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EXERCISE METABOLISM IN RUNNERS

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ABSTRACT

The purpose of this study was to re-examine the commonly accepted association between high maximum oxygen uptake ($\dot{V}O_2$ max) values and the characteristics of metabolic adaptation to endurance training. The metabolic responses of 9 active males and 8 endurance trained females were observed during one hour of treadmill running at two speeds. One speed was common to both groups (3.58 m s^{-1} , Test 1) whereas the second speed represented approximately 62% $\dot{V}O_2$ max for each individual (Test 2). The $\dot{V}O_2$ max values of the males were significantly ($p < 0.01$) higher than those of the females but observations of the respiratory exchange ratio and of the changes in the concentrations of metabolites were indicative of greater fat metabolism in the well-trained female group in both Tests. Thus the results of this study suggest that the benefits of endurance training are independent of the absolute values of $\dot{V}O_2$ max.

Key words: Exercise, Metabolism, Training.

INTRODUCTION

The maximum aerobic running speed is largely dictated by maximum oxygen uptake (Davies and Thompson, 1979) but it is training which allows the individual to sustain a given pace. Training produces an increase in both maximum oxygen uptake ($\dot{V}O_2$ max) and endurance capacity; however the improvements in $\dot{V}O_2$ max are modest when compared with the improvements in endurance capacity (Gleser and Vogel, 1971). The greater increase in endurance capacity in comparison with the increase in $\dot{V}O_2$ max probably relates to peripheral adaptations which result in an increased oxidative capacity of skeletal muscle (Gollnick et al, 1973).

The increased oxidative capacity associated with endurance training is accompanied by a shift towards fat metabolism and away from carbohydrate metabolism. This increase in fat utilisation produces a glycogen-sparing effect which has been shown in rats (Hickson et al, 1977) and in man (Costill et al, 1977). These adaptations are reflected in a lower respiratory exchange

ratio (RER) and lower blood lactic acid concentration during exercise after training (Saltin and Karlsson, 1971; Hardman, Kabat and Williams, 1982). The characteristics of increased aerobic metabolism during exercise are exhibited by highly trained athletes who also have high $\dot{V}O_2$ max values. The purpose of the present study was to re-examine this commonly accepted association between the characteristics of metabolic adaptation to endurance training and high $\dot{V}O_2$ max values. To achieve this a group of well-trained females whose $\dot{V}O_2$ max values were genetically constrained because of their sex were compared with a group of active male subjects who had higher $\dot{V}O_2$ max values than the females but who lacked the background of endurance training. The metabolic response of these two groups was compared at a common running speed, and also at the same relative work load i.e. percentage of $\dot{V}O_2$ max.

MATERIALS AND METHODS

The male subjects, who included 2 orienteers, habitually ran in excess of 20 miles per week. Four of the females were national standard orienteers who had completed

marathons in times ranging from 2 hr. 56 min. to 3 hr. 20 min: the remaining females were middle and long distance athletes, 3 of whom had competed at international level. The females were training a minimum of 40 miles per week. The ages and physical characteristics for both groups are given in Table I. All subjects were familiarised with treadmill running before testing.

TABLE I
Physical characteristics of subjects. Mean $\pm$ SEM.

	Age yr	Height cm	Weight kg	VO ₂ max ml kg ⁻¹ min ⁻¹
Females n = 8	20.2 $\pm$ 1.2	162.7 $\pm$ 1.5	54.71 $\pm$ 1.44	54.5 $\pm$ 1.3
Males n = 9	22.4 $\pm$ 1.3	176.9 $\pm$ 2.0	68.86 $\pm$ 2.01	60.4 $\pm$ 1.2**

** significantly different between males and females $p < 0.01$

Maximum oxygen uptake was determined during uphill running. A modified Taylor treadmill test (Taylor et al, 1955) was adopted, the initial grade of 3.5% being increased by 2.5% every 3 minutes at a speed selected to exhaust the subject in under 10 minutes. Expired air was collected into Douglas bags at each submaximal load and during the last minute of exercise for measurement of oxygen uptake and carbon dioxide production. Finger-prick blood samples were obtained before and 4 minutes after the test for lactic acid determination. A plateau in the oxygen uptake-work load relationship and post-exercise blood lactic acid concentration in excess of 8 mM were adopted as criteria of maximum. The oxygen uptake-speed relationship was obtained for each subject during 6 minutes of steady-state running at each of 3 submaximal speeds (3.13, 3.58 and 4.02 m s⁻¹, i.e. 7, 8 and 9 mile hour⁻¹) to permit selection of a speed to elicit approximately 60% VO₂ max.

On two separate days the subjects reported to the laboratory after an overnight fast (> 12 hours) and performed a 60 minute treadmill run. For females no attempt was made to control for the phase of the menstrual cycle but subjects selected test dates at their own convenience. None of the subjects smoked or, to the knowledge of the authors, used drugs.

All subjects ran at 3.58 m s⁻¹ (Test 1) and also at an average relative workload of 62% VO₂ max (Test 2). Oxygen uptake and carbon dioxide production were measured in expired air samples collected at 10 minute intervals during each test. In addition a venous blood sample was obtained from an antecubital vein immediately before and, for reasons of standardisation, 5 minutes after each test. Glucose (Werner et al, 1970), lactic acid (Olsen, 1971) and haemoglobin were determined in whole blood: the remaining blood was centrifuged and the plasma subsequently analysed for glycerol

(Laurell and Tibbling, 1966) and free fatty acids (FFA) (Chromý et al, 1977). Coefficients of variation for the assays were 2.0%, 2.0%, 1.2%, 2.1% and 4.2% respectively.

Pre-exercise concentrations of metabolites were compared between groups and between Tests by one-way ANOVA. Between group comparisons of respiratory variables and changes in the concentrations of metabolites were made by Student's t-test for uncorrelated means.

RESULTS

Figure 1 shows the respiratory exchange ratio (RER) for Tests 1 and 2; values were clearly below unity and fell with exercise time, demonstrating that work was essentially aerobic. Comparison of RER between groups reveals lower values (Test 1 $p < 0.01$, Test 2 NS) in the well trained females. The contribution of fat to oxidative metabolism, as estimated from RER (Table II), showed considerable inter-individual variation but was greater in females during both tests, the difference between males and females attaining significance ($p < 0.01$) in Test 1.

TABLE II
Mean respiratory exchange ratio (RER) and estimated contribution of fat to oxidative metabolism. Mean $\pm$ SEM.

	Test 1		Test 2	
	RER	% energy from fat	RER	% energy from fat
Females n = 8	.909 $\pm$.007	30.4 $\pm$ 2.7	.872 $\pm$.018	43.6 $\pm$ 6.0
Males n = 9	.956 $\pm$.005**	15.1 $\pm$ 1.6**	.899 $\pm$.017	34.2 $\pm$ 11.4

** significantly different between males and females $p < 0.01$

Fig. 1: Changes in the respiratory exchange ratio during Test 1 (solid symbols) and Test 2 (open symbols). ●○ — Males, ▲△ — females.

Table III shows the concentrations of metabolites pre-exercise and 5 minutes post-exercise. In both subject groups blood glucose, plasma FFA and plasma glycerol were significantly elevated ($p < 0.005$) by Test 1 and Test 2. A significant rise (males $p < 0.01$) was seen in blood lactic acid in Test 1, this increase being in proportion to the percentage of VO_2 max utilised ($r = 0.64$, $p < 0.01$) but minimal change in blood lactic acid was seen during Test 2 (NS).

There were no significant differences in the pre-exercise concentrations of metabolites between groups or between Tests. The exercise-induced changes in the concentrations of metabolites are shown in Figures 2 and 3. The only significant difference between these changes was the greater increase in plasma glycerol in the females during Test 2 ($p < 0.01$) but the rise in both plasma FFA and plasma glycerol concentrations was greater in the well trained female group in both tests. As the maximum increase observed in haemoglobin concentrations was 3.5% no adjustments for haemoconcentration were made.

Fig. 2: Changes in metabolites during Test 1. Open bars – Males, hatched bars – Females. Mean $\pm$ SEM.

VO_2 max was significantly lower in the females ($p < 0.01$), Table I. Mean VO_2 at 3.58 m s^{-1} was 40.2 ml kg^{-1} for males and $39.6 \text{ ml kg}^{-1} \text{ min}^{-1}$ for females (NS, Table IV) but considerable inter-individual variation was seen. This was greater in the males (range $35.2\text{--}44.3 \text{ ml kg}^{-1} \text{ min}^{-1}$) than in the females (range $38.3\text{--}41.5 \text{ ml kg}^{-1} \text{ min}^{-1}$). Oxygen uptake showed a tendency to increase with time; a significant rise ($p < 0.05$) was observed between 10 and 60 minutes of exercise for males during Test 2 and females in Test 1.

Fig. 3: Changes in metabolites during Test 2, symbols as Fig. 2. Mean $\pm$ SEM, * $p < 0.01$.

DISCUSSION

The lower RER values and the greater increases in the concentrations of fat metabolites in the well-trained female runners would be consistent with the view that despite their significantly lower aerobic capacity, they were better adapted to endurance running than the male group in this study. The indications of greater fat metabolism in the females were sustained even when running speed represented a significantly higher percentage of VO_2 max than it did for the males: this observation reinforces the importance of training per se in allowing a runner to sustain a pace demanding a high percentage of his or her VO_2 max.

The use of RER for the indirect estimation of the proportion of fat and carbohydrate utilised during exercise requires that metabolism is aerobic. The present data fulfils this criterion as blood lactic acid concentrations were low, glucose homeostasis was little disturbed and RER fell as the duration of exercise increased. The greater fat utilisation at the lower work load is consistent with previous findings that skeletal muscle preferentially burns FFA unless the rate of energy demand dictates a significant breakdown of carbohydrate (Havel, 1970). The RER, as the only non-invasive method of estimating fat oxidation, has been heavily relied on in most studies of metabolism. Recent invasive studies have questioned (Jones et al, 1980) and confirmed (Jansson, 1980) the validity of this approach but the present data, showing similar trends in the concentrations of fat metabolites and RER values, suggests that RER does reflect fat oxidation in this type of exercise. The observations of higher FFA concentrations together with lower RER values would seem to support the view of Armstrong et al (1961) that the

concentration of plasma FFA is an important factor governing the uptake of FFA by skeletal muscle. Uptake of FFA must necessarily also depend on muscle blood flow but this was not determined in the present study.

The muscle of endurance athletes has been shown to have a high capacity to oxidise fat (Costill et al, 1979) and animal experiments have indicated that this capacity is sensitive to training (Baldwin et al, 1972). The fall in RER after training consistently reported in man (e.g. Saltin and Karlsson, 1971) probably reflects an increased capability for fat oxidation. The effect of training on the concentrations of fat metabolites in blood is less clear: Paul (1971) showed elevated plasma FFA in trained compared with untrained dogs but Bransford and Howley (1979) found a smaller rise in plasma FFA after training in man. The greater rise in plasma glycerol in the well trained females of this study probably reflects a greater hydrolysis of triglyceride and utilisation of FFA than that which occurred in the male runners during exercise.

It might be argued that the differences in metabolic

response between the groups studied are sex-related; van Aaken (1976) has suggested that female runners utilise a greater proportion of fat than males because of their greater fat stores. As fat is stored, even in very lean individuals, greatly in excess of exercise demands this seems unlikely; utilisation of fat is not limited by its availability. Moreover Costill et al (1979) compared equally well trained males and females and found that they derived similar fractions of energy from fat. Powers et al (1980) also found no significant difference in fat metabolism between the sexes in subjects matched for VO_2 max and amount of endurance running. At the present time, therefore, there is no evidence to suggest that exercise metabolism differs between equally well-trained healthy men and women.

Gollnick et al (1973), noting far greater increases in the activities of oxidative and glycolytic enzymes than in VO_2 max after training, attributed much of the improvement in endurance to the increased oxidative potential of muscle. The evidence of greater fat metabolism in the female runners compared to the males in this study supports this view as the characteristics of

TABLE III
Concentration of metabolites pre and post-exercise. Mean $\pm$ SEM.

Metabolite	Test	Females n = 8		Males n = 9	
		Pre-ex	5 min. post-ex	Pre-ex	5 min. post-ex
Blood glucose	1	4.33 $\pm$.14	6.16 $\pm$.50†	4.38 $\pm$.11	5.41 $\pm$.17†
mM	2	4.31 $\pm$.17	5.32 $\pm$.15†	4.42 $\pm$.09	5.19 $\pm$.13†
Blood lactic acid	1	0.71 $\pm$.13	1.87 $\pm$.46**	0.78 $\pm$.13	1.72 $\pm$.48*
mM	2	0.81 $\pm$.11	0.74 $\pm$.13	0.71 $\pm$.15	0.80 $\pm$.13
Plasma FFA	1	0.33 $\pm$.10	0.94 $\pm$.12†	0.26 $\pm$.06	0.73 $\pm$.07†
mM	2	0.37 $\pm$.09	0.85 $\pm$.11†	0.23 $\pm$.05	0.58 $\pm$.06†
Plasma glycerol	1	0.13 $\pm$.03	0.51 $\pm$.05†	0.08 $\pm$.01	0.36 $\pm$.04†
mM	2	0.13 $\pm$.02	0.49 $\pm$.07†	0.09 $\pm$.02	0.30 $\pm$.09†

* significantly higher pre- post-exercise $p < 0.05$

** significantly higher pre- post-exercise $p < 0.01$

† significantly higher pre- post-exercise $p < 0.005$

TABLE IV
Mean oxygen uptake and percentage of VO_2 max for Tests 1 and 2. Mean $\pm$ SEM.

	Test 1		Test 2	
	VO_2 ml.kg ⁻¹ min ⁻¹	% VO_2 max	VO_2 ml.kg ⁻¹ min ⁻¹	% VO_2 max
Females n = 8	39.6 $\pm$ 0.7	73.7 $\pm$ 1.5	33.1 $\pm$ 0.5	60.9 $\pm$ 1.1
Males n = 9	40.2 $\pm$ 1.1	66.9 $\pm$ 2.5*	38.2 $\pm$ 1.0††	63.1 $\pm$ 1.0

* significantly different between males and females $p < 0.05$

†† significantly different between males and females $p < 0.001$

endurance adaptation are evident despite the lower VO_2 max values of the females. Therefore the results of this study suggest that the benefits of endurance training are independent of the absolute values of VO_2 max.

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BOOK REVIEW

Title: THE YEAR BOOK OF ORTHOPAEDICS 1982
Editor: Mark B. Coventry, MD, MS, Consultant Department of Orthopaedics, Mayo Clinic and Professor of Orthopaedic Surgery, Mayo Medical School
Publishers: Year Book Medical Publishers, Inc. Chicago, London
Price: £31.00 456 pages, numerous illustrations and diagrams. Index

This book is made up of summaries of selected papers published in 1981 with editorial comments by the editor and by many of his colleagues at the Mayo Clinic.

A survey of 62 Journals was done and summaries of the works of over 600 authors are presented.

Apart from a regional classification there are special sections on Paediatrics, Sports Injuries, Fractures, Tumours and Infections and one titled Miscellaneous which contains an account of injuries in a rising American sport — mechanical bull riding. It appears that the natural bull is too predictable and the directional forces it can generate to unseat a rider can be improved upon by this machine. Sprains, contusions, fractures, dislocations and combinations of these are described under the title of The Empty Saddle Syndrome which cannot fail to induce pathos. One wonders why it was not included in the Sports Medicine section which contains a paper on Hot Air Ballooning injuries — this, described as an enchanting sport — produces neck, and other spinal injuries, rib cage fractures and lower limb and ankle fractures in a dozen subjects. The relative incidence related to the number of participants is not mentioned but would be of interest to those about to take up this activity.

The Achilles tendon and its investigation by xenographic and mammographic techniques, patellar and symphysis pubic disorders, cycling and volley balling injuries are all discussed.

As always an interesting book to browse through and well worth buying if you are an orthopaedist.

B. Helal