co} data) and 34 with males from experiments 1 and 2. For females lowering of resting T_{co} differed not significantly from zero (0.06 ± 0.22°C) and was significantly ($P < 0.05$, t test) smaller compared to that of the males (0.21 ± 0.23°C). Also the final T_{co} decreased less for females during acclimation (0.19 ± 0.18°C) than for males (0.29 ± 0.23°C), but this difference reached only borderline significance ($P < 0.1$). There was a significant correlation between the lowering of resting and final T_{co} ($r = 0.52$, $P < 0.0001$), and an ANCOVA incorporating the gender effect and different climatic conditions revealed that the regression slopes predicting the change of final T_{co} from that of resting T_{co} were independent of gender and condition ($P > 0.05$). The regression equation for the pooled data was $y = -0.18 + 0.47 \times x$.

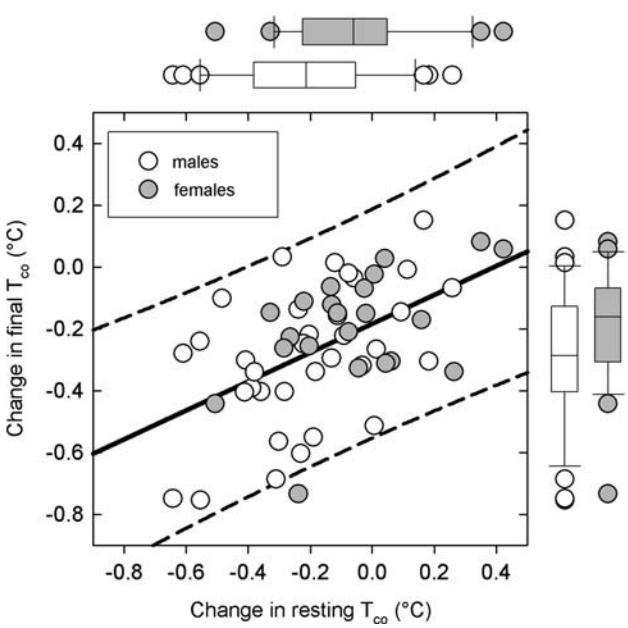


Fig. 4 Regression line with 95% prediction limits (*dashed curves*) for changes in resting and final T_{co} of 22 females and 34 males after 5 days of acclimation to heat with different WBGT. *Box plots* showing the 10th, 25th, 50th, 75th and 90th percentiles of resting and final T_{co} are added in the upper and right border, respectively

Discussion

Acclimation effect on core temperature

The results confirm the lowering of final rectal temperatures whereby the attenuation increased from neutral to warm–humid and hot–dry to radiant heat load. The minor reduction of final rectal temperature in the neutral condition is explainable by the absence of a heat stimulus (Aoyagi et al. 1997). Discussing the acclimation to different types of heat stress with equivalent WBGT, the main result obtained by Griefahn (1997) was that the degree of acclimation was similar for the three groups exposed to heat. This was proved by exposing both groups acclimated to dry and radiant heat each to the warm–humid condition for extra 2 days (days 16 and 17) and comparing their responses with days 14 and 15 of the group acclimated to the warm–humid climate. There were no significant differences in the core temperature, heart rate and sweat production in this comparison, and this was also confirmed when comparing the responses of the extra 2 days in dry heat of the group acclimated to the warm–humid condition with the days 14 and 15 of the group acclimated to dry heat. Thus, the different lowering of final rectal temperature found here across the three heat conditions is explicable by the fact that for persons with a similar degree of heat acclimation the beneficial effect of increased sweat secretion is most effective in low water vapour pressure conditions. Therefore the change of final T_{co} is largest for the radiant heat condition and smallest for the warm–humid climate.

The more interesting finding of the present study concerns the reduction of resting rectal temperatures that was not only verified during acclimation to warm–humid (Buono et al. 1998) but also to dry and radiant heat. The analysis of experiment 1 suggests that about one-third of the average lowering of final T_{co} may be attributed to the lowering of resting T_{co} values.

As the lowering of resting core temperature was also found in neutral climate, and similar reductions were also reported by Shvartz et al. (1974), this leads to the hypothesis that during the acclimation to moderate heat stress the lowering of resting T_{co} is mainly due to the physical work performed. Higher heat stress levels are known to provoke greater acclimation effects on final T_{co}. Whether higher heat stress also leads to a more reduced resting T_{co}, should be a subject of future research.

Inter-individual variability

Additionally, our results reveal a high inter-individual variability with some persons even showing increases of resting as well as of final T_{co} during heat acclimation. The observed range of the lowering of resting core temperature covers the range of data depicted from the literature in Table 1. If the absolute value of the core temperature is the limiting factor for uncompensable heat stress as proposed by Nielsen et al. (1993), the ability of lowering of the resting core temperature may be an important aspect of individual heat tolerance.

The results of the present study show that one source of variability is the gender of the participants, with females showing no significant reduction of resting core temperature and only a small lowering of the final value, i.e. a smaller acclimation effect. One reason for this could be that anthropometric characteristics and aerobic capacity that have been shown to influence the core temperature (Havenith and van Middendorp 1990) were not considered by, e.g. matching the male and female samples. Such a procedure has been shown to attenuate the gender effect (Avellini et al. 1980; Frye et al. 1982).

Furthermore, hormonal fluctuations throughout the menstrual cycle, causing an increase of resting core temperatures of about 0.4°C during the transition from the follicular to the luteal phase (Aoyagi et al. 1997) could have interfered with the change of resting and final core temperature during acclimation as well as using oral contraceptives, leading to a change in core temperature between 0.1 and 0.3°C (Rogers and Baker 1997; Grucza et al. 1993).

In addition, there exist hints to the effect that persons with high physical fitness show lower resting core temperatures compared to persons with lower fitness. This is reported, e.g. by Shvartz et al. (1977) and Cheung and McLellan (1998) describing a smaller reduction of resting core temperature for persons with higher fitness-levels. Besides this, Pandolf (1979) showed that acclimation takes less time for people with higher fitness. Therefore fitness represents a potential confounder that could account for some portion of the observed inter-individual variability. As the present database contains no information concerning physical fitness and hormonal fluctuations by menstrual cycle or oral contraceptive use, the cause of the gender differences in the lowering of resting core temperature cannot be explored here.

However, the relationship between the change in resting core temperature and the change in final core temperature did not differ between males and females. This indicates that similar mechanisms, e.g. reduced metabolism and increased heat dissipation when resting, as proposed by Aoyagi et al. (1997), influence both genders, but to a different degree. Thus, this may cause the coupled reduction of both resting and final core temperature during acclimation.

Conclusions

To conclude, our analyses provide evidence that the acclimation process is accompanied by a lowering in resting core temperature that accounts for a substantial part of the reduced final core temperatures. Givoni and Goldman (1973) used an exponential model with an offset of 0.5°C describing the effect of full acclimation on the decrease of the resting rectal temperature for conditions with higher heat stress. In our study, presumably due to the moderate heat stress level applied, the effect amounts to 0.2°C only, but was also observable in a neutral climate. This justifies the conclusion that under the conditions studied physical exercise was the main stimulus for lowering resting core temperature. These findings may be considered when predicting the effects of heat acclimation (cf. Givoni and Goldman 1973) and may lead to modifications of analytical models of thermoregulation (e.g. ISO 7933 2004). However, more information is required, especially about the modifying influence of physical fitness or hormonal fluctuations, as well as about the relative contribution of exercise to acclimation at higher levels of heat stress.

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