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DETERMINATION OF THE INDIVIDUAL STATE  
OF ACCLIMATIZATION

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#### ABSTRACT

An attempt was made to define a subject's state of acclimatization in terms of the reactions of several physiological variables (sweat rate, core temperature, heart rate) to a heat stress test. For this purpose, four subjects performed work in a warm environment (34°C, 30% RH) both before and after an acclimation procedure to heat (40°C, 20% RH). The overall effect of acclimation was similar to results described in the literature: lower heart rate, higher sweat sensitivity, lower core temperature. Individual effects, however, were more difficult to interpret. Qualitatively, they all showed the above mentioned changes, but comparing their individual physiological reactions, differences could be observed. Ranking orders for their acclimatization state, based on their heart rate response, were different from those based on core temperature and sweat rate-core temperature relation responses. It appears that the heart rate, core temperature and sweat rate-core temperature relations are correlated to the acclimatization state, whereas the heart-rate response is also strongly influenced by a subjects fitness level. However, these relations, as well as the influence of % body fat etc. need further study, using a larger number of subjects.

## 1 INTRODUCTION

In a recent review (Havenith, 1985), a study was made of the physiological parameters, which are relevant for a subjects reaction to heat stress. The aim of this review was to find explanations for the inter-individual variability in reaction to heat stress. The conclusion was that the individuals reaction might be characterized by a number of parameters, defining its state of acclimatization, fitness, hydration and anthropometry. For acclimatization (supposedly the most important parameter) the subject's status is usually discussed in a relative manner: e.g. the difference before and after an acclimation regime. In this study we will, however, try to define an absolute level of acclimatization.

Compared to an unacclimatized subject an acclimatized subject will show during heat stress:

- a lower rectal temperature;
- a lower heart rate;
- an increased sensitivity of the sweat glands;
- a better distribution of sweat over the body surface.

The state of acclimatization can be improved by (repeated) exposures to heat and/or by physical training. In the review it was suggested that the reactions of several physiological variables ( $T_{core}$ , Sweat rate, heart rate) to a heat stress test may be used as a measure for the state of acclimatization: a high heart rate, a low sweat rate or a large increase in core temperature would indicate a low state of acclimatization.

A difficulty in studies regarding the acclimatization state is that the effects, ascribed to acclimatization, are often confounded by changes in other parameters. Especially changes in fitness very often accompany a change in the state of acclimatization. Therefore, the fitness level has to be measured and considered as a possible cause for observed reactions to heat stress.

The subject's anthropometric measures, hydration state and time of day of the heat exposure have their impact on the thermal response to heat stress as well, increasing the number of parameters to an

inconvenient level. Hydration and time of day can be excluded from the analysis, however, by keeping them at a standard value due to resupply of water and experimenting on a fixed time of day. Anthropometric measures cannot be controlled and will have a systematic influence, due to differences in surface to mass ratio and fat content of the subjects. The way to decide whether a reaction to heat stress should be attributed to the state of acclimatization or to other factors is to change the state of acclimatization by a heat exposure program. Reactions, related to the state of acclimatization should be altered significantly after the program. Unchanged reactions must be attributed to other factors. Therefore, an experiment has been carried out, consisting of two heat stress tests (with repeated measurement in morning and afternoon to investigate time of day effect and to check the consistency of the results) followed by a heat exposure (acclimation) program and two post-acclimation heat stress tests, identical to the pre-exposure tests.

## 2 METHODS

Four young (age 24-25) male subjects of unselected level of physical fitness were subjected to heat stress tests before as well as after an acclimation procedure (Table I). During the heat stress tests, heart rate (HR), Core temperature ( $T_c$ ), skin temperature ( $T_{sk}$ ), forearm bloodflow (FBF), sweat rate (SR) and minute oxygen consumption ( $VO_2$ ) were measured. The correlation of these data with the effect of the acclimation procedure, the fitness level and anthropometric data will be investigated. Details will be given successively.

Table I Scheme for the experiment, HST = heat stress test

day	09.00 am	11.30 am - 14.00 pm	03.00 pm
1	HST subj. I		HST subj. I
2	HST subj. II	Acclimation subj. I	HST subj. II
3	HST subj. III	Acclimation I+II	HST subj. III
4	HST subj. IV	Acclimation I+II+III	HST subj. IV
5		Acclimation I+II+III+IV	
6		Acclimation I+II+III+IV	
7		Acclimation I+II+III+IV	
8		Acclimation I+II+III+IV	
9	HST subj. I	Acclimation II+III+IV	HST subj. I
10	HST subj. II	Acclimation III+IV	HST subj. II
11	HST subj. III	Acclimation IV	HST subj. III
12	HST subj. IV		HST subj. IV

## 2.1 Heat stress test

The heat stress test was performed in a climatic chamber at an air temperature of 34°C and a relative humidity (RH) of 30%. The low RH was chosen to avoid drippage of unevaporated sweat, which would spoil the sweat rate measurement. The seminude subjects were seated on a bicycle ergometer on which they had to perform work for three subsequent periods of 30 minutes with work loads of 30, 60 and 90 Watts. The period of 30 minutes was sufficiently long to enable the subjects to reach a thermal steady state. The bicycle ergometer was mounted on a bed balance (Potter) for the recording of weight loss by sweating and respiration.

Lower arm blood flow, representing skin bloodflow (Edholm et al., 1956; Roddie et al., 1956) was determined by venous occlusion plethysmography (Whitney, 1953). The right arm of the subject was supported by two foam blocks; one at the elbow, the other at the wrist. In between the blocks, the lower arm was equipped with two mercury in silastic strain gauges with which the FBF was recorded (Fig. 1).

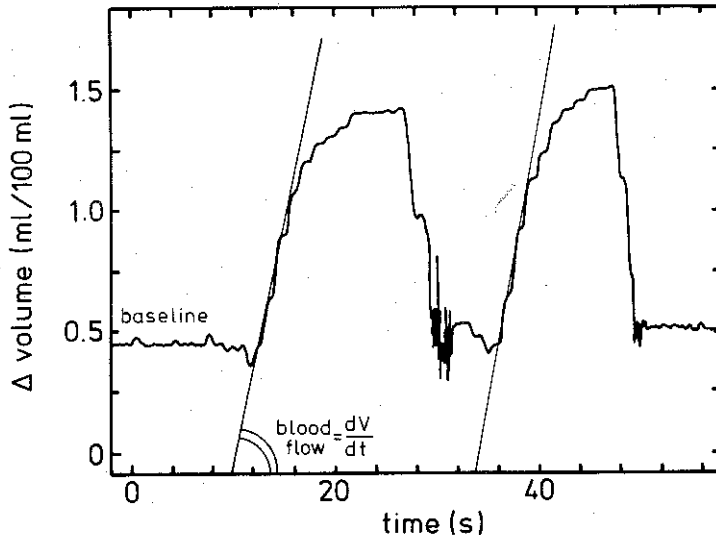


Fig. 1 Example of a recording of forearm blood flow.

Oxygen uptake and carbondioxide output (and by calculation the metabolic rate) were determined by a diaferometer, an open gas analysis system. An ECG was continuously monitored, from which heart rate was deduced and recorded. Body core temperatures were determined by two methods:

- 1 By a rectal probe inserted about 12 cm beyond the rectal sphincter (YSI linear thermistor).
- 2 By a thermocouple, inserted in the oesophagus down to the level of the right atrium (about 37 cm from the nose). During the insertion of the thermocouple probe ( $\emptyset = 2$  mm), the mucous membranes of the nose were locally anaesthetired with Xylocaine spray and gel.

Skin temperature was determined at 7 places on the body (Fig. 2). Average skin temperatures were calculated from these 7 separate measurements, weighted for the surface area they present.

$$T_{\text{skin}} = .07 T_{\text{head}} + .175 (T_{\text{chest}} + T_{\text{back}}) + .07 T_{\text{upperarm}} \\ + .12 T_{\text{lowerarm}} + .19 T_{\text{upperleg}} + .20 T_{\text{lowerleg}}$$



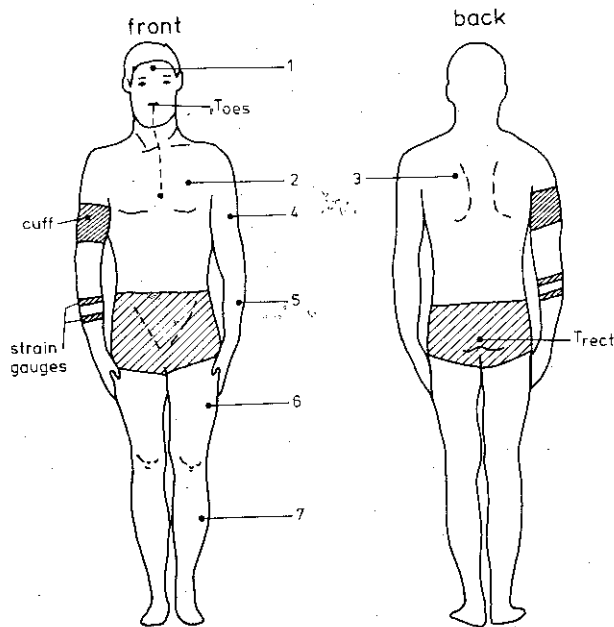


Fig. 2 Sites of skin temperature and core temperature measurements.

## 2.2 State of hydration and time of day

In order to reduce possible influences of dehydration of the subject on the test results, the subjects were encouraged to replace their weight loss (sweating + respiration) with isotonic fluid after each 30 minute work period of the heat stress test. For the determination of the influence of the time of day (circadian body temperature rhythm) on the results, the heat stress tests were carried out both in the morning and in the afternoon.

## 2.3 Fitness and anthropometric data

As the subjects were not matched according to their fitness level and their anthropometric data, an influence of these parameters on observed differences in results between subjects cannot be excluded. Therefore, these parameters had to be measured. The subjects' physical fitness, expressed as either their maximal oxygen uptake or as the gain of the heart rate- $\dot{V}O_2$  relation, was determined from a

submaximal exercise test at three workloads. Extrapolation of the observed oxygen uptake-heart rate relation to the estimated maximal heart rate was carried out according to Astrand (1970):

$HR_{max} = 210 - .65 * \text{Age}$  and corrected for the plateau of heart rate (.3 l/min  $O_2$ ; Maritz, 1961) resulting in the estimated maximal oxygen uptake (Fig. 3).

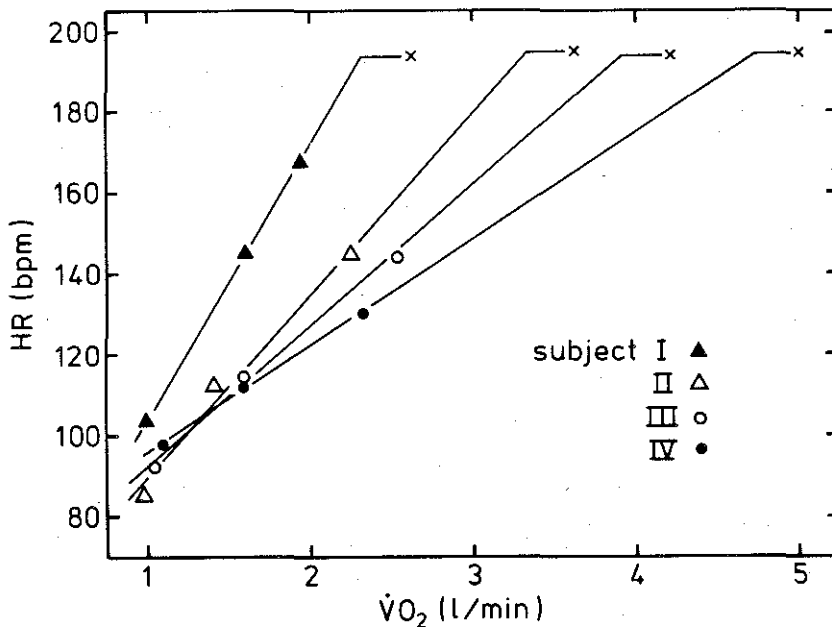


Fig. 3 Determination of maximal oxygen uptake from sub-maximal exercise tests.

Anthropometric data were collected before the experiment, (height, weight, % body fat), twice during the experiment (% fat) or daily (weight). The replications were used to check for dehydration (weight) and to increase the accuracy of the data (% body fat). The percentage body fat was determined by measuring skinfold thickness (Durnin et al., 1967, 1973) at four sites, using a ponderal calliper gauge. The sites were biceps, triceps, subscapular and suprailliacal. The sum of these four measurements was used to determine the % body fat from Durnin's table.

#### 2.4 Acclimation procedure

During 7 subsequent days, the subjects remained in the climatic chamber ( $T_a = 40^\circ\text{C}$ ,  $\text{RH} = 20\%$ ) for 2 hours a day. During their stay their core and skin temperature were measured every 10 minute period. After entering the chamber they rested for about 10 min. Then, work was started in order to raise their core temperature. The work was stopped when the core temperature reached about  $38.3^\circ\text{C}$ . From that moment on, they alternately rested and worked, keeping their core temperature at this level (Fig. 4). This method is supposed to induce a constant heat strain throughout the acclimation regime (Fox, 1968), which is regarded as the most efficient procedure for acclimatization.

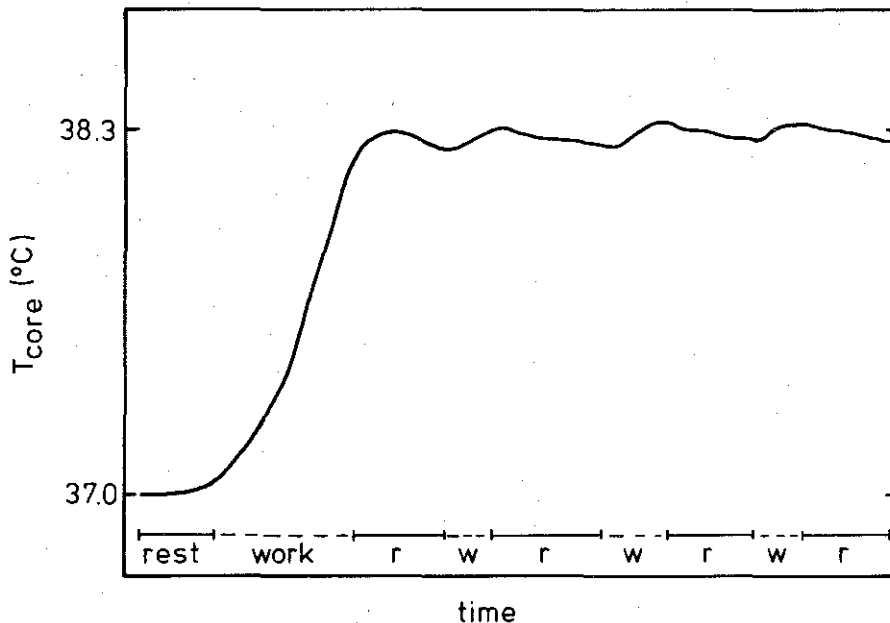


Fig. 4 Time course of core temperature during an acclimation session.

#### 2.5 Statistical analysis

The obtained data were analysed by a four factor analysis of variance using the SPSS statistical package. The independent variables were: subjects, before-after acclimation; morning-afternoon heat stress test; work loads. As dependent variables were tested: Heart rate,

Core temperature, Skin temperature, FBF, SR,  $\Delta HR$ ,  $\Delta T_{core}$ ,  $\Delta T_{sk}$ ,  $\Delta SR/\Delta T_{core}$ ; all values as determined at the end of each 30-minute period.

### 3 RESULTS

#### 3.1 Anthropometric data and fitness

The results of the anthropometric measurements and fitness tests are listed in Table II.

Table II Subject characteristics: H=height (cm), A=age (years); W=weight (kg); SKF=skinfoldthickness (mm); F=percentage fat; BSA=body surface Area ( $m^2$ ); SM=surface to mass ratio;  $VO_2$ max=maximal oxygen uptake (l/min); S=hours of active sports per week.

Subj. no.	H	A	W	SKF	F	BSA	SM	$VO_2$ max	S
I	182	25	66.9	42.2	17.0	1.87	.028	2.60	0
II	190	24	66.8	35.3	14.9	1.92	.029	3.63	.5
III	182	25	72.3	40.3	16.5	1.93	.027	4.23	2
IV	191	24	80.7	45.3	17.8	2.09	.026	5.00	2

The subjects do not differ widely in age, height and % fat. Regarding their weight and especially their fitness however, they differ considerably.

#### 3.2 Morning-afternoon sessions

In the following presentation of the results, the morning and afternoon heat stress test results are lumped together as none of the variables showed any significant time of day effect.

### 3.3 Average changes due to acclimation

The first set of graphs which will be presented relates to the acclimation effect over all subjects, comparing the average results before and after the acclimation procedure. In Fig. 5 the relation between core temperature (Toes) and the work load is presented.

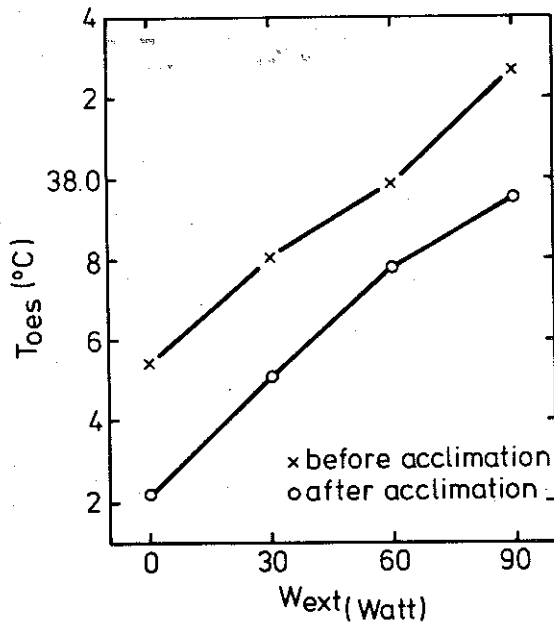


Fig. 5 Toes in relation to work load during a heat stress test both before - and after acclimation.

In accordance with literature results (Havenith, 1985), body core temperature at any work load is lower after acclimation. The difference amounts to about  $.3^{\circ}\text{C}$  for Toes and about  $.2^{\circ}\text{C}$  for Trect and is significant in both cases ( $p < .05$ ). Skin temperature (Fig. 6) decreases with increasing work load and becomes even significantly lower after the acclimation procedure by about  $.3^{\circ}\text{C}$  ( $p < .05$ ). Since Tcore increases with workload, whereas Tskin decreases, the core to skin gradient increases quite steeply with work load, a sign of the increased heat flux through the body shell. As both Tcore and Tskin decrease  $.3^{\circ}\text{C}$  with acclimation, the gradient appears independent of acclimation.

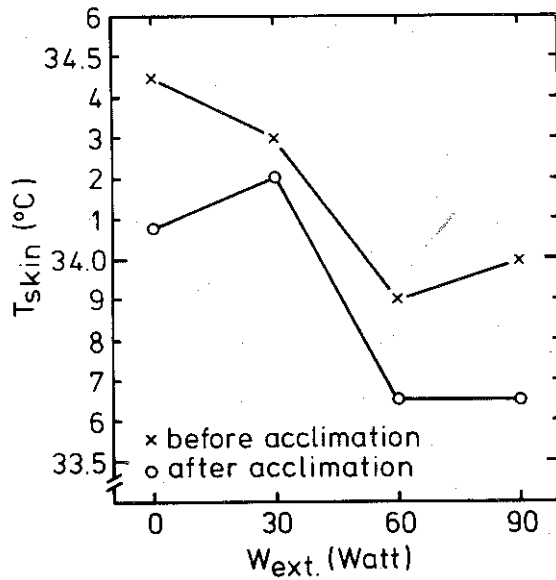


Fig. 6 T<sub>skin</sub> in relation to work load during a heat stress test, both before - and after acclimation.

The heart rate is significantly ( $p < .05$ ) reduced by acclimation too. The decrease amounts to 10-14 bpm. If we subtract from these heart rates (heat + work) the heart rate for the same workload in the

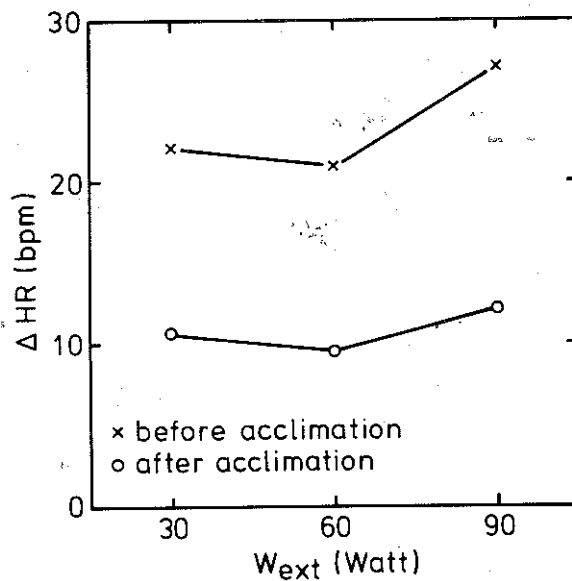


Fig. 7 Increase in HR due to heat only in relation to work load.

fitness test in cool conditions (work only), we may get an indication for the additional heart beats due to the heat ( $\Delta HR$ ). This is presented in Fig. 7.

Clearly these additional heart beats are hardly altered by the work load, whereas the acclimation procedure has a major effect ( $p < .05$ ). Sweat production (Fig. 8) is slightly reduced after acclimation ( $p = .06$ ). In principle, we expect higher sweat-evaporation, since metabolic rate (heat production) is equal and dry heat loss is slightly lower (lower  $T_{skin}$ ).

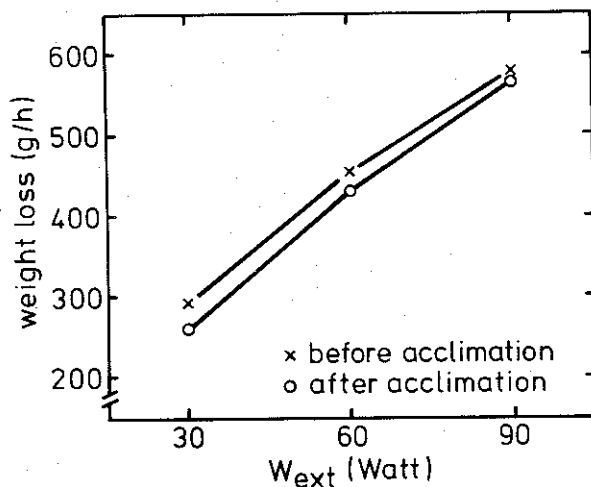


Fig. 8 Sweatproduction during a heat stress test in relation to work load.

This observation suggests an increase of sweating efficiency. Considering sweat sensitivity (sweat rate vs  $T_{core}$ ) we can observe that the slightly lower sweat rates after acclimation occur at a lower core temperature, and that therefore the sweat threshold shifts downward with acclimation (Fig. 9) in accordance with literature.

Forearm blood flow (Fig. 10) seems reduced after acclimation although the effect is not significant. In principle, a lower skin blood flow implies a reduced tissue conduction, which would lead to an increase of the  $T_{core} - T_{skin}$  gradient. This gradient however, was shown to remain equal with acclimation, which suggests that the skin blood flow in other parts of the body may not be decreased.

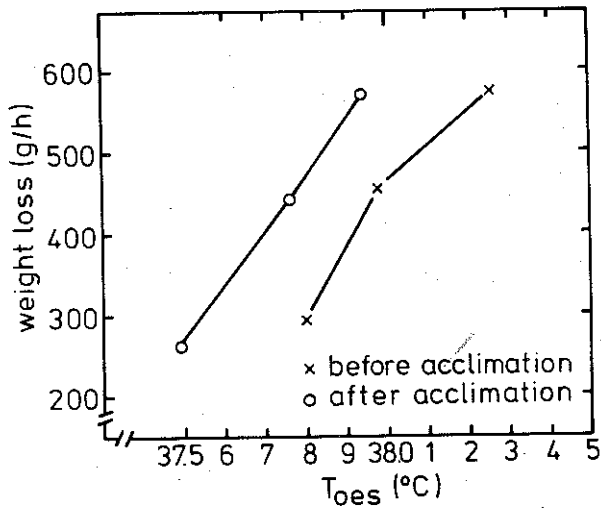


Fig. 9 Sweat rate in relation to core temperature during a heat stress test, before and after an acclimation procedure.

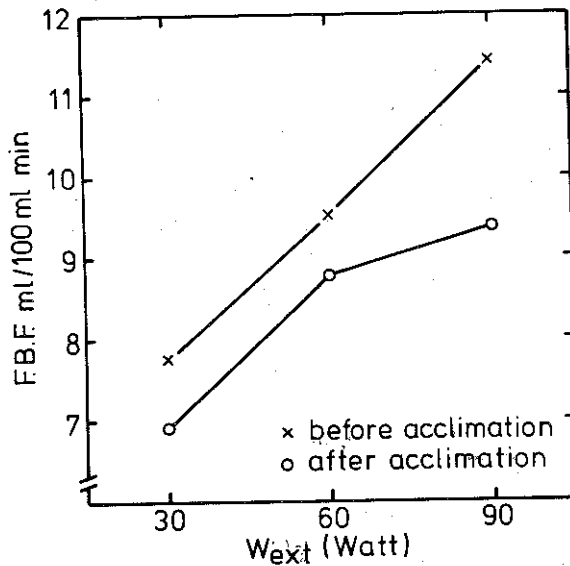


Fig. 10 Forearm blood flow (in ml per 100 ml of tissue per minute) during a heat stress test before and after an acclimation regime.

Summarizing, we may state that most presented results are in accordance with the general image of the effects of acclimation. This implies that for the group of subjects as a whole, the performed heat stress test is effective for the definition of the acclimatization state.



### 3.4 Individual changes due to acclimation

Regarding the effect of acclimation in each subject, all results are qualitatively in accordance with those for the group: lower core temperature, lower heart rates and increased sweat sensitivity. Quantitative comparison between subjects, however, reveals inconsistent results for the different measured variables.

Here, on two different aspects of acclimatization will be focussed: the sweat aspect and the cardiovascular aspect. When the subjects are ranked for the lowest sweat threshold, the order is: IV, II, III, I. The same order is found when ranking for the lowest core temperature, which is related to the sweating. When ranked for the least heart beats due to heat only, the order is III, II/IV, I. Apparently, subject III shows an inconsistent physiological reaction. An explanation for this observation may be found in the subjects physical fitness. It has been shown that physically fit subjects are partially acclimated to heat by their frequent core temperature elevation during training and/or by the training of their cardiovascular system. The benefit for fit people when exposed to heat is most likely to be attributed for the main part to the fitter cardiovascular system. Now, to what extent are the results indeed attributable to the fitness level?

Relating the two forementioned aspects of acclimation to the fitness level (ranking order I, II, III, IV with increasing fitness) shows that core temperature and sweat threshold are hardly related to fitness in this group of subjects. The extra heart beats due to heat only, show an interesting effect, however. In Fig. 11 is shown, that extra heart beats decrease roughly with increasing fitness (before acclimation), be it that there is a large interindividual variability. After acclimation, however, this relation shows to be a strong one, with minimal individual variability. This adds to the theory (Pandolf et al., 1977), that fit people not only are better acclimatized (the less additional heart beats due to the heat, the higher the state of acclimatization), but that they also acclimate faster (with equal acclimation regimes, the fitter people approach the state of "fully acclimatized" (i.e. zero additional heart beats due to heat) much faster (see Fig. 11). In both relations, subject

III is more or less outlying. It seems that his cardiovascular system is very efficient, whereas his sweating is not.

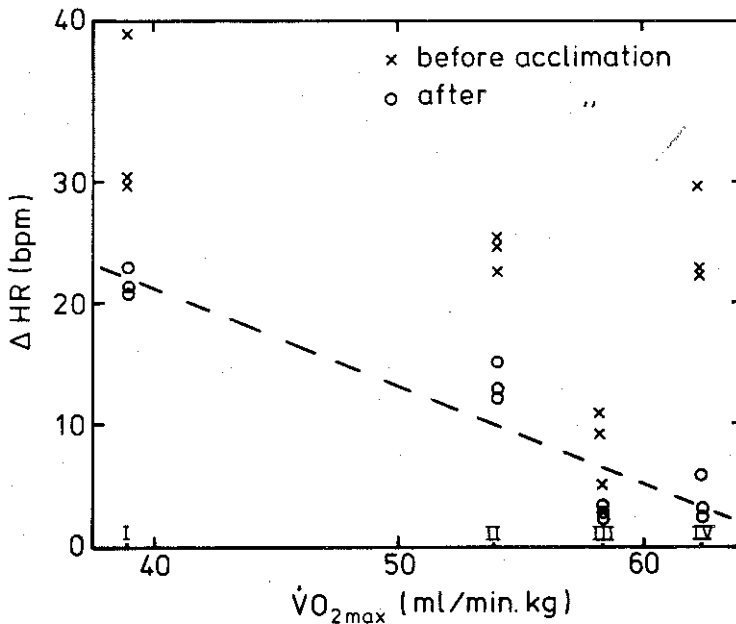


Fig. 11 Individual increase in heart rate due to heat only in relation to fitness levels ( $\dot{V}O_{2max}$  in ml/kg) before and after an acclimation regime.

Regarding anthropometric parameters, (% fat, body surface area, surface to mass ratio) no relation with the observed results has been found.

#### 4 DISCUSSION

The feasibility of the presented heat stress test for the determination of changes in the state of acclimatization has been proven, both for the group as a whole, and for the individual. All involved variables:  $T_{core}$ , heart rate, sweat rate and sweat sensitivity were altered as expected.  $T_{core}$  is reduced ( $.2^{\circ}C$ ) as is heart rate (13 bpm). The sweat rate -  $T_{core}$  relation is shifted to lower  $T_{core}$  (about  $.2^{\circ}C$ ) without clear change in gain. The reductions of  $T_{core}$  and HR are quite low compared to results from other authors, who

observed a .5 (Givonni and Goldman, 1973) to .7°C (Avellini et al., 1982) reduction for  $T_{core}$  and respectively a 25 to 40 bpm reduction of heart rate. The same applies to the shift in the sweat rate -  $T_{core}$  relation for which Roberts (1977) observed a value of .5°C. There are three possible causes for this discrepancy between the here presented and their results:

- 1 The present acclimation procedure (7 days) was shorter than in most other studies (Avellini 10 days, Roberts et al. 10 days).
- 2 The present climate was less stressing (40°C, 20% RH) compared to the others (Givonni + Goldman 49°C, 20% RH; Avellini et al. 49°C, 20% RH and Roberts et al. 35°C, 85% RH).
- 3 The present heat stress test was less stressful compared to others (our test 34°C, 30% RH; Avellini et al. 49°C, 20% RH).

However, qualitatively the results are similar.

The observed absolute values for HR,  $T_{core}$  etc. during the heat stress test are quite low, which may also be attributed to the less stressful heat stress test compared to literature.

The additional increase in heart rate due to the heat load ( $\Delta HR$ ) is, before acclimation, higher than observed by Kamon (1972). Kamon estimates a rise of .5 - 1. bpm in HR for each °C increase in ambient temperature above 25°C. Comparable values from the present test are 1.5 bpm before, and .7 bpm after acclimation. However, Kamon's results are based on 2 subjects only; too few data for a reliable comparison of the tested groups in Kamon's and the present test.

Comparing the individuals ranking order regarding their state of acclimatization a discrepancy between the heart rate reaction to heat and the core temperature and sweat production reaction during heat exposure can be observed. Comparison with literature results is not possible, as other investigations did not focus on the individual under heat strain.

The results suggest that HR during heat stress is determined by a different parameter than core temperature and sweat rate. Comparing a group of female athletes with a group of non athletes, both unac-

climated, Drinkwater et al. (1976) observed only one difference in their reactions to a heat stress test. They found that stroke volume and cardiac output were significantly lower among the non athletic females, which indicates the relation between fitness level and cardiovascular response to heat. In the present results such a relation is suggested by the preacclimation results (Fig. 11) and is clearly present in the "after acclimation" results in terms of extra heart beats due to heat. However, if the heart rate response can be related to the fitness level, then what about the core temperature and sweat rate response. Drinkwater did not observe a relation with fitness. Piwonka (1965) however, observed lower core temperatures for fitter subjects, as if they already were partially acclimated. In the present results, only a low correlation between fitness level and core temperature resp. sweat rate - core temperature relation can be found. This low correlation is not changed by acclimation.

Thus, the presented results still suggest the involvement of three parameters in acclimation. Tcore and sweat sensitivity seem correlated with the acclimatization state only while the heart rate reaction is also correlated to the fitness level. All three of them indicate heat strain, when the subject is subjected to heat stress. The question remains about their relative importance. Further, it should be kept in mind that this experiment involved only 4 subjects, which is far too small for the analysis of the influence of various other factors (weight, % fat etc.), that could be significant.

## 5 CONCLUSIONS

The conclusion to be drawn from this experiment is that the heat stress test as used enables the detection of changes in the acclimatization state through changes in the response of Tcore, heart rate and sweat rate - Tcore relation. The test may be improved by an increase of the heat stress on the subject which should lead to an increase of the test's resolution. The experiment showed that changes in the state of acclimatization are strongly correlated to changes in core temperature, sweat rate and heart rate reactions to heat. Thus, the acclimatization state may be defined in terms of these three parameters, where the cardiac response shows also a high correlation

to the subject's fitness level. For the absolute classification of an individual state of acclimatization, the  $T_{core}$  - sweat relation seems to be the best defined parameter. The change in heart rate due to heat appears to be partially independent of this relation and also important for the determination of the subjects' heat strain. However, to elucidate the relative importance of these two parameters, data on more subjects are needed. This is also the case for the determination of the effect of other parameters (anthropometric values) on the subject's heat strain.

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