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Scheduling Cycles of Work for Hot Ambient Conditions

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Schedules of working and resting periods were designed separately for work at 40% $\dot{V}_{O_{2max}}$ and for work at 60% $\dot{V}_{O_{2max}}$ each under the two following ambient conditions: (a) warm-humid, T_{db} 36°C, T_{wb} 31°C and; (b) hot-dry, T_{db} 50°C, T_{wb} 25°C. Two conditions were provided for the resting period: (1) under the same ambient conditions as for the working conditions; (2) under neutral ambient conditions of T_{db} 23°C, T_{wb} 16°C. The working periods were determined by the total sum of the expected work specific heart rate (HR) and the expected heat induced increments in HR. The total sum of the HR was treated in terms of its equivalence to the fraction of $\dot{V}_{O_{2max}}$, based on the linear relationship between the two parameters. The limiting factor was taken to be the lower end of the 95th percentile maximal HR for the population of the 20-30 yr old participants. Six heat acclimatized male subjects participated in testing the adequacy of the design of the work and rest periods. The schedule of work and rest periods were 20 min for each session of work at 40% $\dot{V}_{O_{2max}}$ and, 10 min and 20 min respectively for the session of work at 60% $\dot{V}_{O_{2max}}$. A session at each work level included four to five cycles of work and rest. The results showed that based on the levelling off of HR and rectal temperature (T_{re}), and setting the limit of T_{re} rise to 38°C, the work and rest periods were adequate for the hot-dry ambient conditions irrespective of the resting area, but were adequate for the warm-humid conditions only when the resting periods were under the neutral ambient conditions.

1. Introduction

Ergonomists often are asked to advise on the design of work cycles for strenuous conditions, as for example, when physically demanding tasks are performed under hot ambient conditions. Work and rest cycles, as a safe practice measure for work under hot environments, could be based on the expected cardiovascular and bodily thermal responses, as demonstrated in the following two examples. 1. The observed changes in the heart rate (HR) during cyclic work under warm-humid and hot-dry ambient conditions lead to the design of work cycles according to the recovery rate of the HR (Brouha 1960); the resting periods should allow a drop in HR to below 110 beats min^{-1} . 2. An international group of physiologists (WHO, 1969), advised that prolonged daily occupational exposures to heat should not include a rise in core body temperature beyond a level normally produced by the work *per se* under thermally neutral environments. Presumably a body temperature limit of 38°C was considered safe for the activities involved in regular industrial tasks. These general suggestions were short of an exact design of the working or the resting periods.

Allowable working periods were best correlated with strain in terms of the oxygen uptake (\dot{V}_{O_2}) as a fraction of the maximal aerobic capacity ($\dot{V}_{O_{2max}}$). Thus, the closer the metabolic demand of the work was to $\dot{V}_{O_{2max}}$, the shorter was the allowable working period (Astrand and Rodahl 1970). An example for the allowable working time as a function of the relative metabolic cost (\dot{V}_{O_2} as a fraction of $\dot{V}_{O_{2max}}$) was given by Bonjer (1971), and an example for the rest requirements as a function of the relative strain of the work was given by Rohmert (1973). These examples showed exponential relationships; as the work load increased, the work endurance time decreased exponentially, but the rest requirement increased exponentially. The strain, due to the

workload, could be defined by the relative metabolic cost (\dot{V}_{O_2} as a fraction of $\dot{V}_{O_{2max}}$; $f\dot{V}_{O_{2max}}$), or by its close correlate, the HR.

Since the limit to physical work seems to be the capacity of the cardiovascular system to meet the oxygen demands of the muscles (Rowell 1974), HR can be used as a strain indicator. Similar to \dot{V}_{O_2} , HR is limited by the maximal attainable HR. The submaximal HR is linearly correlated with $f\dot{V}_{O_{2max}}$. This correlation and the expected HR_{max} were recently used to define the strain of forestry work (Tomlinson and Manenica 1977). The use of HR as a strain indicator could also be useful when hot ambient conditions are involved. Heat stress increases the HR because of the increase in skin blood flow for heat dissipation. The practical use of the separation between the work specific HR and heat induced HR were shown by Vogt *et al.* (1973). The heat induced increments in HR above the work specific HR reduces the reserve capacity of the heart in proportion to its proximity to the HR_{max} . Therefore, the cumulative strain due to both muscular work and heat exposure, treated in the relative terms of the proximity to the maximal attainable value could be used to design cyclic work under hot ambient conditions.

The present investigation was undertaken in order to: (a) design work cycles on the basis of the expected increments in HR due to the combined effect of muscular work and heat stress, and; (b) to experimentally validate the design of the cyclic work on heat acclimatized subjects.

2. Rationale

2.1. Heart Rate Correlations

The design of the working periods was based on the following linear correlations: (a) under temperate ambient conditions the linear relationship between HR and $f\dot{V}_{O_{2max}}$ could be assumed to be within the range of about 130 beats min^{-1} at 0.5 $\dot{V}_{O_{2max}}$, and HR_{max} at 1 $\dot{V}_{O_{2max}}$; (b) heat induced increments in HR above the work specific HR are expected to be in the magnitude of 1 beat min^{-1} per 1°C of air temperature above 25°C, for dry ambient conditions (Kamon and Belding 1971a). These relationships were applied to the formulation of the work periods along the following reasoning. Assuming the HR_{max} equals 220 minus one beat per year for age; $HR_{max} = 220 - \text{Age}$ (American Heart Association 1972, adopted from the Scandinavian Committee on ECG Classifications 1967), and using the mean and standard deviation of HR_{max} from observations by others (*e.g.* Astrand 1960), the expected HR_{max} and standard deviation for our subjects (age 20–30 yrs) was 195 ± 7 beats min^{-1} . The lower end of the 95 percentile, that is HR_{max} of 180 beats min^{-1} was used as a safety margin. This meant that in terms of the above mentioned linear correlation the applicable regression was

$$\frac{\dot{V}_{O_{2max}} - 0.5 \dot{V}_{O_{2max}}}{(180 - 130) \text{ beats } \text{min}^{-1}},$$

or a slope of 0.01 $\dot{V}_{O_{2max}}$ per 1 beat min^{-1} .

The slope 0.01 $\dot{V}_{O_{2max}}/1$ beat min^{-1} was used to correlate the heat induced increments in HR with an equivalent value in terms of $f\dot{V}_{O_{2max}}$. In other words, the criteria for strain consisted of the total summation of the work specific $f\dot{V}_{O_{2max}}$ and the $f\dot{V}_{O_{2max}}$ equivalence of the heat induced increments in HR. This could be best illustrated with the values used in this study. One series of tests involved work load at 0.40 $\dot{V}_{O_{2max}}$ and hot-dry ambient conditions of T_{db} 50°C. From the above mentioned

correlation between HR and air temperature the expected heat induced increment in HR was 25 beat min^{-1} . In terms of $f \dot{V}_{O_{2\max}}$ this was equivalent to $0.25 \dot{V}_{O_{2\max}}$. Thus the strain of work at $0.40 \dot{V}_{O_{2\max}}$ under T_{db} of 50°C was taken to be equivalent to work at $0.65 \dot{V}_{O_{2\max}}$. Similarly, in the other series of this study which involved work at $0.60 \dot{V}_{O_{2\max}}$ under dry heat of T_{db} 50°C , the strain was considered to be equivalent to work at $0.85 \dot{V}_{O_{2\max}}$.

2.2. Design of Work Cycles

The information from other investigations on the endurance time to exhaustion for continuous and for intermittent work (Gleser and Vogel 1971, 1973, Detry *et al.* 1972), was used to quantify the endurance time for different work levels. The endurance time to exhaustion was inversely related to $f \dot{V}_{O_{2\max}}$ similar to the description given by Astrand and Rodahl (1970), and by Bonjer (1971) for individuals who are not specifically fit. Since defensive health and safety standards call for prevention of exhaustion, some of the reports on the shortening of work/rest cycles, which provided some answers to the optimal working period for heavy work loads, were consulted (Astrand *et al.* 1960, Simonson 1971). It could be inferred from these reports that working periods of one third of the time to exhaustion could be regarded as safe in maintaining prolonged work without undue fatigue. Consequently we derived the following formula for allowable working time (T_w):

$$T_w = 40 \div (f \dot{V}_{O_{2\max}}) - 39$$

Where T_w is in minutes and $f \dot{V}_{O_{2\max}}$ is the fraction of the $\dot{V}_{O_{2\max}}$ demanded by the task performed.

This formula was used to derive the working period from the HR strain equivalence in terms of $f \dot{V}_{O_{2\max}}$ for the work under the hot-dry ambient conditions. The derived working periods were 22.5 min and 8.1 min for the $0.65 \dot{V}_{O_{2\max}}$ and the $0.85 \dot{V}_{O_{2\max}}$ respectively. Since in practice, work-rest cycles call for a rotational system, the work and rest periods should not unduly overlap for a given number of workers. Therefore, the derived working periods were rounded to 20 min and 10 min for the strain equivalence of $0.65 \dot{V}_{O_{2\max}}$ and $0.85 \dot{V}_{O_{2\max}}$ respectively. The resting periods were adjusted to allow rotation between two workers for the $0.65 \dot{V}_{O_{2\max}}$ and between three workers for the $0.85 \dot{V}_{O_{2\max}}$. Thus, work at the $0.40 \dot{V}_{O_{2\max}}$ with a strain equivalence of $0.65 \dot{V}_{O_{2\max}}$ the work-rest cycles were equal; 20 min each, and work at the $0.60 \dot{V}_{O_{2\max}}$ with a strain equivalence of $0.85 \dot{V}_{O_{2\max}}$ the resting periods were twice the working periods; 20 min and 10 min respectively.

The same working and resting periods were designed for the work under the warm-humid ambient conditions for the following reason. When the limiting factor is humidity, a continuous increase in HR was expected at a rate of about 1 beat min^{-1} for each minute of work at $0.40 \dot{V}_{O_{2\max}}$ and about 2 beats min^{-1} for each minute of work at $0.60 \dot{V}_{O_{2\max}}$. In 20 min work in the first case and in 10 min work in the second, the end value HR presumably would be about $20 \text{ beats min}^{-1}$ above the work specific HR (Kamon and Belding 1971b). Therefore, the strain was expected to be similar to the strain for the same work loads under the hot-dry ambient conditions.

3. Methods

3.1. Subjects

Six male college students participated in this study. Their physical characteristics are summarized in table 1. The study comprised two series of tests, divided by the

Table 1. Anthropometric data, and the metabolic cost of the work in watts (W) and as a function of the maximal aerobic capacity ($f\dot{V}_{O_{2max}}$) of the subjects

Subj.	Age (yrs)	Weight (kg)	Height (cm)	S.A. (m ²)	Metabolic Work Levels			
					(W)	($f\dot{V}_{O_{2max}}$)	(W)	($f\dot{V}_{O_{2max}}$)
1	29	49.4	160	1.49	325	0.45	—	—
2	22	67.3	180	1.85	394	0.37	—	—
3	22	68.1	178	1.84	615	0.42	706	0.63
4	21	66.5	176	1.82	418	0.37	817	0.56
5	24	72.7	180	1.92	—	—	842	0.61
6	20	65.0	180	1.83	—	—	825	0.65

work load; 0.40 $\dot{V}_{O_{2max}}$ and 0.60 $\dot{V}_{O_{2max}}$. Four subjects were assigned to each of the two series of tests thus, two of the six participated in the two series of tests while each of the other four subjects participated in one series only (table 1).

After an informed consent was obtained, each subject passed physical examinations and successfully completed progressive treadmill stress tests to exhaustion. Exercise cardiograms and maximal O₂ uptake ($\dot{V}_{O_{2max}}$) were obtained during the stress tests which were supervised by a physician.

3.2. Measurements

Rectal temperature (T_{re}) was measured by a thermistor inserted 10 cm beyond the anal sphincter. Mean skin temperature (\bar{T}_{se}) was calculated as the unweighted average of six skin temperatures measured with uncovered, copper-constantan thermocouples located on the forehead, chest, back, forearm and both thighs. The output from the thermistor and the thermocouples were recorded continuously throughout the test period. Heart rate (HR) obtained from an electrocardiogram, was taken every 5 min. Oxygen uptake (\dot{V}_{O_2}) was determined by the open circuit method. Expired air, collected through a low resistance valve into a Douglas bag, was analyzed for O₂ and CO₂ content with a *Beckman E2 paramagnetic analyzer* and a *MSA Lira Infrared Meter* respectively. Volume was measured with a *Parkinson Cowan dry gas meter*.

Total sweat production (S) was calculated as the change in nude body weight, measured before and after the experimental session, and corrected for water intake. Evaporation rate (E_v), measured at the end of each period was determined by the change in total body weight, corrected for water intake. No corrections were made for respiratory evaporation or metabolic gas exchange weight loss.

3.3. Clothing

This included a T-shirt and shorts, long sleeve cotton shirt, khaki trousers, tennis shoes and socks.

3.4. Work

Work was performed on a treadmill, the walking speeds were individually adjusted in order to obtain work levels at either 0.40 $\dot{V}_{O_{2max}}$ or 0.60 $\dot{V}_{O_{2max}}$. The periods of working and resting were: 20 min each for the tests at 0.40 $\dot{V}_{O_{2max}}$ and respectively 10 min and 20 min for the tests at 0.60 $\dot{V}_{O_{2max}}$.

3.5. Ambient Conditions

There were pre-set in a heat controlled room. The combination of the dry bulb and wet bulb temperatures for each of the two hot ambient conditions and for the cool outside resting area are summarized in table 2. The warm-humid conditions are noted

Table 2. The mean dry bulb (T_{db}) and wet bulb (T_{wb}) temperatures for the working and resting periods

Notation	Description		Ambient Conditions*			
			Work Period		Rest Period	
	Ambiance	Period	T_{db} °C	T_{wb} °C	T_{db} °C	T_{wb} °C
WH-1	Warm-Humid	Working	36	31		
	Warm-Humid	Resting			36	31
WH-2	Warm-Humid	Working	36	31		
	Neutral	Resting			23	16
HD-1	Hot-Dry	Working	50	25		
	Hot-Dry	Resting			50	25
HD-2	Hot-Dry	Working	50	25		
	Neutral	Resting			23	16
C	Control	Working	23	16		
		Resting			23	16

* Temperatures were within a standard deviation of 1°C. Mean air movement was 1 m s⁻¹ in the heated room and 0.18 m s⁻¹ in the cooler resting room.

as WH, and were numbered according to the resting conditions used; WH-1 for work and rest under the warm-humid conditions and WH-2 for work under the warm-humid conditions and rest under the cool neutral conditions. Similarly, the hot-dry conditions are noted as HD-1 for resting under the same hot-dry conditions as the working, or HD-2 for resting under the cooler neutral conditions.

3.6. Heat Exchange

Heat equivalent of sweat was calculated using 0.67 Wh g⁻¹ as latent heat. Dry heat exchange ($R + C$) was calculated using the equation $(R + C) = h_0(T_0 - \bar{T}_s)$ where, $h_0 = 8 \text{ W m}^{-2} \text{ °C}^{-1}$, derived according to Kerslake (1972) for nude men and corrected by a factor of 0.65 for clothing as suggested by Hertig and Belding (1963). The operative temperature (T_0) was equal to T_{db} since no radiant heat existed; the measured globe temperature was within 0.5°C of the T_{db} . The ambient evaporative capacity (E_{max}) was calculated as $E_{max} = h_e(P_s - P_a)$, where: $h_e = 92 \text{ W m}^{-2} \text{ kPa}^{-1}$, derived according to Kerslake (1972) and corrected for clothing (Hertig and Belding 1963); P_s and P_a , the saturated skin vapour pressure and air vapour pressure respectively.

Metabolic heat production was derived from the measured \dot{V}_{O_2} , where a steady state \dot{V}_{O_2} of 1 l min⁻¹ was equivalent to 348 W. The required evaporation (total heat load): $E_{req} = M + R + C$, was calculated in units of W m⁻².

3.7. Heat Acclimatization

Prior to the experimental session each subject was heat acclimatized by daily, two hour exposures to T_{db} 50°C, T_{wb} 25°C, for four consecutive days and 2–3 days of exposure to T_{db} 36°C, T_{wb} 31°C. The exposures included level treadmill walking requiring 0.3 $\dot{V}_{O_{2max}}$. Full acclimatization was determined by the reduction and levelling off in T_{re} and HR, and by the improved tolerance time.

3.8. Procedures

Upon arrival at the laboratory the subject rested while sitting for 20–30 min and then prepared himself. He measured his nude weight, inserted the rectal probe, and with the help of the experimenter attached to his skin the chest electrodes for the electrocardiograph and the thermocouples for temperature reading. The subject then donned the experimental clothing and entered the heated room where total weight

was measured and within five minutes after entry he started the first working period on the treadmill. Following the working period body weight was immediately measured and then the subject rested sitting either inside or outside the heated room (see table 2). Weight was again measured before the onset of the working period of the next cycle.

Water drinking was permitted *ad libitum*. Two minutes expired air sample was taken every other day during one working and one resting period between the 5th and 10th minute. Upon conclusion of the final resting period the subject was weighed and then quickly undressed for a final nude weight.

4. Results

4.1. Heart Rates (HR) and Rectal Temperature (T_{re})

The rise in T_{re} and the increments in HR are considered to be the most apparent criteria for physiological strain. Therefore, the changes in T_{re} and HR are described in some detail.

4.2. Control Observations

The T_{re} and HR responses to the cyclic work at $0.40 \dot{V}_{O_{2max}}$ and at $0.60 \dot{V}_{O_{2max}}$, under the non-stressing ambient conditions were shown in figure 1. It can be seen

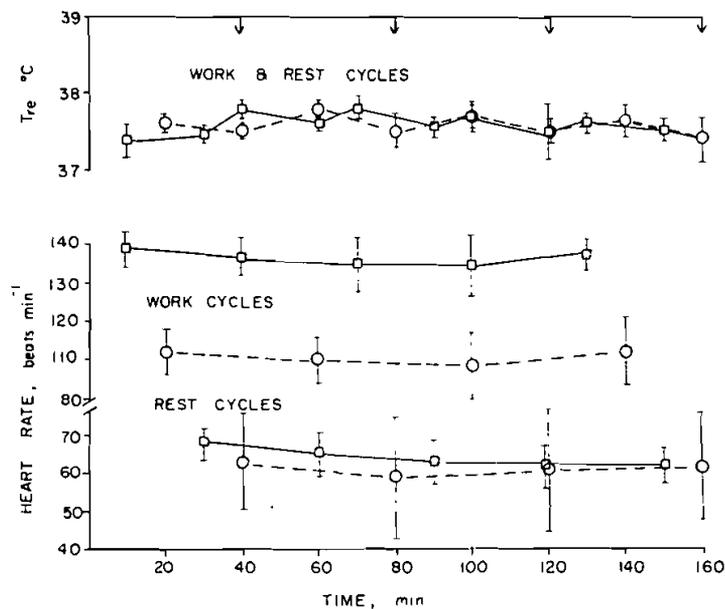


Figure 1. Mean end values of the rectal temperature and heart rate for the work cycles at $0.40 \dot{V}_{O_{2max}}$ (\circ) and $0.60 \dot{V}_{O_{2max}}$ (\square), under the neutral ambient conditions (see control study in table 2). Vertical bars represent one standard deviation, arrows indicate end of resting period.

that these responses were similar for the consecutive cycles. The T_{re} responses were within the same range for the two work loads, both fluctuating between 37.5°C to 37.8°C for most of the work and rest cycles. As expected, HR was higher during the working cycle at $0.60 \dot{V}_{O_{2max}}$ when compared to $0.40 \dot{V}_{O_{2max}}$, but the end value of the HR practically did not change from cycle to cycle for each work level.

4.3. Heat Observations

4.3.1. *Work at 0.40 \dot{V}_{O_2}* : The T and HR responses to the cyclic work at 0.40 $\dot{V}_{O_2\max}$ were shown in figure 2A for work under the warm-humid (WH) and in figure 2B for

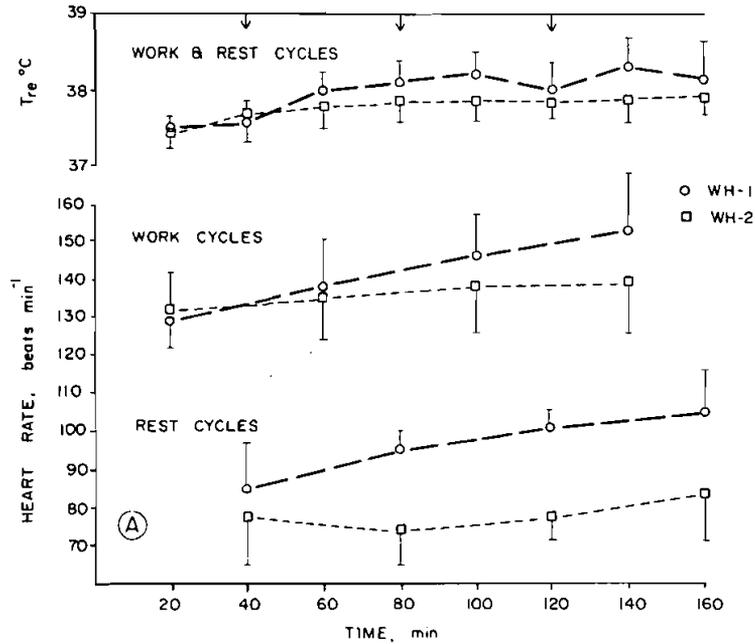


Figure 2A. Mean end values of rectal temperature and heart rate for the work cycles at 0.40 $\dot{V}_{O_2\max}$ under the warm-humid ambient conditions: (○) work and rest in the heat; (□) work in the heat, rest under neutral ambient conditions (see table 2). Vertical bars represent one standard deviation. Arrows indicate end of resting period.

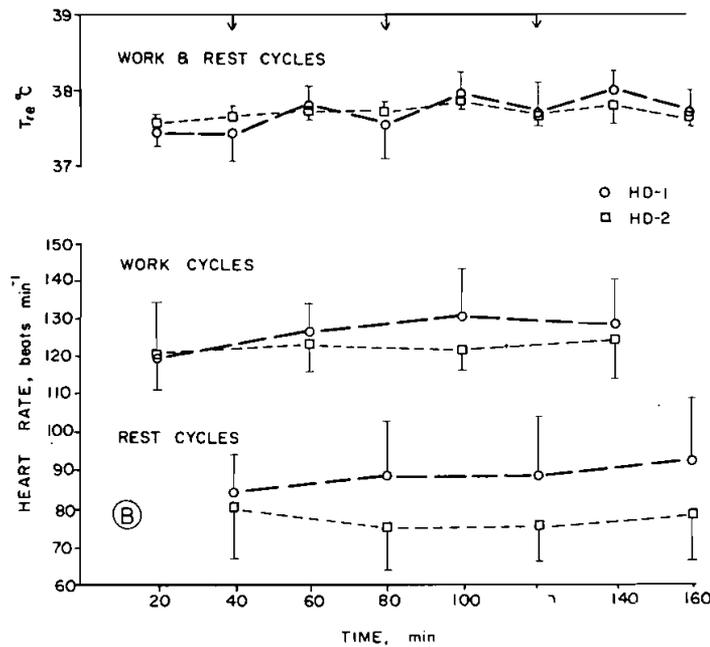


Figure 2B. Mean end values of rectal temperature and heart rate for the work cycles at 0.40 $\dot{V}_{O_2\max}$ under the hot-dry ambient conditions. Symbols as in figure 2A.

work under hot-dry (HD) ambient conditions. It can be seen that these responses were different for each ambient condition, in particular when the resting periods were confined to the same ambient conditions as the working periods.

When working and resting were under the same warm-humid conditions (WH-1), T_{re} and HR continuously increased from cycle to cycle to respectively reach 38.3°C and 153 beats min^{-1} at the end of the last working period (figure 2A). Moreover, even the resting HR was rising during the consecutive cycles.

When the resting periods were under the cooler neutral ambient conditions (WH-2), T_{re} levelled off at about 37.8°C during the working periods, and practically the working HR also levelled off; the increments were from 135 beats min^{-1} during the second cycle to 140 beats min^{-1} during the last (5th) cycle.

Exposure to cyclic work under the hot-dry ambient conditions (HD-1 and HD-2) resulted in less strain as compared to the exposure to the WH conditions. The T_{re} seemed to have levelled off at 38°C for the last two working cycles under the hot conditions (HD-1) and slightly under 38°C during the last two working cycles when resting was under the cooler neutral conditions (HD-2). Although the HR under the HD-1 conditions were higher than under the HD-2 condition, levelling off was seen for all the cycles in both cases (figure 2B).

4.3.2. *Work at 0.60 $\dot{V}_{O_{2\max}}$* : The T_{re} and HR responses to the cyclic work at 0.60 $\dot{V}_{O_{2\max}}$ are shown in figure 3A for work under the WH conditions and in figure 3B

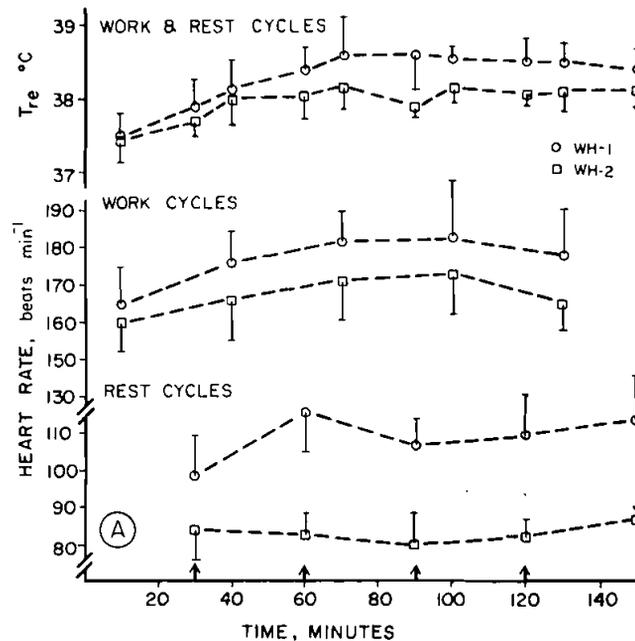


Figure 3A. Mean end values of rectal temperatures and heart rate for the work cycles at 0.60 $\dot{V}_{O_{2\max}}$ under the warm-humid conditions. Symbols as in figure 2A.

for work under the HD conditions. It can be seen that levelling-off of these responses occurred for most of the working cycles under both ambient conditions. As expected, the levelling-off values were lower during the conditions where resting was outside the heated room (WH-2, HD-2). The T_{re} levelled off at about 38.6°C and HR at 182

beats min^{-1} under the WH-1 conditions and at 38.2°C and $170 \text{ beats min}^{-1}$ under the WH-2 conditions.

Similar to the work at $0.40 \dot{V}_{\text{O}_2\text{max}}$, the HD conditions were less stressful than the

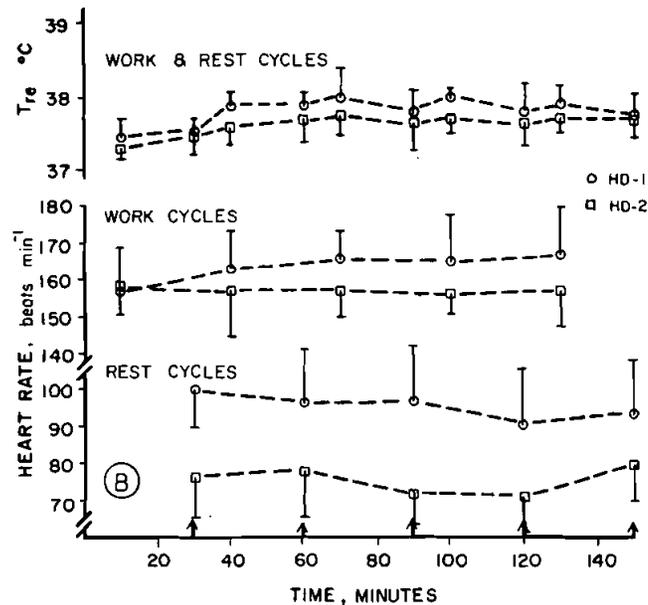


Figure 3B. Mean end values of rectal temperature and heart rate for the work cycles at $0.60 \dot{V}_{\text{O}_2\text{max}}$ under the hot-dry ambient conditions. Symbols as in figure 2A.

WH conditions. The T_{re} levelled off at temperatures below 38°C and the HR during the working periods levelled off at $165 \text{ beats min}^{-1}$ and $155 \text{ beats min}^{-1}$ respectively, for the HD-1 and HD-2 ambient conditions.

4.3.3. Mean skin temperature (\bar{T}_s) and heat exchange: Tables 3 and 4 are a summary of the mean values of: \bar{T}_s averaged for the last two cycles; the corresponding calculated ambience evaporative capacity (E_{max}) and the required heat loss ($E_{\text{req}} = M + R + C$); sweat evaporative heat loss, averaged for the last two cycles (E_v) and

Table 3. Mean and standard deviation of skin temperature (\bar{T}_s), the air evaporative capacity (E_{max}), the total heat required for dissipation ($E_{\text{req}} = M + R + C$), the evaporative sweat loss (E_v) and the total sweat loss (S) for the work at $0.40 \dot{V}_{\text{O}_2\text{max}}$ under the different ambient conditions

	Period	WH ₁ *	WH ₂	HD ₁	HD ₂
\bar{T}_s	Work	36.1 ± 0.6	35.6 ± 0.5	34.9 ± 0.7	34.8 ± 0.5
	Rest	35.9 ± 0.5	33.6 ± 0.5	35.6 ± 0.6	33.6 ± 0.6
E_{max} (W m^{-2})	Work	94	82	327	296
	Rest	97	65	294	62
	Average	96	74	311	179
E_{req} (W m^{-2})	Work	244	253	374	369
	Rest	57	10	183	7
	Average	151	132	279	188
E_v (W m^{-2})	Work	203†	201†	387	389
	Rest	172†	111	245	64
	Average	188	156	316	227
S (W m^{-2})		305	233	323	200

* For notations see table 2.

† Included dripping sweat.

Table 4. Mean and standard deviation of skin temperature (\bar{T}_s), the air evaporative capacity (E_{\max}), the total heat required for dissipation ($E_{\text{req}} = M + R + C$), the evaporative sweat loss (E_v) and the total sweat loss (S) for work at 0.60 $\dot{V}_{O_{2\max}}$ under the different ambient conditions

	Period	WH ₁ *	WH ₂	HD ₁	HD ₂
\bar{T}_s	Work	36.9 ± 0.7	35.9 ± 0.5	35.3 ± 1.0	34.5 ± 0.8
	Rest	36.6 ± 0.8	34.3 ± 1.3	35.4 ± 0.8	33.3 ± 0.6
E_{\max} (W m ⁻²)	Work	103	81	318	241
	Rest	90	68	255	49
	Average**	94	72	276	113
E_{req} (W m ⁻²)	Work	461	456	592	524
	Rest	57	10	206	24
	Average**	192	159	335	190
E_v (W m ⁻²)	Work	262†	269†	565	519
	Rest	250†	211	267	103
	Average**	256	240	416	311
S (W m ⁻²)		553	329	496	343

* For notations, see table 1.

† Included dripping sweat.

** Time weighed average.

total sweat loss for the whole exposure (S). It can be seen that during the working periods under the WH conditions E_{\max} was inadequate for the E_{req} . This was also apparent in the highly wet surface of the subjects and the noticeable dripping of sweat. Since E_v was derived from weight loss, it did not represent true evaporative cooling. However, under the WH-2 conditions the first few minutes outside the heated room allowed rapid evaporative cooling of the wet body. This was reflected in the lower ratio between S and the average E_v , for the WH-2 as compared to the WH-1 conditions. The E_{\max} for the HD conditions allowed a substantial E_v cooling. During work and rest at 0.40 $\dot{V}_{O_{2\max}}$ the E_v and the S matched closely the E_{req} without apparent excessive sweating; the subjects were dry. However during work at 0.60 $\dot{V}_{O_{2\max}}$, E_{\max} was somewhat less than adequate during the working periods and despite the improved ratios of E_{req} to E_{\max} during the resting periods there was some excessive sweating, but not as much as under the WH conditions.

5. Discussion

The design of the working periods under the hot ambient conditions was based on what is now common knowledge in applied physiology, namely the predictable magnitude of the responses of HR to work and heat stress. These responses were expected to be as follows: (a) certain HR values for \dot{V}_{O_2} as a fraction of $\dot{V}_{O_{2\max}}$ ($f\dot{V}_{O_{2\max}}$); (b) assured maximal attainable HR for a large percentage of a given population and; (c) specific heat induced increments in HR for heat acclimatized subjects.

The work specific HRs were expected to be 120 beats min⁻¹ and 140 beats min⁻¹ respectively for the work at 0.40 $\dot{V}_{O_{2\max}}$ and at 0.60 $\dot{V}_{O_{2\max}}$. The observed mean and standard deviation of the HR during the work under the neutral ambient conditions, was 111 ± 8 and 137 ± 6 for the respective work levels. The somewhat lower HR for the 0.40 $\dot{V}_{O_{2\max}}$ can be explained by the larger changes in stroke volume, rather than in HR, in the control of cardiac output during work under 0.50 $\dot{V}_{O_{2\max}}$.

Using an expected HR_{max} for the lower end of the 95th percentile of young male population seemed to provide the appropriate measure for the strain involved in the combined stresses of muscular work and heat. Since HR_{max} is sex and age dependent, different schedules should be designed for different worker populations.

The heat induced increments in HR, like the work-specific HR, were expected to be linearly related to the stress of the environment at least for the non-humid conditions (Vogel *et al.* 1973). Although these increments were within the expected values (Kamon and Belding 1971a) some deviations from it were noticeable. The HR continuously rose during the working periods under the humid conditions. The increase was more than the anticipated $1-2 \text{ beats min}^{-1}$ for each minute of exposure, but only when the resting was in the warm-humid room. The end values of HR for the working periods always were lower when the resting was outside as compared to resting inside the heated room, and actually resting outside the hot-dry ambient conditions resulted in lower than the anticipated HR levels for the working periods. It could be concluded that the design of the work cycles on the basis of the increasing HR was adequate when the resting periods were assigned to neutral ambient conditions. The most inadequate conditions were for the high work level ($0.60 \dot{V}_{O_{2\max}}$) with resting under the warm-humid ambient conditions (WH-1, figure 3A).

The adequacy of the work-rest design for all, except the work and rest under the wet-humid conditions, was also apparent in the rise of T_{re} . Under neutral ambient conditions and continuous work, T_{re} was expected to equilibrate in proportion to $f \dot{V}_{O_{2\max}}$; at 37.9°C and 38.4°C for work at $0.40 \dot{V}_{O_{2\max}}$ and $0.60 \dot{V}_{O_{2\max}}$ respectively (Saltin and Hermansen 1966, Kamon 1975). However, the pauses between the working periods prevented the rise in T_{re} to those levels (figure 1). Moreover, even under the stressing ambient conditions the resting periods under the cooler neutral conditions prevented the T_{re} rise to the work specific equilibrium levels (figures 2 and 3). Although T_{re} levelled off during the consecutive working periods for the conditions of work and rest inside the heated room, it did so at levels above 38°C . This was taken to indicate unnecessary strain, which was also apparent in the continuous rise in HR (figure 2A), or the approach of the HR close to maximum (figure 3A). One solution to the strain of work and rest inside the heated room could be to shorten the working periods. Judged by the heat exchange, designing very short working periods could be of little help because of the E_{\max} limitation even during resting. Thus, the T_{re} rise to above 38°C , and the increments in HR, both indicated the preference of designing the resting periods in a neutral environment. This need for resting under the neutral condition was also apparent in the heat exchange. The limiting evaporative capacity, in particular under the WH conditions, resulted in oversweating as was indicated by the dripping of sweat. Resting under the cooler neutral ambient conditions was relatively more beneficial for the WH than for the HD conditions because of the increased wetness. Stepping out into the neutral ambient conditions with fully wet skin at high temperature, provided immediate evaporation into a gradient of more than 4 kPa. As the skin temperature dropped and sweating was inhibited, the cooling shifted to dry heat exchange. The ratio between S and the average E_v also indicated the increased strain under the WH as compared to the HD conditions. While the ratio was larger than 1 for the exposure to the WH conditions, it was at about 1 indicating no excessive sweating for the exposure to the HD conditions (tables 3 and 4).

In conclusion, the design of cyclic work under hot ambient conditions for heat acclimatized subjects, can be based on the cumulative circulatory strain of the work load and the heat stresses. Heart rate can be used as a strain indicator by equating the heat induced increments with the expected HR for work in terms of the fraction of the maximal aerobic capacity. However, it seems that when humid ambient conditions are involved the resting periods must be scheduled for cooler neutral ambient conditions.

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Des périodes d'alternance de repos et de travail ont été déterminées séparément pour un travail à 40% de la $\dot{V}_{O_{2max}}$ et pour un travail à 60% de la $\dot{V}_{O_{2max}}$, chacune sous les deux conditions d'ambiances thermiques suivantes:

(a) chaude—humide, T_S : 36°C et T_H : 31°C;

(b) chaude—sèche, T_S : 50°C et T_H : 25°C.

Pour la période de repos deux conditions ont été expérimentées:

(1) Les conditions ambiantes étaient les mêmes que pour le travail.

(2) Conditions ambiantes neutres avec T_S à 23°C et T_H à 16°C.

Les périodes de travail ont été déterminées à partir de la somme de la fréquence cardiaque (HR) relative au travail et de la fréquence cardiaque induite par l'ambiance chaude. Cette somme a été traitée en termes d'équivalence pour la fraction de $\dot{V}_{O_{2max}}$, basée sur la relation linéaire existant entre les deux paramètres. Le facteur limitant considéré a été pris dans le 95^e percentile pour la fréquence cardiaque maximale déterminé dans la population des sujets âgés de 20 à 30 ans. Six sujets masculins, acclimatés à la chaleur, ont servi à valider le cycle des périodes travail-repos. Celui-ci était de 20 mn pour chaque période de travail à 40% de la $\dot{V}_{O_{2max}}$ et de 10 mn (travail) et 20 mn (repos) pour la condition à 60% de la $\dot{V}_{O_{2max}}$. Une passation à chaque niveau de travail comprenait cinq cycles de travail-repos. Les résultats ont montré que ces cycles d'alternance convenaient bien pour la condition chaude-sèche quelque soit l'emplacement où le repos est pris, lorsqu'on prend en compte la récupération de la fréquence cardiaque et la température rectale avec sa limitation à 38°C, mais ne convenaient aux conditions chaude-humide que lorsque les périodes de repos s'effectuaient dans une ambiance thermique neutre.

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