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Effects of Active, Passive or no Warm-up on the Physiological Response to Heavy Exercise

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Summary. Six endurance-trained young men were subjected to a 4 min maximal aerobic treadmill run (100% of $\dot{V}O_2$ max), after active or passive warm-up or rest on separate days. The increase in body temperature during the active and passive warm-up was controlled, so that the temperature reached the same level, before the subject was exposed to the maximal exercise. On average the rectal temperature rose to 38.3° C (range 38.1–38.6° C). The standard work resulted in a significant higher oxygen uptake, lower lactate concentration and higher blood pH when the work was preceded by active warm-up as compared with passive or no warm-up. The difference in total oxygen uptake during the run between the active and passive warm-up procedure was 0.8 l. No significant difference in minute volume of expired air or respiratory quotient was found. It is concluded that the physiological effects of a thorough active warm-up may be of substantial benefit to athletic performance.

Key words: Warm-up – Oxygen uptake – Lactate concentration – Heart rate – Respiration

It is generally accepted that warm-up is an integral part of physical training and competitions. However, there is a considerable variation as to the warm-up ritual used among athletes, coaches and physical educators. The most common warm-up procedure seems to be active warm-up, involving muscular exercise of varying intensity. Passive warm-up using hot showers, steam bath, massage, or shortwave diathermy have also frequently been used.

The assumed benefits of active warm-up may be ascribed to changes in physiological mechanisms caused by an increase in muscle and rectal temperature [1], in circulatory and oxygen transport systems [3, 19] an in mobilization of various hormones [5, 7, 13, 26, 28].

Numerous studies have been carried out to clarify the assumed effects of warm-up, but the results have been conflicting. Some reports conclude that active warm-up

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is beneficial for optimal performance [1, 10, 17, 18, 20], while other studies have failed to find any favourable effects of warm-up [12, 14–16, 23, 24, 27]. Common to all these investigations is the test of performance as the only measure of the effects of warm-up.

A few studies have used physiological variables as criteria for the effects of warm-up. Thus, Falls and Weibers [9], Elbel and Mikols [8] and Busuttil and Ruhling [4] reported no beneficial effects of active warm-up as compared to passive or no warm-up. On the contrary Inbar and Bar-Or [10] concluded that the benefits of intermittent active warm-up could be attributed to physiological rather than psychological mechanisms.

However, a poorly controlled variable in most studies has been the warm-up procedure itself. The type, duration, and intensity of the warm-up regimens have varied considerably, from light knee bends to bicycling or jogging. Furthermore, the level of body temperature reached during active and passive warm-up has not been identical.

The aim of the present investigation was to study the effects of active, passive, or no warm-up on the physiological response to a maximal aerobic work load, consisting of running uphill on a treadmill for 4 min. The increase in body temperature during the active and passive warm-up procedures was controlled, so that the temperature during each procedure reached the same level before the subject was exposed to maximal exercise. Oxygen uptake, heart rate, RQ, pulmonary ventilation, blood pH, and lactate concentration were measured to evaluate the physiological response.

Methods

Subjects

Six males, ranging in age from 23–29, were the subjects of this investigation. The subjects were physically well-trained individuals, regularly engaged in training and competition (cross-country skiing or long distance running). Table 1 gives the physical characteristics and exercise data of the subjects.

Table 1. Physical characteristics of the subjects

Subjects	Age (year)	Height (cm)	Weight (kg)	Maximal oxygen uptake ($ml \cdot kg^{-1} \cdot min^{-1}$)	Running speed during standard work (+3° inclination) $m \cdot min^{-1}$
I. B.	24	190	77	68.5	275
A. E.	29	180	72	60.9	256
R. E.	24	178	70	68.6	286
A. L.	26	177	68	68.9	296
K. T.	23	183	74	59.8	256
T. S. T.	26	182	77	67.0	276
Mean	25.3	181.7	73.0	67.3	274

Determination of Standard Work

The standard work consisted of running uphill (3°) on the treadmill for 4 min at a speed requiring 100% of the subjects maximal aerobic power.

A few days prior to the warm-up experiments the subjects maximal aerobic power was measured during running on a motor driven treadmill at 3° uphill inclination, using four sub-maximal and one maximal load on two different days. The speed corresponding to the point of "levelling off" of the oxygen uptake was then applied when the subjects performed the standard run.

Experimental Procedure

The active warm-up consisted of running on the treadmill at a speed corresponding to a sub-maximal work load of 50—60% of the subjects maximal oxygen uptake. During the passive warm-up the subject was sitting immersed to the neck in a tank containing water kept at constant temperature (40° C).

The rectal temperature was recorded continuously during both the warm-up periods, which lasted until the same temperature was reached for each of the two procedures. On average this temperature level was 38.35° C (range 38.1—38.6) after 20—25 min of warm-up (Table 2).

During the experiments with no warm-up the subjects rested for about 20 min prior to the standard work. The time from the end of the warm-up and no warm-up procedures to the start of the standard work was about 5 min.

The intramuscular temperature was recorded prior to the warm-up procedures, immediately before and 90 s after completion of the standard work.

Heart rate was telemetered continuously and recorded on an ordinary electrocardiograph during the standard work and during the first 4 min of the recovery period. Blood samples for lactate and pH determinations were taken before and after the warm-up procedures, and at 1, 3, and 5 min after the standard work.

Expired air was continuously collected in Douglas bags during the standard work. The collection time was 30 s per bag.

Each subject participated in the active, passive and no warm-up experiments twice on separate days (a total of six warm-up experiments per subject). The sequence of the three experimental conditions was randomly chosen for each subject.

The results are given as mean values for the whole group. The significance of differences was tested by the Student's *t*-test.

Metabolic Measurements

Gas analyses were performed by use of a Scholander apparatus or a direct reading paramagnetic oxygen analyzer (Beckman E 2) and an indirect reading infrared carbon dioxide analyzer (Beckman IR

Table 2. Rectal temperatures (Tr) and intramuscular temperatures (Tm) during the active, passive and no warm-up experimental conditions. Mean values in °C ± SD

Temperature	Stage of experimental procedure	Active warm-up	Passive warm-up	No warm-up
Tr	Before warm-up	37.05 ± 0.2	37.00 ± 0.2	37.00 ± 0.2
	Prior to standard work	38.35 ± 0.2	38.30 ± 0.2	37.00 ± 0.2
Tm	Prior to standard work	38.75 ± 0.3	38.25 ± 0.2	35.90 ± 0.3
	90 s after standard work	39.55 ± 0.3	39.40 ± 0.2	37.90 ± 0.3

215 A). The performance of these instruments was frequently checked by concurrent gas analyses employing the Scholander technique [22].

Blood for lactate and pH determinations was taken from a prewarmed, clean and dry finger tip, using 25 μl smaples. The lactate concentrations were analyzed according to the Strøm modification [25] of the colorimetric method of Barker and Summerson [2]. pH values were measured using a pH meter (Radiometer type BMS 2, Copenhagen) at a temperature of 37° C.

Temperature Measurements

Rectal temperature (Tr) was recorded by a potentiometer, using a thermocouple probe inserted approximately 8 cm beyond the anal spincter. Intramuscular temperature (Tm) was measured by a thermocouple implanted 4–5 cm deep into the lateral part of quadriceps femoris.

Results

Oxygen Uptake

As demonstrated in Fig. 1A and B oxygen uptake during the 4 min standard work was significantly higher after active warm-up than after passive or no warm-up. The total oxygen consumption during the run preceded by active warm-up was 16.4 l, as compared to 15.6 and 15.7 l after the passive or no warm-up regimes, respectively ($p < 0.005$ at both comparisons). The difference in oxygen uptake between passive and no warm-up runs was not significant.

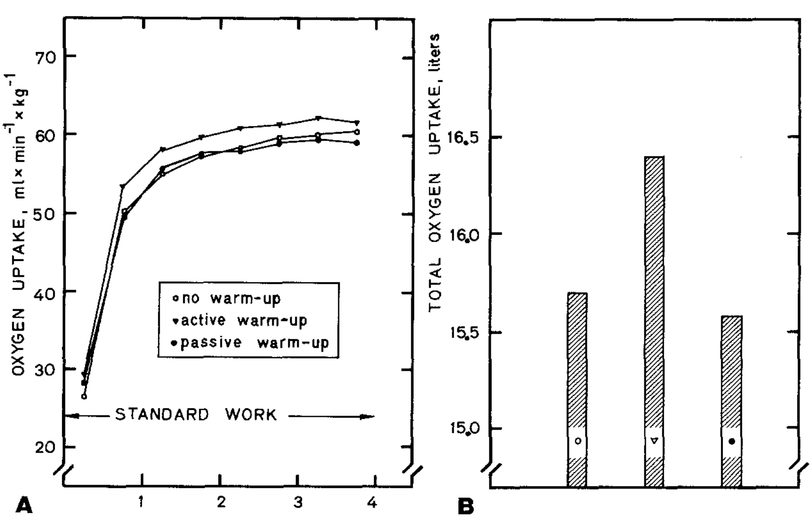

Fig. 1. A Mean values for oxygen uptake during standard work following active, passive and no warm-up procedures; **B** Mean values for the total oxygen cost of standard work following the same three warm-up procedures

Blood Lactate Concentration

The highest values for the lactate concentration following passive and no warm-up were found 3 min after the end of the standard work (8.3 and 9.9 mmoles · l^{-1}, respectively) while the highest value following active warm-up (6.5 mmoles · l^{-1}) was found 30 s after the run (Fig. 2).

When comparing the three warm-up procedures, a significant difference ($p < 0.005$) between the highest levels of lactate concentration after the standard runs was observed. However, it should be pointed out that there was a fairly large individual variation in these maximal levels of lactate concentration (4.5—12.6 mmoles · l^{-1}).

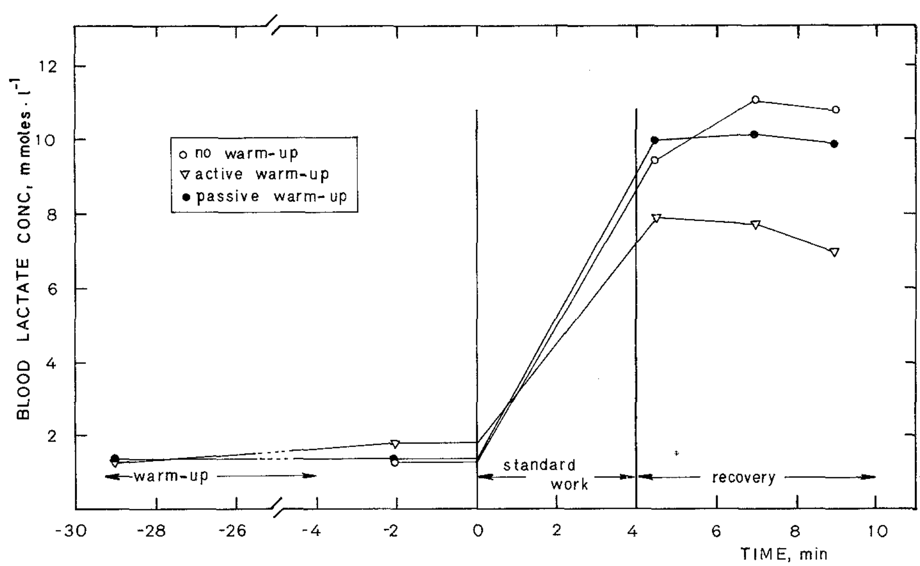

Fig. 2. Mean values for lactate concentration in blood, sampled before and after the warm-up procedures and after standard work following the active, passive and nor warm-up experimental conditions

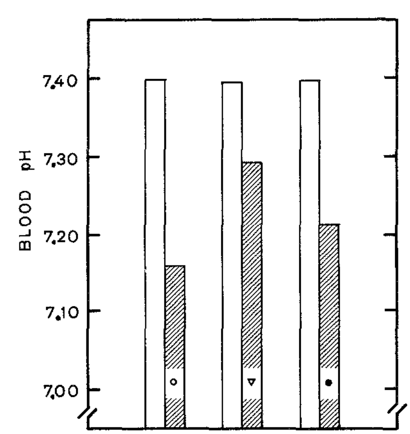

Fig. 3. Mean blood pH values before the warm-up procedures and 3 min after standard work following the active (▽), passive (●) and no warm-up (○) experimental conditions

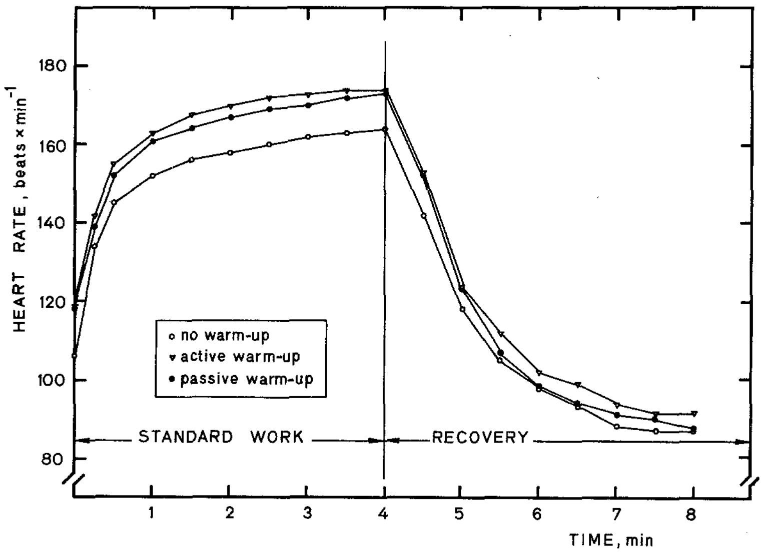

Fig. 4. Mean values for heart rate during standard work preceded by active, passive and no warm-up and during the following 4 min of recovery

Blood pH

Figure 3 shows the blood pH values before the various warm-up procedures and 3 min after completion of the accompanying standard works. Similar to the lactate concentrations, there was a significant difference ($p < 0.005$) between the pH values after the standard work when comparing the active, passive and no warm-up procedures.

Heart Rate

As illustrated in Figure 4, heart rate during the standard work was about 10 beats/min higher in the experiments with active and passive warm-up, than during the run preceded by no warm-up ($p < 0.005$). There was no significant difference in heart rate during recovery between the three experimental procedures (Fig. 4).

Minute Volume of Expired Air

The minute volume of expired air during the standard work was similar in all three experimental procedures (Fig. 5).

Respiratory Quotient (RQ)

When comparing the three warm-up procedures, there was a slight, but not significant, difference in RQ measured during the last 3 min of standard work (Fig. 6). The RQ was lowest after the run preceded by active warm-up.

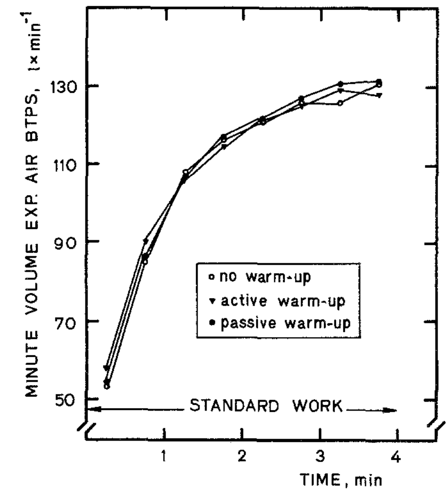

Fig. 5. Mean values for minute volume of expired air during standard work following active, passive and no warm-up procedures

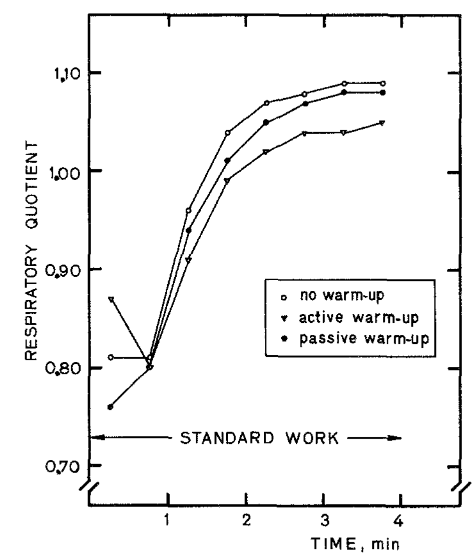

Fig. 6. Mean values for respiratory quotient during standard work following active, passive and no warm-up procedures

Discussion

Oxygen Uptake and Heart Rate

Figure 1A shows that on average a higher percentage of total energy expenditure was due to aerobic processes when the standard work was preceded by active warm-up as compared to passive or no warm-up. One can only speculate about the physiological mechanism behind the increased oxygen uptake. A plausible explanation may be the vasodilatory effect of active warm-up on the precapillary resistance vessels, and the local effect of increased metabolism on the capillaries of the working muscle fibers, leading to increased blood flow. Concomitantly, activity in the sympathetic adrenergic vasoconstrictor fibers will cause redistribution of the blood volume, reducing the flow to splanchic area, kidneys and skin. Thus, Rowell [21] has estimated that about 2.2 l/min^{-1} can be redistributed to the working muscles during maximal vasoconstriction of the splanchnic and renal blood vessels. Increased mobilization of hormones, e.g., adrenaline which dilates the resistance vessels in skeletal muscles, undoubtedly also contribute to increased blood flow, and acts on other mechanisms to increase the preparedness of the body. Furthermore, increased intramuscular temperature during the active warm-up enhances the enzyme activity, and shifts the oxygen dissociation curve to the right. These changes may in turn increase the aerobic energy liberation during the following standard work load. During passive warm-up, the temperature increase will exert a similar effect, but the blood flow to the muscles will hardly be changed, and redistribution of the blood volume may not be expected to occur, except for an increased blood flow to the skin, due to peripheral vasodilatation.

Falls and Weibers [9] and Elbel and Mikols [8] failed to find any significant difference in oxygen uptake during submaximal standard work load after respective active, passive or no warm-up. However, in their studies neither rectal nor muscle temperatures were measured during the warm-up procedures. Therefore, it is difficult to evaluate the physiological effects of active or passive warm-up. Judging from the intensity and duration of the active warm-up applied by these authors, one can assume that such moderate exercise is not sufficient to cause changes in the physiological mechanisms probably responsible for increased oxygen uptake during the standard work load in the present study. Furthermore, in order to be able to detect any difference in oxygen uptake, the standard test load should not be submaximal, but of such an intensity that the subjects maximum aerobic capacity is reached.

Recently, Busuttil and Ruhling [4] reported no significant difference in oxygen uptake during a maximal test load, preceded by active or no warm-up. But again, the active warm-up procedure seems to have been inadequate. Three minutes of exercise at a standard load of only 98.1 W (600 kpm $\cdot$ min^{-1}) can hardly be regarded as sufficient, particularly in view of the fact that redistribution of blood volume during exercise seems to be related to the severity of the exercise in relation to the individual's maximal aerobic power [6, 21]. On the contrary, Inbar and Bar-Or [10] found that maximal oxygen uptake was significantly higher after 15 min of intermittent treadmill running, as compared to the oxygen uptake after no warm-up. Also the total mechanical work output during the test increased after warm-up.

The higher heart rate during standard work after active and passive warm-up, compared to after no warm-up (Fig. 4) correspond well with results from other studies [8–10]. The increased body temperature after active or passive warm-up may in itself be responsible for most of the higher heart rates observed. This increased heart rate should therefore not be regarded as indicative of a better preparedness of the circulatory system.

Blood Lactate Concentration and pH

The minor increase in lactate concentration resulting from the active warm-up procedure (Fig. 2) confirms that the intensity during active warm-up was suitable. As illustrated in Fig. 2, blood lactate concentration during the 5 min recovery period after standard work was on average 30% lower when the work was preceded by active warm-up as opposed to passive or no warm-up. The relative changes in pH values (Fig. 3) correspond well with the observations of lactate concentrations in the three different experimental conditions.

Figures 2 and 3 also indicate that blood lactate concentration is lower, and pH higher after standard work when it is preceded by passive warm-up as compared to no warm-up. This may suggest that the increase in body temperature after passive warm-up has caused less anaerobic energy expenditure during the standard work following passive warm-up as compared to no warm-up. This hypothesis however, is not supported by the oxygen uptake measurements (Fig. 1).

Although not significant, the differences in RQ presented in Figure 6 agree with the measurements of blood pH (Fig. 3). On the other hand, the respiratory changes expected from changes in blood pH were not observed, pulmonary ventilation being similar in the three different runs (Fig. 5). One might have anticipated a higher minute volume of expired air during the run preceded by passive or no warm-up. Nevertheless, alveolar ventilation was not measured, and it is possible that the breathing pattern during these runs was characterized by a somewhat greater tidal volume and lower respiratory frequency, leading to a higher CO_2 concentration in the expired air.

The observations of blood lactate concentrations and pH correspond with the oxygen uptake during standard work, and confirm that a greater part of the total energy expenditure originate from aerobic processes when the work is preceded by active warm-up. This strongly emphasizes the beneficial effects of a thorough active warm-up on athletic performance. Thus, impediment of the oxygen uptake, when a certain work is to be carried out, is associated with a lowering of blood pH, resulting in an inhibition of glycolysis. It is known that rate limiting enzyme systems in the glycolytic pathway, such as phosphofructokinase, are inhibited by decrease in pH. Moreover, acidosis is associated with an inhibition of lipolysis, and has been shown to reduce endurance time [11].

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