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PHYSIOLOGIC REACTIONS DURING FIVE WEEKS OF CONTINUOUS RESIDENCE IN AN ARTIFICIAL HUMID AND HOT CLIMATE

Ulrich Laaser

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302

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16. Abstract
During 5 weeks in a climatic room total sweat during work almost doubled. Initial hour-differences increasingly equalized. There was a displacement of sweat secretion from trunk to extremities till the end of week 3, occurring earlier and more clearly for the arm than for the leg. Work temperatures dropped rapidly and evenly to a constant level by day 11. Circulation behavior matched that of temperature. Pulse rate during work dropped like rectal temperature and pulse rate during rest was phasically like the pattern of corresponding temperatures. Except for the first days urine output was adequate and even, Na decreasing in the urine until week 3, then returning to initial values. Na and K in sweat declined but with opposite patterns for hours 1-4. Total salt elimination decreased. The conclusive phenomena of redistribution occurred within the first 3 weeks. A few functions changed later also. Relatively trivial changes in an otherwise uniform reaction pattern indicated that after 3 or even 5 weeks of acclimatization the process is not over or at least not completely so. The tempo of the process appears to be a function of the degree of loading.

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PHYSIOLOGIC REACTIONS DURING FIVE WEEKS OF CONTINUOUS RESIDENCE IN AN ARTIFICIAL HUMID AND HOT CLIMATE

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Introduction and Statement of the Problem /279*

Investigations of heat acclimatization have been carried out in a natural climate (Adolph, 1947; Adolph and Dill, 1938; Dill et al., 1938; Henschel, 1963; Höfler, 1966; Jungmann, 1962; Lee, 1963; Macpherson, 1960) and in an artificial climate (Eichna et al., 1945; Eichna et al., 1950; Gläser, 1950; Henschel et al., 1943; Horvath, 1946; Ladell, 1951; Robinson et al., 1941; Robinson et al., 1943; Robinson, 1965; Schmoll, 1966; Strydom et al., 1966; Taylor et al., 1943; Wenzel, 1961; Wyndham, 1954; Wyndham et al., 1960). The results obtained under artificial conditions could not always be corroborated under natural tropical climatic conditions (Edholm et al., 1963). Moreover the test conditions are also different: chiefly a fairly high heat load for a few hours in a climatic room as opposed to, on the average, a longer but more persistent load in the natural climate. Until now apparently only Eichna et al. (1945) have carried on unremitting multi-week residence in a climatic room under artificial conditions but reported the results only for the first 12 days. Recently Schmoll (1966) carried out such an experiment in our laboratory. One of the conclusions reached was, that a 3 week observation period is inadequate.

Our own experiment as reported here occupied five weeks and dealt with the following questions:

1. To what degree and at what point in time is acclimatization achieved in case of protracted residence in a hot humid climate?

2. What physiologic magnitudes permit us at the earliest to assert the condition of acclimatization?

3. Is it possible to establish, particularly in reference to sweat secretion, changes that go beyond the familiar simple increase?

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* Numbers in the margin indicate pagination in the foreign text.

Method:

The male test subject (age 25, height 189 cm, weight 80 kg) resided for 35 days, from November 2 to December 6, 1966, in a climatic room (put out by Meisser and Wurst, Stuttgart) measuring 360 cm in length, 230 cm in width and 200 cm in height. /280

The work was done on a bicycle ergometer at 60 rpm and 8 mkp/s. On 10 days previous to the commencement of the actual experiment the identical program of work for four times 40 minutes was executed at normal room temperature. The development of pulse rate during this cold training period is recorded in Figure 6.

During thès principal experiment the DB temperature between 8 a.m. and 6 p.m. ranged from 36.0 to 37.0°C for an average value of 36.5° and the WB temperature lay between 30.0 and 32.5°C for an average value of 31.3°C. Mean relative humidity was 69% with fluctuations between 66 and 73%. Effective temperature was 32.3°C. From 6 p.m. to 7:30 a.m. the climate was set at 31.5°C DB with relative humidity unaltered. On day 34 of the experiment , by raising the DB temperature to a mean of 32.9°C, the relative humidity was increased to up to 77% , so that it would be possible to observe the reaction of the acclimatized organism to this intensification of evaporation conditions.

The following measurements were taken:

pulse rate in rest and in work every five minutes with the photoelectric pulsimeter of E. A. Müller,

blood pressure during the rest period following the second bout of work (auscultatorily with the apparatus put out by ELAG, Cologne),

oral and skin temperature at forehead, chest, dorsal side of the hand and the thigh every 5 minutes with thermocouples (ELLAB, Copenhagen),

sweat rate for each hour (40 min work and 15 minutes rest) from weight loss,

sweat rate for hours 1 and 4 at the forearm and crus by collection of sweat in plastic bags and

local distribution of sweat production after the fourth bout of work using the method of Weiner (1945): plexiglass rings 19.2 cm deep and measuring 55 mm or 40 mm across (inside measurement) were attached with adhesive tape to the following body sites: tonsured occiput, forehead, left cheek, directly over the nipples as well as over the spina iliaca anterior superior, on the shoulder blades and also the dorsal lumbar region, on the left upper arm and forearm each time on the inner and outer side, on the left thigh and leg each time on the inner and outer side.

After drying of the pertinent skin area the capsules were closed with a cotton plug for 6 minutes in designated sequence with parafilm. Following removal of the film the sweat that had accumulated in the interval was collected with a cotton swab previously weighed to within 1 mg and its weight increment was then measured in a second weighing. Before the capsules were closed the skin temperatures in the capsules were determined with a thermoelectric sensor.

While the ergometer work was going on two thirds of the previous hour's water loss was replaced by the drinking of weak tea at body temperature. In addition two sour pickels were eaten during each rest period.

The day's urine output was measured daily before the experiment began and analyzed by flame photometry for sodium and potassium content. These electrolytes were likewise determined in the sweat collected during hours 1 and 4 from the forearm and leg.

Daily schedule: /281

7.30 Climate set to ca. 36.5°C DB and 31.3°C WB
8.00 Measurement of 24 hour urine; breakfast
10.00 Experiment begun with 15 minute rest period in chair
10.15 Weighing
10.20 Work begun
11.00 Work ended, chair rest
11.15 Weighing
11.20 Work begun
12.00 Work ended, chair rest
12.15 Weighing
12.20 Work begun
13.00 Work ended, chair rest
13.15 Weighing
13.20 Work begun
14.00 Work ended
14.10 Measurement of local distribution of sweat secretion
14.30 Weighing followed by warm shower; "midday" rest period
17.00 Standing test
18.00 Climate set to ca. 31.5°C DB, relative humidity unchanged

Results

I. Changes in Sweat Secretion

1. Calculation from weight loss

Sweat production (ml/kg/hr) calculated from weight differences and keeping in mind the amount of fluid intake for the individual work periods was averaged over the 5 days (Figure 1).

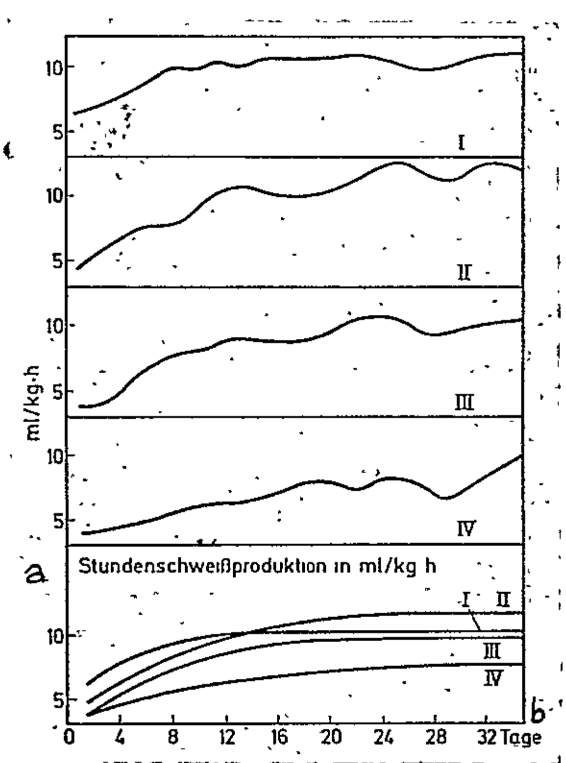

Fig. 1. Temporal course of sweat production for hours 1-4, comprehensively averaged above and below flattened and projected in overlay.
Key: a. hour sweat rate in ml/kg/h
b. days

The functions of all four hours show during the first days an increment phase of varying slope and duration, which then reduces itself — with the exception of hour 4 — to a specific plateau. It is true that hour 1 has at first the highest values by far; however after only 14 days hour 1, after its flatter and only shortlived rise, shows a sweat rate less than that of hour 2 and only slightly higher than that of hour 3. The function of hour 2 mounts much more rapidly and, together with that of hour 3, reaches its level only around day 20.

The values for hour 4, except for the first three days and day 35, are far below those of the previous three hours. For hour 4 the steady climb is particularly steep for the last 6 days and it remains to be seen, whether the values thus finally arrived at would persist, if the experiment went on, or whether they would drop to those of week 4.

The phasic fluctuations, inasmuch as they are expressed more clearly, follow the fluctuations of the room climate.

Sweat rates for day 1 are approximately doubled during the first 5 weeks of the experiment and in the case of hours 2-4 more than doubled. They all wind up around /282
10 ml/kg/hr. In accordance with the literature it may be asserted, that in the course of acclimatization the sweat secretion goes up by 100-200% (Kuno, 1956; Ladell, 1957; Schmoll, 1966). The relationship of the individual hours meanwhile chan-

ges in the direction of mutual accommodation. After about 2 weeks the sweat production of hour 2 becomes greater than that of hour 1 (on days 20 and 30 the maximum is even found in hour 3). Strydom (1966), under somewhat higher climatic stress, achieved an analogous displacement of the maximum to the second hour after only 10 days.

2. The "integral sweat rate"

The columns of Figure 2 give the sum of sweat losses for all four work periods. Their function averaged to cover five values rises from 1450 ml/4 hrs on day 1 to a level of 3125 ml/4 hrs on day 18, an average rise daily of about 100 ml/4 hrs or about 115% in 2.5 weeks. As the time goes on, days 25, 26, 32,34, 35 far exceed the average level in correspondence with fluctuating climatic conditions; days 28 and 31 are far below the average level. 3J /283

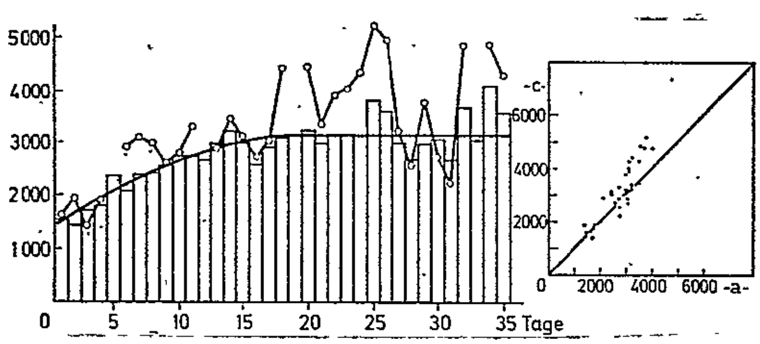

Fig. 2. Temporal course of total sweat production for hours 1-4 from weight losses and capsule values as bases of calculations. On the right correlation of sweat rates obtained.

The "integral sweat rate" plotted as a curve over the columns was calculated from the capsule values keeping in mind the surface sites involved; the latter were designated on the basis of Dubois' data (1915) (head 1251 cm^2, trunk 6710 cm^2, arm and leg 3696 and 8282 cm^2 respectively).

In the direction of its fluctuations the integral four hour sweat rate moves to some degree along with the deviations of the sweat rate determined from weight loss, yet on nearly half of all comparable days it lies clearly above their level and only on 5 days is it below their level. The correlation, likewise presented in Figure 2, shows a good agreement for values up to about 3000 ml but above that the integral sweat rate rises disproportionately.

A clarification is offered by the recent results of Bakri and Ben Jelloun (1968) according to which the sweat production during work reckoned from weight loss is less than during the rest period immediately following, since under more intensified evaporation conditions the excessive formation of unevaporated sweat might be greater during the rest period than during the work bout. However in our experiment the data for calculating the integral sweat rate were gathered exclusively on the resting subject at the time when weight loss was determined for 40 min work and 15 min rest.

The approximate doubling of the sweat rates leads one to pose the question of their effectiveness in the framework of a thermal balance:

A rough estimation of the thermal balance shows, that the quantity of sweat finally produced is about twice that of the evaporated sweat. This finding, which agrees well with model experiments of Kerslake (1963) and observations by Eichna et al. (1945) and Humphreys et al. (1966), is developed in greater detail in a specific work (Ladipoh, 1968). /284

3. Local distribution of sweat secretion

If one combines the capsule values for the individual body regions and does a percentage calculation using the surface sites of Dubois (1915), the result is the curves found in Figure 3, which are an averaging of 5 values.

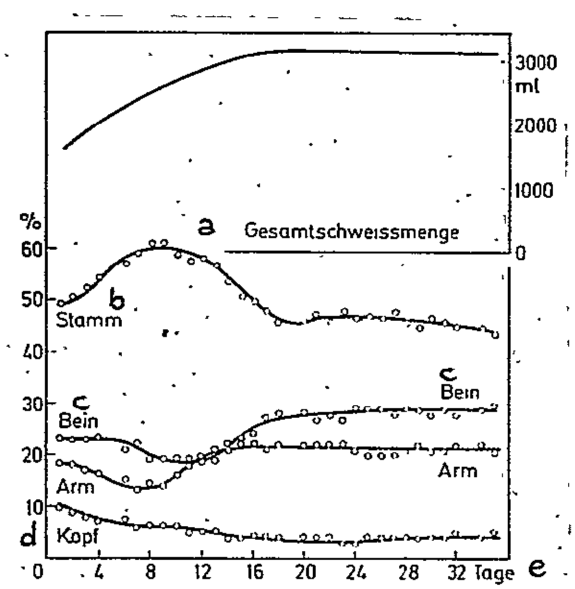

Fig. 3. Temporal course of participation of head, trunk and extremities in total sweat production; temporal course of total sweat output in absolute values plotted above

Key: a. total sweat production
b. trunk
c. leg
d. head
e. days

Very obviously the trunk plays the principal role in the increase of secretion during the first days; its sweat glands react most quickly to the climatic loading and its participation increases to over 60%. In contrast the other regions even show a relative drop and thus have little or no share in the absolute secretion increase of the first two weeks. After transient minima of 13% for the arm and 18% for the leg, the extremities participate — starting with the beginning of the second week — at a higher than initial level and the trunk meanwhile drops below it.

At the end of week 3 the mutual relationships have been stabilized and vary little to the end of the experiment. The situation on day 35 is this: trunk, leg, arm, head in the ratio 44.5, 29.0, 22.0, 4.5; the ratio on day 18 is 46.5, 27.0, 22.0, 3.5 and on day 1 it is 49.0, 22.0, 19.0, 10.0.

About the same temporal course is taken /285 by the quantities of sweat collected in plastic bags from the forearm and leg. They rise absolutely to approximately 4 or 6 times the initial value. Their relative participation increases about 6 times for the arm and about 4 times for the leg.

In summary it may be said, that under continuous heat loading there is an increase in sweat production displacement from trunk to extremities. The fourth week sees these relationships stabilized. Agreeing well with this finding are the published data of Höfler, Schmoll and Voigt (1967) on the decreased participation of trunk and head -- from 72.5% on day 1 down to 61.7% on day 21 -- and a corresponding increase for the participation of the extremities -- from 27.5 to 38.3%.

In principle this signifies the involvement of the bodily parts under especially favorable evaporation conditions (Aschoff, 1956, 1958a, 1958b; Kerslake, 1963). Thus a lesser amount of sweat might have the same cooling effect as a larger amount when there is lesser participation of the extremities.

This mechanism might also explain observations of situations where, during a longterm observation of heat acclimatization, sweat production that had originally increased took a downward turn (Macpherson, 1960).

II. Change in Body Temperatures

1. Rectal temperatures*

The rest rectal temperature falls slowly and in phases similar to those of the integral skin temperature derived from the capsule measurements (Fig. 5a), i.e. from days 1 to 7 in a steeper phase from 37.0 to 36.3°C. It remains at this level till about day 16 and thereafter falls again till it finally reaches 35.7°C on day 24. Then it rises again until day 35 up to 36.0°C, so that from day 20 on one may reckon on an approximate average of 36.0°C.

On the other hand the work rectal temperatures drop much more quickly to an end level, which lies between 37.0 and 37.5°C for work bouts 2-4 (each time rising ca. 0.1°C from hours 2 to 4) and is reached jointly on day 11. Hour 1 follows rather the behavior pattern of the rest rectal temperature. Figure 4 presents an overview of all measurement sites for body temperatures during the 4 bouts of work. In reference to the initial drop in rectal temperature it follows from Figure 4:

a) The intervals separating maximal and minimal values for rectal temperature decrease. For the first 8 days they are 0.9-1.7°C, for the last 5 days they are 0.2-0.8°C.

* Translator's note: "Rectal temperature" (RT) has been used consistently to render the German "core temperature" (Kerntemperatur), fairly infrequent in the English language literature (cf. Robinson et al.).

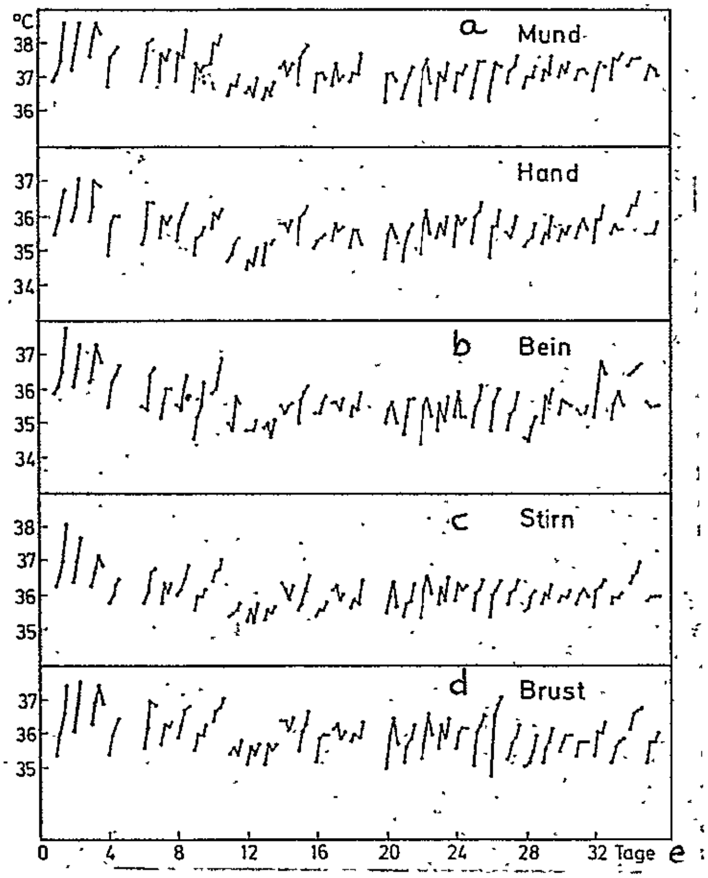

Fig. 4. Temporal course of the various body temperatures during hours 1-4.
Key: a. mouth
b. leg
c. forehead
d. chest
e. days

b) The rise in temperature does not always develop continuously from hours 1 to 4. Particularly after week 2 there are many days on which the values for hour 3 or even hour 2 are highest; in the first two weeks there is only one occasion each week when hour 4 is not highest, whereas thereafter hours 3 or 2 taken together are higher than hour 4 ten times. /286

2. Skin temperatures and their relationship to rectal temperature (Inner temperature gradient IT)

The skin temperature (Figure 4) behaves like the rectal temperature. Theyskin temperatures too have dropped to their end level by day 11; this is somewhat higher for the forehead and chest values than for the extremities (ca. 36.0 in contrast with 35.5). Correspondingly, the values of day 1 for the trunk are also a bit higher than for the extremities. In broad terms one may /287
assign to three phases, in respect to diminution, the body temperatures presented in Figure 4, which are not averaged across the board; each time there are somewhat constant plateaus during these periods: days 1-3, days 4-10 and days 11-35.

The differences between rectal and skin temperatures, therefore the inner temperature gradient, show no decisive change over the entire experimental period. This is in contrast to the results of Schmoll (1966) with a flattening of the inner temperature gradients and those of Eichna et al. (1950) and Höfler (1966) as well as Wyndham (1954) with increased slope. On the average the skin temperatures are about 1.5°C lower than the rectal, at about 36°C.

In connection with hour 4 (Figure 5b) the value for the inner temperature gradient is higher, i.e. around ca. 2°C but it does not remain here unchanged and drops until day 14 to 1.5°C, only to rise once more to 2.6 as compared with 2.25°C at the

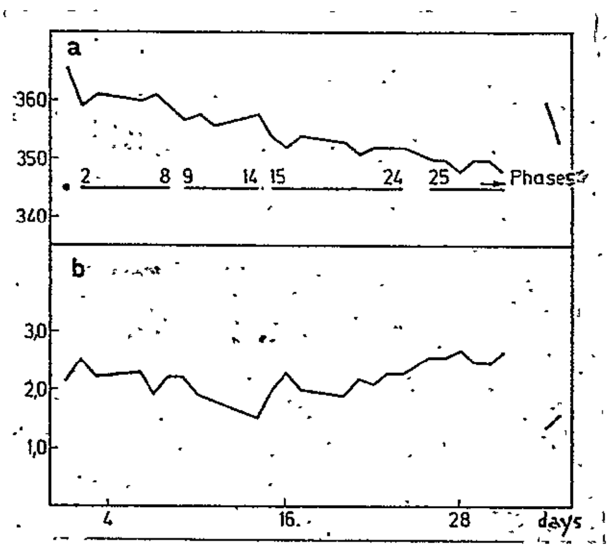

Fig. 5a. Temporal course of integral skin temperature measured with reference to work hour 4. Under the over-all-average curve an attempt is made to compare individual phases

Fig. 5b. Temporal course of inner temperature gradient (IT) between rectal temperature and integral skin temperature in reference to work hour 4

start of the experiment. The new surge results from the steady decline of the integral skin temperature in reference to hour 4 (Figure 5a) with largely constant rectal temperatures.

Figure 5a shows, that between days /288
1 and 35 the integral skin temperature falls by 1.8°C and it does that in phases which agree well when compared with the behavior of the rectal temperature and with the behavior of the body temperatures during the work bouts (Figure 4):

Rectal temperature: days 1-6, 7-16, 17-20, 21-35

Work temperature: days 1-3, 4-10, 11-35.

Integral skin temperature: days 2-8, 9-14, 15-24, 25-35

Schmoll (1966) found phases covering days 1-6, 7-15, 16-21 (end of experiment) for rectal and skin temperatures.

One may thus assume a stepwise decline in body temperatures and its phases are practically identical with weeks 1, 2, 3 and 4-5 of the experiment.

Finally it is clear from Figures 5a and 5b, that day 34 with its high load because of the rise in the integral skin temperature causes a considerable drop in the inner temperature gradient by 1.3°C.

In summary it may be said, that all body temperatures decline — partly in corresponding phases — in approximation with the individual hourly averages. During the work periods the inner temperature gradient remains about the same but in respect to the fourth period it rises toward the end of the experiment.

III. Behavior of Blood Circulation

The temporal behavior of work pulse rates is like that of rectal temperatures. The initial decline terminates also with day 11 at the latest; the earlier hours go down more slowly and reach their end level earlier than the later hours. For all hours this level lies between 105 and 110/min. In no hour were the cold training values — before the experiment began — attained, but the differences are more min-

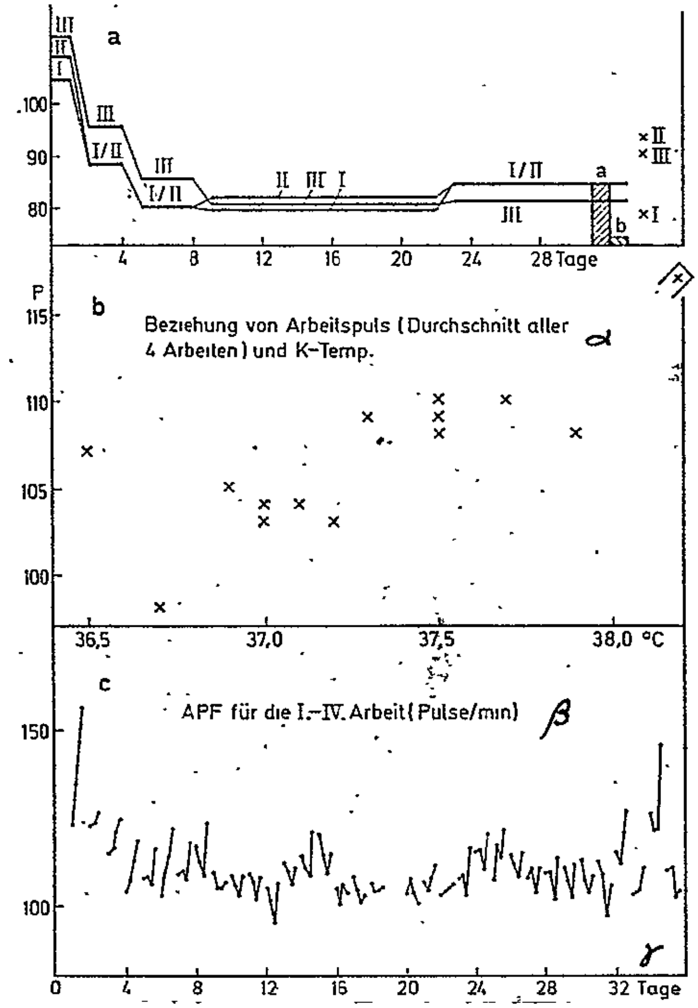

Fig. 6a. Rest pulse rates after work hours 1-3 summarized periodically. Day 34 is presented separately. Columns present mean values of cold training period

Fig. 6b. Correlation of work pulse rates on basis of average of 4 work periods with corresponding rectal temperatures during the first 18 days

Fig. 6c. Temporal course of work pulse rates during hours 1-4

Key: alpha - Relationship of work pulse rate (average of all four work periods) to RT
beta - Work pulse rates for work periods 1-4 (beats/min)
gamma - days

ute (smaller than 10/min).

The course of the rest pulse rate shows the stepwise decline already discussed in the case of the rest rectal temperature: days 1-7, 8-16, 17-35.

The hourly averages of the work pulse rates are summarized in Figure 6c in a manner similar to the presentation of the body temperatures (Figure 4). In accord with the temporal course of the temperatures there appears, after week 1, rather regularly a minimum in hour 3, less often in hours 2 or 4. No matter in what hour they are found, there is a tendency for the intervals between maxima and minima to diminish. The increased pulse rates on day 34 testify to the intensified climatic loading.

The relationship between work pulse rate and rectal temperature exhibits a closer correlation only for the first 18 days (Figure 6b). The correlation pre- /289
sented roughly shows a ratio of 10 beats to 1° rise in temperature. During the last weeks about 31.5 cal/heart beat are transported (calculated from the mean work pulse rate of 107.5/min and surplus heat production of 204 kcal/hr). In its order of magnitude this value agrees /290
with Collins (1966), who assumes 30 cal per heart beat for the first acclimatization phases and 40 for the later ones. The rest pulse rate during the rest periods indicates a behavior pattern that corresponds to the work pulse rates with

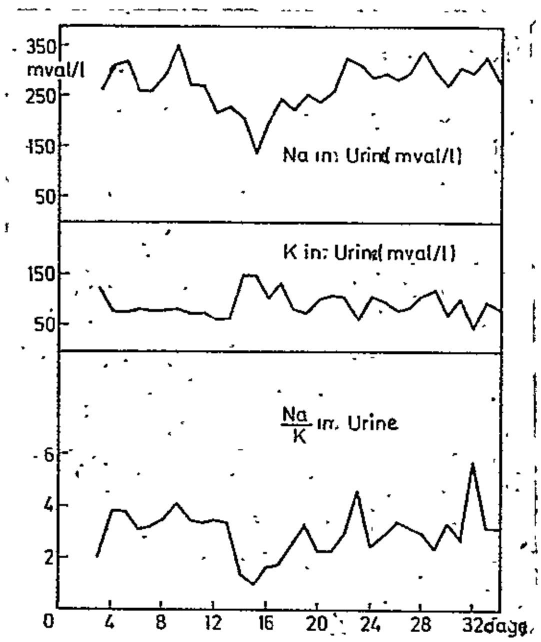

Fig. 7. Temporal course of electrolytes Na and K as also their Na/K quotient in collected urine

a sharp drop-off during the first week (Fig. 6a). The end level is around 85/min, thus in the range of the rest pulse rate during the first phase of cold training.

In summary it may be said, that the behavior of the blood circulation affords almost no new information on adaptation to work in heat that might not be obtained in a more exact and generally simpler fashion through observation of the temperature patterns (Williams, 1967).

IV. Change of Electrolyte Concentration in Sweat and Urine

The electrolyte concentrations found in the collected urine show relatively minute fluctuations (Fig. 7). Na, after setting up a level at 270 mval/l initially, drops during days 11-15 to about 140 mval/l; then during week 3 it returns to the old level. If Na concentration is reckoned by the formula of Locke (cited by Kuno, 1956, p. 228) to the corresponding chloride concentrations ((Cl) = ((Na) - 3)/1.12), the result viewed from the order of magnitude agrees well with the results of the personal experiment of Höfler in Nigeria (1966). There is scarcely a change in K concentration at an overall average of 96 mval/l. The mean Na/K quotient is 2.85. Talbott (1933) offers an explanation of the initial drop in Na or salt elimination during the first 3 weeks: "In the course of the acclimatization process the initially high output of salt in the sweat is followed by a regression of chloride in the urine. This is followed by adaptation of the sweat gland and consequent reduction of chloride in the sweat, which, once the salt deficit of the first days has leveled off, once more produces increased salt elimination." Voigt (1967) however found no change in the urinary electrolytes in 3 weeks. /291

2. Electrolyte concentration in bag sweat

The electrolytes concentrations determined in the bag sweat collected from the arm and leg during the first and last hour decline exponentially over the total experiment period. Meanwhile the Na concentrations drop during a first phase to about day 15 rather sharply (from values around 140 mval/l to values around 70 mval/l) and finally show almost no change at all. However the Na concentration of the first hour seems to rise a little.

The decline of K concentrations is more gradual and terminates on day 22 at the earliest. The concentrations in the sweat from the leg are almost uniformly greater than those from the arm: toward the end of the experiment the plateau values are around 14.4 mval/l (as against about 11.3), the initial values around 45 mval/l (as against about 25).

For any given day the Na concentrations for hour 4 are always higher than those for hour 1. For K the hour-relationship is rather the reverse but less distinct.

The mutual relationship ofthe two electrolytes changes during the experiment in the direction of an increase in the Na/K quotient. On a given day the quotient for hour 4 is generally higher than for hour 1.

3. Discussion of electrolyte changes in bag sweat

The literature is unanimous in stating, that in cases of protracted sweat secretion there is a rise in the chloride concentrations contained in the sweat (or the Na concentrations to be converted according to Locke (cited by Kuno, 1956, p. 228))(Dill, 1966; Kuno, 1956; Ladell, 1945a). This agrees likewise with the development of hours 1-4 in this experiment and might be based on diminishing aldosterone activity /292 due to rather extended demands made on the adrenal cortex (Conn, 1949; Furman, 1963; Ladell, 1957).

According to Fukuda and Kawahat (both cited by Kuno, 1956) the K concentration, in contrast to the behavior of Na, diminishes with prolonged sweat secretion. Correspondingly in our experiment the concentrations are not higher during the fourth hour but rather lower than during the first. Kuno (1956) explains the behavior of K as due to flushing of the sweat gland cells when sweating begins. Later the K is probably replaced in part by Na. However there may be the same or additional involvement of the mechanism discussed above in respect to Na.

It is controversial to what extent the higher chloride concentrations associated with increasing sweat rate are also connected, directly or indirectly, with the generally rising skin or rectal temperatures. Epperlein (1964) along with Cramer (1890), Johnson et al. (1944), Kittsteiner (1911 and 1913), Kittsteiner et al. (1939), Robinson (1949), Robinson et al. (1949a) and Weiner et al. (1952b) cites authors who favor at least a connection with skin temperatures. Dill (1966) and Masui (cited by Kuno, 1956) reject such a connection. Our test results do not permit us to take a univocal position: for one thing the increment in sweat rate and decrement is Na concentration follow about the same temporal course; again, the Na concentration increases with

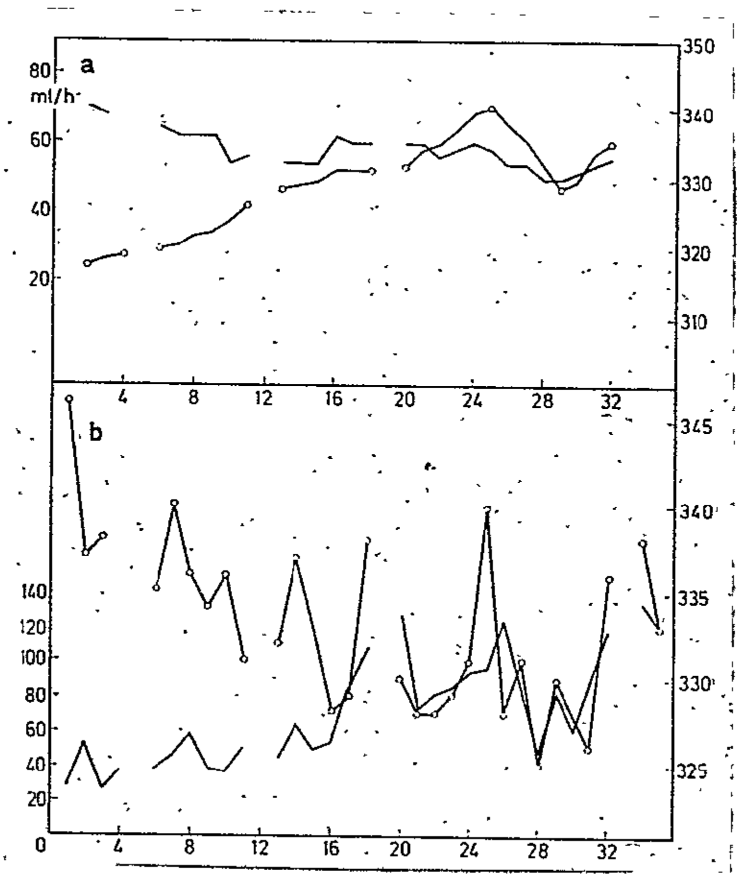

Fig. 8a. Temporal course of sweat secretion and skin temperatures of the forearm in respect to hour 4, overall average

Fig. 8b. Temporal course of sweat secretion and skin temperatures of the leg in respect to hour 4, not averaged

continuous sweat secretion in the course of the 4 hours work each day; furthermore, on day 16, when there is an intermittent very low total sweat production, the Na concentrations are likewise very low, while the skin temperatures have scarcely changed.

If we assume with Ladell (1948) and Kuno (1956), that the mean Na concentration in sweat from the extremities is fairly representative for the Na content of total body sweat, a calculation can be made of total Na elimination in hours 1 and 4. In this case no difference is observed between hours 1 and 4.

Assuming a mean Na concentration in the sweat for hour 4 of 1.6 g/l at the outset of the experiment and 1.0 g/l toward the end, an estimate is possible for the drop in total salt elimination during the 5 weeks of the experiment: positing a daily sweat production of 6l the decline was from about 25 g/day to about 15 g/day. However in the report of Schmoll (1966) daily salt intake with nourishment is given as 13-17 g. Thus there might have been a slight deficit of salt in the early period. Na elimination in the urine also dropped until week 3 and only on day 22 did it reach its former level. There were also mild heat cramps after the last work bout of day 2.

V. Relationship between Body Temperature and Sweat Formation /293

1. Skin temperature and sweat formation

A relatively simple relationship may be set up between local skin temperature and local sweat formation. These magnitudes are presented in Figure 8 for the forearm (overall average of 5 values) and the leg (not averaged). (For method see p. 2).

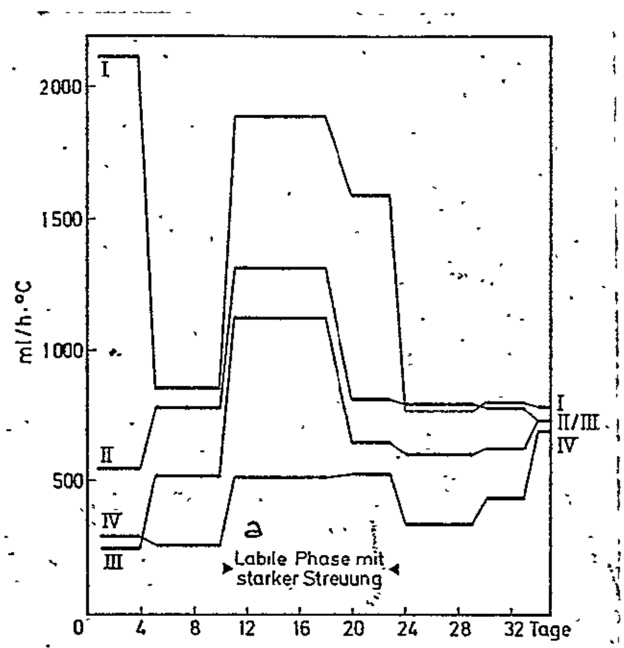

Fig. 9. Temporal course of sweat response (acc. to Ladell) for work hours 1-4, periodic summary
Key: a. labile phase with much scattering

In both extremities two phases with contrasting interconnection of skin temperature and sweat rate may be clearly distinguished. In the first 2 weeks skin temperature drops as sweat rate rises. In the following 3 weeks their course is parallel and the sweat rate /294 is higher as the skin temperature is higher. The first phase of this ratio was also noted in the 3-week experiment of Schmoll (1966).

2. Rectal temperature and sweat rate

In the course of acclimatization a tendency was shown both by the sweat rate (Fig. 1) and the rectal temperature (Fig. 4) toward a lessening of the differences between the four work bouts. Now what relationships can be established between these two values?

Figure 9 presents a relationship between the hourly sweat rate and the rise in rectal temperature during the same given hour. The values were periodically combined on account of the unusually high scattering of individual values in the middle phase. During the first days this so-called "sweat response" (Ladell, 1957) declines sharply from hour 1 to the following hours; later a more even descent sets in, even though differences between individual hours continue to be considerable. Beginning with day 24, hours 1 and 2 are similar. Only on the last two days are sweat response values for all hours the same -- about 750 ml per hourly °C.

The temporary significant elevation of the sweat response during week 3 points /295 to the special position of this time period in the acclimatization process. In the third week the total sweat rate, the work temperatures and the blood circulation values have attained their end level and at the same time the ratio between skin temperature and sweat formation (Fig. 8) is reversed. However the acclimatization process is not yet complete. It is only at the end of week 3 that local distribution of sweat secretion (Fig. 3). Temporal redistribution in the direction of a reciprocal approximation of sweat rate and sweat response for the individual hours still goes on. Only in week 3 at the end of the fourth work bout (Fig. 5b) does the inner temperature gradient begin to rise following an initial decline. In week 3 there is a

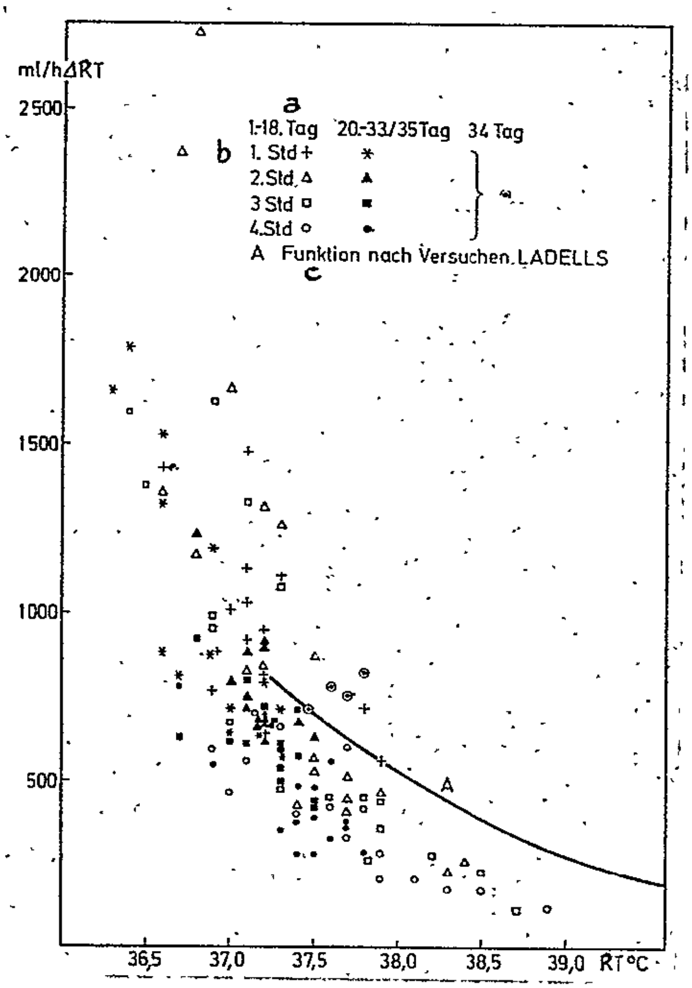

Fig. 10. Sweat response for individual work hours (ordinate) in relation to the pertinent rectal temperature (abscissa). Period from days 1-18 marked by lighter, days 20-35 by darker symbols. Day 34 with its modified test conditions is presented separately. Function A from results of Ladell (1957)

Key: a. day
b. hour
c. function acc. to Ladell's experiment

temporary sharp decline in the Na/K quotient for urine and sweat (Fig. 7). In contrast to the relatively simple picture of the first 2 weeks, the events of week 3 can be put into a total picture only with difficulty. Jungmann (1962) speaks of an adaptation crisis in week 3, which he also affirms for residence at high elevations.

3. Sweat response and RT

The highly scattered sweat responsee values connected with the temporal course are easily put in order, if they are plotted against the appropriate rectal temperature value using the procedure of Ladell (curve A in Figure 10).

The temporal distribution of these values is shown in Figure 11 by a combination of periods 1-18 and 20-35. From this representation the following may be gathered:

a) On the average the values for the second half of the experiment are in lower areas than initially.

b) The intervals between the individual hours have shrunk both in respect to rectal temperature and in respect to sweat response.

c) An extrapolation beyond week 5 of the experiment of the path taken by the critical points for each hour leads to points of intersection in a very restricted field at 36.8°C and 500 ml/hrΔRT.

d) The load increase of day 34 produces acclimatization regression and of course further levelling of the differences between the work periods. All the individual critical points cluster around the value designated as D in Figure 11.

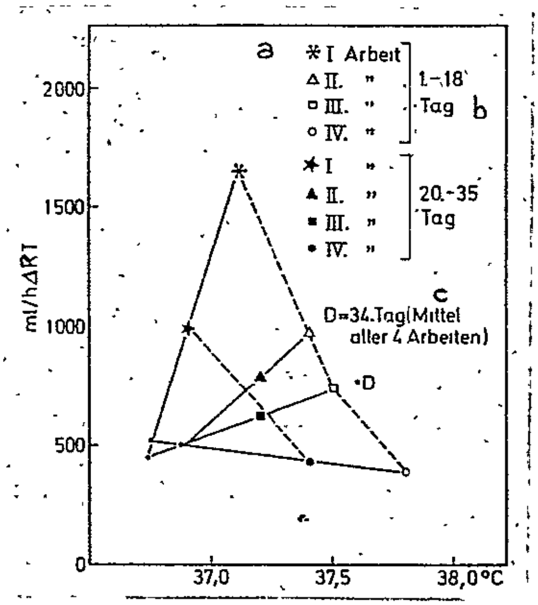

Fig. 11. Sweat response averages for first and second half of experiment in relation to appropriate RT (calculated from data of Fig. 10). As in that figure, day 34 presented separately. Connecting lines for corresponding critical points of hours in periods 1 and 2 are projected to field of intersection where they delimit a conceivable area of maximal acclimatization

Key: a. work period
b. day
c. (average of all four work periods)

The field of intersection of the lines of projection would, in case the acclimtization process actually developed in this direction, represent its definite termination, since with a relatively small sweat output the rise in /296 temperature during the work program is only minimal. This direction is already indicated by the decrease in sweat formation found by Macpherson (1960), and Schmoll (1966) and the only smaller increase of work rectal temperatures for work periods 1-4 found in this experiment. The question is still open as to whether the /297 values of 500 ml/hrΔRT at 36.8°C obtained here are likewise valid for other experimental setups or if they can also be realized under natural conditions provided their is no interference from malnutrition or deficient training (Lehmann, 1965).

4. Degree of loading and RT

Furthermore it may be shown from Figure 12 that even under varying load there is a quantitatively similar development, which runs an only temporarily slower or faster course for each case of climatic loading or loading due to work performance. In order to clarify this dependence of acclimatization rate, the experiments of Höfler (1966), Schmoll (1966) and Strydom et al. (1966) in respect to the temporal decline of work RT were compared with the results obtained in this experiment. The variable degree of loading was calculated, using the "predicted 4-hour sweat rate" (McArdle, 1947), from the climatic data and the values indicated for the pertinent work performance.

	Höfler	Schmoll	Laasser	Strydom	
P_4SR	0.10	0.80	1.40	1.80	(liter)

The definitive decline in rectal temperature in all experiments is about 1°C and is reached at ever shorter intervals as loading increases. /298

A corresponding dependence of successful acclimatization on the amount of loading was already found by Eichna (1945); in the case of a 5-day period of residence

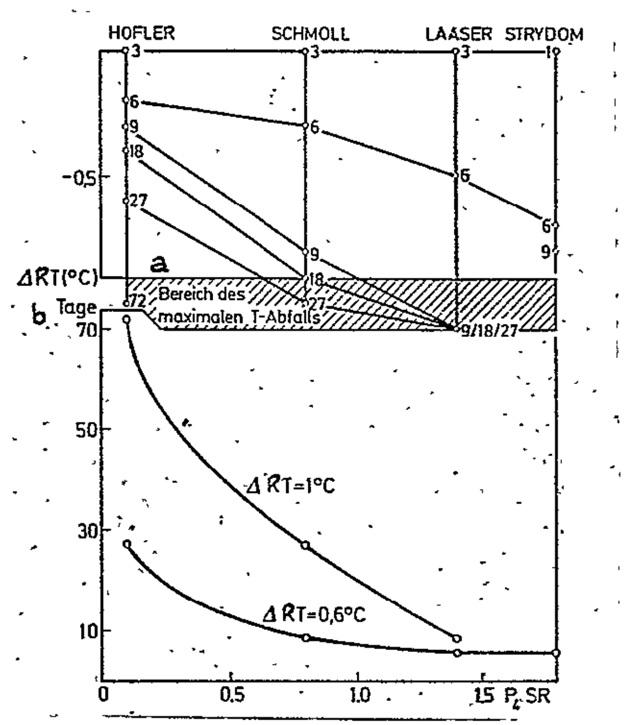

Fig. 12. Drop in RT with acclimatization to hot work as a temporal function of degree of loading in various authors. Above: temperature fall on days 6, 9, 18 and 27 (as well as 72) compared with day 3 and day 1. Below: temperature drop of 0.6 and 1.0°C always occurs earlier with higher degree of loading. Predicted four-hour sweat rate (P_4SR acc. to McArdle et al., 1947) used as index of degree of loading

Key: a. area of maximal drop in temperature
b. days

in a climatic room no changes or else very minute ones were found in rectal temperatures and heart rate as opposed to a clear decrease when work loading was continuous. Under natural conditions Jungmann (1962) ascertained incompete acclimatization even after 2.5 months; the climatic loading and work loading were relatively small and discontinuous. The attempt to establish a similar relationship with the amount of loading for the development of pulse rates produced no usable results that /299
would agree with the findings of E. A. Müller et al. (1961), that there is a great variation in the interdependency of heart rate and amount of work in individuals and the results of Kranning et al. (1966), that probably the rectal temperature, but not the pulse rate and cardiac volume, may be predicted from sweat production during heat or work loading.

Summary

In the course of a five week residence in a climatic room total sweat secretion during work practically doubled. The initial differences between the individual hours became increasingly equalized (temporal redistribution). Furthermore there resulted a secretion redistribution in the direction of a displacement from trunk to extremities (local redistribution), which terminated about the end of the third week. This displacement was earlier and relatively easier to notice for the arm than for the leg.

As differences between individual hours decreased work temperatures dropped rather rapidly and uniformly to a fairly constant end level by day 11.

The behavior of the blood circulation matches that of the temperatures. Pulse

rate during work, like rectal temperature during work, drops during the first 10 days to a constant end level, which is only slightly higher than the values obtained during cold training. The behavior of the pulse rate during rest is phasically like that of the corresponding temperatures.

Outside of the first days, urine output was adequate and even. Na in the urine decreases until week 3 of the experiment, probably due to a salt deficit, but then returns to initial values.

Over the experimental period the Na and K concentrations in the sweat decline. However from hour 1 to hour 4 the Na concentration increases, whereas the K concentration declines. Total salt elimination decreases in the course of the acclimatization process.

Incidentally the conclusive results of Schmöll's work (1966) are confirmed, i.e. the increase of sweat production, its local redistribution, the partially phasic decrease in body temperatures and pulse rates as well as the more rapid improvement in heat loss during work periods as opposed to rest periods.

According to our test results the conclusive phenomena of redistribution occur within the first 3 weeks. Only a few functions undergo change later as well:

a) The integral skin temperature (Fig. 5a) and associated with it the inner /300
temperature gradient at the end of hour 4 in the direction of a renewed rise (Fig. 5b) of the inner temperature gradient.

b) Sweat secretion in the fourth hour in the form of increased approximation to hours 1 to 3.

These relatively inconsequential changes in an otherwise uniform reaction pattern indicate, just as does the behavior of the sweat response (Fig. 11), that after 3 or even after 5 weeks the acclimatization process is not over or at least not completely so.

The tempo of the acclimatization process appears to be a function of the degree of total loading.

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