EXCERPTUM

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The Influence of Rest Pauses on Mechanical Efficiency

By

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Abstract

CHRISTENSEN, E. H., R. HEDMAN and I. HOLMDAHL. *The influence of rest pauses on mechanical efficiency.* Acta physiol. scand. 1960. *48.* 443—447. — Two subjects performed a given quantity of work on a Krogh bicycle ergometer within one hour. With a relatively low load the work was continuous, with higher loads breaks of varied length and periodicity were introduced. Mechanical efficiency was the same or slightly less when continuous work was replaced by discontinuous work.

During the later years KARRASCH and MÜLLER (1951) and MÜLLER and KARRASCH (1955) have investigated the influence of work pauses of different length and frequency on fatigue. As an index of fatigue the total number of heart beats above resting level during the recovery period after work (Erholungspulssumme E.P.S.) has been introduced. The following experiments were performed with a similar technique as used by the above mentioned authors but the main interest was concentrated on mechanical efficiency. From a theoretical as well as from a practical point of view it was of interest to investigate to what an extent large changes in work load and varied duration and frequency of work pauses influence the total energy output for a given quantity of work.

Subjects and Methods

The subjects were two well trained students. One was a female, I. H., 21 years old, weight 60 kg and height 174 cm. Her capacity for oxygen intake was 3.2 l/min or 53 ml/kg×min, her observed basal oxygen intake was 0.22 l/min and the basal pulse rate averaged 62. The other subject was a male, R. H., 25 years old, weight 74 kg and height 177 cm. His capacity for oxygen intake was 4.6 l/min or 62 ml/kg×min, his observed basal oxygen intake was 0.26 l/min and his basal pulse rate averaged 49. The female subject, I. H., had to perform a total quantity of 24.000 kpm and the male subject, R. H., 36.000 kpm within one hour.

Four series of experiments were performed and each one was repeated three to five times to make sure that no training effect should influence the results. In series (I) the work load on the Krogh bicycle ergometer was 400 and 600 kpm/min for the female and the male subject respectively, and the work was carried on for 60 min without rest pauses. In series (II) the loads were 1.000 and 1,500 kpm/min respectively, and 2 min of work were followed by 3 min of rest during the one hour period. In series (III) the loads were the same as in (II) but the periods of work and rest were reduced to 0.5 and 0.75 min respectively. In series (IV) the loads were 500 kpm/min and 750 kpm/min respectively, and rest pauses of 6 min duration were introduced after 24 and 54 min. During the rest pauses the subjects were sitting on the bicycle. The pedal frequency was always 50 rpm. With a work load of 1,000 kpm/min I. H. could work in a steady state for 30 min with only a slight increase in the blood lactic acid concentration, her maximal value was 20 mg per 100 ml. The male subject could do the same at 1,500 kpm/min, with a corresponding value of 30 mg per 100 ml.

The experiments started at 7 or 8 o'clock in the morning with the subjects in basal conditions. The oxygen consumption was determined with the Douglas bag technique. The total amount of expired air was collected during the one hour work period and during recovery. The recovery time lasted from 30 to 50 min beyond the one hour work period. For heart rate measurements an electrocardiographic pulse counter was used and the heart rate was continuously recorded during the one hour and during recovery.

B.M.R. and basal heart rate were determined when the subject had rested on a couch for about 30 min: even during recovery, after the work hour was finished, they rested on the couch placed close to the bicycle ergometer. The room temperature ranged between 16° and 19° C. A small electrical fan, placed at a convenient distance from the subjects, was put on whenever wanted to secure sufficient skin cooling by evaporation of sweat. In this way an attempt was made to avoid a possible increase in pulse rate due to disturbances in heat regulation.

Results and Discussion

Oxygen consumption and mechanical efficiency

In Table I mean values and standard errors of the means for oxygen intake are given. The oxygen consumption during the one hour period exclusive of the observed basal oxygen intake (*i. e.* net oxygen intake) was for I.H. 51.49, 51.73, 52.47 and 50.82 l for series (I), (II), (III) and (IV) respectively. No statistical significant difference between the four series was found. For R.H. the corresponding net oxygen consumption ranged between 73.70 and 78.80 l. A statistical significant difference was found when the series (II) and (III) at 1,500 kpm/min were compared with (I) and (IV) where the lower loads of 600 and 750 kpm/min were used. The difference is however small, amounting to less than 7 per cent. The same results are reached when the total net O_2 intake during 1 h "work period" and recovery are compared (see Table I). The energy cost per kpm of work or the mechanical efficiency is consequently the same or practically the same, whether the work is performed continuously

Table I. Total net oxygen intake during continuous and intermittent work for the two subjects

Series	I continuous work	II 2 min work 3 min rest	III 0.5 min work 0.75 min rest	IV work 2×24 min rest 2×6 min
I. H. ♀ 24.000 kpm	400 kpm/min n = 5	1,000 kpm/min n = 5	1,000 kpm/min n = 4	500 kpm/min n = 4
total net O_2 intake (l) during 1 h "work period"	51.49 ± 0.51	51.73 ± 0.80	52.47 ± 1.12	50.82 ± 0.85
total net O_2 intake (l) during 1 h "work period" and recovery	52.72 ± 0.38	53.24 ± 0.73	53.35 ± 1.56	52.25 ± 1.05
mech. efficiency per cent[1]....	22.0	21.8	21.7	22.2
R. H. ♂ 36,000 kpm	600 kpm/min n = 4	1,500 kpm/min n = 4	1,500 kpm/min n = 3	750 kpm/min n = 3
total net O_2 intake (l) during 1 h "work period"	73.70 ± 0.74	[2,3] 78.80 ± 0.56	[2,4] 77.92 ± 0.38	74.16 ± 0.31
total net O_2 intake (l) during 1 h "work period" and recovery	75.47 ± 0.62	[2,3] 80.20 ± 0.55	[2,4] 79.55 ± 0.39	75.39 ± 0.33
mech. efficiency per cent[1]....	23.0	21.7	21.9	23.1

[1] The caloric coefficient of oxygen was set to 4.85

[2] Significantly higher than series I, $0.01>P>0.001$

[3] » » » » IV, $P<0.001$

[4] » » » » IV, $0.01>P>0.001$

for one hour with an easy load or discontinuously with heavier loads (see Table I).

These results are in agreement with the results of CROWDEN (1934) but hardly with the assumption of MÜLLER and HETTINGER (1957) that pauses of 0.75 min or more should increase the oxygen demand for a following work period significantly compared to the normal steady state level.

At present we are inclined to think that the increased oxygen intake during recovery after a single short spell of work does not allow any definite conclusions as to the actual muscle metabolism during work. Work always means a certain disturbance from basal conditions as also MÜLLER and HETTINGER mention. The hormonal balance, the heat balance etc. will be disturbed, and it is therefore quite understandable that basal conditions are not attained immediately when work stops. We are of course not denying the existence of a true oxygen debt, but think that it might lead to erroneous conclusions if the total increase in oxygen intake during recovery is used for calculating the

Table II. Total number of heart beats during continuous and intermittent work for the two subjects

	I continuous work	II 2 min work 3 min rest	III 0.5 min work 0.75 min rest	IV work 2 × 24 min rest 2 × 6 min
I. H. ♀ 24,000 kpm	400 kpm/min n = 5	1,000 kpm/min n = 5	1,000 kpm/min n = 4	500 kpm/min n = 4
total number of heart beats during 1 h "work period"	6,572 ± 106	6,658 ± 159	6,681 ± 234	6,315 ± 79
number of heart beats above resting level after 1 h "work period"	120 ± 13	307 ± 83	75 ± 26	21 ± 6
R. H. ♂ 36,000 kpm	600 kpm/min n = 4	1,500 kpm/min n = 4	1,500 kpm/min n = 3	750 kpm/min n = 3
total number of heart beats during 1 h "work period"	5,870 ± 109	5,991 ± 98	5,848 ± 93	5,874 ± 67
number of heart beats above resting level after 1 h "work period"	108 ± 26	397 ± 46	257 ± 25	171 ± 11

true oxygen demand and the mechanical efficiency of the metabolic processes that take place during short spells of muscular work.

Our criticism does not only effect the conclusions of Müller and Hettinger (1957) but also the ones of Asmussen (1946) and of Christensen and Högberg (1950).

Heart rate

The total number of heart beats during the one hour "work period" ranged for I.H. between 6,315 and 6,681 and for R.H. between 5,848 and 5,991. Compare Table II. No statistical significant difference was found between any of the series. The marked difference in pulse reaction of the two subjects — the work load for R.H. was 50 per cent higher than for I.H. — corresponds well to the marked difference in aerobic capacity of the two subjects.

If in our experiments the total number of heart beats above resting level after the 1 h work period is taken as an index of fatigue, the results for R.H. agree fairly well with those of Müller and Karrasch (1955): "Die Ermüdung ist am geringsten, wenn das geforderte Stundenpensum in pausenloser Arbeit bewältigt wird." However, I.H. had the lowest number of heart beats after 500 kpm/min with two rest pauses of 6 min each, and no significant differences were found between series (I) and (II), or between (I) and (III). For the high work loads of 1,000 and 1,500 kpm/min, respectively, the lowest number of heart beats for both subjects is found in series (III) with short spells of work (0.5 min) and rest (0.75 min). This result is in agreement with those of Müller and Karrasch (1955).

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References

Asmussen, E., Aerobic recovery after anaerobiosis in rest and work. *Acta physiol. scand.* 1946. *11.* 197—210.

Christensen, E. H. and P. Högberg, The efficiency of anaerobical work. *Arbeitsphysiologie.* 1950. *14.* 249—250.

Crowden, G. P., The effect of duration of work on the efficiency of muscular work in man. *J. Physiol.* 1934. *80.* 394—408.

Karrasch, K. and E. A. Müller, Das Verhalten der Pulsfrequenz in der Erholungsperiode nach körperlicher Arbeit. *Arbeitsphysiologie.* 1951. *14.* 369—382.

Müller, E. A. and Th. Hettinger, Der Energiemehrbedarf bei Arbeitsbeginn. *Arbeitsphysiologie.* 1957. *16.* 480—499.

Müller, E. A. and K. Karrasch, Der Einfluss der Pausenanordnung auf die Ermüdung bei Schwerarbeit. *Arbeitsphysiologie.* 1955. *16.* 45—51.

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Intermittent and Continuous Running

(A further contribution to the physiology of intermittent work.)

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Abstract

CHRISTENSEN, E. H., R. HEDMAN and B. SALTIN. *Intermittent and continuous running. (A further contribution to the physiology of intermittent work.)* Acta physiol. scand. 1960. *50*. 269—286. — Intermittent running on a tread mill at a speed of 20 km/h (12.4 miles/h) is analysed and a comparison between this work and continuous running at the same speed has been done. The present results are in agreement with the assumption that stored oxygen plays an important role for the oxygen supply during short spells of heavy work. When running intermittent 6.67 km in 30 min (effective work 20 min and rest 10 min), a trained subject attained a total O_2 uptake of 150 l. With an O_2 uptake of 0.4 l/min at rest standing at the tread mill, or 4 l per 10 min of rest, 146 l O_2 are due to the 20 min of work. The actual uptake at work was only 101 l and if normal values are assumed during rest pauses, a deficit in oxygen transport of 45 l arises during the 20 min of actual work. This quantity will be taken up during the 120 rest pauses of 5 sec each. Two thirds of the oxygen demand during the 120 work periods of 10 sec each will accordingly be supplied by oxygen transported with the blood during work, and one third will be covered by a reduction in the available oxygen stores in the muscles, which in turn will be reloaded during the subsequent 5 sec rest periods. Respiratory and circulatory functions at intermittent and continuous running with special reference to maximal values are discussed. Research on intermittent work may open up a new field in work physiology.

In earlier investigations from this laboratory intermittent heavy work on the bicycle ergometer was analysed in respect to certain physiological functions (Christensen 1956, 1960, Åstrand *et al.* 1960 a and b). It was shown that the length of the individual work period is most critical, whereas the length of the rest pauses and the total work output might be of secondary importance as far as the physiological load is concerned.

Oxygen stored in the muscles, probably mainly in combination with myohemoglobin, was postulated to explain why a trained subject could perform intermittent, heavy work (2,520 kpm/min) with short spells of activity (10 sec) aerobically or practically so.

In the present investigation intermittent running on a treadmill at a speed of 20 km/h (12.4 miles/h) and with short spells of work is analysed in details and a comparison between this work and continuous running at the same speed has been done. Special attention has been payed to the circulatory and respiratory functions and to the blood lactic acid concentrations obtained at intermittent and continuous work.

Material and Methods

Two physically well trained, male subjects were used. One of them, R. H., was also a subject in the earlier experiments mentioned above. His age was now 29 years, weight about 72 kg and height 177 cm. His capacity for oxygen uptake at 5 to 6 min of work on the bicycle ergometer was 4.60 l/min or 64 ml/kg × min. B. S. was 24 years old, weight about 83 kg and height 187 cm. His maximal oxygen uptake at work on the bicycle ergometer was 5.60 l/min or 68 ml/kg × min.

The experiments were done at about 8 o'clock in the morning and the subjects were in fasting conditions. The treadmill, in horizontal position, was set at a speed of 20 km/h. The exact time for the work and rest periods was read from an electrical clock. Usually, however, the subjects run a definite number of steps for the different work periods of 5, 10 or 15 sec. For B. S. the number of double steps were 15, 30 and 45, whereas R. H. had a slightly higher frequency or 17—19, 34 and 51. The distance run in 5 sec corresponded to 27.8 m, in 10 sec to 55.6 m and in 15 sec to 83.3 m. Due to the short periods and to the high speed slight variations might occur, but they are of no importance for the general trend, even if they might have some slight influence on work efficiency.

Blood samples for lactate determinations were collected at 5 min intervals during pauses of 30 sec. This procedure too will have only a slight influence on the total O_2 uptake and other functions at intermittent work. Blood was taken from a prewarmed fingertip to secure full arterialisation. The analyses were done according to the method of Barker and Summerson (1941), modified by Ström (1949).

The expired air was collected in Douglas bags and gas analyses were done on a modified Haldane apparatus. Due to short spells of work and rest the expired air from a certain number of work or rest periods were collected in the same bags. For closer analysis the collection time was often cut down to 5 sec periods. The exact timing was done with two electrically activated stop watches, which were started or stopped from the threeway stop cock when the subjects' expiratory air at the end of an expiration was collected in the "work bag" or in the "rest bag".

Table I. B. S. intermittent running 20 km/h; work 15 sec, rest 10 sec

Time after start of experiment, min	Specimen of expired gas	$\dot{V}_E$, l BTPS	f	V_T, l BTPS	$\dot{V}_{O_2}$, l STPD	RQ
5—8	W. 0—15 sec	108.5	32.9	3.30	5.06	0.80
5—8	R. 0—10 sec	115.4	32.6	3.54	4.50	0.85
12—15	W. 0—15 sec	115.9	37.9	3.06	4.94	0.83
12—15	R. 0—10 sec	124.4	—	—	4.54	0.83
18—20	W. 0—5 sec	123.0	40.6	3.03	4.49	0.85
18—20	W. 5—10 sec	125.9	48.2	2.61	5.07	0.79
18—20	W. 10—15 sec	140.4	50.7	2.77	5.31	0.82
27—29	W. 0—15 sec	138.8	48.2	2.82	5.06	0.82
27—29	R. 0—5 sec	151.2	49.6	3.05	5.13	0.83
27—29	R. 5—10 sec	136.4	—	—	3.99	0.94

The heart rate was taken with an electrocardiographic pulse counter and every pulse beat was recorded with a four channel pen recorder (Kelvin & Hughes) with a paper speed of 10 mm/sec. Two channels were used for exact timing. Before running and immediately after rectal temperature was taken with a calibrated fever thermometer and the weight of the naked subject was determined with an accuracy of ± 50 g.

The room temperature was between 17° and 21° C with a humidity of around 50 per cent. To secure optimal sweat evaporation electrical fans were placed at a short distance from the subjects.

All experiments were done without any warming up exercise. When a work period started the experienced subjects jumped on to the running treadmill, and when the work period finished, they jumped off it to a standing position with one leg on each side of the running belt.

Results

I. *Intermittent running*

O_2 *uptake*

Table I gives an example of the sampling procedure, used for determining O_2 uptake and related functions. From the 5th to the 8th minutes after the experiment had started, the expired air from a number of work periods of 15 sec duration each was collected in the first Douglas bag. The corresponding O_2 uptake was 5.06 l/min. During the same interval the expired air from a number of rest periods of 10 sec each was collected in a second Douglas bag resulting in an O_2 uptake corresponding to 4.50 l/min. The following determinations from the 12th to the 15th minutes gave practically identical results, 4.94 l/min and 4.54 l/min respectively. Between the 18th and the 20th minutes a more detailed fractioning of the expired air was done. In one bag the expired air from the first 5 sec of work was collected, in a second bag air from the following 5 sec, and in a third bag air from the last 5 sec was collected. A marked increase in O_2 uptake is seen between the first (4.49 l/min), second (5.07 l/min)

Table II. B. S. intermittent running 20 km/h; work 5 sec, rest 5 sec

Time after start of experiment, min	Specimen of expired gas	$\dot{V}_E$, l BTPS	f	V_T, l BTPS	$\dot{V}_{O_2}$, l STPD	RQ
5— 6^{30}	W. 0—5 sec	101.6	28.0	3.63	4.41	0.82
5— 6^{30}	R. 0—5 sec	95.7	25.7	3.72	4.52	0.79
15—16^{30}	W. 0—5 sec	102.6	31.1	3.30	4.36	0.81
15—16^{30}	R. 0—5 sec	100.8	29.5	3.42	4.55	0.77
20—21^{30}	W. + R.	100.8	30.5	3.30	4.44	0.78
25—26^{40}	W. 0—5 sec	100.1	29.7	3.37	4.29	0.79
25—26^{40}	R. 0—5 sec	101.6	29.0	3.50	4.57	0.75

and third bag (5.31 l/min). For the whole period of 15 sec the result, 4.96 l/min, agrees closely with the two earlier determinations (5.06 l/min and 4.94 l/min) as well as with the final one (5.06 l/min) collected between the 27th and 29th minutes of the experiment. In a similar way the expired air from the rest periods between the 27th and 29th minutes was fractioned for the first 5 and the last 5 sec of the 10 sec rest periods. Here a marked decrease in O_2 uptake was found from the first 5 sec period (5.13 l/min) to the second one (3.99 l/min). But again the result (4.56 l/min) for the whole period of 10 sec agrees closely with the two earlier ones (4.50 l/min and 4.54 l/min).

Of interest is a comparison between the oxygen uptake (5.31 l/min) during the last 5 sec of the work period and the first 5 sec of the rest period (5.13 l/min). Apparently the O_2 uptake declines immediately when work stops.

The only experimental condition, where a higher oxygen uptake was found during the first 5 sec of rest compared to work, was when B. S. ran in 5 sec periods. Table II illustrates such an example. The maximal difference was 0.28 l/min or some 5 per cent. The reason for this discrepancy between the results of the 5 sec work periods for B. S. and the other results both with B. S. and R. H. can not be given.

Here again the stability of the results is remarkable. If the O_2 uptake for the work and rest periods are added for the three intervals referred to in Table II, the results are the following: 4.47 l/min, 4.46 l/min and 4.43 l/min, which again agree closely with the forth determination (4.44 l/min) after the 20th minute, where the expired air for work plus rest was collected in the same Douglas bag.

In Table III the results from an experiment with the highest work output are given. B. S. ran for 30 min with 10 sec of work alternating with 5 sec of rest. The total distance was 6.67 km. Of interest here is to notice that the lowest O_2 uptake was seen during the first 5 sec of work (4.44 l/min), second came the 5 sec of rest (average 4.92 l/min) and the highest value (5.60 l/min)

Table III. B. S. intermittent running 20 km/h; work 10 sec, rest 5 sec

Time after start of experiment, min	Specimen of expired gas	$\dot{V}_E$, l BTPS	f	V_T, l BTPS	$\dot{V}_{O_2}$, l STPD	RQ
5—6^{15}	W. 0—10 sec	124.6	44.2	2.84	5.02	0.86
5—6^{15}	R. 0— 5 sec	135.5	41.9	3.23	5.14	0.89
12—13^{15}	W. 0—10 sec	142.4	50.4	2.83	5.28	0.87
12—13^{15}	R. 0— 5 sec	137.4	52.4	2.63	4.90	0.87
20—21^{30}	W. 0— 5 sec	138.9	53.9	2.56	4.44	0.91
20—21^{30}	W. 5—10 sec	156.7	57.3	2.73	5.60	0.87
25—26^{15}	W. 0—10 sec	142.9	51.2	2.79	4.87	0.90
25—26^{15}	R. 0— 5 sec	143.7	43.3	3.32	4.71	0.86

corresponded to the last 5 sec of the 10 sec work period. This equals the highest oxygen uptake ever recorded with B. S.

Fig. 1 gives an illustration of the changes in oxygen uptake for the two subjects, when the periods of work and of rest are of identical length, 5, 10 and 15 sec. The total distance run in 30 min was always 5 km.

Table IV summarizes the different work and rest combinations used. The total O_2 uptake per minute (work plus rest) were determined in the way mentioned before, 7—12 Douglas bags were collected during work and rest periods from the fifth minute on. The results show, as expected, a marked increase in total oxygen uptake per minute with effective work time or total distance

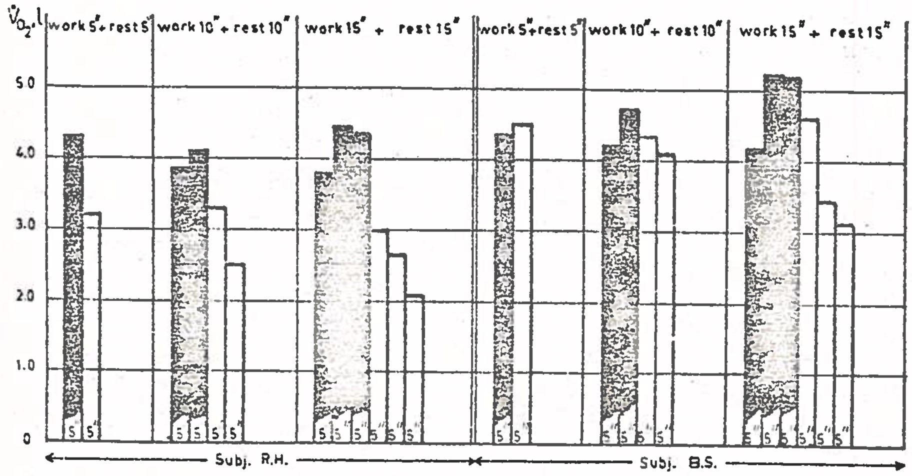

Fig. 1. Oxygen uptake at work (filled columns) and rest (unfilled columns) running 5 km at 20 km/h in 30 min as intermittent work with 5, 10 and 15 sec periods of work and rest. Subjects R. H. and B. S.

Table IV. O_2 uptake at different work and rest combinations for the two subjects, intermittent running, 20 km/h

Work period sec	Rest period sec	Work: rest	Distance run at each work period m	Number of runs in 30 min	Total distance run in 30 min km	Subject	$\dot{V}_{O_2}$, l net STPD	O_2 uptake l/km	Subject	$\dot{V}_{O_2}$, l STPD	Net O_2 uptake l/km
5	15	1:3	27.8	90	2.50	R. H.	2.16	22.2	B. S.	—	—
5	10	1:2	27.8	120	3.34		2.64	20.9		3.10	24.3
5	5	1:1	27.8	180	5.00		3.75	20.7		4.45	24.3
10	30	1:3	55.6	45	2.50		1.92	19.3		—	—
10	20	1:2	55.6	60	3.34		2.53	19.9		3.11	24.3
10	10	1:1	55.6	90	5.00		3.40	18.5		4.08	22.1
10	5	2:1	55.6	120	6.67		—	—		5.00	20.7
15	45	1:3	83.3	30	2.50		2.05	20.9		—	—
15	30	1:2	83.3	40	3.33		2.39	18.7		2.97	23.2
15	15	1:1	83.3	60	5.00		3.40	18.5		4.20	22.8
15	10	3:2	83.3	72	6.00		—	—		4.82	22.1

run in the 30 min experiments. There may be a slight tendency for a higher oxygen consumption with the short spells of work of 5 sec compared to 10 or 15 sec. But the differences are too small, and the possible errors in exact timing of the work periods are probably too large to allow any conclusive statements as to a statistical significant difference in running efficiency. The highest determined O_2 uptake for work plus rest was for R. H. 3.75 l/min, when the periods of work and rest were 5 sec each; when the periods were 10 or 15 sec, the O_2 uptake was 3.40 l/min. The corresponding values for B. S. were 4.45 l/min, 4.08 l/min and 4.20 l/min.

The higher O_2 uptake for B. S. compared to R. H., even when the distances run were the same for both, is mainly explained by the higher body weight of B. S., 83 kg compared to 72 kg for R. H. B. S. had an oxygen uptake of 400 ml/min when standing at rest with one leg on each side of the running belt, whereas R. H. had only 310 ml/min. The net O_2 uptakes in liters per km in Table 4 are calculated with a deduction of 310 ml/min for R. H. and 400 ml/min for B. S. Based on these values the average O_2 uptake per kg body weight and km was calculated to be 0.277 l for both. Obviously the efficiency in running at a speed of 20 km/h was the same for the two.

Both subjects reached O_2 uptakes during intermittent running close to or equal to their maximum. When running for 15 and resting for 15 sec R. H. reached 4.53 l/min, and when running for 10 and resting for 5 sec B. S. reached 5.60 l/min.

Pulmonary ventilation

Although oxygen uptake usually reached some sort of a steady state already from the 5th minute on, the other respiratory functions were at the highest work output less stable. Running for 15 sec and resting for 10 (Table I) the respiratory minute volume for the work periods increased for B. S. from 108.5 l to 138.8 l and for the rest periods from 115.4 to 143.8 l. The volume found for the last 5 sec of the work period was 140.4 l/min and for the first 5 sec of rest, 151.2 l/min. The respiratory frequency showed a steady increase from about 35 to about 50 per minute. A tendency for a decrease in tidal volume is also seen from Table I. The ventilation per liter of O_2 uptake showed during the latter part of the half hour an increase, at work from 21.4 l to 26.8 l, and at rest from 25.6 l to 34.2 l. One possible reason for this steady increase in ventilation was undoubtedly the blood lactic acid, which was 40 mg per 100 ml at the 5th minute and 66 mg per 100 ml at the 30th minute (comp. Table VI).

In Table III the highest pulmonary ventilation for B. S. at intermittent work, 156.7 l/min, is given; at continuous work as shown later the highest value was 158 l/min. For R. H. the corresponding values were definitely lower at intermittent work with a maximum of 107 l/min compared to 142.5 l/min at continuous work, where the blood lactic acid concentration was very much higher, which may explain some of this difference.

Heart rate and oxygen pulse

Fig. 2 gives an illustration of the recorded heart rates for R. H. when running at 20 km/h 2.5 km for 30 min with work periods of 5, 10 and 15 sec and with the corresponding rest pauses of 15, 30 and 45 sec. The heart rate for work belongs to the last 5 sec of this period; one rest value belongs to the first 5 sec, the other one to the last 5 sec of rest, which even means to the 5 sec preceding the following work period. It is clearly demonstrated that the heart rate at work and for the first 5 sec of the rest period are identical or practically identical.

This general finding for all work and rest combinations is of significance as to the reliability of judging the rate at work from pulse counts obtained during the first sec after work has stopped. In this laboratory a commonly used procedure is to take the exact time with a stop watch for 10 pulse beats immediately when work stops. Specially when using the heart rate as an indicator of physiological load in athletics or in industrial work, where pulse counting during actual work often is difficult or impossible, it is of importance to know, that post exercise values, when taken immediately after work, that is within the first 5 sec, are reliable indicators of the actual work situation, at least under normal climatic conditions.

Due to the fact that the oxygen uptake decreases immediately when work stops (exception see p. 272) and the heart rate stays unchanged for the first

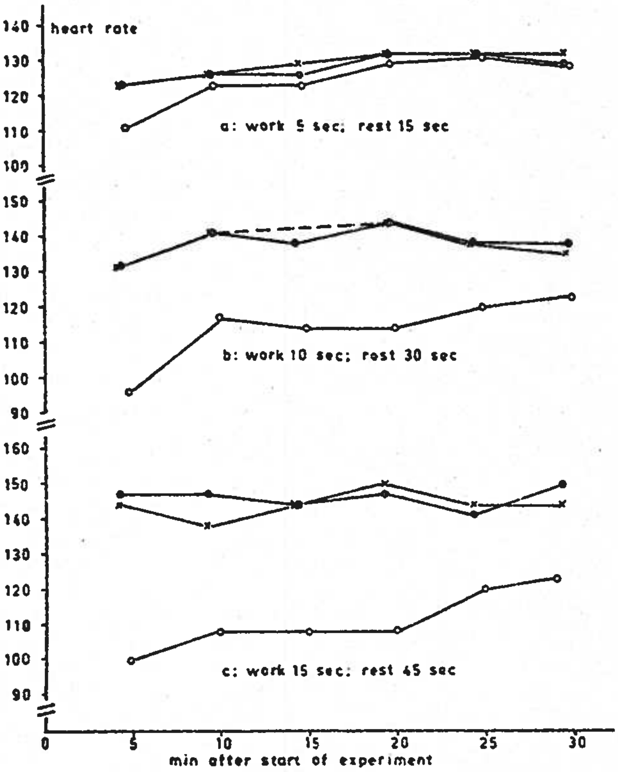

Fig. 2. Heart rate at different work and rest periods, intermittent work. Subject R. H. (×) last 5 sec of work period, (●) first 5 sec of rest period, (○) last 5 sec of rest period. The heart rate when standing at rest before the work experiments ranged 72—76 beats/min.

5 sec, an immediate decrease in O_2 pulse occurs. This decrease will go on until the next work period starts again.

Since a detailed fractioning in 5 sec periods during the work and rest periods has not always been done, a more complete calculation of the oxygen pulse at all different work and rest combinations could not be done. The available results show, however, that for subject R. H. the oxygen pulse was always lower during rest, even during the first 5 sec, than during the preceding work period. The same holds true for B. S. except for the 5 sec running periods, where a slightly higher oxygen pulse, 27.5 ml, was found during the first 5 sec of rest compared to 26.7 at work (running for 5 sec and resting for 10 sec). For both subjects similar maximal values for oxygen pulse were obtained at continuous and at intermittent work, for R. H. about 27 ml and for B. S. about 32 ml. (For further discussion on oxygen pulse at intermittent work see CHRISTENSEN 1960.)

Table V. Blood lactate concentrations at different time intervals intermittent running, 20 km/h. Subject R. H.

Work period sec	Rest period sec	Blood lactate, mg per 100 ml							Average
		Rest before work experiment	Min after start of work experiment						
			5	10	15	20	25	30	
5	20	18	14	12	9	11	11	8	11
5	15	13	18	21	14	14	11	11	15
5	10	—	18	17	16	13	10	9	14
5	5	10	42	50	51	48	45	45	47
10	30	9	19	15	14	16	13	11	15
10	20	14	20	16	19	19	16	20	18
10	10	16	46	53	47	43	39	42	45
15	45	13	15	12	13	14	13	14	14
15	30	18	32	30	24	30	32	23	29
15	15	14	62	72	74	79	82	80	75
	average	14	29	30	28	29	27	26	

Blood lactic acid

Table V and Table VI give the blood lactic acid concentrations at the different time intervals from the 5th to the 30th minutes of the experiments. The results from the single experiments are averaged and so are the determinations done at the fixed time intervals in all different experiments.

The results in Table V (subject R. H.) show that there is no, or only a slight increase in blood lactic acid concentrations at work compared to normal rest, when the periods of work are 5 or 10 sec, and the total distances run in 30 min are 3.33 km or less, or, when the work periods are 15 sec and the total distance is 2.5 km (work : rest = 1 : 3). With 15 sec work periods and a total distance of 3.33 km (work : rest = 1 : 2) a slight increase in blood lactic acid takes place during the first 5 min, and a level averaging 29 mg per 100 ml is seen for the following 25 min. If the total distance reaches 5 km (rest : work = 1 : 1) a more definite increase in blood lactic acid concentration is seen. When running for 5 or 10 sec this increase, however, only takes place the first 5 min of the experiments, from there on a level at an average of 47 and 45 mg per 100 ml respectively is found. When running for 15 and resting for 15 sec the increase is larger and continuous, 62 mg per 100 ml at the 5th minute and 80 mg at the 30th minute. This represents the only work situation examined with subject R. H. where anaerobic conditions are indicated for the whole experiment which, with a longer work time than 30 min, would limit his work performance.

Looking at the averaged values from all experiments for the 5th, the 10th

Table VI. Blood lactate concentrations at different time intervals intermittent running, 20 km/h. Subject B. S.

Work period sec	Rest period sec	Blood lactate, mg per 100 ml							Average
		Rest before work experiment	Min after start of work experiment						
			5	10	15	20	25	30	
5	20	—	13	8	9	7	7	9	9
5	15	14	20	13	9	10	10	12	12
5	10	16	14	14	15	14	21	17	16
5	5	12	28	23	20	22	23	24	23
10	30	12	11	11	11	10	11	10	11
10	20	17	22	18	27	27	25	23	24
10	10	15	19	18	17	21	17	25	20
10	5	14	42	43	38	49	47	47	44
15	45	9	13	9	16	11	12	10	12
15	30	23	21	16	16	14	16	14	16
15	15	15	—	18	19	19	23	28	21
15	10	11	40	42	48	54	54	66	51
	average	14	22	19	20	21	22	24	

minute a. s. o., it is obvious that the blood lactic acid concentration is more likely to decrease than to increase from the 5th minute on. This is even more clearly shown when the determinations from the experiment with 15 sec work and 15 sec rest are excluded from the averages, then a decrease from 25 mg per 100 ml at the 5th minute to 20 mg at the 30th minute is seen.

The results in Table VI show the same general trend for subject B. S. with low lactic acid concentrations when the total distances run are 2.5 or 3.33 km. Even at a distance of 5 km the lactic acid level is low, averaging 23, 20 and 21 mg per 100 ml respectively when running for 5, 10 and 15 sec. The only work situation examined, where a definite increase in lactic acid between the 5th and the 30th minutes occurred, was when running a total distance of 6 km with work periods of 15 and rest periods of 10 sec. If the results from this last experiment are excluded from the average values in Table VI, the concentration at the 5th minute of work is 18 and at the 30th minute 17 mg per 100 ml.

Both subjects showed consequently a more marked tendency for increased lactic acid concentrations, anaerobic work, when the work periods were 15 sec compared to 5 or 10 sec.

Body temperature and heat regulation

When running a total of 5 km R. H. showed an increase in rectal temperature of 1.9° C in all three instances referred to in Table IV. The highest temperature, measured immediately after work, was 39° C. After running a total of 6.67 km in 30 min B. S. showed an increase of 2.25° C and reached 39.2° C. The corresponding weight loss showed for R. H. an average of 0.58 kg and for B. S. with the higher work load 0.85 kg in 30 min.

A rough estimation will give some information about the heat balance in the case of B. S. At an oxygen uptake of 5.00 l/min, an average RQ of 0.88 (compare Table III) and a heat equivalent of 4.9 kcal per liter of oxygen, the total energy output in 30 min will be 740 kcal. If we assume, that the measured increase in rectal temperature of 2.25° C is representative for the whole body (83 kg) — the working muscles will have a somewhat larger and other tissues as the skin a lower increase, — 150 kcal will be stored in the body. If 0.8 kg of the total weight loss of 0.85 kg is due to evaporation, about 450 kcal are eliminated that way, some 10 per cent from the respiratory track and 90 per cent from the skin (compare the results of NIELSEN (1938)). Obviously the sweat rate has been of the order of 1.5 l/h, which undoubtedly is on the upper limit of what the sweat glands are supposed to handle at the actual climatic conditions. The high body temperature or the steep increase was subjectively not at all felt unpleasant. Unpleasant was, however, the profuse sweating from the face with sweat running into the eyes.

II. *Continuous running*

Continuous running at a speed of 20 km/h is even without wind resistance, as on the treadmill, a typical non steady state work, where the work time will be limited by an accumulation of anaerobic metabolites in the working muscles and in the organism as a whole. For the subject R. H. three minutes of continuous running was the limit for what he could perform. Five minutes after work had stopped, his blood lactic acid reached a maximal value of 151 mg per 100 ml (cf. Fig. 4). The other subject B. S. also went on for three minutes, but was not totally exhausted at the end. His blood lactic acid concentration also showed a maximum after 5 min of recovery and reached 117 mg per 100 ml indicating a close to but not maximal performance.

The values for O_2 uptake, pulmonary ventilation and heart rate are given in Fig. 3. *Oxygen uptake* showed a steep increase and a value corresponding to more than 4 l/min was reached 1 to 1.5 min after start of work for R. H., and more than 5 l/min for B. S. Already between 0.5 and 1 min the O_2 uptake for B. S. reached a value corresponding to 4.88 l/min. Both subjects reached an O_2 uptake very close to the earlier determined maximal values, for R. H. 4.54 l/min (max. 4.60 l/min) and for B. S. 5.55 l/min (max. 5.60 l/min) before the end of the three minutes' work period. For both subjects the O_2 uptake was increased some 18 times compared to the normal basal values and a tenfold increase took place during the first 0.5 min of work.

The *respiratory minute volume* (at B. T. P. S.) reached for B. S. 158 l between 2 and 2.5 min; the highest volume for R. H., 142.5 l, was measured between 1.5—2 min. At these high respiratory volumes B. S. had an electrically re-

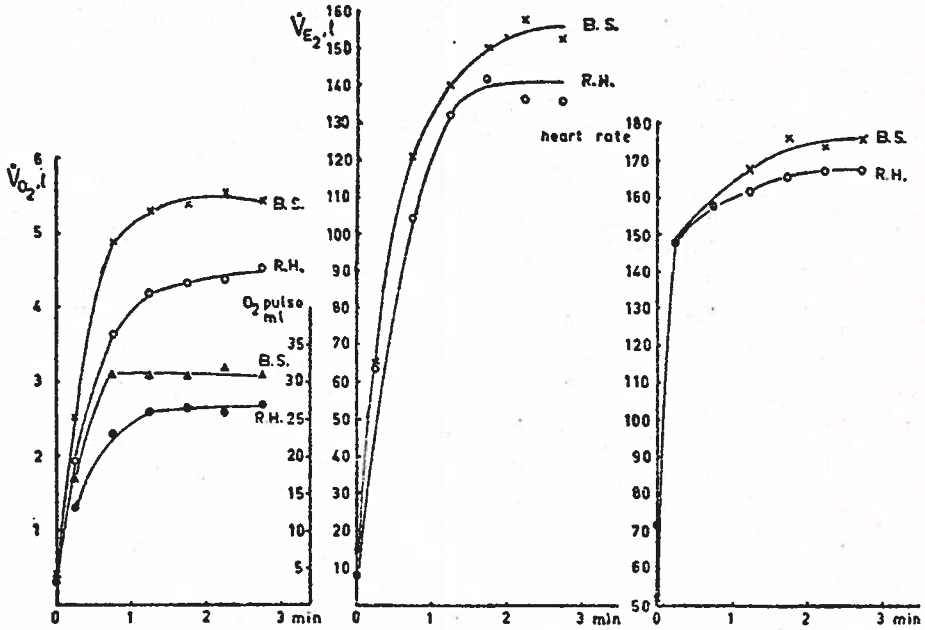

Fig. 3. Oxygen uptake, oxygen pulse, pulmonary ventilation and heart rate at continuous work (running 20 km/h for 3 min). Subjects R. H. and B. S.

corded *respiratory rate* of 48.9/min and a *tidal volume* of 3.23 l. R. H. had a rate of 48.2 and a tidal volume of 2.96 l. Per liter of oxygen the corresponding respiratory volumes varied between 24.9 l and 28.5 for B. S., and between 29.4 and 33.0 l for R. H. during the three minutes of work.

The *heart rate* showed for both subjects a steep increase during the first minute of work, a rate above 150 per min was reached during the first 0.5 min. For B. S. the rate levelled off around 175 per min, whereas for R. H. it levelled off below 170. This is an atypical pulse reaction for R. H., who usually would show maximal values of more than 180 at such a work load. The reason for this atypical reaction can not be given. An after control of the records showed no indication of experimental errors.

The calculated *oxygen pulse,* showed for B. S. a practically constant value of 31 ml, reached already 0.5 min after work had started; for R. H. the value of 26 ml was attained after 1 min of work.

For R. H. the average resting *blood lactate* in 9 determinations was 10.5 mg per 100 ml with the range of 6 to 15 mg per 100 ml. For B. S. the corresponding average was 12.5 mg per 100 ml in 8 determinations, range 8 to 18 mg per 100 ml.

After each work experiment six blood samples were taken, one during the first minute of recovery and five samples spread out over the following 10 to

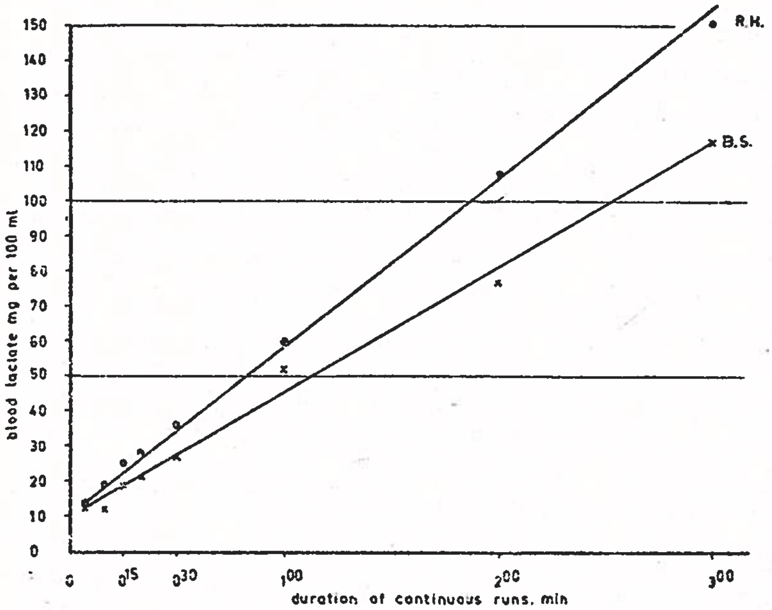

Fig. 4. Blood lactate concentrations. Maximal post-exercise values obtained during recovery after continuous running of different duration, from 5 sec to 3 min. Subjects R. H. (•) and B. S. (×).

15 min. The highest recorded post-exercise value for each experiment is given in Fig. 4.

The lactic acid concentration increases practically rectilinear, for R. H. roughly with 50 mg per 100 ml for each minute of work. Only after the 5 sec run no increase was found; the resting value before running was 15 mg per 100 ml and the post-exercise values were 10, 12, 11, 10, 10 and 14 mg per 100 ml. For B. S. the lactic acid increase per work min was roughly 40 mg per 100 ml. After running for 5 and for 10 sec all the post-exercise values were lower than the rest values before running. In the experiment with 10 sec running the rest value was 15 mg per 100 ml and the following post-exercise values were 10, 12, 9, 7, 8 and 9 mg per 100 ml. With a linear increase of 40 mg per cent per minute an increase of some 7 mg per 100 ml should be expected in this latter experiment, instead a slight decrease was found.

Discussion

The here mentioned results are in agreement with the assumption that oxygen stored probably mainly in combination with myohemoglobin in the working muscles, plays an important role for the oxygen supply during short spells of heavy work.

The "buffering" effect of the stored oxygen as to the total oxygen supply during heavy intermittent work may be illustrated by the following example. When running 6.67 km in 30 min (work 10, rest 5 sec) B. S. had an average O_2 uptake (work plus rest) of 5.00 l/min or a total of 150 l. His effective work time was 20 min and he rested for 10 min. As his normal oxygen uptake at rest, standing at the treadmill, was 0.4 l/min, a total of 4 l has to be subtracted from 150 l to get the total O_2 demand of 146 l due to the 20 min of work, which corresponds to 7.3 l O_2 per work minute. The actual uptake per minute (cf. Table III) corresponded to 5.05 l/min during the work periods, or for the 20 min of work 101 l. Obviously a deficit in oxygen transport of 45 l arises during the 20 min of actual work, and this quantity is supplied during the 120 rest pauses of 5 sec each. The quantity that has to be repayed during each of the 120 rest pauses amounts to an average of 375 ml. With a demand of 7.3 l/min or 1.217 l per 10 sec two thirds will be supplied by oxygen transported with the blood during actual work, and if exclusively aerobic metabolism is assumed at work, one third will be covered by a reduction of the available oxygen stores in the muscles, which in turn will be reloaded during the subsequent 5 sec rest period.

In our earlier investigations (ÅSTRAND *et al.* 1960 b) with the subject R. H. we came to the conclusion that about 0.43 l O_2 ought to be available in the working muscles at the beginning of each work period. As subject B. S. definitely, in respect to physical work capacity, is the stronger of the two, the above mentioned calculations for B. S. indicate, that with 10 sec work periods he should have a fair margin for a further O_2 supply from the depots in the working muscles. With work periods of 15 sec this margin should, however, be reduced markedly, and the tendency shown for increased anaerobic condition with these longer work periods agrees with this assumption.

A further analysis of the results in Table VII, which were calculated in the same way as the before mentioned example, gives the following results.

Table VII. Calculated O_2 demand and O_2 deficit at different work and rest combinations. Intermittent

Subject	Work period sec	Rest period sec	Total work min	Total rest min	Average $\dot{V}_{O_2}$, l work + rest	O_2 demand for work l
R. H.	5	5	15	15	3.75	108.0
	10	10	15	15	3.40	97.35
	15	15	15	15	3.40	97.05
B. S.	5	5	15	15	4.45	127.8
	10	10	15	15	4.08	116.4
	15	15	15	15	4.20	120.0
	10	5	20	10	5.00	146.0
	15	10	18	12	4.82	139.8

For subject R. H. the same average blood lactic acid concentration is seen, 47 and 45 mg per 100 ml respectively, when the work periods were 5 and 10 sec; the O_2 deficit was, however, only 0.240 l per work period at 5 sec but 0.402 l at the 10 sec periods. At 15 sec periods the corresponding values were 75 mg per 100 ml and 0.570 l.

To find a possible explanation for the relatively high lactic acid values even at the 5 sec work periods a consideration of the average load and of the maximal load on the oxygen transport system may be of some significance. The average O_2 uptake per min for work plus rest (at 5 sec of work) was 3.75 l/min or 82 per cent of the maximal aerobic capacity for this subject. The actual uptake during the work period corresponded to 4.30 l/min or 94 per cent of the aerobic work capacity. At 10 sec work periods the average load on the oxygen transport system was 74 per cent and the highest load 89 per cent. This could give some explanation for the relatively high lactic acid values with the 5 sec work periods, and could of course also be valid for the results with the 15 sec work periods, where 99 per cent of the aerobic capacity is engaged during the latter part of the work periods. It is well known from earlier investigations, both from this and from other laboratories, that an increase in blood lactic acid concentration always takes place, especially during the first minutes of work, when the actual O_2 uptake in continuous work surpasses a certain percentage of the aerobic capacity.

The same explanation may fit the results with subject B. S. with exception of those from the experiment with 15 sec work and 15 sec rest periods (compare Table VI and VII). In this experiment the lactic acid stays constant or practically constant at an average concentration of 21 mg per 100 ml indicating aerobic or practically aerobic condition during the whole experiment. The relative load on the oxygen transport system corresponds to 75 per cent of the maximum, if the average O_2 uptake for work plus rest (4.27 l/min) is

running, 20 km/h.

O_2 demand per min of work, l	O_2 demand for each work period l	Actual $\dot{V}_{O_2}$, l at work	O_2 uptake each work period, l	O_2 deficit each work period, l	Max $\dot{V}_{O_2}$, l at work	Average blood lact. mg per 100 ml
7.20	0.598	4.29	0.357	0.240	4.30	47
6.49	1.082	4.08	0.680	0.402	4.10	45
6.47	1.618	4.19	1.048	0.570	4.53	75
8.52	0.710	4.35	0.363	0.347	4.40	23
7.76	1.293	4.38	0.730	0.563	4.71	20
8.00	2.000	4.54	1.135	0.865	5.34	21
7.30	1.217	5.05	0.842	0.375	5.60	44
7.77	1.943	5.02	1.255	0.688	5.31	51

considered, but as much as 95 per cent (or 5.30 l/min) if O_2 uptake for the last 5 sec of the work periods is considered.

It is quite remarkable that subject B. S. within 30 min can make 60 runs of 83.4 m each, with an O_2 demand corresponding to 8.00 l/min, and with a maximal O_2 uptake corresponding to 5.34 l/min, without hardly any increase in blood lactic acid. This can only be explained by an exceptional high ability to "flatten out" the work load over the subsequent rest period, which is indicated by the enormous deficit for transported oxygen of 0.865 l that he can compensate for at each work period of 15 sec duration.

In calculating the O_2 demand and O_2 deficit for the actual work periods as done in Table VII, we have assumed that the "rest O_2 uptake" is the same during the 30 min experiment as determined separately before the experiment, or 0.310 l/min for R. H. and 0.400 l/min for B. S. This assumption is not strictly justified. A number of physiological functions are highly elevated above the rest level, and this may involve a certain but indeterminable extra demand for oxygen, which is unrelated to a real deficit in uptake during actual work. The given values for O_2 deficit should therefore be taken as possible maximal values and they may not in a quantitative exact way be used for calculating the amount of stored oxygen, as we have done before. To our opinion the possible errors must, however, be relatively small. If the metabolism during rest pauses is much higher than assumed, this would involve a decrease in mechanical work efficiency at intermittent work. In two of our earlier publications (CHRISTENSEN, HEDMAN and HOLMDAHL 1960, and ÅSTRAND *et al.* 1960 a) where work efficiency at continuous and intermittent work on the bicycle ergometer were compared, such marked differences were not found. A tendency for a slightly lower efficiency at intermittent work was seen, however, even at short work and rest periods involving no or only a very slight increase in blood lactic acid. Part of this difference and perhaps the whole might be explained by the fact, that at intermittent work on the bicycle ergometer the subject has to accelerate the heavy flywheel from standstill at every work occasion. At continuous work the flywheel runs at a constant speed all through the experiment, which really means a somewhat lower work output and consequently a somewhat lower demand for O_2 uptake at continuous work compared to intermittent.

It is remarkable that at a work load asking for an O_2 uptake of 5.00 l/min (work plus rest) the RQ for the 30 min experiment averaged only 0.88 with a maximal deviation of 0.03 (cf. Table III). This and the other low values for RQ indicate, that in spite of the high work output the metabolism has been almost entirely aerobic, which is further confirmed by the relatively low and after the 5th minute usually stable blood lactic acid concentrations.

There are obvious differences between the two subjects with respect to their reaction to increasing length of the work periods. When running a total distance of 5 km the oxygen uptake for R. H. reached almost identical values, at 5 sec 4.30 l/min, at 10 sec 4.09 l/min and at 15 sec 4.45 l/min. In all instances they are close to his maximum (4.60 l/min). When running the same distance B. S. had at 5 sec work periods 4.35 l/min, at 10 sec 4.71 l/min and at 15 sec 5.34 l/min (cf. Fig. 1). The relatively low value at 5 sec work is possible only because of the extremely high value, 4.50 l/min during the following rest period. For R. H. the corresponding value was only 3.20 l/min. When comparing the work and the rest periods for B. S. there is a definite trend towards more or less identical values for oxygen uptake during the short work and rest periods. Subject R. H. on the other hand shows a steep decrease in oxygen uptake as soon as work stops, even at the short work periods of 5 sec.

For several reasons the reaction of B. S. seems to be superior to that of R. H.; to a higher degree he will be able to "flatten out" the effect of the work load over the work and rest period. At the work period R. H. with an uptake of 4.30 l/min used 94 per cent, whereas B. S. with an uptake of 4.35 l/min only used 78 per cent of his maximum for oxygen uptake. The low lactic acid concentration, average 23 mg per 100 ml (cf. Table VI) in contrast to 47 mg (cf. Table V) for R. H., might be significant in this respect.

Especially the results from intermittent running with B. S. are of interest as to the problem of the respiratory control at work. Looking at Table I, II and III it may be difficult to decide whether a given pulmonary ventilation belongs to the work or to the rest periods. Changes in O_2 uptake and pulmonary ventilation are synchronized independently of work or rest, most likely with the concentration of metabolites and "oxygen demand". Therefore the pulmonary ventilation can not, at least not to any greater extent, be governed by nervous impulses, either radiating from the motorregion of the cortex cerebri or from proprioceptors in muscles, joints and tendons, which all should show a high activity during work but not at rest. Here again subject R. H. reacts somewhat differently. His pulmonary ventilation (and oxygen uptake) declines more abruptly when work finishes, even at the short periods of work.

The results of the experiments with continuous running at 20 km/h show without doubt that for subject R. H. the running time of 3 min, in which he covered a distance of 1 km, represented a maximal performance in respect to both his aerobic and anaerobic work capacity. For subject B. S. the running time and speed was sufficient to load his aerobic work capacity, or oxygen transporting system, to maximal values, but the blood lactate concentration was definitely below maximum, indicating a submaximal load on his anaerobic capacity. If we assume a maximal tolerable blood lactate value of 150 mg per 100 ml as for R. H., B. S. should be able to run for 4 min or cover a distance of 1.35 km, cf. Fig. 4.

It is difficult to settle if the low lactic acid concentrations found after a single short run has any significance as to aerobic or anaerobic conditions during the first 5 or 10 sec of work. The total production of anaerobic metabolites are of course relatively small due to the short work time, and a dilution by the body fluids will anyhow result in low blood concentrations. Only direct determinations in the venous blood from the working muscles might give a definite answer to the question, whether a single run of 5 or 10 sec duration at a speed of 20 km/h can be performed aerobically due to oxygen stored in the muscles.

For further discussion as to the possible role of myohemoglobin as an oxygen store, the reader is referred to the earlier publications by Åstrand *et al.* (1960 b). Independent of the validity of this assumption the following experimental findings are of significance.

Two physically trained subjects can run continuously for 3 respectively 4 min on the treadmill at a speed of 20 km/h, reaching maximal values for oxygen uptake and for blood lactic acid. At the end of this time when they have run a total distance of 1 and 1.3 km respectively they will be totally exhausted and will need a comparatively long time for recovery. Running at the same speed but intermittent with short spells of activity and rest, the character of work will change entirely; despite a marked decrease in oxygen uptake during the actual work periods, the work can be performed without or with only a comparatively slight increase in blood lactic acid concentration, indicating aerobic or practically aerobic work conditions. The trained subjects can stand an effective work time of 15 respectively 20 min within the experimental time of 30 min and run a total distance of 5 respectively 6.67 km without being totally exhausted.

We are inclined to think that the before and here mentioned results concerning intermittent work opens up a new field of research, and the results may have rather far reaching consequences for practical work studies. Too little emphasis may until now have been laid on the critical length of the active phases in intermittent work.

References

Åstrand, I., P.-O. Åstrand, E. H. Christensen and R. Hedman, Intermittent muscular work. *Acta physiol. scand.* 1960 a. *48.* 443—453.

Åstrand, I., P.-O. Åstrand, E. H. Christensen and R. Hedman, Myohemoglobin as an oxygen store in man. *Acta physiol. scand.* 1960 b. *48.* 454—460.

Barker, S. B. and W. H. Summerson, The calorimetric determination of lactic acid in biological materials. *J. biol. Chem.* 1941. *138.* 535—554.

Christensen, E. H., Lactic acid, circulatory and ventilatory rate during continuous and discontinuous work of extreme high intensity. Abstracts of Comm. XXth intern. Physiol. Congr. Brussels. 1956. 175.

Christensen, E. H., Intervallarbeit und Intervalltraining. *Int. Z. Physiol.* 1960. (In press.)

Christensen, E. H., R. Hedman and I. Holmdahl, The influence of rest pauses on mechanical efficiency. *Acta physiol. scand.* 1960. *48.* 443—447.

Nielsen, M., Die Regulation der Körpertemperatur bei Muskelarbeit. *Skand. Arch. Physiol.* 1938. *79.* 193—230.

Ström, G., The influence of anoxia on lactate utilization in man after prolonged muscular work. *Acta physiol. scand.* 1949. *17.* 440—451.

Stockholm 1960. Kungl. Boktr. P. A. Norstedt & Söner

EXCERPTUM

Acta physiol. scand. 1960. 48. 454—460

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Myohemoglobin as an Oxygen-Store in Man

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Abstract

ÅSTRAND, I., P.-O. ÅSTRAND, E. H. CHRISTENSEN and R. HEDMAN. *Myohemoglobin as an oxygen-store in man.* Acta physiol. scand. 1960. *48.* 454—460. — The aim of the present research was to investigate further the possible rôle of myohemoglobin as an oxygen-store during the initial stage of muscular work. One subject worked intermittently with a work load of 2.520 kpm/min with varied duration of work and rest pauses on a bicycle ergometer. A highly significant difference in the blood lactic acid concentration during the experimental time of 30 min was found, at work with short work periods (10 sec, lactic acid concentration about 10—20 mg per 100 ml) compared with relative long ones (60 sec, lactic acid concentration 110—140 mg per 100 ml). The conclusion was drawn that the first type of work is performed aerobically. The calculated oxygen demand, during the work period of 10 sec, however, does not correspond to the measured oxygen intake. A deficit of about 0.43 l O_2 for each period of work will occur. It was suggested that this amount of 0.43 l O_2 is supplied to the working muscle mainly from oxymyohemoglobin. This store function of myohemoglobin is discussed in relation to the present findings and to the results mentioned in the literature.

In an earlier investigation concerning intermittent heavy work (2,160 kpm/min) it was shown that blood lactic acid concentration remains low if work alternates with rest pauses every half minute. If work and rest periods are increased to 3 min the lactic acid concentration will reach high values and the total work time will be limited due to exhaustion (ÅSTRAND *et al.* 1960).

A possible explanation for the aerobic work metabolism when 0.5 min periods are used was given by the assumption that the oxygen bound to the myohemoglobin plays an important rôle in the supply of oxygen to the working muscles in the initial stage of work. With increasing duration of the work period the relative importance of this oxygen fraction diminishes, and if the transport of oxygen is insufficient for the local demand, anaerobic processes have to cover a certain fraction of work metabolism, and lactic acid accumulates in the muscles and in the blood.

The present work was planned to further elucidate the rôle of myohemoglobin in this respect. To obtain more conclusive results the work load was increased to 2,520 kpm/min. Furthermore, the periods of work and rest were varied independently of each other so that more decisive results as to the relative importance of the rest pauses could be obtained.

Methods

Work was performed by one male, physically well trained subject, R. H., on a Krogh bicycle ergometer. The subject and the methods used were the same as in the earlier experiments (Åstrand *et al.* 1960). The work of 2,520 kpm/min corresponds to a load of 6 kg with 70 pedal revolutions per minute. The total experimental time was, if possible, 30 min. The work periods were always of the same duration throughout one experiment. They lasted for 10, 15, 30 or 60 sec. The rest pauses lasted from 20 up to 240 sec (compare Table I). Due to the different duration of rest pauses the total quantities of work produced on the different experimental days ranged between about 6,000 and 38,000 kpm, and the average work load for the 30 min varied between some 200 kpm/min and 1,260 kpm/min.

Results

Table I summarizes the experiments done and gives the maximal values for blood lactic acid concentration, the total quantity of work performed in the 30 min experiment and other calculated values of importance for the discussion. The total quantity of 25,200 kpm of work will be represented in all series, I—IV arranged according to the duration of the work period in the table, and the quantity of 15,120 kpm will be found in three of the sections. This makes a direct comparison possible. If the work period lasts for 10 sec, 420 kpm will be produced at every work occasion; with longer duration this quantity increases and reaches, at 60 sec, 2,520 kpm. The calculated oxygen demand for these different work quantities are given in the table. These values are, of course, approximate but still they give a good illustration of the varying demands, which are 0.9 l of O_2 for the 10 sec periods and 5.6 l for the 60 sec periods. The calculated values are based upon a mechanical efficiency of 23.0 per cent and a caloric coefficient for oxygen of 4.85.

Fig. 1 and 2 illustrate the changes in blood lactic acid concentration during work with a total quantity of 25,200 and 15,120 kpm respectively. The relationship between work and rest time is always 1 to 2 in Fig. 1, and 1 to 4 in Fig. 2. With the short work periods of 10 sec followed by pauses of 20 sec, the blood lactic acid concentration was about 20 mg per 100 ml, while in the experiment with 40 sec pauses it was approximately 15 mg per 100 ml; that is, in both cases

Table I. Peak blood lactic acid concentration in experiments with intermittent work of various duration of work and pause periods. Work production, effective work time and oxygen demand have been calculated and tabulated

Series	I		II		III					IV		
work periods, sec	10		15		30					60		
pause periods, sec	20	40	30	180	30	60	120	180	240	120	180	240
kpm produced in each work period	420		630		1260					2520		
total production in 30 min, kpm	25,200	15,120	25,200	5,800	37,800	25,200	15,120	10,840	8,320	25,200	18,900	15,120
effective work time in 30 min experiment, min	10.0	6.0	10.0	2.3	15.0	10.0	6.0	4.3	3.3	10.0	7.5	6.0
O_2 demand in each work period, l	0.9		1.4		2.7					5.6		
maximal values for blood lactic acid conc. mg per 100 ml	23	17	31	29	78	70	56	58	41	142	114	114

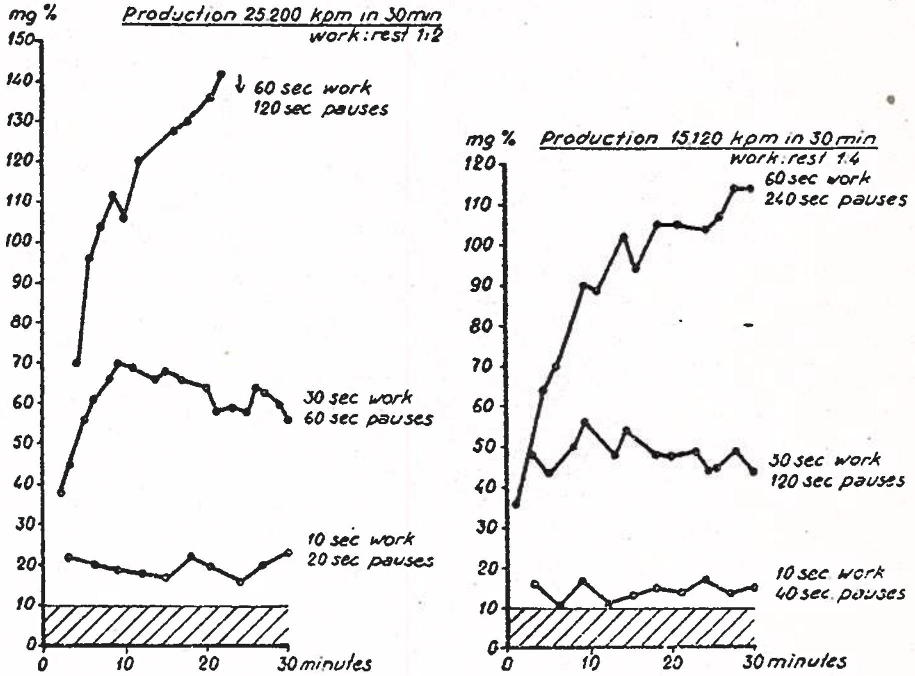

Fig. 1 and 2. The blood lactic acid concentration at a total work production of 1) 25,200 kpm and 2) 15,120 kpm during an experimental time of 30 min. The work is performed with a load of 2,520 kpm/min. The work periods last for 10, 30 and 60 sec and the corresponding rest periods for 1) 20, 60 and 120 sec and for 2) 40, 120 and 240 sec.

very close to the normal rest value of about 10 mg per 100 ml. If the work periods are lengthened to 30 sec and the pauses to 60 sec, one finds a significant increase in the blood lactic acid concentration; after about 9 min a maximal value of 70 mg per 100 ml is reached (see Fig. 1). After that there is a small reduction and the values remain approximately at 60 mg per 100 ml until the end of the experiment. At the longer pauses of 120 sec, and consequently a smaller amount of work performed (Fig. 2), a maximal value is also obtained after about 9 min, now at 56 mg per 100 ml, and thereafter the values are stabilized between 40 and 50 mg per 100 ml. Therefore, even with work periods of 30 sec a certain equilibrium is reached between the production and the elimination of lactic acid. With work periods of 60 sec, however, a corresponding balance is never reached; the lactic acid concentration increases until the end of the experiment. With the relatively short pauses of 120 sec (Fig. 1), the blood lactic acid concentration reached a maximal value of 142 mg per 100 ml after 22 min. The experiment was then interrupted because the subject was no longer able to continue. With pauses of 240 sec (Fig. 2) the task could be fulfilled for 30 min and the blood lactic acid concentration reached a value of 114 mg per 100 ml at the end.

Discussion

The present results confirm earlier findings by Åstrand *et al.* (1960). They show conclusively that a principal difference exists in man's reaction at intermittent work to short and relatively long work periods, even if the total amount of work in a certain time is the same. Furthermore, the results answer the question, whether the length of the work period or the length of the pause is the deciding factor for the blood lactic acid concentration. In the earlier series of experiments, as stated above, the length of the work periods and pauses were always equal in the same experiment, which brought about difficulties for making a conclusive interpretation in this respect. It can be seen from the results in Table I that the most decisive factor is the length of the work period (compare series I—IV). From the results in series III it is most apparent that even the length of the pause has a certain significance. In this series the work period was 30 sec and the pauses on the different experimental days varied between 30 and 240 sec. With a pause of 30 sec there were 30 work occasions during the half hour, with a pause duration of 240 sec there were only 7 work occasions. Fewer work periods naturally decrease the possibilities to produce lactic acid, and longer pauses provides greater possibilities for the elimination of lactic acid. That explains the decrease in blood lactic acid concentration from 78 mg per 100 ml, which was the maximal value with 30 sec pauses, to 41 mg per 100 ml with 240 sec pauses. Accordingly, the duration of the pauses has a secondary importance in comparison to the duration of the work periods. This is also illustrated by the results given in Fig. 1 and 2.

It is of great interest whether or not the present results are in agreement with the hypothesis mentioned above that the difference in the reaction at short (10 and 15 sec) and long (30 and 60 sec) work periods can be explained by the rôle of myohemoglobin as an oxygen-store.

One knows that the oxygen transport by the blood to the working muscles increases with the duration of the work period, and that equalization between oxygen need and supply can take several minutes to occur. In the series of experiments performed with 10 sec of work and 20 sec of rest, the oxygen intake was determined during the work period, and corresponds to 2.80 l/min. During the 10 sec of work the actual oxygen intake was 1/6 of this, or 0.47 l. The oxygen intake during work was 10 times greater than a corresponding rest value of 0.043 l. The oxygen intake during the last 30 sec of a 60 sec work period with 120 sec pauses gave a maximal value of 4.08 l O_2/min, or 0.68 l O_2 for 10 sec. In the latter case the oxygen intake was 16 times greater than the rest value. To be adequate for a load of 2,520 kpm/min an oxygen supply of 5.6 l/min or 0.9 l per 10 sec is required according to Table I. During the experiment with work for 10 sec and pauses for 20 sec we must calculate with a deficit of 0.90 — 0.47 = 0.43 l O_2. With work for 60 sec and pauses for 120 sec, the oxygen intake during the whole work period was maximally 3.26 l

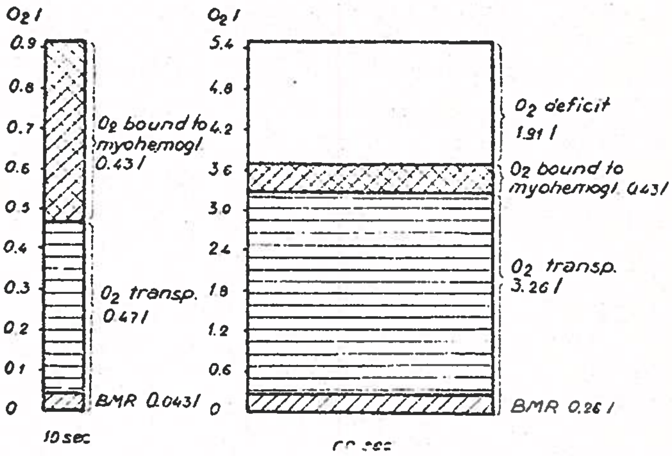

Fig. 3. The oxygen demand for 10 and 60 sec work with a load of 2,520 kpm/min. An attempt is made to illustrate the fraction of O_2 that is a) bound to myohemoglobin, b) transported by the blood and c) O_2 deficit.

(during the first half min 2.43 l/min and during the second half 4.08 l/min). This means a deficit of 5.60 — 3.26 = 2.34 l O_2. The reason that the oxygen intake during the first half minute of a 1 min work period is relatively smaller than during the 10 sec periods (2.43 and 2.80 l/min respectively) is that during the short pauses of 20 sec the circulation and respiration never decline severely before the work is begun again. If the pauses are lengthened to 2 min, the time for adjustment becomes significantly increased.

With work for 10 sec and pauses for 20 sec we must assume practically aerobic conditions in the working muscles. If such were not the case, the 60 work occasions should have brought about a successive accumulation of lactic acid as a consequence, compare Fig. 1. We believe that the conclusion can be drawn that approximately 0.43 l O_2 have been available in the working muscles at the beginning of each new work period, naturally even at the 60 sec periods. Quantitatively this means, that a supply of oxygen for the 10 sec periods is assured by that amount, which is already in the muscles and by the amount which can be transported by the blood during the work itself. For 60 sec work, a deficit of 1.91 l arises. This must be covered by anaerobic processes, which results in an increase of the lactic acid concentration in the blood.

Fig. 3 illustrates schematically the relative importance of the postulated amount of oxygen in the muscles at 10 sec and 60 sec work periods respectively.

Naturally, the oxygen supply to the muscles becomes smaller at a single work occasion, and the anaerobic factor is of greater importance quantitatively. If the work time is sufficiently short the amount of oxygen bound to myohemoglobin should, however, be able to play a decisive rôle for the muscle metabolism even in those cases. A revaluation of the so-called Simonsen-effect must be the consequence. According to Müller and Hettinger (1957) this effect is important during the first 10 sec of work and results in an extra oxygen consumption as a result of the anaerobic conditions in the muscles.

On the basis of the results given here the amount of the oxygen which is available at the beginning of the work can not, of course, be determined. If one attempts to calculate the amount of oxygen bound to myohemoglobin, one is immediately confronted by a whole series of more or less unknown factors. One is not familiar with the size of the active muscle mass, the myohemoglobin concentration of the musculature or the degree of reduction of oxymyohemoglobin. If one uses the values given in the literature for myohemoglobin for example by Biörck (1949, p. 131), one finds that each gram of muscle can bind about 10 mm^3 O_2. If one assumes 20 kg of active muscles for the subject in the work mentioned here, one arrives at a value of 200 ml O_2. There is still a deficiency of about 230 ml, according to the above. The values given by Biörck are in this case too low, since it is generally accepted that the amount of myohemoglobin increases with training, and the values given above are not derived from specially well trained individuals.

It is quite evident from the investigations of Scholander, Irving and Grinnell (1942) on diving seals that myohemoglobin can constitute an important factor for oxygen supply to the musculature. According to our conception, the experimental results laid forth here indicate that myohemoglobin has an important function as an oxygen-store even in man. The reader is referred to Biörck (1949, p. 42), regarding references for and against such a conception based on earlier findings.

Before a definite answer can be given to the question of the quantitative rôle which myohemoglobin plays in this respect, further investigations are required on myohemoglobin concentration in trained individuals. It is our hope that the experimental results related here will help to create greater interest into this field of research.

References

Åstrand, I., P.-O. Åstrand, E. H. Christensen and R. Hedman, Intermittent muscular work. *Acta physiol. scand.* 1960. *48.* 448—453.

Biörck, G., On myoglobin and its occurrence in man. *Acta med. scand.* 1949. Suppl. 226. 42. 131.

Müller, E. A. and Th. Hettinger, Der Energimehrbedarf bei Arbeitsbeginn. *Arbeitsphysiologie.* 1957. *16.* 480—499.

Scholander, P. F., L. Irving and S. W. Grinnell, Aerobic and anaerobic changes in seal muscles during diving. *J. biol. Chem.* 1942. *142.* 431—440.

Stockholm 1960. Kungl. Boktr. P. A. Norstedt & Söner

EXCERPTUM

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Intermittent Muscular Work

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Abstract

Åstrand, I., P.-O. Åstrand, E. H. Christensen and R. Hedman. *Intermittent muscular work.* Acta physiol. scand. 1960. *48.* 448—453. — The physiological effect of rest pauses on a non-steady state work (2,160 kpm/min) was studied. A physically well trained subject performed in one hour a total amount of 64,800 kpm on a bicycle ergometer by intermittent work with 0.5, 1, 2 or 3 min periods of work and rest. Total O_2 intake, total pulmonary ventilation, total number of heart beats and blood lactic acid concentration during the work hour and during recovery were determined. It was found that the heavy work when split into short periods of work and rest (of 0.5 or 1 min duration) was transformed to a submaximal load on circulation and respiration and was well tolerated during one hour. With longer periods (of 2 or 3 min duration) the work output got close to the upper limit of performance and could be fulfilled only with the utmost strain. These findings are discussed from a physiological and practical point of view. In order to explain the low lactic acid values during the short periods of work and rest it was proposed that the myohemoglobin has an important function as an oxygen store during short spells of heavy muscular work.

It is a well known fact that the oxygen intake during the initial period of heavy work does not correspond to the energy demand; due to a time lag in respiration and circulation a certain oxygen deficit arises. It takes one or several minutes, depending upon the work load and the physical fitness of the individual, before the oxygen intake reaches a steady state level. At severe work a steady state will never be reached, and the work time will be limited by anaerobic metabolites in the muscles, blood and other tissues.

The problem for our present research work is to analyze the effect of rest pauses on different physiological functions responsible for the increased metabolism during such a non-steady state work (2,160 kpm/min).

In these experiments the work periods and the pauses varied between 0.5 and 3 min. During the same experiment they were always constant and of equal length. The total work time was one hour and the effective work time and the rest time were consequently always 30 min each. During the one hour the total work amounted to 64.800 kpm, or an average of 1,080 kpm/min. In this way it was possible to compare the physiological effect of intermittent work of 2,160 kpm/min and continuous work of 1,080 kpm/min. The trained subject could perform the latter work for hours without fatigue.

If the periods for work and rest are 0.5 min, 60 initial work periods will occur with all the consequences this may have as far as O_2 intake, heart rate, pulmonary ventilation and so forth are concerned; if the periods are 3 min the number of initial periods will only be 10, and the different physiological functions responsible for O_2 transport may, towards the end of the work period, reach values that are fairly close to the demand. Consequently one might expect to find a reduced tendency for anaerobic metabolism in experiments with 3 min periods compared to the shorter ones in which the oxygen transport during work always will be far below the demand. The following experiments, however, gave the opposite result.

Subject and Methods

All experiments were done with one physically well trained male subject, R. H., age 25 years, weight 74 kg and height 177 cm. His capacity for oxygen intake at 6 min of work on the bicycle ergometer was 4.6 l/min or 62 ml/kg×min. His basal pulse rate averaged 49 beats per min and his basal O_2 intake was 0.26 l/min.

Work was performed on a Krogh bicycle ergometer at 60 pedal revolutions per min with a load of 6 kg corresponding to 2,160 kpm/min; in the experiments with continuous work for one hour the load was 3 kg and the work load was 1.080 kpm/min. The expired air was collected in Douglas bags and analyzed according to the Haldane technique. The heart rate was recorded with an electrocardiographic pulse counter during the work hour and during 60 min of recovery after work. The resting values for pulse rate and O_2 intake, and the recovery values were taken with the subject reclining on a bed close to the bicycle. The determinations during work pauses were done with the subject sitting on the bicycle. Blood samples for lactic acid determination were taken from the warmed up finger tip and the analyses were done according to Barker and Summerson (1941) with the modification of Ström (1949). Rectal temperature was determined before and immediately after work, as was the weight ± 50 g to get information about the heat regulation.

Results

Certain of the investigated functions are shown in Table I to make possible a comparison between different work forms. The number of experiments is limited, motivated partly by the high accuracy of the methods used and partly by the extreme demands which a work form of 2 or 3 min places upon the

Table I. Total O_2 intake, work efficiency, total number of heart beats and total pulmonary ventilation during continuous and discontinuous work

		I total O_2 intake (l) "work hour" STPD	II total O_2 intake (l) "recovery hour" STPD	III work efficiency per cent	IV total number of heart beats "work hour"	V total number of heart beats recovery hour"	VI total pulm. vent. (l) "work hour" BTPS
continuous work 1,080 kpm/min		145.5	19.9	23.4	7,904		2,847
1,080 kpm/min		145.9	19.1	23.4	7.859	3.683	2,916
discontinuous work 2,160 kpm/min							
work min	pause min						
0.5	0.5	154.1	21.8	21.5	8,637	4,299	3,266
0.5	0.5	154.2	19.6	21.9	8.493	4,276	3,202
1	1	152.2	21.7	21.6			3,330
1	1	152.4	20.0	21.9	8,295	4,211	3,406
2	2	160.1	21.0	20.4	8,579	4,715	3,908
3	3	162 9	24.2	19.4	9,215	5,219	4,355

subject when the work shall be carried on for one hour. However, further experiments were made although only some of the functions given in the table were measured, and these results are in agreement with the values in the table. Furthermore, it should be pointed out that each result given in Table I on O_2 intake and pulmonary ventilation during work and recovery is based on a large number of determinations in one and the same experiment. For example, the values for O_2 intake at 1,080 kpm/min are based upon a total of 38 determinations made between the 2nd and the 60th min of work. An average for O_2 intake of 2.44 l/min, with a standard deviation of $\pm$ 0.038 l/min and an error of the mean of $\pm$ 0.006 l/min, illustrate the accuracy of the method and the stability of the subject.

From Table I it can be seen that the mechanical efficiency is highest (23.4 per cent) at continuous work of 1,080 kpm/min; at discontinuous work with 0.5 or 1 min periods the mechanical efficiency is 21.7 per cent, at 2 min periods, 20.4 per cent and at 3 min periods, 19.4 per cent. The moderate lowering of the efficiency at the short periods as compared with the 2 and 3 min periods is also illustrated by the difference in the total number of heart beats (IV and V). The pulse sum increased from approximately 11,500 at continuous work to about 12,500 with the one min periods and to about 14,400 with the 3 min periods. The total pulmonary ventilation (VI) shows the same tendency;

Table II. Maximal and minimal values of O_2 intake, pulmonary ventilation, heart rate and blood lactic acid concentration during continuous and discontinuous work

	O_2 intake l/min STPD		pulm. vent. l min BTPS		heart rate beats/min		lactic acid mg per 100 ml
	max	min	max	min	max	min	
continuous work 1,080 kpm/min	2.44		49.0		134		12
2,160 kpm/min 9 min....	4.60		124.0		204		150
discontinuous work 2,160 kpm/min.............							
work min pause min							
0.5 0.5............	2.90	2.30	62.5	44.5	150	137	20
1 1	2.93	2.23	65.3	47.5	167	99	45
2 2	4.40	1.00	95.0	35.0	178	106	95
3 3	4.60	1.00	107.0	36.0	183	118	120

it increased from 2,880 l during the work hour at continuous work to 3,370 l at work with 1 min periods and to 4,350 l at the 3 min periods, which means an increase of 17 and 51 per cent respectively. With regard to heat regulation, work at 3 min periods seems to differ from the others, with an increase in the rectal temperature of 2.0° C (38.9° C). In the other cases, the rectal temperature after the work hour was around 38° C, with a maximal increase of 1.35° C. Loss of weight was more or less identical for the different forms of work and amounted to about 700 g.

Work with short periods was subjectively felt to be relatively light, and the subject experienced no fatigue after one hour. Work at 2 and specially at 3 min periods meant a nearly maximal or a maximal load. Only by strong motivation could this work be performed for a whole hour. A closer analysis of the values in Table II, which contains maximal and minimal values for O_2 intake, pulmonary ventilation and pulse rate for intermittent work, provides an explanation for this difference in subjective strain. The values for continuous work at 1,080 and 2,160 kpm/min respectively, are also included in Table II for comparison. The maximal values refer to determinations made during the last half minute of the work period. In the same way, the minimal values refer to the last half minute of the rest period. It should be pointed out that due to the technique used for collection of expiratory air during 0.5 min, the given figures do not represent the absolute maximal or minimal values; this may have a certain significance at the 0.5 and 1 min periods. Since the high values for O_2 intake and pulse rate are first reached 15 to 20 min after the beginning of the work hour, the values given in Table II are representative for the latter part of the work period and not for the first 5 or 10 min. The lactic acid values are valid for the time immediately following the end of the work hour, but generally the blood lactic acid concentration reached a more or less constant level about 15 to 20 min after the beginning of the work hour; a continuous accumulation of lactic acid consequently did not take place.

The most surprising results obtained were the low lactic acid values, about 20 mg per 100 ml, at the work with short periods. According to the introductory considerations, this work form might be expected to result in relatively unfavourable conditions for oxygen supply to the active muscles. The low lactic acid values found contradict this assumption.

Discussion

The results given above are of interest for several reasons. They confirm findings reported elsewhere by CHRISTENSEN, HEDMAN and HOLMDAHL (1960) that the mechanical efficiency at intermittent work, with suitable load and duration of work and rest periods, does not lie on a considerably lower level than at continuous work.

The fact that one can obtain a great amount of work done at an extremely heavy load with a clear submaximal load on circulation and respiration by suitable application of short work and rest periods, is of great practical and physiological interest.

The results illustrate that one can divide the total amount of work into suitable periods in such a way that one can induce training of large muscle groups without simultaneously loading the respiratory and circulatory organs (work with short periods over long time). By choosing longer periods, for example 2 to 3 min, one can obtain a high training effect also on respiration and circulation. This is of interest not only for the training of sportsmen, but also for rehabilitation of patients during the convalescent period, etc.

The reason why older workers in spite of lowered capacity for oxygen intake, to a surprisingly high degree, remain in physically heavy jobs such as forestry and farming may also be explained. If these workers spontaneously choose a suitable length of work and pause periods, the acute loads on respiration and circulation do not need to exceed the moderate range corresponding to the old individual's reduced capacity. If, however, the work pace is determined by a machine, even a less heavy work with relatively long work periods may involve an elimination of the older workers.

In the present investigation the work periods and the rest pauses were always equal in duration in the same experiment. Therefore it is difficult to decide whether the short work periods or the short pauses cause the favourable results obtained. This problem will be more thoroughly analyzed in a following investigation.

A relationship between the time for work and for rest of 1 : 1 seems to give practically full recovery if the duration of the period is 0.5 min. On the other hand, this is not at all the case if the period length is 2 or 3 min. It is important to stress the fact that the so called rest allowances used in industry to avoid overloading of the workers, based on average caloric consumption during the 8-hour work day, according to our findings may have entirely different physiological effects dependent on the duration of work and rest periods.

In order to explain the low lactic acid values at the short periods, two hypotheses may be proposed. The first postulates that the rate of formation of lactic acid is the same, independent of the length of the period, but that lactic acid during the short periods of rest is eliminated almost at the same rate. According to Lehmann (1953 p. 49) many short rest pauses should imply a more favourable recovery than longer, but thereby fewer, pauses.

The other hypothesis assumes that the formation of lactic acid during the short work periods is reduced to a minimum. This would mean that the liberation of energy during the initial phase (0.5 min) of a work of 2,160 kpm/min could take place practically aerobically. This conflicts with earlier assumptions but seems nevertheless to give the most probable explanation for the experimental findings related here. Oxygen transport by the blood to the muscles during work is both absolutely and relatively less during the short work periods; if in spite of this the work is aerobic, this must depend upon the amount of oxygen which the muscles dispose of at the very moment when the work is started. The oxygen bound to myohemoglobin and to hemoglobin in the muscles and the amount which comes to the muscles with the blood during the 0.5 min of work must be the prerequisite for this aerobic work. During the pauses, even if they are only 0.5 min long, the myohemoglobin must certainly have time to be reloaded with oxygen before the next work period begins. During work periods of 2 or 3 min, the oxygen transport to the muscles is relatively greater but never becomes adequate, and the oxygen bound to myohemoglobin, which suffices for only a short part of the whole work period, becomes of much less importance.

If this assumption is correct, myohemoglobin has a fundamentally important function in addition to the traditionally accepted one, *i. e.* that it plays a certain role as an O_2 buffer in the muscle, being re-charged during relaxation so that it can be reduced during the following contraction. According to the viewpoints presented here, myohemoglobin should represent an oxygen store which is used during the initial phase of work before circulation and respiration are able to reach the values which correspond to the actual oxygen demand. Further research on these points will be taken up in another investigation.

References

Barker, S. B. and W. H. Summerson, The colorimetric determination of lactic acid in biological materials. *J. biol. Chem.* 1941. *138.* 535—554.

Christensen, E. H., R. Hedman and I. Holmdahl, The influence of rest pauses on mechanical efficiency. *Acta physiol. scand.* 1960. *48.* 443—447.

Lehmann, G., Praktische Arbeitsphysiologie. Stuttgart, Georg Thieme Verlag. 1953. 49.

Ström, G., The influence of anoxia on lactate utilization in man after prolonged muscular work. *Acta physiol. scand.* 1949. *17.* 440—451.

Stockholm 1960. Kungl. Boktr. P. A. Norstedt & Söner

1967 Yant Award

Occupational Health Institutes: An International Survey

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Yant Memorial Lecture

Occupational Health Institutes: An International Survey

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The William P. Yant Memorial Award was established shortly after the death of Dr. Yant, to commemorate his dedicated years of service and pioneering achievements in industrial hygiene. He was for many years affiliated with the Mine Safety Appliances Company, becoming director of research and vice-president, and in memory of this service the company sponsors and supports this award under the auspices of the American Industrial Hygiene Association. The award is presented to a person from outside the United States who is outstanding in one or more of the industrial health sciences. The first award was presented in 1965.

Dr. Sven Forssman, Director of the National Institute of Occupational Health, Stockholm, Sweden, is the recipient of the 1967 Yant Award. Dr. Forssman is also Professor of Occupational Health of the Caroline Institute (Stockholm) and President of the Permanent Commission and International Association on Occupational Health. He received his degree of Medical Doctor from the University of Lund, where he was later Professor of Pharmacology. He served also as Professor and Chief of Occupational Health at the National Institute of Public Health (Stockholm), as medical adviser to the Swedish Employers Confederation, and President of the Joint Industrial Safety Council. He has been active as a consultant of the World Health Organization and as Chief of their Social and Occupational Health Unit.

Dr. Forssman has been honored repeatedly in many countries by honorary membership in professional societies and institutions. His outstanding work in the toxicology and pharmacology of occupational health has earned the world-wide recognition which so fittingly has led to his present honor of receiving the 1967 Yant Award.

History and Background

DURING THE industrialization of the 19th century, the health hazards from work and working environment became increasingly important in many countries, especially with the increase in the number of people exposed. More study gradually was devoted to occupational diseases and accidents by physicians and surgeons. Institutes on occupational health were then mainly concerned with clinical studies of occupational diseases and injuries, either in a general way as was the case at the first institutes, founded in Italy, Milano and Naples; or devoted to some special problems, as at the institute on silicoses in South Africa. Other countries followed later the same pattern, and clinics on occupational diseases were established, among other places, in Berlin, Germany. In some countries, however, the first studies on occupational diseases were carried out by pathologists or experts on legal medicine, and legal medicine and occupational medicine were thus combined in the institutes set up in countries, such as France.

In addition to the clinical studies on occupational diseases industrial hygiene engineering was developed in several countries, especially in the USA, hence making evaluation of exposure and technical prevention more efficient.

It was gradually recognized that the influence of work and working conditions upon man was not limited to occupational diseases. Industrial fatigue was studied, for instance in England and the USA. The adjustment of man to work and the adjustment of work to man was considered to be important. Methods for job analysis, selection and placement were developed. Applied anatomy, physiology and psychology were now included in occupational health, and these experiences were used in industry for the design of machines. A new field (human engineering or ergonomics) was developed. The scope of occupational health institutes was widened. Occupational health was defined in 1950 by a joint ILO/WHO Committee on Occupational Health as follows:

> "Occupational health should aim at: the promotion and maintenance of the highest degree of physical, mental, and social well-being of workers in all occupations; the prevention among workers of departures from health caused by their working conditions; the protection of workers in their employment from risks resulting from factors adverse to health; the placing and maintenance of the worker in an occupational environment adapted to his physiological and psychological equipment and, to summarize: the adaptation of work to man and of each man to his job."

When developing countries entered the industrializing stage during 1950-1960, it was recognized that there was great need to build up occupational health and industrial health services at the same time. The establishment of occupational health institutes in developing countries, considering their special problems, has lately been recognized as very important to the health of the working population. Model plans for occupational health institutes of different sizes, minimum, average and complete establishments, were described in a report of the Joint ILO/WHO Committee on Occupational Health. (WHO Techn. Report Series No. 135, Geneva 1957).

Scope and Functions

The main functions of occupational health institutes are *research, service* and *teaching,* according to the wide definition of occupational health recognized today.

At the beginning of the 20th century occupational health was mainly considered to consist of studies on occupational diseases, their causes, diagnoses, treatment and prevention. Well equipped clinical departments for occupational diseases were included in the institutes organized in that era. In most countries they are still kept as an important part of an occupational health institute. Modern occupational health engineering methods are now commonly used in prevention of occupational diseases, in addition to medical methods.

As many occupational diseases are of the internal medicine class, (diseases of lungs, liver, kidneys, and blood-forming organs), clinics on occupational diseases are also open in several countries to patients with nonoccupational diseases relating to internal medicine. Methods to evaluate lung function or physical working capacity may well be applied to occupational diseases such as silicoses as well as to nonoccupational diseases such as chronic bronchitis and emphysema. This combined concern with occupational and nonoccupational diseases is of value also in keeping the personnel abreast with developments in general clinical sciences.

The prevalence of occupational diseases is gradually decreasing in many countries but it is still necessary to retain the special clinical departments for diagnosis and treatment. It is then practical to use the available experts and techniques also for studying nonoccupational diseases, whereby the evaluation of working capacity and rehabilitation is of special concern.

The experience gained on occupational exposure to toxic gases will also be of value in studying air pollution in cities. In several countries the field of activities of occupational health institutes have been widened to "environmental health," which usually means occupational health and air pollution.

Since occupational health now includes the general adaptation of work to man and of man to work, physiological and psychological aspects have been included in the field of activities. Ergonomics and human engineering are applied when production methods and working environment are adjusted to man. Industrial psychology and sociology are used in studying the mental capacity of the worker in relation to the demand of the work, the worker's attitudes towards his job, and human relations at work.

Research

In principle it has been found most efficient to devote the research activities mainly to applied research, dealing with occupational health problems of practical importance to the country concerned.

Research on *occupational diseases* has during recent years mainly studied the mechanism of action of toxic substances, methods to detect already minor deviation from health, and diagnosis at an early stage of disease. As examples of research of this type we may mention the studies on silicoses concerning the mechanism of collagen formation. the lung clearance of inhaled particles and factors influencing it, the distribution of metals such as cadmium, lead. mercury in different tissues, the inhibition of the synthesis of haemoglobin and the increased excretion of ALA (aminolaevulic acid) with lead exposure and the metabolism of chlorinated hydrocarbons such as the transformation of trichlorethylene to trichlorethanol and trichloracetic acid. The effect of certain toxic substances upon higher nervous functions have also been studied, for instance, in institutes in Moscow, Prague and Zurich.

Importance has been placed on the study of occupational and nonoccupational diseases as well as accidents at work from the epidemiological approach. It has been emphasized that a disease or an accident is a result of many factors, and to understand the mechanism and to achieve efficient prevention it is necessary to study the complex interaction of all these factors. The approach "one disease - one cause" has sometimes oversimplified the problem of occupational diseases. Already the great individual differences in sensitivity to exposure to occupational hazards will show that many factors are involved in the effect of a toxic substance upon man.

During the last 40 years *occupational health engineering* has been gradually developed. The activities of occupational health institutes in the USA have been of greatest value in developing this field. Methods have been worked out for dust counts or analysis of gases in order to study exposure through industrial hygiene surveys, evaluating the concentration of contaminating substances in air, their variation according to production, weather conditions, seasons, etc., taking into account the time of exposure of the individual worker. The outstanding contributions of research workers, such as Philip Drinker, Theodore Hatch and William Yant, whom I have had the honour to know personally, should be especially mentioned.

Studies on incidence of diseases in relation to occupational exposure have resulted in the establishment of maximum allowable concentrations (MAC) and threshold limit values (TLV) of toxic substances in air, to be used for guidance in prevention. Considerable differences are found in some values from different countries. International agreement on the principles applied would be of value for future progress. A new approach would be to establish four different values, from the concentration with an effect within normal variations up to a concentration with obvious symptoms of intoxication. Permanent cooperation between different institutes in different countries and guidance from an international organization are of equal significance. Maximum allowable concentrations in biological material (blood, urine, tissues) have been studied as well as "normal" values of toxic substances.

The prevention of occupational diseases is based nowadays chiefly on an industrial hygiene engineering approach. Medical prevention is useful but mainly to support the technical prevention, and to control its efficiency, especially in regard to its practical application and its relation to the human factors. Efficient research and field studies on occupational diseases is today a result of team work between physicians, chemists, physicists and engineers.

Methods for physiological measurements, such as pulse rate, oxygen consumption, body temperature, have made it possible to study in detail the physical work load on the human being in order to eliminate peak loads at work and thus increase the possibilities of placing "ordinary" workers in formerly "heavy" jobs. Studies of *work physiology* on such problems as heavy work, hot environment, fatigue, have been carried out in many institutes, for instance by Belding (Pittsburgh), Bonjer (Leyden), Grandjean (Zurich), Karvonen (Helsinki), Christensen and Lundgren (Stockholm), Lehmann (Dortmund), Metz (Strasbourg).

In most countries heavy work is now gradually disappearing due to mechanization. Consequently, in industry there seems to be a gradual change of work load from the physical to the mental side. Psychology will thus be of greater future significance, when ergonomics is concerned with designing instrument panels and the like. Among problems of *industrial psychology* may be mentioned perception of signals, instrument panels, decision-making, job design and variation of performance with age. Methods of selection and placement have been developed.

Research on occupational health should closely follow current developments and try as far as possible to estimate future problems. One side of research activities should be *concerned with production.* It is essential to study the introduction of new methods of production and their possible health hazards as well as general changes in production, which may create problems of human adjustment to work, such as the introduction of mechanization and automation. Research conducted by occupational health institutes should try to be a few years ahead of the technical development of production methods and hence be prepared to issue recommendations on preventive measures when changes of production are introduced in practice.

The other side of research activity should deal with the labor force, the *human aspect of man at work,* his adjustment, etc. It would be of great importance for occupational health institutes to follow changes in the labor force of the country and changes on the labor market.

A shortage of labor, for instance, may call for the increased employment of handicapped workers and married women. It will therefore be desirable to study methods for the proper placement and adjustment of especially vulnerable groups.

The increasing expectation of life and the reduced birth-rate in many countries will change the age distribution of the population and of the labor force, resulting in an increased number of middle-aged and old people at work. An important task for occupational health research is to study the abilities and disabilities of the aging man in order to ensure him a proper adjustment to work.

It is of greatest importance that the results from research should not only be published in scientific journals but should also be made available to industry and applied in practice, if necessary through practical experiments. The research activities of occupational health institutes will thus promote the health of the worker, contribute to his adjustment to work and prevent occupational health hazards.

Service

Industries and other places of employment, employers' and workers' organizations, and government authorities have need now and then for expert advice in order to solve special occupational health problems. It is imperative that the occupational health institutes be prepared to carry out such studies upon request as a service. It is essential for the country concerned to solve its many practical occupational health problems in such a way. These studies, however, are also of value for the occupational health institute as a source of information to the institute as to what practical problems are significant at places of work.

As examples, the following studies from Sweden may be mentioned. The workers of a storage battery plant complained of fatigue; the problem was discussed at the joint safety committee, and the factory asked the national institute for a study which led to the discovery of cadmium proteinuria.

The management of a chemical factory was apprehensive that a health hazard was connected with a certain part of their production. It involved possible exposure to a substance of which then little knowledge was available as to its toxicity. A health examination of the exposed group and of a nonexposed group, as well as an industrial hygiene survey, carried out by the national institute, showed no difference between the two groups, and the safety of working conditions from the industrial hygiene point of view seemed to be acceptable.

An iron mine, where diesel-engine trucks were used extensively for underground transport, was the source of a request for a study on possible health hazards from exhaust gases. Health examinations on an exposed group compared with a nonexposed group, as well as an industrial hygiene survey on gases in the mine, were carried out by the national institute.

There is, however, a certain danger that the demand for service upon an institute may be so considerable that there will be insufficient time left for research and teaching. It is very important for an institute to keep a proper balance between activities of their own initiative, such as research and teaching, and service upon request. One institute (Prague) has found it practical to devote about 25% of its activities to service and the rest to research and teaching. This seems to me to be a reasonable proportion also for the Swedish National Institute of Occupational Health. At another institute (Helsinki) it has been practical to devote more time to service work, which provides 70 to 80% of the annual budget of the institute.

If an institute cannot deal with all service problems referred to them by industries, trade unions, etc., the possibility must exist to refer these problems to other organizations, such as regional or local institutes on occupational health, hospital departments on occupational diseases, university institutions, occupational departments of large industries, and private research organizations. A national institute of occupational health will work efficiently only if it has a proper regional organization to which it can delegate a certain part of its activities. As an example, the organization of health centers in Yugoslavia can be mentioned. The system here is that the occupational health institute in each republic of the federation may refer local problems to these centers and they on their part can refer more complicated problems to the national institute.

An institute of occupational health carrying out service work will be of material value to its country. Practical problems on occupational health will be solved, safety and health at places of work will be promoted and service problems of general scope will stimulate the institute to carry out more extensive research work.

Teaching

The development of occupational health in a country calls for the availability of trained personnel, such as physicians, engineers, nurses, psychologists and physiologists. The aim of *undergraduate teaching* for medical students and engineering students and so forth should be to give a short introduction to the main problems of occupational health, excite their interest in occupational health and inform them on literature and where they can procure more information.

The teaching of occupational health institutes, however, will be mainly at graduate and post-graduate level. The *graduate teaching* of specialists, such as industrial physicians or industrial hygiene engineers, will be one of the major teaching activities of occupational health institutes. In many countries, courses of one or two years' duration are given, leading to a diploma in occupational health. The training courses in the USA such as at Harvard University, University of California (Berkeley), University of California at Los Angeles, University of Cincinnati, Pittsburgh University and Michigan University should be especially mentioned. Some institutes or occupational health departments of schools of public health have their graduate courses open also for students from other countries, as in England, France and the USA. It is extremely important that the teaching gives practical information to be used in the field by the participants when they go back to industries or other field activities.

Post-graduate training includes courses on special problems such as pneumoconiosis, prevention of industrial noise, mental health in industry, ergonomics of machine design, or general refresher courses for specialists.

Many countries do not have enough specialists available to organize institutes and training courses. *International training courses* have therefore been organized by the World Health Organization and the International Labor Office. These courses have been either training courses, with a duration of a few months up to a year, or shorter courses or seminars, for already experienced participants, where special problems are examined such as ergonomics, occupational health problems in agriculture, and occupational health in developing countries.

As occupational health is today essentially a matter of team work among specialists from different fields, it has been found most valuable to organize graduate and post-graduate courses in the form of joint instruction for engineers, physicians or other experts. This will make it possible for each group to understand the problems and the language of the others and will foster a team spirit right from the teaching stage.

Organization

The occupational health institutes may be set up within universities, where they may be separate institutes or they may be a department within a school of public health as in England (London), the USA (Harvard University, Michigan University, Pittsburgh University), the Netherlands (Leyden), the United Arab Republic (Alexandria), or a medical school, as in France and Italy. In Zurich, Switzerland, the occupational health department is organized within the Technical University. In several countries, including Japan and Sweden, the institutes are directly under the Ministry of Labor or the Ministry of Health, sometimes closely connected with the Chief Factory Inspectorate of the country. Some institutes may be organized by labor unions, by insurance companies, by large industrial concerns or by a mixed state and private foundation as in Finland (Helsinki). In some countries the leading occupational institute of the country is closely connected with the Academy of Science such as in USSR, Moscow, and Yugoslavia, Zagreb.

A national institute of occupational health should be organized, if possible, to comprise all necessary departments or units, such as medical unit, industrial health engineering unit, physiology unit, toxicology unit, psychology unit, rehabilitation unit, statistical unit and educational unit. In the third report of the Joint ILO/WHO Committee on Occupational Health, Geneva, 1957, plans are published for minimum establishment, average establishment and complete establishment of an occupational health institute. This stepwise approach may be of great value for countries planning to organize such institutes.

In several large countries where there are several occupational health institutes, a certain degree of specialization will very often take place. This is so in the USSR, for instance, where there are about 15 institutes on occupational health, including a leading institute in Moscow. Some institutes have specialized on certain problems of great importance in the region where the institute in question is located. For instance the Kiev Institute specializes on the health problems of agriculture, and the Charcow Institute, on silicoses. In USSR special "problem committees" have been created within the institute in order to coordinate research to decide what occupational health problems should be given priority and to which institute they should be referred.

In many countries there are local institutes or departments of occupational health within the local institute on public health. These local institutes will deal with local problems. A national institute can also refer the practical application of results from research to these institutes in order to have the results applied in the field.

Some countries have preferred to establish special institutes or units for special problems instead of always organizing a complete institute on occupational health with all available specialists. This is partly the situation in the United Kingdom, where research units are established, such as the research center on pneumoconiosis and research center on toxicology. The Federal Republic of Germany has a research institute on pneumoconiosis (Institut für Staublungenforschung) in Münster, and an institute on work physiology (Dortmund).

Developing Countries

Industrialization especially in developing countries will cause a transfer of large groups of the population from agriculture and rural areas into industries and industrial cities. Such a shift will create many health problems related to working conditions as well as to social conditions and these will call for preventive measures. There is great need to develop industrial health services apace with industrialization in order to prevent the health hazards that will occur when people, often with high morbidity and unaccustomed to industrial work, are absorbed into industry and industrial cities. If prevention is not applied and included at the planning stage a high frequency of accidents and occupational diseases may occur.

It must also be borne in mind, although it is outside the field of occupational health, that the health aspects must be considered when new industrial communities are being planned, since serious health hazards and difficulties in social adjustment will occur.

An occupational health institute organized in a developing country at the beginning of an industrialization era will be of greatest value in promoting the health of the worker. Applied research and service will deal with the practical health problems in industry, teaching courses will provide the new industry with industrial physicians and safety and industrial hygiene engineers.

The organization of occupational health services in industries, mines and other places of employment can be supported by the institute, in studying the needs and the problems that should have priority in such a service.

Several developing countries have organized occupational health institutes either separately or as departments within a public health school as in Alexandria and Calcutta. In some countries occupational health institutes have been organized with support from international organizations (United Nations, International Labor Office, World Health Organization) as in India and Chile.

Occupational health institutes, through their activities in research, service and teaching, will contribute to the promotion of occupational health in a country and to the health of its workers.

References

1. Forssman, Sven: Industrial Health in Industrial and Nonindustrial Countries. *J. Occup. Med. 1*:15 (Jan. 1959).
2. Forssman, Sven: International Development of Occupational Medicine. *Ind. Med. & Surg. 28*:465 (1959).
3. Forssman, Sven: Occupational Health - Recent Trends and Future Problems. *Proceedings of 13th Int. Congress on Occupational Health*, pp. 68-72, New York (1960).
4. Forssman, Sven: Age and Employment, OECD Seminar on Age and Employment, Stockholm, 15-19 April, 1962. Training for Progress in Europe and the World, 1962, II, 2.
5. Forssman, Sven: Women at Work. Health and Sociomedical Problems Related to the Employment of Women. 14th Int. Congress on Occupational Health, Madrid, 1963, Sept. 16-21. *Int. Congr. Ser. No. 62*, Excerpta Medica Foundation, Amsterdam (1963); and *Ind. Med. & Surg. 33*:125 (March 1964).
6. Forssman, Sven: The Present International Situation and the Probable Future Development of Occupational Medicine. Opening lecture, Int. Congress on Occupational Health, Vienna, 19-24 Sept. 1966. Proceed. XV-XXVI.
7. Harashima, Susumu, and Seiya Yamaguchi: Historical Developments and the Present State of Industrial Health in Japan. Int. Congress on Occupational Health, Vienna 19-24 Sept. 1966. Proceed. B XII-6, pp. 345-348.
8. International Labour Office: *Recommendation No. 112 on Occupational Health Services in Places of Employment*. International Labour Office, Geneva (1959).
9. Noro, Leo: *Work-Environment-Health*. Vol. 2, pp. 1-11, Institute of Occupational Health, Helsinki (1966).
10. World Health Organization: *Joint ILO/WHO Committee on Occupational Health, Third Report*. WHO Techn. Report Series, No. 135, Geneva (1957).
11. Bruusgaard, A., S. Forssman, J. Goldwater, J. Shoib, and L. Noro: *Occupational Health for Developing Countries*. World Health Organization, WHO/Occ. Health/29, Geneva (1963).
12. Taylor, Lord: *Report of the Inter-Regional Travelling Seminar on Occupational Health: Occupational Health in Four Countries—Yugoslavia, the USSR, Finland, Sweden*. World Health Organization, MHO/PA/4. 63, Geneva (1963).
13. Wofinden, R. C.: *Report on the Inter-Regional Seminar on Occupational Health Emphasizing Especially Health in Agriculture, Moscow and Kiev, USSR, 16-28 August 1965*. World Health Organization, PA/66. 102, Geneva (1966).

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