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SUMMARY

Blood lactate levels and sweat lactate excretion were determined during exercise and subsequently during heat induced sweating, in the same subjects in an attempt to investigate the contribution of blood lactate to the sweat lactate excretion. Eighteen male volunteers of ages 15 - 32 participated in the study. Exercise was performed on a cycle ergometer and involved a stepwise increase in workload until exhaustion. A passenger van with shutters up, parked in the afternoon sun was used to create a warm environment for heat-induced sweating.

Both exercise (0.017 ± 0.001 L/min/m^2) and the warm environment (0.013 ± 0.001 L/min/m^2) induced comparable rates of sweating. Pretest blood lactate levels were similar before exercise (2.2 ± 0.16 mmol/L) and heat test (1.9 ± 0.12 mmol/L). However, blood lactate levels during exercise (10.4 ± 0.42 mmol/L) were significantly higher than levels during heat induced sweating (1.9 ± 0.10 mmol/L) ($P < 0.001$). Sweat lactate excretion during exercise (1.03 ± 0.11 mmol/min/m^2) was significantly greater than sweat lactate excretion during heat induced sweating, (0.54 ± 0.04 mmol/min/m^2) in spite of comparable volumes of sweat production. During heat induced sweating, sweat lactate excretion increased with increased sweat rates and the correlation was significant ($r = 0.48$) ($p < 0.001$).

These results demonstrate that raised blood lactate levels during exercise contribute significantly to sweat lactate excretion. Sweat gland metabolism also contributes to sweat lactate excretion. The results cannot quantify the relative contributions of these two factors. Such quantification will necessitate further studies in the future. Whatever these respective contributions may be, sweat lactate excretion is probably not a sufficiently reliable index of aerobic capacity, to be recommended as a routine measurement because of its variability with varying sweat gland metabolism.

KEY WORDS - Aerobic capacity, exercise, blood lactate, sweat lactate, heat-induced sweating.

INTRODUCTION

Physical fitness is the most important determinant of the ability of an individual to perform strenuous physical activity without significant physical fatigue(1). During physical exercise, onset of physical fatigue coincides with the onset of anaerobic metabolism, which in turn starts when aerobic energy production almost reaches its full capacity. Thus physical fitness correlates well with the aerobic metabolic capacity of the individual. The term aerobic capacity, therefore, has been used as an alternative term for physical fitness(2). A high aerobic capacity is obviously essential for a high performance in any endurance sport. Programmes that are geared to increase aerobic capacity are a necessary and important part of training for athletes participating in such sports. The term aerobic capacity, however, is a concept and not a quantifiable entity by itself. Thus it is important to have a reliable index of aerobic capacity, measurement of which may be used to assess athletes in training.

Maximum oxygen uptake has been, for many years, used as a measurement of aerobic capacity(2,3,4). It has been shown to be a very reliable index of aerobic capacity(5). Determination of maximum oxygen consumption necessitates exercising the athlete to exhaustion in the laboratory and measurement of oxygen uptake. This has two main disadvantages. Firstly it is time consuming especially if one needs to assess many athletes repeatedly. Secondly it is not easily carried out in the field.

There are also methods of predicting the maximum oxygen uptake without exercising the subject to exhaustion. These include Astrand Rhyming Normogram(6) and extrapolation from submaximal exercise(7). However many investigators have demonstrated that there are limitations to prediction of maximum oxygen uptake by these methods(8,9).

Blood lactate levels are known to increase during exercise(10). This is due to an increase in anaerobic metabolism during physical activity. Though the increase in anaerobic metabolism and therefore the rise in blood lactate level occurs almost immediately on commencement of exercise, the rise is minimal at low levels of activity. If the intensity of exercise is gradually increased, a sharp rise in blood lactate is observed at one point, and this point has been shown to correlate with the point at which aerobic metabolism on its own can no longer meet the energy demands.This point denotes the anaerobic threshold i. e. the time when anaerobic metabolism increases sharply. Thus onset of blood lactate accumulation has been used as another index of aerobic capacity and has been shown to correlate well with maximum oxygen uptake(12,13). Blood lactate levels at submaximal levels of exercise have also been shown to be accurate predictors of anaerobic threshold(12,14).

It has also been shown that sweat lactate excretion is greatly elevated during exercise(15). Sweat lactate excretion during exercise at a given workload decreases with physical training(16,17). During graded exercise to exhaustion sweat lactate excretion demonstrates a sharp increase at the same time as the onset of blood lactate accumulation(18). These observations suggest that sweat lactate excretion could be another index of aerobic capacity. Nevertheless it has not been used as such perhaps because it is known that sweat glands themselves produce lactate, and therefore the increased sweat excreted during exercise may partly be independent of plasma lactate levels(19,20).

INTRODUCTION TO THE STUDY

One of the important aims of any athletic training programme is increasing the aerobic capacity of the athletes. Any ongoing training programme must repeatedly assess progress and compare them with the intended objectives. This enables modifications to be made to the programme if necessary, so as to be sure of achieving the initial aims. Thus a programme designed to improve aerobic capacity, if it is to be successful, must also incorporate serial measurement of aerobic capacity during the training.

An ideal method of assessment of aerobic capacity should be inexpensive, easily carried out in the training field and without elaborate equipment, must be acceptable to athletes and should have the least interference with the training programme both physically and psychologically.

Measurement of sweat lactate excretion, if indeed it is a reliable index of aerobic capacity, comes closes to this ideal than the other two methods commonly used - namely maximum oxygen consumption and blood lactate level. But before sweat lactate excretion can be recommended as a reliable index of aerobic capacity, its relationship to blood lactate must be clearly defined. If other factors too influence sweat lactate excretion significantly, any changes seen with training may be due not necessarily to parallel changes in blood lactate and therefore those of aerobic capacity, but due to alteration in those other factors. Lactate is a product of sweat gland metabolism(21). One factor that might influence lactate excretion in sweat is the rate of sweating, which is in turn related to the metabolic activity of sweat glands(22).

The aims of this study, therefore, are -

1. To further define the relationship of plasma lactate with sweat lactate excretion.

2. To investigate the contributions of plasma lactate and sweat gland-produced lactate to lactate excretion in sweat.

MATERIALS AND METHODS

Subjects

Eighteen male subjects aged between 15 and 32 years participated in the study. All subjects were voluntary participants. They were all healthy with no history of cardiovascular or respiratory disease or reduced exercise tolerance. The physical examination, the resting electrocardiogram and pulmonary function tests at rest were normal in all subjects. The procedure of the test was explained to all participants and each signed a consent form before being included in the study. In the case of minors the consent of parents was also obtained. The study was approved by the Ethical Committee of Universiti Sains Malaysia.

Measurements and Methods

Basic anthropometric measurements of height and weight were recorded. A resting 12 lead electrocardiogram was recorded using a cardioline electrocardiograph. The pretest pulmonary function tests comprised of the measurement of forced vital capacity and timed forced expiratory volume (FVE1.0), using a dry spirometer (Minihart, Vicatest VCT).

Following the above measurements, the subjects were put through a standardised exercise protocol (see below). On a subsequent occasion, one to two weeks later, they were subjected to heat induced sweating (see below). During both tests blood and sweat specimens were obtained for analysis of blood and sweat lactate levels.

Exercise test - all exercise tests were carried out at least 2 hours after a light meal. Exercise was carried out on an electromagnetically braked cycle ergometer (Lode NV L-77). The subjects were made to sit on the cycle ergometer and cycle at a speed of 60 revolutions per minute (RPM). The workload of the ergometer was set initially at 50 watts and was increased by 16 watts at the end of each minute in a stepwise manner, until the subject reached exhaustion i.e. was unable to maintain a cycling speed of 60 RPM. From the point of exhaustion, the subjects cycled at 20-30 RPM with all load taken off from the ergometer. (0 watts) for one minute and continued to sit on the cycle and rest for a further period of four minutes. The subject's electrocardiogram was monitored continuously throughout the exercise and recovery period. Blood samples were collected immediately prior to start of exercise, at the point of exhaustion and at the end of 1st and 2nd minute of the recovery period. Three sweat samples were collected, the first for the duration of the minute ending at point of exhaustion and the next two for the duraton of the 1st and 2nd minutes of recovery respectively (Figure 1).

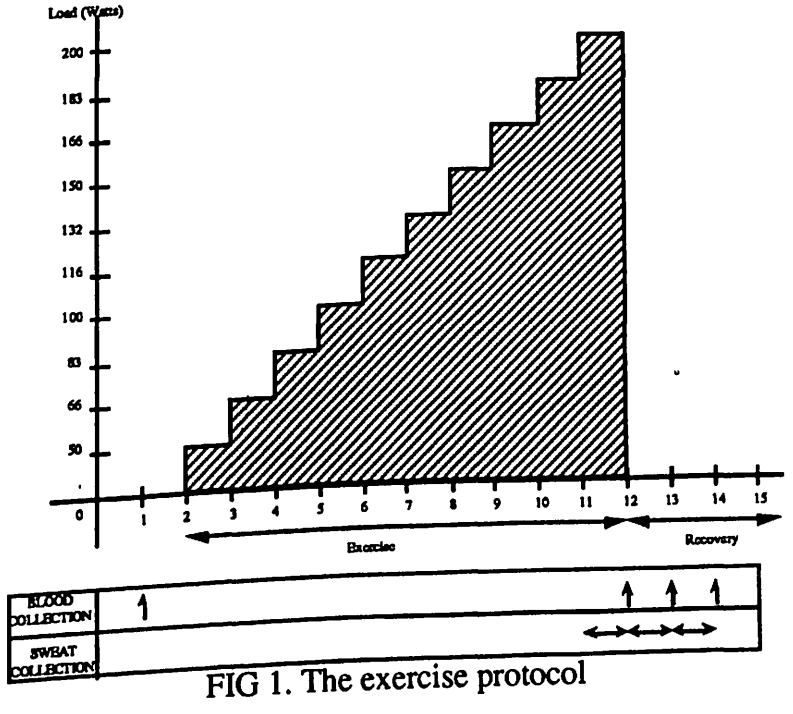

FIG 1. The exercise protocol

Collection of blood- a forearm vein was cannulated immediately prior to exercise using an indwelling catheter (Venofix G21, B. Braun). The catheter was left in situ throughout exercise and recovery. Blood specimens, amounting to 1 ml each were withdrawn via the catheter at the times indicated above.

Collection of sweat- Immediately prior to the start of exercise, the scapular area was cleaned with surgical spirit and allowed to dry. A perspex chamber measuring 2 cm x 3 cm x 2 cm was taped firmly onto the cleaned scapular area (Figure 2). Squares of filter paper 4 cm x 4 cm in size were folded and stored in test tubes with air tight stoppers and weighed. These filter papers were used to swab the area under the perspex chamber throughout the duration of collection of each specimen. Sweat soaked filter papers were returned to their original test tubes. The quantity of sweat during each collection period was determined by reweighing the test tubes containing filterpapers with sweat. Sweat rate in L/min/m^2 was calculted using this value, assuming 1 kg of sweat = 1 L of sweat.

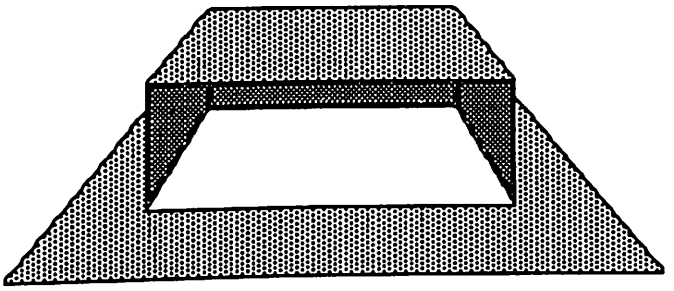

FIG. 2. Chamber used for sweat collection

Heat Induced Sweating- a passenger van with all shutters up and parked exposed to the afternoon sun was used to create a warm environment. Before subjects entered the van, a forearm vein was cannulated and a perspex chamber taped to the scapular region as for the exercise test. A specimen of blood was collected for determination of resting blood lactate levels. Subjects then entered into the van. After 5-8 minutes, collection of blood and sweat specimens was commenced. Three sweat specimens, each for one minute, were collected for three consecutive minutes. Three specimens of blood, 1 ml on each occasion at the end of each period of sweat collection were also obtained (Figure 3).

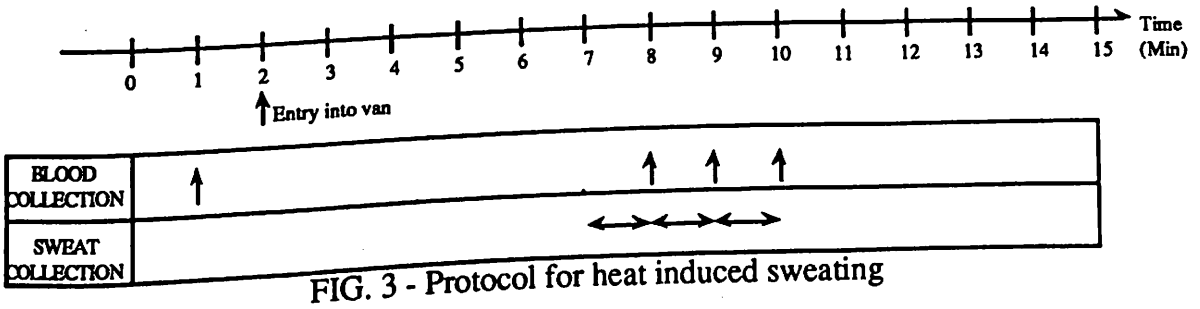

FIG. 3 - Protocol for heat induced sweating

Analysis of blood and sweat lactate -

A lactate analyser (YSI 23 L) was used to determine lactate levels in both blood and sweat.

The blood specimens were centrifuged (3000 rpm for 10 min) immediately after collection and plasma analysed soon thereafter. The filter papers were soaked in 2 mls of double deionised water, left to equilibrate, centrifuged, and the solution was analysed for lactate levels. Sweat lactate excretion rate in mmol/min/m^2 was calculated for each specimen.

Statistical Analysis

Mean values with their standard errors of mean (SEM) were calculated. Differences in blood lactate, sweat rate and sweat lactate secretion between the exercise test and heat test were tested using analysis of variance (ANOVA). The conventional level of statistical significance of $p < 0.05$ was used. Calculations were made on an IBM compatible computer using the Statistical Package for Social Sciences (SPSS) programme.

RESULTS

Anthropometric data of the subjects are shown in table 1.

	Mean ± SD	Range
AGE (yr)	21.9 ± 5.0	15 – 32
HEIGHT (cm)	166.8 ± 3.3	158 – 173
WEIGHT (kg)	59.2 ± 9.5	49.4 – 85

TABLE 1. Anthropometric data of the subjects.

There was no significant difference between pretest plasma lactate levels between exercise and heat induction protocols, Plasma lactate levels rose significantly during exercise ($p < 0.001$) but not during heat induced sweating. (Fig. 4, Table 2).

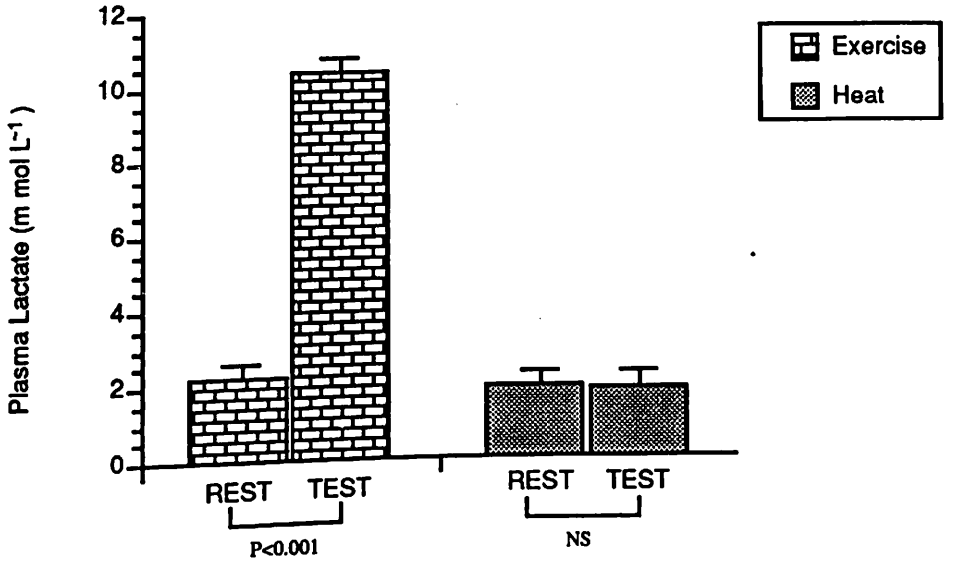

FIG. 4 Mean Plasma lactate levels compared with mean levels during test for exercise and heat induced sweating.

Mean plasma lactate levels during exercise were significantly higher than levels during heat induced sweating for each comparable minute ($p < 0.001$). Mean plasma lactate for all specimens during exercise was 10.4 mmol/L. This was significantly higher ($p < 0.001$) than the mean plasma lactate for all specimens during heat induction which was 1.9 mmol/L (Fig. 5 Table 2).

Plasma lactate ± SE (mmol/L)

	Exercise	Heat
Pretest	2.2 ± 0.16	1.9 ± 0.12
Minute 1	9.6 ± 0.66	2.1 ± 0.19**
Minute 2	11.0 ± 0.58	1.9 ± 0.15**
Minute 3	10.7 ± 0.20	1.7 ± 0.16**
Pooled	10.4 ± 0.42	1.9 ± 0.10**

TABLE 2. Plasma lactate levels during exercise and heat test.
(** $p < 0.001$)

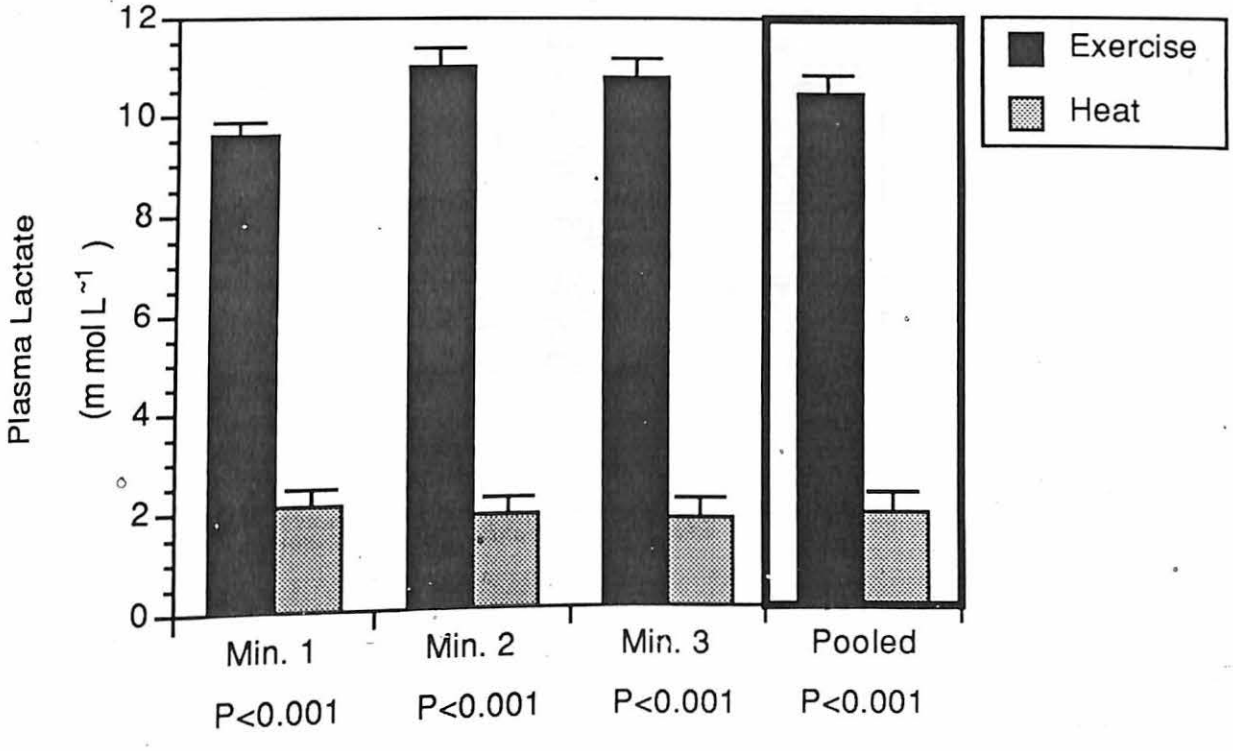

FIG. 5 Mean Plasma lactate levels during exercise and heat induced sweating over three consecutive minutes and pooled results.

The calculated mean sweat rates were higher during exercise than during the heat test. The difference was however not significant statistically except in the second minute when exercise sweat rate was significantly higher ($p < 0.05$) than heat induced sweat rate (Fig. 8, Table 3). The cumulative mean sweat rate during exercise was 0.017 L/min/m^2 as compared with a mean value of 0.013 L/min/m^2 during heat induced sweating. There was no significant difference between these values (Fig.6, Table 3).

Sweat Rate ± SE (L/min/m2)

	Exercise	Heat
Minute 1	0.018 ± 0.002	0.013 ± 0.002
Minute 2	0.017 ± 0.002	0.012 ± 0.001*
Minute 3	0.016 ± 0.002	0.014 ± 0.002
Pooled	0.17 ± 0.001	0.13 ± 0.001

TABLE 3. Sweat rates during exercise and heat induction.
(* $p < 0.05$)

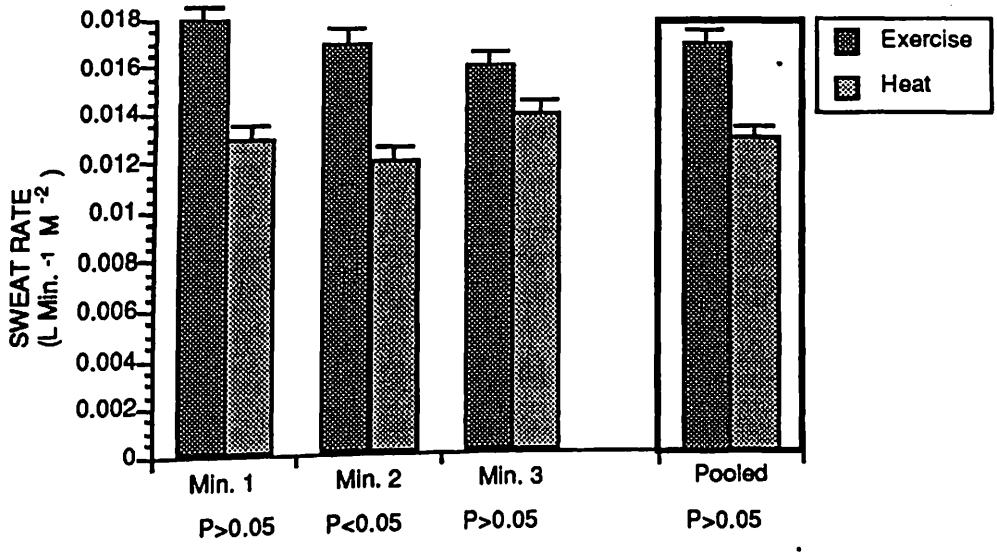

FIG. 6 Mean sweat rates during exercise and heat induced sweating for each minute and overall result.

lactate excretion rate was higher during exercise. The difference in lactate excretion between the two procedures was significant in the 1st and 2nd minute but not significant in the 3rd minute (Fig. 7, Table 4). The overall lactate excretion during exercise was 1.029 mmol/min/m^2. This was significantly higher than the mean lactate excretion in heat induced sweating, which was 0.542 mmol/min/m^2 ($p < 0.05$) (Fig. 7, Table 4).

Sweat Lactate Excretion Rate ± SE (mmol/min/m^2)

	Exercise	Heat
Minute 1	1.200 ± 0.256	0.507 ± 0.060*
Minute 2	0.944 ± 0.154	0.503 ± 0.060*
Minute 3	0.943 ± 0.152	0.617 ± 0.073
Pooled	1.029 ± 0.111	0.542 ± 0.037*

TABLE 4. Sweat lactate excretion rates during exercise and heat induced sweating.
(* $p < 0.05$)

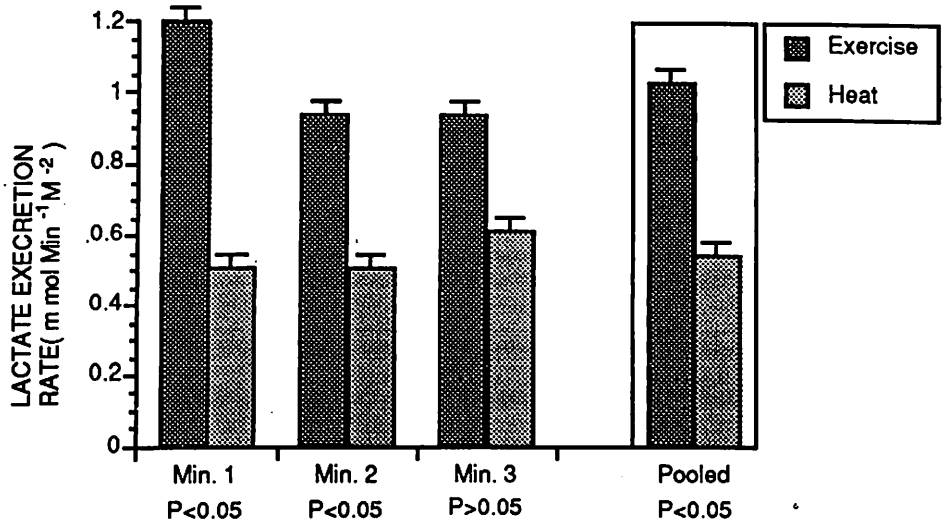

FIG. 7 Mean lactate excretion rates during exercise and heat induced sweating.

Within the exercise protocol, comparison of sweat lactate excretion rate and the sweat production rate of each sweat specimen collected did not show any significant correlation between the two parameters (r = -0.11)

Sweat lactate excretion during heat induced sweating showed a significant correlation with the rate of sweat production (r = 0.48) (fig. 8).

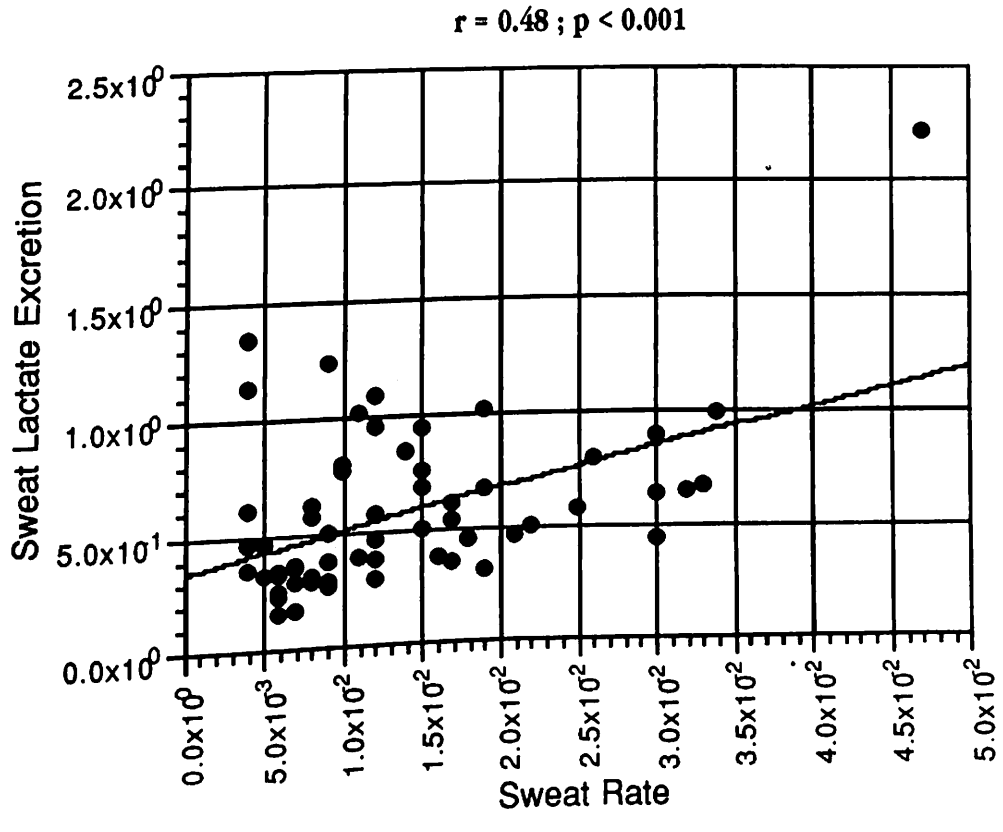

FIG 8 Correlation between sweat rate and lactate excretion during heat induced sweating

DISCUSSION

Numerous methods have been used for sweat sampling for analysis(23). One of these is pad absorption where an absorbant material is applied to a known area of the skin to absorb the sweat. Many investigators have used gauze sponges(24). Others have used filter paper(25). Both materials have given reproducible results if saturation of absorbant pads with sweat is avoided(24,26).

Times of blood and sweat collection were chosen to obtain specimens at peak lactate levels. During graded exercise to exhaustion blood lactate levels and sweat excretion peak within two minutes of exhaustion(18). This ensured the maximum difference in blood lactate levels between the exercise test and heat induced sweating.

Previous investigators have studied sweat lactate concentrations during exercise and shown a decrease in sweat lactate concentration. More recently it has been shown that sweat lactate excretion rate increases in spite of a falling lactate concentration and that it correlates with blood lactate(18).

The results of this study confirm the findings of previous studies that blood lactate levels increase significantly during exercise(10).

The overall sweat rates achieved during the exercise protocol and heat induced sweating were not significantly different. Thus the metabolic activity of sweat glands during the two tests have been similar. Therefore any difference in the sweat lactate excretion between the two tests can not be due to differences in sweat gland metabolism, but due to other factors.

Blood lactate levels during exercise are significantly higher than during heat induced sweating. This is to be expected because the subjects were at rest during heat induced sweating, and no increase in energy metabolism occurred. The sweat lactate excretion rate is also significantly higher during exercise than during sweating in the warm environment. The obvious conclusion from these findings is that the higher lactate excretion during exercise is due to higher blood lactate levels, as sweat gland metabolism itself was comparable in the two tests. This is in constrast to some studies in the past which have suggested that sweat lactate is almost entirely derived from the glands themselves(21), but confirms the findings of more recent studies(18,25).

The correlation between sweat lactate excretion and blood lactate levels during exercise does not necessarily exclude a significant contribution to sweat lactate excretion by sweat gland metabolism. This is because as exercise progresses, both blood lactate and sweat gland metabolism increase, and the demonstrated increase in sweat lactate excretion could be due to both these factors. The results of this study, in fact, demonstrate a correlation between sweat lactate excretion and sweat rate during heat induced sweating. Since blood lactate levels remained constant during heat induced sweating, this correlation confirms that sweat gland metabolism too contributes significantly to sweat lactate excretion.

Therefore the increase in sweat lactate excretion during exercise is due to both raised blood lactate levels and increased sweat gland metabolism. This is in keeping with suggestions made by previous investigators(25).

The fact that sweat gland metabolism contributes to sweat lactate excretion does not, by itself, preclude the use of sweat lactate excretion as a index of blood lactate concentrations, and therefore of aerobic capacity. Lactate excretion in sweat will accurately reflect changes in blood lactate levels if the contribution from sweat gland metabolism remained constant over serial measurements. But sweat rate during exercise, in any given individual depends on many other factors. Environmental temperature(27) and relative humidity are two such factors(28). Sweating response to environmental temperature will in turn be influenced by the degree of heat acclimatization of the individual(29). Furthermore physical training itself influences the sweating response, causing an increase of sweat rate both during exercise and in response to heat and drugs(17,30,32). Sweat rate itself has been shown to correlate will with maximum oxygen uptake(32). Therefore in serial estimations of sweat lactate excretion of an individual, the values will reflect accurately his or her aerobic capacity only if all the other factors influencing sweat rate can be standardised during each estimation. This would be practically difficult, and any attempt to standardise these will take away the advantage of sweat lactate estimation i.e. the simplicity of the test.

In conclusion, therefore, both blood lactate and sweat gland metabolism contribute to lactate excreted in sweat. Sweat lactate excretion increases with exercise. However sweat lactate excretion does not seem to be a reliable index of aerobic capacity because it is influenced by many other factors which are unlikely to remain constant over serial measurements.

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