

**Physiological differences in
performance - matched male
and female athletes.**

Compiled by: David P. Speechly

*In fulfilment of an MSc(MED) degree
Department of Physiology
University of the Witwatersrand Medical School
Johannesburg, SOUTH AFRICA.*

To Toni

TABLE OF CONTENTS

	Page
ABSTRACT	vi
LIST OF PAPERS	x
DECLARATION	xi
ACKNOWLEDGEMENTS	xii
DEFINITIONS	xiv
LIST OF FIGURES	xv
LIST OF TABLES	xix
CHAPTER 1: LITERATURE REVIEW	1
1.1. Introduction	1
1.1.1. Historical Perspective	1
1.2. Differential Considerations	8
1.2.1. Structural	8
1.2.1.1. Morphological	8
1.2.1.2. Body composition	9

1.2.2. Physiological	13
1.2.2.1. Aerobic	13
i. VO_2max	13
ii. Running economy	14
iii. Fraction of VO_2max used (F)	14
iv. Cardiovascular ratios	16
1.2.2.2 Muscular	18
i. Fibre Types	18
ii. Strength	19
iii. Endurance exercise	21
1.2.2.3. Metabolic	23
1.2.3. Psychological	27
1.2.4. Training Adaptations	29
1.3. Summary	31

CHAPTER 2:	Physiological comparison between performance-matched male and female athletes.	33
	2.1. Introduction	33
	2.2. Methods	35
	2.3. Results	39
	2.4. Discussion	52
	2.5. Conclusion	56
CHAPTER 3:	Endurance exercise responses over varying distances in performance-matched male and female athletes.	57
	3.1. Introduction	57
	3.2. Methods	58
	3.3. Results	61
	3.4. Discussion	77
	3.5. Conclusion	81
CHAPTER 4:	Summary	82

APPENDIX	84
-----------------	-----------

1. Assay for lactate	84
2. Assay for glucose	85
3. Assay for free fatty acids	86

REFERENCES	87
-------------------	-----------

" Men depressed by finishing second to the fair sex should be philosophical. In the greatest ultra of them all - LIFE - women consistently achieve greater performances, outliving their male peers. Basically they are just tougher."

Milroy (1992b)

" The performances of (Paula) Newby-Fraser and (Frith) van der Merwe raise the possibility that men and women are indeed not equal and that relative to their respective performances in shorter distance races, women perform better than do men in very prolonged exercise. This is in line with anthropological evidence that in traditional societies the women performed the chores requiring endurance."

Noakes (1992)

ABSTRACT

Our study comprised of a two fold investigation into i. the comparing of physiological function in a performance-matched (running 42.2km) group of females (n=10) and males (n=10), and ii. the analysis of the performance changes over four different distances.

The female group ran an average of $3:36 \pm 0:42$ hours, and the male group an average of $3:39 \pm 0:47$ hours for a standard marathon.

After matching the two groups we measured physical characteristics, maximal aerobic capacity ($\text{VO}_{2\text{max}}$), fitness level (lactate accumulation), energy cost of running (running economy), and muscle function (isokinetic dynamometry).

The female group had a significantly lower ($P<0.05$) relative $\text{VO}_{2\text{max}}$ ($48.3 \pm 2.8 \text{ml}_{\text{O}_2} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ vs $51.3 \pm 3.3 \text{ml}_{\text{O}_2} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$), lower absolute peak muscle torque for quadriceps at all angular velocities investigated (60° ; 180° ; and $240^\circ \cdot \text{sec}^{-1}$), but only at $240^\circ \cdot \text{sec}^{-1}$ for the hamstrings ($29.0 \pm 15.1 \text{Nm}$ vs $46.6 \pm 15.3 \text{Nm}$). However, females had lower ($P<0.05$) relative peak torques (expressed relative to the lean thigh volume) than males only for the quadriceps group of muscles at $180^\circ \cdot \text{sec}^{-1}$ ($12.19 \pm 4.75 \text{Nm} \cdot \text{l}^{-1}$ vs $18.87 \pm 7.01 \text{Nm} \cdot \text{l}^{-1}$). The females had a greater ($P<0.05$) percentage body fat than the males ($22.0 \pm 3.2\%$ vs $16.1 \pm 3.0\%$).

There were no significant differences in the running economies of the respective groups ($179.67 \pm 14.71 \text{ml}_{\text{O}_2} \cdot \text{kg}^{-1} \cdot \text{km}^{-1}$ for the females vs $176.90 \pm 11.34 \text{ml}_{\text{O}_2} \cdot \text{kg}^{-1} \cdot \text{km}^{-1}$ for the males), or in lactate accumulation. Furthermore, there were no gender-related differences in any of the personality profiles determined using the Profile of Mood States (POMS) test, and the Personal Motivation (PM) test.

The female group matched their male counterparts over 42.2km in spite of a lower aerobic capacity, a greater percentage body fat, and if anything a lower muscle function. Compensation for these apparent disadvantages was not the result of differences in lactate accumulation, running economy or psychological profile.

The second part of the study investigated endurance performances over four distances, in a performance-matched (running 42.2km) group of females (n=10) and males (n=10). The four distances examined were 10km, 21.1km, 42.2km, and 90km.

Using the aerobic variables obtained in the first part of the study (ie $\text{VO}_{2\text{max}}$, running economy, and lactate accumulation) from each subject, and we calculated running speeds with the approximate fractional utilisation of the $\text{VO}_{2\text{max}}$ at each distance studied. We also measured free fatty acids (FFA) levels, plasma osmolality and glucose levels before and after the 90km run.

Our female subjects performed as well as their male counterparts at 42.2km ($194.8 \pm 12.9 \text{m} \cdot \text{min}^{-1}$ vs $192.6 \pm 16.3 \text{m} \cdot \text{min}^{-1}$), but the

performance time for 90km was significantly better ($P < 0.05$) in the female group, ($171.0 \pm 11.7 \text{ m} \cdot \text{min}^{-1}$ vs $155.2 \pm 14.7 \text{ m} \cdot \text{min}^{-1}$). The average fraction of the $\text{VO}_{2\text{max}}$ (F) sustained by each subject indicated that the females achieved their performances by working at a higher ($P < 0.01$) F ($73.4 \pm 5.5\%$ vs $66.3 \pm 3.7\%$ for 42.2km and $59.8 \pm 6.2\%$ vs $50.2 \pm 3.1\%$ for 90km). The female group expended more ($P < 0.05$) energy ($10.4 \pm 1.3 \text{ W} \cdot \text{kg}^{-1}$) over the 90km distance than did their male counterparts ($9.2 \pm 0.9 \text{ W} \cdot \text{kg}^{-1}$). The degree of decline in the fraction of the $\text{VO}_{2\text{max}}$ sustained as the distance of running increased was significantly less ($P < 0.05$) in the females.

There was a difference in fat utilisation where the females exhibited a lower ($P < 0.01$) FFA level ($0.370 \pm 0.28 \text{ mM}$ vs $0.880 \pm 0.48 \text{ mM}$) after the 90km run. There were no differences in the blood glucose concentrations, nor in the plasma osmolalities between the two groups before and after the 90km run.

The better performance by the females at 90km was not related to greater maximal aerobic capacity, running economy, fitness level, or fatty acid metabolism. These results indicate that during endurance exercise the females were able to sustain higher intensities of exercise for longer.

In conclusion, these results indicate that endurance-trained female athletes may have an ability to exercise for longer at a higher percentage (F) of their $\text{VO}_{2\text{max}}$ compared to endurance-trained male athletes of similar performance-levels at the

standard marathon distance. Furthermore, female athletes (matched on performance-levels) appear to achieve their performances in a physiologically dissimilar fashion compared to their male counterparts. Finally, it may be postulated from this study, that an elevated level of β -oxidation may not necessarily indicate a performance-enhancement in ultra-endurance exercise as previously thought.

LIST OF PAPERS

Much of the work in support of this dissertation has been published in the proceedings of the 22nd annual congress of the Physiology Society of Southern Africa (October 1994) and submitted for publication to the journal "Medicine and Science in Sports and Exercise".

1. Speechly, D.P., Taylor, S.R., and Rogers G.G. Physiological comparison in performance-matched male and female athletes. Presented at the 22nd annual congress of the Physiology Society of Southern Africa, October 1994. (Winner of the C.H. Wyndham Award for the best paper read in pre-doctoral work).

2. Speechly, D.P., Taylor, S.R., and Rogers G.G. Physiological comparison in performance-matched male and female athletes: I. Physiological Responses. Submitted to the journal "Medicine and Science in Sports and Exercise". August 1994.

3. Speechly, D.P., Taylor, S.R., and Rogers G.G. Physiological comparison in performance-matched male and female athletes: II. Endurance Responses. Submitted to the journal "Medicine and Science in Sports and Exercise". August 1994.

DECLARATION

I declare that this dissertation is my own work, except where others have helped as quoted in the acknowledgements and the reference list. This dissertation is being submitted for the degree of Master of Science in the Faculty of Medicine at the University of the Witwatersrand, Johannesburg, South Africa. It has not been submitted before for any degree or examination in this, or any other university.

Furthermore, I certify that the studies contained in this dissertation have the approval of the Committee for Research on Human Subjects at the University of the Witwatersrand (Protocol Number 7/8/88).

Signed in Johannesburg on this the twenty-seventh day of March 1995.


David P. Speechly

ACKNOWLEDGEMENTS

I would like to thank the following people and institutions, without whose help, this dissertation would not have been possible:

Professor Geoff Rogers, whose assistance not only in his capacity as supervisor, but for teaching me both the finer aspects of testing athletes and the art of scientific writing, and for helping in the field-work.

Sister Fikile Makhaye, for all the help in the laboratory and administration.

Mrs Sheila Taylor, for all the advice and in her capacity as co-supervisor.

Professor Duncan Mitchell for the statistical advice.

Ms Margaret Badenhorst for the technical assistance and osmolality analysis.

The Department of Physiology, at the University of the Witwatersrand Medical School for the administrative assistance and advice.

Chris Adams, from Drs Mauff, Zail, Skudowitz & partners,
for helping with the glucose analyses.

The Irene Institute of Animal Research for analysing the
free fatty acid samples.

The Comrades Marathon Association, in particular Mrs Gill
Cohen and Dr John Godlington for all their assistance
during testing at the Comrades Marathon 1993.

All the subjects who have participated in this study: for
the early morning testing, the trauma involved during and
after running the Comrades Marathon.

DEFINITIONS

VO ₂ peak	maximal ability of an individual to produce energy using aerobic mechanisms (units given as ml _{O₂} .kg ⁻¹ .min ⁻¹).
RE	running economy, or energy cost of running (units given as ml _{O₂} .kg ⁻¹ .m ⁻¹).
OBLA	onset of blood lactate accumulation where the increase in blood lactate follows an exponential rise with the increase in work intensity. It is used as a measure of fitness.
F	average fraction that an athlete is able to utilise over a set distance.
Δv _s	is the absolute change in the average running speeds at each particular distance (s) compared to the respective pace set at 10km (v _s - v ₁₀) in this study.

LIST OF FIGURES

Figure 1	Regression line of world records in males and females since 1905 (adapted from Whipp & Ward, 1992).	3
Figure 2	Comparison of world records over all distances between men and women (From Noakes, 1992).	7
Figure 3	Running speeds of men and women whose excess body weights have been equated by artificial weighing (From Cureton & Sparling, 1980).	12
Figure 4	The curves comparing lactate accumulation as work intensity increases in both the male and female groups.	40
Figure 5	The absolute torques produced by the quadricep group of muscles shown in relation to the angular velocities investigated.	42
Figure 6	The absolute torques produced by the hamstring group of muscles shown in relation to the angular velocities investigated.	43

Figure 7	The relative torques produced by the quadricep group of muscles shown in relation to the angular velocities investigated.	45
Figure 8	The relative torques produced by the hamstring group of muscles shown in relation to the angular velocities investigated.	46
Figure 9	The effect of running 42.2km on plasma glucose concentrations.	48
Figure 10	The absolute scores from the profile of mood states (POMS) test performed under resting conditions showing the six personality traits measured.	50
Figure 11	The absolute scores from the personal motivation (PM) test performed under normal resting conditions.	51
Figure 12	The changes in average running speeds as racing distance increases (where 90km was performed at sea-level (760 Torr) compared to altitude (625 Torr) for the other distances).	62

Figure 13	The absolute changes in average running speeds (using 10km as a reference pace) as racing distance increases (where 90km was performed at sea-level (760 Torr) compared to altitude (625 Torr) for the other distances).	64
Figure 14	The percentage changes in average running speeds (using 10km as a reference pace) as racing distance increases (where 90km was performed at sea-level (760 Torr) compared to altitude (625 Torr) for the other distances).	65
Figure 15	The differences in O_2 -consumption with increasing distance between the two groups: the fraction of the VO_{2max} (F) that each group works at.	67
Figure 16	The differences in O_2 -consumption with increasing distance between the two groups: the average VO_2 that each group is able to sustain.	68
Figure 17	The differences in O_2 -consumption with increasing distance between the two groups: the approximate relative energy expenditure (in $W.kg^{-1}$) between the two groups over the four distances studied.	69

Figure 18	The effects of running 90km on plasma glucose concentrations.	71
Figure 19	The effect of running 90km on plasma FFA concentrations.	72
Figure 20	The effect of running 90km on plasma osmolality.	73
Figure 21	The psychological effects of running 90km on personality profiles as ascertained from the POMS test performed at rest (Figure 10) and then immediately upon completion of the 90km distance.	74
Figure 22	A comparison in the gender- and racial differences in running performances over varying distances.	76

LIST OF TABLES

Table 1.	Comparison of body composition, and aerobic capacities of elite male and female distance runners of the same body mass.	2
Table 2	Physical characteristics of subjects.	39
Table 3	Comparison of aerobic capacities between males and females.	41
Table 4.	Ratio of average peak torques depicting endurance ratios in the quadriceps (leg extensions) and hamstrings (leg flexions) at an angular velocity of $240^{\circ}.\text{sec}^{-1}$.	47
Table 5.	The running times for men and women over the 42.2km and 90km distances	61

CHAPTER 1: Literature review on gender differences in endurance exercise.

1.1. INTRODUCTION

1.1.1. Historical perspective

A 100m race for women was held under the auspices of the International Olympic Committee for the first time in 1928; the 200m in 1936; the 400m and 800m in 1960; and the 1 500m race took place for the first time only in 1972 (Noakes, 1992). It was not until the 1984 Los Angeles Games that women were allowed to exceed this distance, and both the 10 000m and marathon races were staged. Despite the prolonged absence of female athletes in the longer endurance-type events, women showed extraordinary progress in performance. In 1981, Allison Roe ran the New York City Marathon in a record-breaking time of 2h 25:09. Her time was good enough to have won the men's gold medal for the marathon (2h 34:51,6) in the 1948 Olympics (Noakes, 1992).

The womans' marathon in the 1992 Olympic Games was a keenly contested event, but the winning time (2:32,41) was not even close to that of the first man home over the same distance (2:13,23). Elite male athletes have a more advantageous physiological function for the stress of endurance exercise,

compared to elite female athletes (Table 1) (Noakes, 1992).

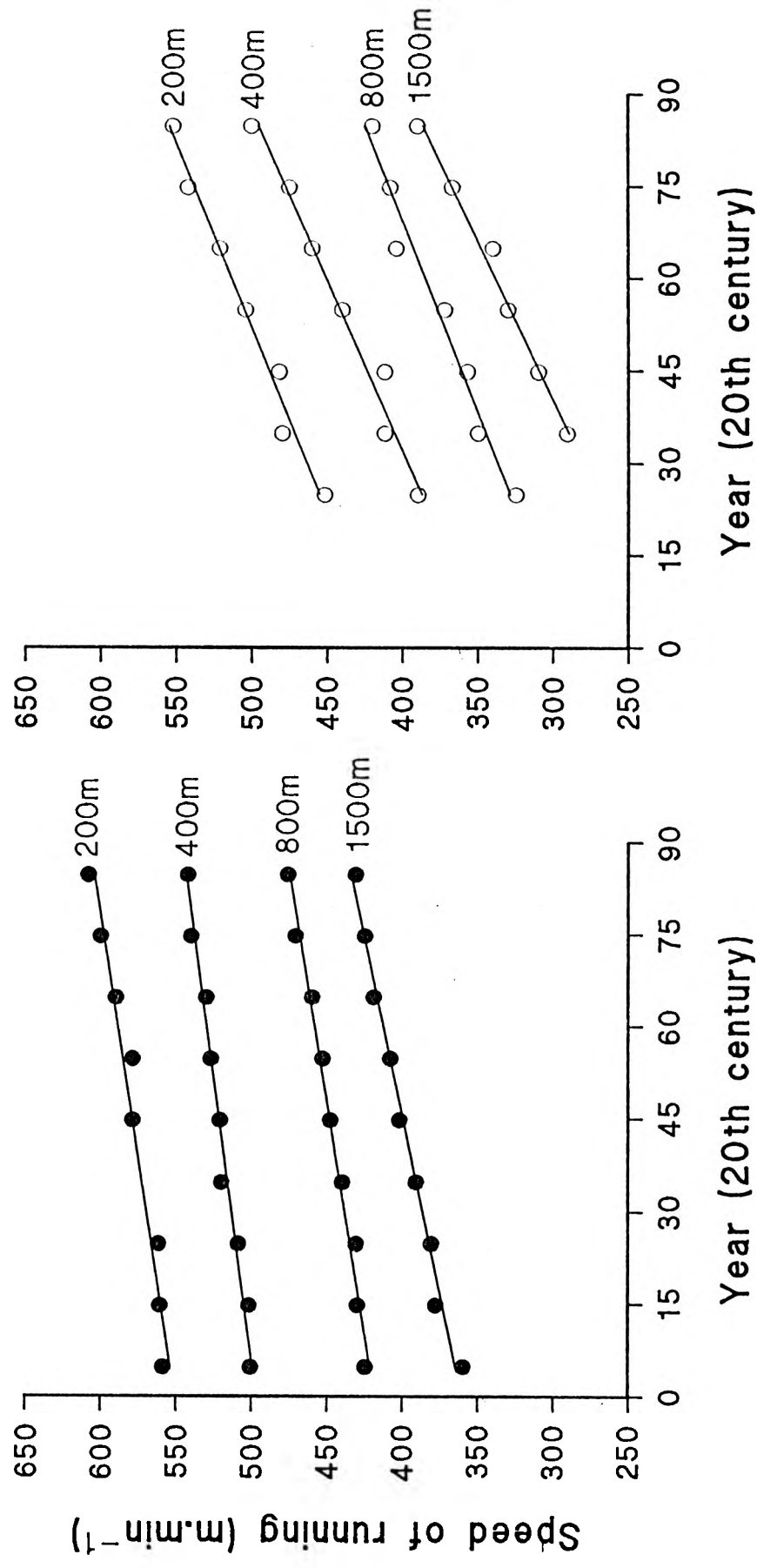
Table 1. Comparison of body composition, and aerobic capacities of elite male and female distance runners of the same body mass.

		Female	Male
Body mass	(kg)	52.0	52.0
% body fat	(%)	10.0	5.0
Mass of body fat	(kg)	5.2	2.6
Lean body mass	(kg)	46.8	49.4
Muscle mass	(kg)	15.4	18.0
VO ₂ max	(l.min ⁻¹)	3.3	3.9
VO ₂ max	(ml.kg ⁻¹ .min ⁻¹)	64.0	75.0

(From Noakes, 1992)

In spite of the latter observation, an investigation conducted by Whipp & Ward (1992), has shown that when the regression lines of the progression of world records in men and women were compared, the slopes of the lines for women were greater than those for men. This phenomenon implies that by the year 2025, female athletes may perform as well as their male counterparts. Beyond this time period, the trend implies superior performances by women. However, figure 1 shows that the regression lines are not of equal length. This is because women have not been competing in competitive sport for as long as men, and the progression of female performance has probably been influenced by advances in exercise science over the past 30 years (Sparling et al., 1993).

Fig 1. The progression of world records in men (●) and women (○).



(Adapted from Whipp & Ward, 1992)

Be that as it may, the current trend is that males outperform females in most aspects of sporting endeavour. The findings of Whipp & Ward (1992), have been slated by their peers for using pure mathematics to explain physiological function (Sparling et al., 1993). Sparling et al., (1993), argued that Whipp and Ward (1992) analysed athletic performance progression in a non-real (based on false premises) fashion. Sparling and co-workers proposed that such an analysis implies a unique sex-specific biological endurance capability inherent to women, that would, in the context of the analysis, allow for an eventual superior performance capability by women athletes. Sparling et al., further proposed that the reason for the advancement of female record times is that the rate of improvement in a world record for a given event depends on the following factors: the newness of the event; number of participants in the event; amount of training for it; and how popular it is. They concluded that the reason for the greater improvements by female athletes was a combination of all four factors, and that since females have only been participating for a shorter period compared to the males, endurance exercise is "newer" for females than it is for males. Furthermore, these authors report that the bulk of the improvement took about twenty years to mature (from the early 1960's to the early 1980's), and that since the early 1980's the womens' world records for the marathon have started to level off.

Finally, on the linear regression method employed by Whipp and Ward in 1992, Sparling and co-workers criticise these authors for making the same mistake as did a similar study in 1976 (Ryder et

al., 1976). Sparling et al., point out that the predictions from either of these studies using a linear regression are unrealistic and will not give a true estimation of future performance between the genders. They propose that an asymptotic curve as described by Morton (1983) is the best curve to describe the progression of world-records with time.

The truth of the matter lies in the primary question: what are the differences between males and females that allow males to perform so much better than their female counterparts? Sparling et al., (1993) explain that there is an average of 11% difference in the world-records between males and females (see fig 2, Comparison of world-records over all distances, adapted from Noakes, 1992). It is the inherent sex-specific differences in relative body-fatness (% fat), haemoglobin concentration (Pate et al., 1985) and size of the oxygen transport organs (Hutchinson et al., 1991) that are responsible for this difference., at least in the endurance events.

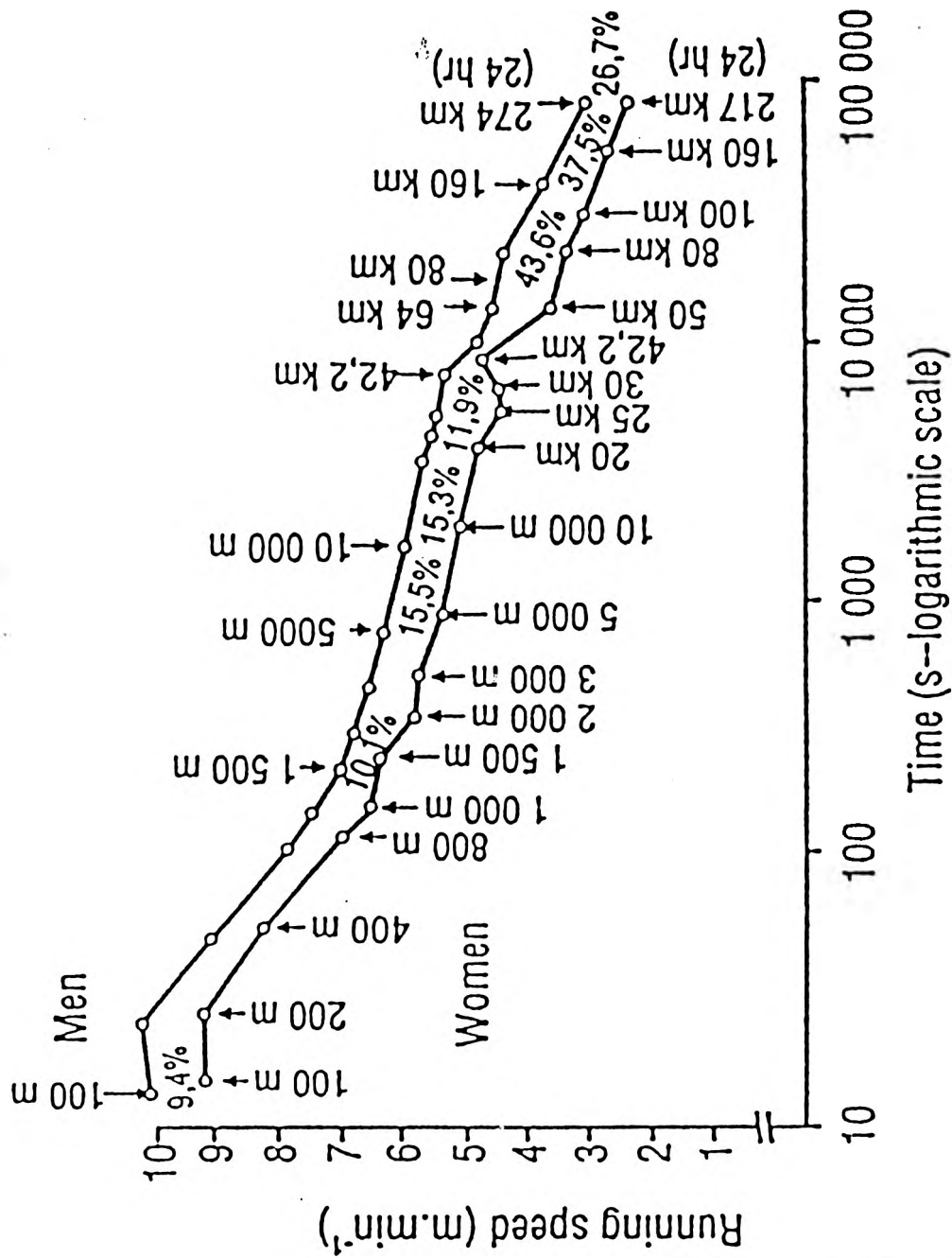
Numerous studies have compared the physiology of elite female endurance athletes with that of elite male endurance athletes, (Cureton & Sparling, 1980; Hutchinson et al., 1991; Noakes, 1992; Sparling et al., 1993; Wells & Plowman, 1983). In all these studies, the males had a significantly greater aerobic capacities than the females.

To our knowledge, only one study (Pate et al., 1985) has considered matching male and female athletes on the basis of

their performances (in this case the distance was $\pm 24.1\text{km}$), and then comparing physiological function. These authors found that the similar performances by both groups were achieved in physiologically similar fashions.

In a preliminary study conducted in this laboratory (Lewis et al., 1988) it was found that male and female athletes who were matched purely on their aerobic abilities performed equally well at the shorter distances (ie 15 to 21.1km). However, females tended to outperform their male counterparts as the distance of the race increased (42.2km to 90km). This study was undertaken to confirm and broaden this investigation.

Figure 2. The comparison of world records over all distances between men and women.



T.D. Noakes (1992)

1.2 DIFFERENCES TO CONSIDER:

1.2.1. Structural

- 1.2.1.1 Morphological
- 1.2.1.2 Body composition

1.2.2. Physiological

- 1.2.2.1 Aerobic aspects
 - (i) VO_2max
 - (ii) Running economy
 - (iii) Fraction of VO_2max used
 - (iv) Cardiovascular ratios
- 1.2.2.2 Muscular
 - (i) Fibre Types
 - (ii) Strength
 - (iii) Endurance exercise
- 1.2.2.3 Metabolic

1.2.3. Psychological

1.2.4. Training Adaptations

1.2.1. STRUCTURAL DIFFERENCES

1.2.1.1. MORPHOLOGICAL DIFFERENCES

At first sight, the physical differences between the genders is fairly obvious: adult males are larger on the average than their

female counterparts. The significance of this somewhat obvious phenomenon becomes more relevant as the investigation continues: the larger male will have a smaller surface area to volume ratio (SA:V) when compared to the smaller female. In addition, the males exhibit larger organs (ie cardiovascular and respiratory systems (Hutchinson et al., 1991; Pate et al., 1985)) and muscles (Lauerbach, 1976; Costill et al., 1987). In line with the current theories governing exercise physiology, the adult male will outperform an adult female purely on physiological profile (ie he has larger muscles to produce force for the work output, and he is able to transport and utilise more oxygen to fuel the working muscles).

1.2.1.2. BODY COMPOSITION

Keyes & Brozek (1953) divided the body into two compartments and measured the relative masses of both (ie that mass of the body which is fat, and that mass of the body which is fat-free. Females have a greater percentage body fat than do males (Brodie, 1988; Durnin & Womersley, 1974; Lukaski, 1987; Hutchinson et al., 1990; Pate et al., 1985). The question that needs to be addressed is does the excess dead weight hamper female performance?

The lower percentage body fat in males compared to their female counterparts occurs in all population groups from sedentary individuals to Olympic athletes (Wells & Plowman, 1983). In a

study done by Sparling (1980), the body fat in the men was 12.95%, compared to 24.32% in the women. The ranges for percentage body fat given by Wells & Plowman (1983) are 12-16% for men, and 22-26% for women.

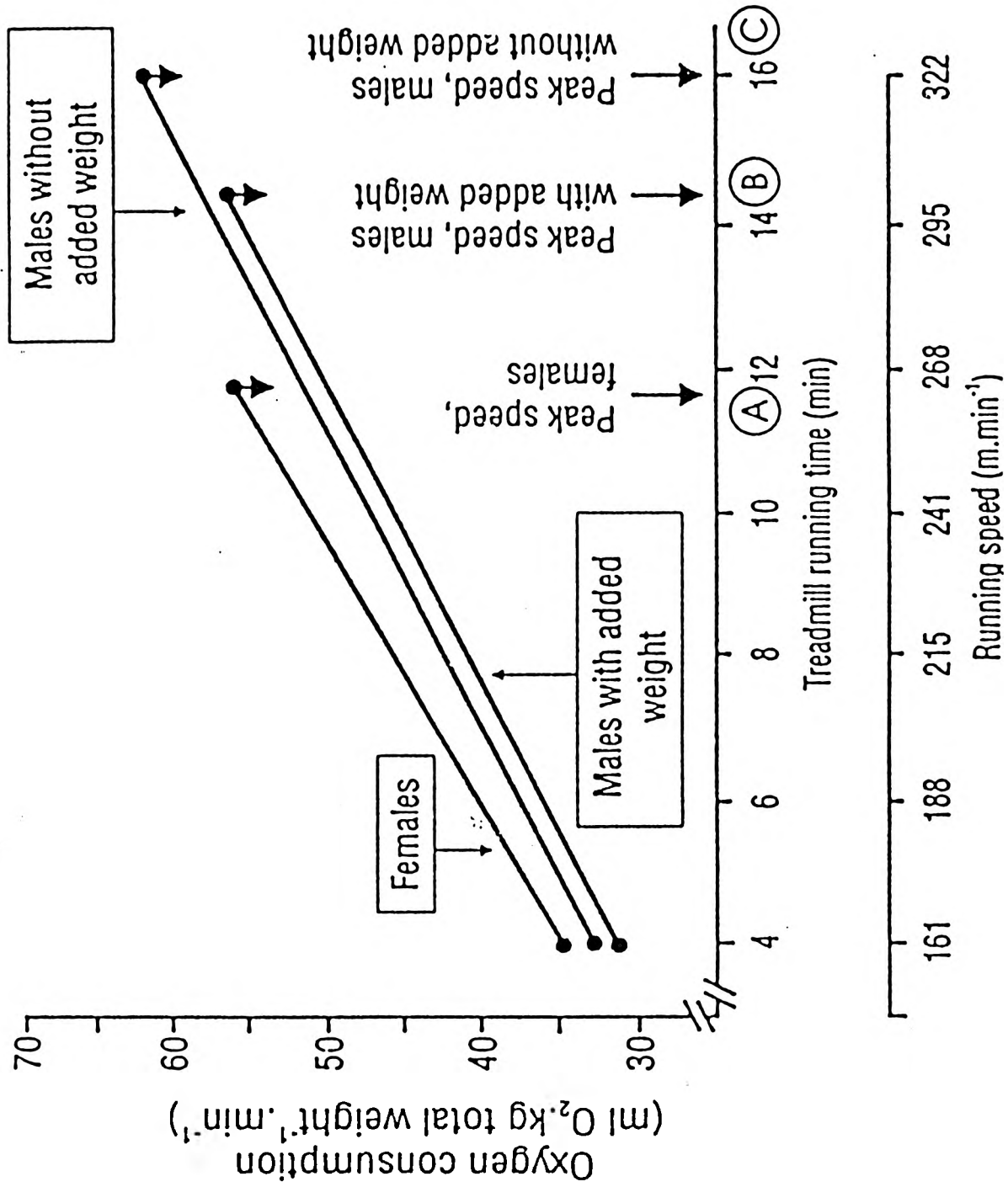
Wells & Plowman (1983) postulate that the effect that the elevated fat stores has on women is two-fold: i. there is less muscle mass (also depicted in table 1) on a woman with which to exert force in exercises that require muscular strength, power and endurance; and ii. the elevated fat stores increase the metabolic cost of weight bearing exercises (running, walking) without increasing the body's ability to produce energy.

Table 1 reinforces Wells & Plowman's notion that one of the variables which could hamper performance in females is their excess body fat. The excess body fat is considered as extra "dead weight" which has to be carried, and which therefore effectively reduces the relative oxygen consumption value. Cureton and Sparling (1980) artificially weighed-down male athletes with weight-belts, so that the ratios of lean mass to fat- or "useless"- mass were identical in their female and male athletes: the males had to increase their "dead weight" by 7.5%. This additional weight reduced the difference in running time between the sexes by 32%, and in VO_{2max} by 65%. The results in their study showed males to perform 23% better than females in spite of equalising dead weight in the two genders. They concluded that running at any given submaximal speed is done at a higher percentage of maximum for the women compared to the men.

Furthermore, it is important to note that this study concentrated on eliminating dead weight alone, and did not allow for differences in performance which may result from either peripheral (muscle function and fuel utilisation) or central (circulation) factors.

Cureton and Sparling (1980) postulated that the average female would reach her VO_{2max} at a lower work intensity than the average male would his (VO_{2max}). From their data, they hypothesised that the pace (v) that can be maintained over time is proportionally greater for an individual carrying less fat.

Figure 3. Running speeds of men and women whose excess body weights have been equated by artificial weighing.



Cureton & Sparling (1980)

1.2.2. PHYSIOLOGICAL DIFFERENCES

1.2.2.1 Aerobic aspects

The differences to consider here are:

- (i) VO_2max
- (ii) Running economy
- (iii) Fraction of the VO_2max used
- (iv) Cardiovascular ratios

i..The capacity for oxygen consumption and its plateau effect: the VO_2max .

The VO_2 , by definition, is essentially the rate of oxygen that is consumed by a body at any given work-load (Fox and Mathews, 1981). The relationship between VO_2 and work intensity is linear, ie as the amount of work that is done by the body increases, there is a proportional increase in the rate of oxygen consumption (Fox and Mathews, 1981). However, a level is reached where in spite of increases in work intensity no further increase in VO_2 occurs, ie the ability to derive energy by aerobic mechanisms reaches a maximum. This level is referred to as the maximal oxygen consumption or VO_2max (Fox & Mathews, 1981). Current research has shown that VO_2max is 40-60% greater in males compared to females when expressed in absolute terms (ie $\text{l}\cdot\text{min}^{-1}$) (Washburn and Seals 1984, Hutchinson et al., 1990,

Pate et al., 1985, Costill et al., 1979). However, if VO_2max values relative to body mass (ie $\text{mlO}_2\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$) are compared, the differences are reduced to 20-30%. Finally, if the VO_2max values are compared relative to the lean body mass, the differences between the sexes is reduced even more, and in some cases assumes statistical insignificance (Hutchinson et al., 1990; Noakes, 1992).

ii. Running Economy

There have been a number of studies (Pate et al., 1985; Daniels et al., 1977) that have investigated a possible gender-related difference in running economy. Of those reviewed, none showed a difference. This is not surprising as there is no a priori reason pointing to such a difference existing.

iii. Fraction of the VO_2max used (F)

The percentage of VO_2max at which the genders exercise is an important consideration when making comparisons in endurance performances between the two groups. Various studies have reported that female athletes can run at

equivalent percentages of their VO_2max to that of the best male runners (Davies & Thompson, 1979; Conley et al., 1981a; Wells et al., 1981). In addition to this finding, Peronnet & Thibault, (1989) reported that even the less good female athletes competing in marathons run at a higher percentage VO_2max (85%) than the male world record holders (83%).

The quantification of the F value under controlled conditions in the laboratory is a standard procedure. During a field study, the F value can be estimated using laboratory measurements. di Prampero et al., (1986), reported the relationship between the average speed of running, VO_2max , the energy cost of running (or running economy), and the average sustainable fraction of VO_2max for an event. The relationship was given algebraically as:

$$F = \text{RE} \cdot v_s / \text{VO}_2\text{max}$$

Where :

F	is the average sustainable fraction of the VO_2max .
RE	is the energy cost of running (or running economy) units in $\text{ml}_{\text{O}_2} \cdot \text{kg}^{-1} \cdot \text{m}^{-1}$.
VO_2max	is the maximal aerobic capacity, with units in $\text{ml}_{\text{O}_2} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$.
v_s	is the average speed of running over a specific distance (s) with units in $\text{m} \cdot \text{min}^{-1}$.

iv. Cardiovascular Ratios

Males, on average, have a higher VO_2max than females (Hutchinson et al., 1991; Wells & Plowman, 1983). This is due to the greater size of the oxygen transport organs and muscles (Fox & Mathews, 1981). Of particular importance is heart size, which is closely associated with differences in the left ventricular mass (LVM) (Hutchinson et al., 1991). It has been shown that irrespective of whether heart size is expressed as an absolute volume (ml) or relative to body size (ml.kg^{-1}), the female heart is 80% as large as the male's heart. The indications of this size difference manifest as a smaller stroke volume (Rowell et al., 1969). Since there is very little difference in maximal heart rates, the smaller stroke volume results in about a 30% difference in maximal cardiac output between the genders (Wells & Plowman, 1983).

Hutchinson et al., (1991) concluded that the difference in the VO_2max could be attributed predominantly to the gender-related difference in left ventricular mass. Other differences in body size (ie larger muscle mass, greater respiratory indices), they postulated, contributed the remaining factors to the gender-difference in VO_2max . However, there is a mean difference of about $2\text{gm.100ml}_{\text{blood}}^{-1}$ in haemoglobin concentration in men (being greater) and women: this results in a reduced O_2 carrying capacity in women compared to men, which leads to a lower a-vO_2

difference in females. They concluded that the essential difference between males and females in aerobic capacity should be considered a true gender difference linked to the genetic difference in general body size.

1.2.2.2. MUSCULAR DIFFERENCES

The two main aspects that require consideration within the scope of muscle function are the possibility of any gender-related differences in muscle structure and the torques produced by the exercising muscle. In the assessment of the functioning of the exercising muscle, isokinetic dynamometry appears to be the most valuable technique available (Perrin, 1992). Isokinetic dynamometry creates a muscular profile which may be used (apart for numerous other purposes) in the evaluation of a subjects ability to generate peak torque (strength), and endurance.

i. MUSCLE FIBRE TYPES

Current research (Prince et al., 1977; Wells & Plowman, 1983; and Costill et al., 1987) shows that the fibre types of female athletes are similar in distribution (percentage of Type I to Type II fibres) and histochemical properties to those of male athletes. What these scientists did find however, is that the males athletes have larger (diameters) muscle fibres (both Type I and Type II, the greatest gender-related difference occurring in the fast-twitch fibres). Does the fact that muscles in males are larger than in females (Laubach et al., 1976., Wells & Plowman, 1983, Costill et al., 1987), have any bearing on the

reason for enhanced endurance-exercise performances posted by males?

The reasons for the gender-related inequality in volume of muscle tissue has been attributed primarily to hormonal variation with special emphasis on the level of testosterone, the male hormone that causes the majority of the secondary male characteristics at adolescence (Wells & Plowman, 1983). Since muscle volume is the main muscle difference between the genders, consideration should be given to the influence that muscle volume would have on performance.

ii. STRENGTH DIFFERENCES

Laubach (1976), found that males were stronger than females, and he reviewed the literature of 9 studies reporting results from static and dynamic muscle strength trials. This review took into consideration those strengths from different anatomical sites of the body. The main findings were:

- a. that upper extremity strength measurements in women were found to range from 35 - 79% (averaging 55.8%) to that of their male counterparts.
- b. that lower extremity strength measurements in women ranged from 57 to 86% of mens', averaging 71.9%.
- c. trunk strength for women ranged from 37 - 70% compared to that of mens', (average 63.8%).

- d. the dynamic strength indicators revealed that women were approximately 59 - 84% as strong as men (averaging 68.6%).

Noakes (1992) agrees with the findings of Laubach (1976) and he emphasises that when muscle strength is expressed absolutely, the inter-gender differences are great, as shown above. However, when these strengths are expressed relative to the fat-free mass, the differences become less marked. Finally, Noakes (1992) proposed that if the strengths are expressed relative to the cross-sectional diameter of the muscle fibre, the differences would be eliminated. This proposal is supported by the study of Wilmore (1974) who found that average force production increased by $\pm 20\%$ in females when expressed relative to fat-free mass compared to the original absolute strength produced. Wells & Plowman (1983) indicate that in "studies relating strength to cross-sectional area of muscle show no sex difference, so the ability of the muscle fibres to exert force must be independent of sex". They continue that the differences observed in strength between the genders is a direct result of the larger male size, greater LBM, and larger muscle fibres.

Perrin (1992) reports that when the isokinetic strength is expressed as a percentage of total body weight, the difference in strength between males and females is reduced: this difference is even more pronounced when the peak torques are expressed relative to lean body mass. This report is supported by Smith

et al., (1985) who found a high correlation in expressing muscular strength in these two ways (ie relative to body weight, and to lean body mass) but Perrin (1992) suggests the former (relative to body weight) since "adipose tissue cannot be shed when participating in athletic activities".

There is no difference in the way that males' and females' muscle fibres respond to training ie. the rate of hypertrophy and change in contractility are similar in both sexes (Holloway and Baechle, 1990).

iii. ENDURANCE EXERCISE

The importance of muscular strength to the performance during endurance running is unclear; what does however seem to be important is the endurance capability of the muscles performing the work (Perrin, 1986). Perrin (1992) assessed muscle endurance capacity the capacity of the muscle to produce force over a series of consecutive isokinetic contractions, which has also been expressed as a fatigue index. Kannus et al., (1992) reported that the work performed during the last 5 of 25 repetitions were valuable in the assessment of an endurance capacity, or fatigue index. Furthermore, they (Kannus et al., 1992) suggested that such an index would be valuable in the documentation of progress during endurance training. A study into a gender-related difference with regards correlating the fatigue index (obtained via isokinetic dynamometry as described

above) and performance during endurance exercise has not been attained, but it has however been reported that the muscles of endurance-trained female athletes may be more resistant to fatigue than are mens' when repeated contractions are undergone (Misner et al., 1990). This requires further attention. What can be deduced from the current literature however, is that there are no known studies that relate the larger diameter muscle fibres to a superior endurance performance (ie that males are not at an advantage over females (with smaller diameter muscle fibres) with regards endurance exercise).

2.3. METABOLIC DIFFERENCES

The variables to consider in this section are:

- (i) Glucose
- (ii) Free fatty acids

The substrates listed are important because they serve as substrates in metabolism during endurance exercise.

As has been described above in the section relating to muscle function, it was noted that during endurance and ultra-endurance exercise it is the Type I (oxidative) muscle fibres that are responsible for the force generation required for the power-output required to do the work. Type I fibres produce ATP from the oxidative metabolism of glucose and free fatty acids (FFA).

During an endurance event such as a marathon, the major fuel for oxidative phosphorylation is mainly muscle glycogen (Noakes, 1992). This premise has stood in good stead with exercise physiologists for over 30 years. Hultman (1967) concluded from his studies that "the limiting factor in the performance of long term heavy muscular work (ie the marathon) is the pre-formed glycogen store in the working muscle".

Fatigue in activities requiring approximately 60-85% $\text{VO}_{2\text{max}}$ is closely associated with muscle glycogen depletion (Bergstrom et al., 1967). Using this model on fatigue and performance during endurance exercise, sparing the intra-muscular glycogen levels

should make it possible to delay fatigue. The concept of glycogen-sparing has received huge attention over the past 30 years, and perhaps the most remarkable results obtained in this field are those from studies that manipulated the mobilisation and availability of free fatty acids (FFA). Bergstrom et al., (1967) found that during prolonged exercise, there was a rise in the FFA concentration with a concomitant drop in the respiratory quotient (RQ). The drop in the RQ represents a shift from carbohydrate oxidation to fat oxidation. They (Bergstrom et al., 1967) reasoned that the increased availability, uptake, and subsequent use of endogenous adipose tissue could have a sparing effect on carbohydrate use in skeletal muscle similar to that in heart muscle as described by Randle et al., (1967). The point in question however, is not so much whether glycogen-sparing prolongs endurance exercise, but rather whether there is a gender-related difference in glycogen-sparing during endurance exercise.

It has been noted that women run better, for longer compared to the men runners during endurance exercise (Ullyot, 1976). Motivated by the findings of Bergstrom et al., (1967), Ullyot (1976) postulated from her observations of enhanced female performances during endurance exercise, that this phenomenon was a result of a superior ability on the part of the female runners to oxidise fat as a fuel substrate compared to the male runners.

Costill et al., (1979) took up the challenge proposed by Ullyot (1976), and they showed that men and women who were equally

trained and with similar $\text{VO}_{2\text{peak}}$ values burned the same amount of fat in a 60-minute treadmill run. There were no differences in free fatty acid or glycerol levels during the run. They (Costill et al., 1979) concluded that if Ulliyot's proposal were true, there would have been higher lipid concentrations in the female group. The argument against this study was that a 60-minute treadmill run may not be sufficiently long enough for the "superior fat oxidation capacity" to be activated.

In a later study, Costill et al., (1987) studied muscle samples in vitro to investigate the muscles inherent ability to metabolise fats. The muscle samples were taken from men and women athletes. Their main finding in this study was contrary to that expected: female muscle metabolised less fat than male muscle. They (Costill et al., 1987) proposed that female muscles contain a lower mitochondrial density compared to males, thereby reducing, by mass action, the capacity to oxidise fat.

However, Tarnopolsky et al., (1990) presented findings which indicate that women do burn more fat than men do. A finding of this study was that muscle glycogen use during exercise at 65% $\text{VO}_{2\text{peak}}$ was less in females than in males. This would mean a greater glycogen-sparing factor in females, and in view of the deleterious role played by glycogen depletion during ultra-endurance activities, this difference would be a great advantage to women during these events. Noakes (1992) agrees with the findings of Tarnopolsky et al., 1990, and interprets the data contained therein as beneficial to female athletes in very long

aces.

Ravussin et al., (1988) however, noted that in a study involving a 2½ hour exercise bout the only benefit of raised FFA levels for carbohydrate metabolism occurred during the first 30 minutes (of a 2½ hour exercise bout) of exercise (Ravussin et al., 1988). These authors concluded that the persistent elevation of FFA over the next two hours of exercise had no further carbohydrate-sparing effect. The intensity of the exercise used in their study was only 44% of $\text{VO}_{2\text{peak}}$, and muscle glycogen depletion was not measured.

Since there are very few studies that have tackled the question on substrate dynamics (and the associated mechanism of utilisation) in endurance exercise bouts of prolonged duration (ie longer than 5-6 hours), much controversy surrounds these concepts. It seems that more research is required in this field.

1.2.3. PSYCHOLOGICAL DIFFERENCES

The literature containing gender-related differences in the psychology of endurance athletes proved to be fairly scarce. It seems that all the work done so far has focused primarily on either the changes that occur with exercise, psychological profiles of the elite ultra-endurance athletes, and the affective benefits of exercise with regards to psychological disposition (Morgan, 1985).

It is believed however, that females exhibit a stronger psychological disposition, or that they may be able to withstand greater levels of pain (Noakes, 1992). The premise of these notions is that an ultra-endurance exercise bout induces less of a shift in the psychological homeostasis of the female athlete when comparing the effect the same exercise bout has on the male athlete (Koltyn et al., 1991). Koltyn et al., (1991) found that women perceive equivalent levels of exercise as less stressful than do men.

As a means of assessing the possible gender-related differences in psychological dispositions, the profile of mood states (POMS) and personal motivation tests may be employed. The POMS test is divided into six personality traits: tension; depression; anger; vigour; fatigue; and confusion (McNair et al., 1992). The personal motivation (PM) test is divided into three and two subfactors respectively: goal directedness (AA) and personal excellence (BB) comprise the overall PM. Individuals who score

highly in the AA factor are intent on achieving personal goals and will persevere despite adversity. The AA is comprised of (A) persistence; (B) awareness of time; and (C) action orientation. The second subfactor (BB), is challenge - oriented. Individuals who score highly on the BB factor believe that their fate is entirely in their hands, and goals will be achieved by taking the initiative rather than leaving them to luck. The BB is comprised of (D) aspirational level; and (E) personal causation (Pottas et al., 1988) (Figure 11).

1.2.4. TRAINING ADAPTATIONS

Drinkwater (1984) reports that there are no gender-related differences in the effectiveness of aerobic conditioning programmes. As a result of endurance-training, Eddy et al., (1977) found that males were able to increase their VO_2max value by 15% compared to the 14.2% improvement by females. Maximal heart rate shows little or no difference between the genders as a result of training (Drinkwater, 1984).

Jacobs (1986) relates the measurement of blood lactate concentration during exercise in the evaluation of its use as a training tool. It has been proposed (Nygaard, 1981) that females possess skeletal muscle characteristics which favour oxidative metabolism, and that their ability to derive energy from glycolysis is limited compared to males. Jacobs (1983b) tested this hypothesis during a 30 second Wingate Test and found no differences, and he concluded that the ability of an individual to tolerate the accompanying perceived fatigue associated with high lactate accumulation is more an acquired rather than a gender-related talent.

The most effective monitor of endurance-trained adaptations is the analysis of the curves relating lactate accumulation to the work production (Sjodin & Jacobs, 1981). One form of analysis is the assessment of the onset of blood lactate accumulation (OBLA) (Sjodin & Jacobs, 1981). It is well documented that endurance training results in the accumulation of lactate at a

higher work intensity (Jacobs, 1986), thereby allowing for an improved submaximal running performance. When considering gender-related differences, an assessment needs to be made whether training effects occur to the same extent, and at the same rate in both genders (ie do the curves relating lactate accumulation to the work production between the two genders follow the same dynamics?).

Strangely, there are no known studies comparing lactate dynamics in male and female athletes. However, from the findings of Jacobs et al., (1983b), there is no apparent reason for a gender-related difference in the dynamics of the lactate curves in endurance-trained male and female athletes. It seems that the only factors controlling the point at which lactate starts accumulating is based on genetic and training factors (Jacobs, 1986).

1.3. SUMMARY

It is well documented that elite male athletes perform better than elite female athletes (Cureton & Sparling, 1980; Hutchinson et al., 1991; Noakes, 1992; Sparling et al., 1993; Wells & Plowman, 1983). The differences, pertinent to endurance-exercise, that exist between the genders have been discussed at length with the obvious differences in the physical characteristics: males are both taller and heavier than females. Males have less body fat as a percentage of their body mass. Males are also stronger than females, their muscular strength and function tending to be higher than women. Furthermore, males also have a more effective cardio-pulmonary function.

An area which deserves more attention is gender-related differences in substrate utilisation during ultra-endurance exercise. The psychology of ultra-endurance exercise is also important. It has not been incorporated into the equation with great fervour, probably due to the complexity in attaining concrete data.

It has been reported that female athletes can run at equivalent percentages of their $\text{VO}_{2\text{max}}$ to that of the best male runners (Davies & Thompson, 1979; Conley et al., 1981a; Wells et al., 1981), and that even the less good female athletes competing in marathons run at a higher percentage $\text{VO}_{2\text{max}}$ (85%) than the male world record holders (83%) (Peronnet & Thibault, 1989). In addition to this, it appears that the muscles of the female

athletes could be more resistant to fatigue than are mens' when repeated contractions are undergone (Misner et al., 1990). This hypothesis requires a great deal more investigation. However, these findings could prove to be invaluable when considering female performances in the ultra-marathon distances and beyond (Noakes, 1992).

CHAPTER 2: Comparison of physiological function in performance-matched male and female athletes.

2.1. INTRODUCTION

When the progression of athletic world records between the genders was analysed, Whipp & Ward (1992) predicted that, since female records are being broken at such a rate, by the year 2025 female athletes will perform as well as their male counterparts. Beyond this period, the trend predicts superior performances by females.

Although data exists on gender-differences between endurance athletes (Conley et al., 1981a; Costill et al., 1979; Cureton & Sparling, 1980; Davies & Thompson, 1979; Maughan & Leiper, 1983; Tarnopolsky et al., 1990; and Wells & Plowman 1983), only one has made a physiological comparison after equating performances (time to run ± 25 km) between a group of male and a group of female athletes (Pate, Barnes & Miller, 1985). The latter study found that no gender-related differences in physiological function occur, and that the equal performances are achieved in physiologically similar ways.

However, a preliminary study conducted in this laboratory suggests that when aerobic physiological function is matched,

female athletes tend to outperform their male counterparts in events longer than 21.1km (Lewis et al., 1988).

Therefore, the purpose of this study was to compare the physiological profiles of male and female athletes who perform at similar levels over 42.2km, and assess whether these athletes achieve their similar performances in physiologically similar fashions.

2.2. METHODS

Twenty runners, ten males and ten females, volunteered to participate in this study after providing informed consent. Each male runner was matched with a female runner according to the time taken to complete a given standard marathon (42.2km). The female group ran an average of $3:36 \pm 0:42$ hours, and the male group an average of $3:39 \pm 0:47$ hours for a standard marathon.

The subjects reported to a laboratory situated at an altitude of 1800m (625 torr) and regulated at a room temperature of 20-22°C. All subjects were familiarised with the testing equipment and procedures prior to the commencement of testing.

Body composition was measured according to the method of Durnin and Womersley (1974), by measuring skinfold thickness at the biceps, triceps, suprailiac, and subscapular sites. Body mass (accurate to 0.05kg, Mettler TE/J, Zurich, Switzerland) and height (accurate to 0.1cm, SECA, Germany) measurements were taken.

Each subject was then asked to run on a motorised treadmill (Powerjog, E10, Sport Engineering Limited, Birmingham, England). Oxygen consumption (VO_2) was measured during steady-state treadmill running (2-3min) using a pre-calibrated on-line system (Oxycon-4, Mijnhardt, Bunnik, Holland) and heart rate was monitored by means of subcostal ECG leads (Hewlett Packard 78351, Andover, Ma, USA). Measurements to calculate running economy

(RE) were made during steady state submaximal exercise (12 km·hour⁻¹ and 0.0% gradient) (Conley et al., 1981b). Running economy was calculated from:

$$\text{Running economy} = (\text{VO}_{2\text{max}} - \text{VO}_{2\text{rest}}) / \text{speed of running.}$$

Maximal aerobic capacity (VO₂max) was measured using a discontinuous incremental model (Wyndham et al., 1959). The speed of the treadmill remained constant (13.0 km·hour⁻¹), and load was increased by increasing the gradient (1.0% increments). Each work-load was of three-minute duration. The VO₂max was considered to have been reached when the change in the VO₂ was not more than 1.0 ml_{O2}·min⁻¹·kg⁻¹ with an increment in the gradient of 1%.

The blood lactate curve for each subject was determined as a measure of fitness level (Jacobs, 1986). Blood was collected from an in-dwelling winged infusion set inserted into a forearm vein. The blood samples were collected into tubes containing an anticoagulant (potassium oxalate) and a metabolic inhibitor (sodium fluoride). The subjects performed a graded exercise protocol on a treadmill in which the gradient was progressively increased every 3.5 minutes until a VO₂ of at least 90% VO₂max had been reached (Jacobs, 1986). Blood was drawn and steady state VO₂ was measured at each level. The plasma was frozen at -20°C until analysis using an enzymatic-spectrophotometric method (Boehringer Mannheim, Mannheim, Germany). The lactate curve for the female group and for the male group respectively was constructed using least squares-regression on an exponential

model (Fig 4). The assay used for lactate concentration is described in appendix A.

Muscle torque developed by the dominant leg was measured using an isokinetic dynamometer (Cybex II, Ronkonkoma, USA). The subjects (9 females and 9 males) performed leg extensions and leg flexions at angular velocities of $60^{\circ}\cdot\text{sec}^{-1}$, $180^{\circ}\cdot\text{sec}^{-1}$, and $240^{\circ}\cdot\text{sec}^{-1}$. The average peak torques (five contractions) obtained for the first was used as a measure of strength, and for the second as a measure of functional force development. Separate measurements were obtained for leg extension and flexion. A fall-off in peak torque over the 20 contractions at a velocity of $240^{\circ}\cdot\text{sec}^{-1}$, (expressed as the ratio of average peak torque in the first five leg extensions and flexions compared to the average peak torque in the last five leg extensions and flexions) was used as a measure of muscle endurance. In all instances a correction was made for the effects of gravity on vertical leg extension and leg flexion.

An estimate of thigh muscle volume would allow individual torque measurements to be expressed relative to individual muscle volumes (ie $\text{Nm}\cdot\text{l}^{-1}$). The volume of the thigh muscle was estimated using a truncated cone model:

$$\text{volume} = (\pi h/3) \cdot (r_1^2 + r_1 r_2 + r_2^2).$$

Thigh radius was calculated after measuring the circumference of the thigh 2cm inferior to the gluteal fold (r_1) and 2cm above the

superior edge of the patella (r_2). The vertical height (h) was calculated using the principle of Pythagoras. A measurement of thigh skinfold thickness was made to correct for subcutaneous fat (Fox & Mathews, 1981) and correction was made for bone radius.

The subjects were also asked to complete the Profile of Mood States (POMS) and Personal Motivation (PM) questionnaires under normal resting conditions. The personal motivation (PM) test is divided into three and two subfactors respectively: goal directedness (AA) and personal excellence (BB) comprise the overall PM. Individuals who score highly in the AA factor are intent on achieving personal goals and will persevere despite adversity. The AA is comprised of (A) persistence; (B) awareness of time; and (C) action orientation. The second subfactor (BB), is challenge - oriented. Individuals who score highly on the BB factor believe that their fate is entirely in their hands, and goals will be achieved by taking the initiative rather than leaving them to luck. The BB is comprised of (D) aspirational level; and (E) personal causation (Pottas et al., 1988).

Blood samples were obtained before and after the marathon in six females and five males: these were for the analysis of plasma concentrations of glucose (Glucose GOD/PAP; colorimetric method with deproteinisation, Randox Laboratories, Antrim, N. Ireland). Student's t-statistic for independent data (Glantz, 1981) was used to analyse differences between groups. The null hypothesis was rejected at the 5.0% level. The data are presented as means $\pm$ SD.

2.3. RESULTS

The female group was lighter ($P < 0.01$) than the male group ($57.33 \pm 6.4\text{kg}$ vs $72.1 \pm 11.4\text{kg}$ respectively). The percentage body fat values of the female group was significantly higher ($P < 0.01$) than that of the male group ($22.04 \pm 3.2\%$ vs $16.1 \pm 3.0\%$) (Table 2).

Table 2. Physical characteristics of subjects

		FEMALES	MALES	P
Age,	(years)	33.7 ± 5.6	35.0 ± 8.8	NS
Height,	(cm)	166.4 ± 7.6	177.4 ± 6.2	0.01
Body mass,	(kg)	57.3 ± 6.4	72.1 ± 11.4	0.01
Fat-free mass,	(kg)	45.0 ± 5.2	60.2 ± 7.8	0.01
% body fat,	(%)	22.0 ± 3.2	16.1 ± 3.0	0.01
Fat mass,	(kg)	12.6 ± 2.2	11.9 ± 3.8	NS
Lean thigh volume,	(l)	5.6 ± 0.9	6.7 ± 1.1	0.05

Values are means $\pm$ SD for 10 females and 10 males.

Table 3 shows that the female $\text{VO}_{2\text{max}}$ values were 5.7% lower ($P < 0.05$) than their male counterparts when expressed relative to body mass ($48.3 \pm 2.8 \text{ ml}_{\text{O}_2} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ vs $51.3 \pm 3.3 \text{ ml}_{\text{O}_2} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$), but were not significantly different when they were expressed relative to the fat-free mass ($61.6 \pm 2.7 \text{ ml}_{\text{O}_2} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ vs $61.1 \pm 3.4 \text{ ml}_{\text{O}_2} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$). There were no significant differences in the running economies of the respective groups ($179.67 \pm 14.71 \text{ ml}_{\text{O}_2} \cdot \text{kg}^{-1} \cdot \text{km}^{-1}$ for the females vs $176.90 \pm 11.34 \text{ ml}_{\text{O}_2} \cdot \text{kg}^{-1} \cdot \text{km}^{-1}$ for the males) (Table 3) or between the lactate curves for the two groups (Fig 4).

Fig 4. Curves comparing lactate accumulation as a function of work intensity in the male and female groups.

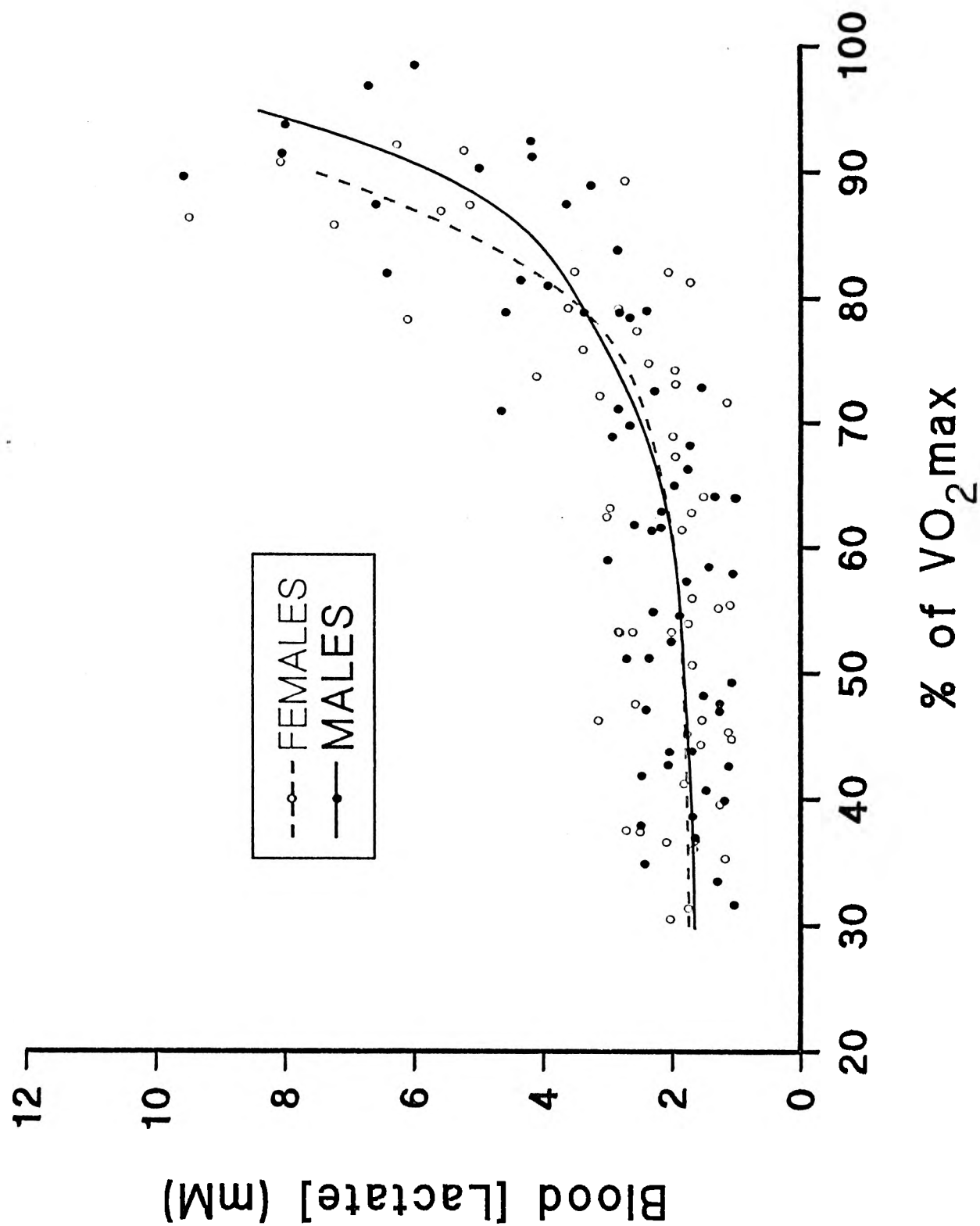


Table 3. Comparison of aerobic capacity between males and females

		FEMALES	MALES	P
VO ₂ peak, (absolute)	(l _{O2} ·min ⁻¹)	2.80±0.33	3.62±0.56	0.01
VO ₂ peak (<u>alt</u>)	(ml·kg ⁻¹ ·min ⁻¹)	48.3±2.8	51.3±3.3	0.05
VO ₂ peak (<u>sl</u>)	(ml·kg ⁻¹ ·min ⁻¹)	51.5±3.0	54.6±3.5	0.05
VO ₂ peak,	(ml _{O2} ·min ⁻¹ ·kg _{FFM} ⁻¹)	61.6±2.7	61.1±3.4	NS
RE,	(ml _{O2} ·kg ⁻¹ ·km ⁻¹)	179.7±14.7	176.9±11.3	NS

Values are means ± SD for 10 females and 10 males.

Where: RE is the running economy.
 BM is body mass
 FFM is the fat-free mass
 VO₂peak (alt) is the maximal aerobic capacity at an altitude of 1800m (barometric pressure of 625 Torr).
 VO₂peak (sl) is the maximal aerobic capacity at sea level (barometric pressure of 760 Torr).

Muscle torques were expressed either as the absolute value measured (Nm) or relative to the thigh volume (Nm·l⁻¹). The volume of thigh muscle was smaller (P<0.05) in the female group (5.64 ± 0.9l) compared to the male group (6.71 ± 1.2l). The absolute torques produced by the major muscles (essentially the quadriceps for extension, and the hamstrings for flexion) are shown in figure 5. Significant differences were noted in the absolute quadriceps torques at all angular velocities measured: at 60°·sec⁻¹ (P<0.05) females 117.0 ± 30.8Nm vs the males 150.0 ± 34.6Nm; at 180°·sec⁻¹ (P<0.01) females 68.5 ± 26.2Nm vs the males 114.0 ± 25.7Nm; and at 240°·sec⁻¹ (P<0.01) the females 61.2 ± 16.6Nm vs the males 95.9 ± 24.5Nm. There was a significant difference (P<0.05) between the absolute torques produced by the hamstring group of muscles in the females at 240°·sec⁻¹ compared

Fig 5. Absolute muscle function curves of the quadriceps.

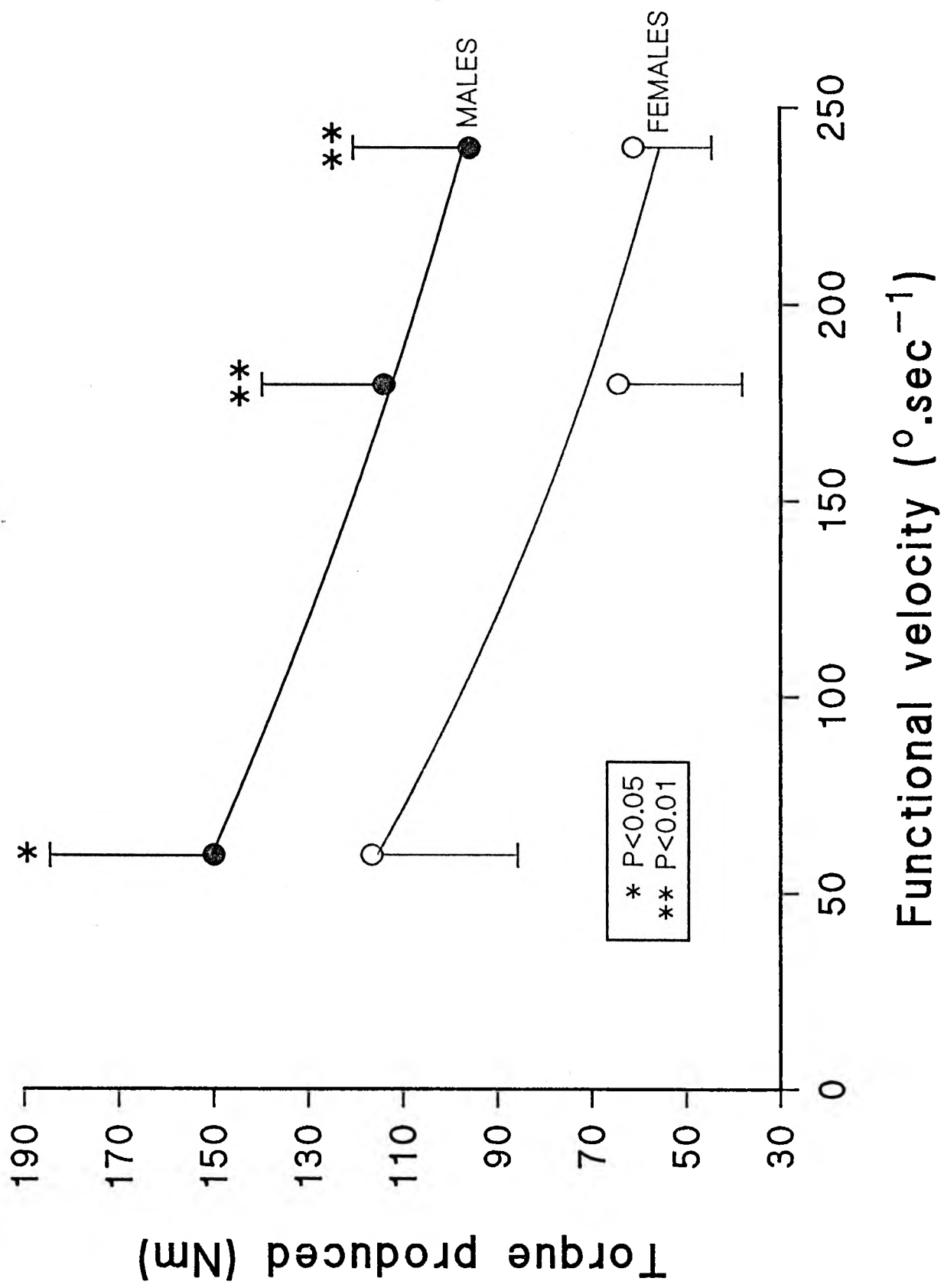
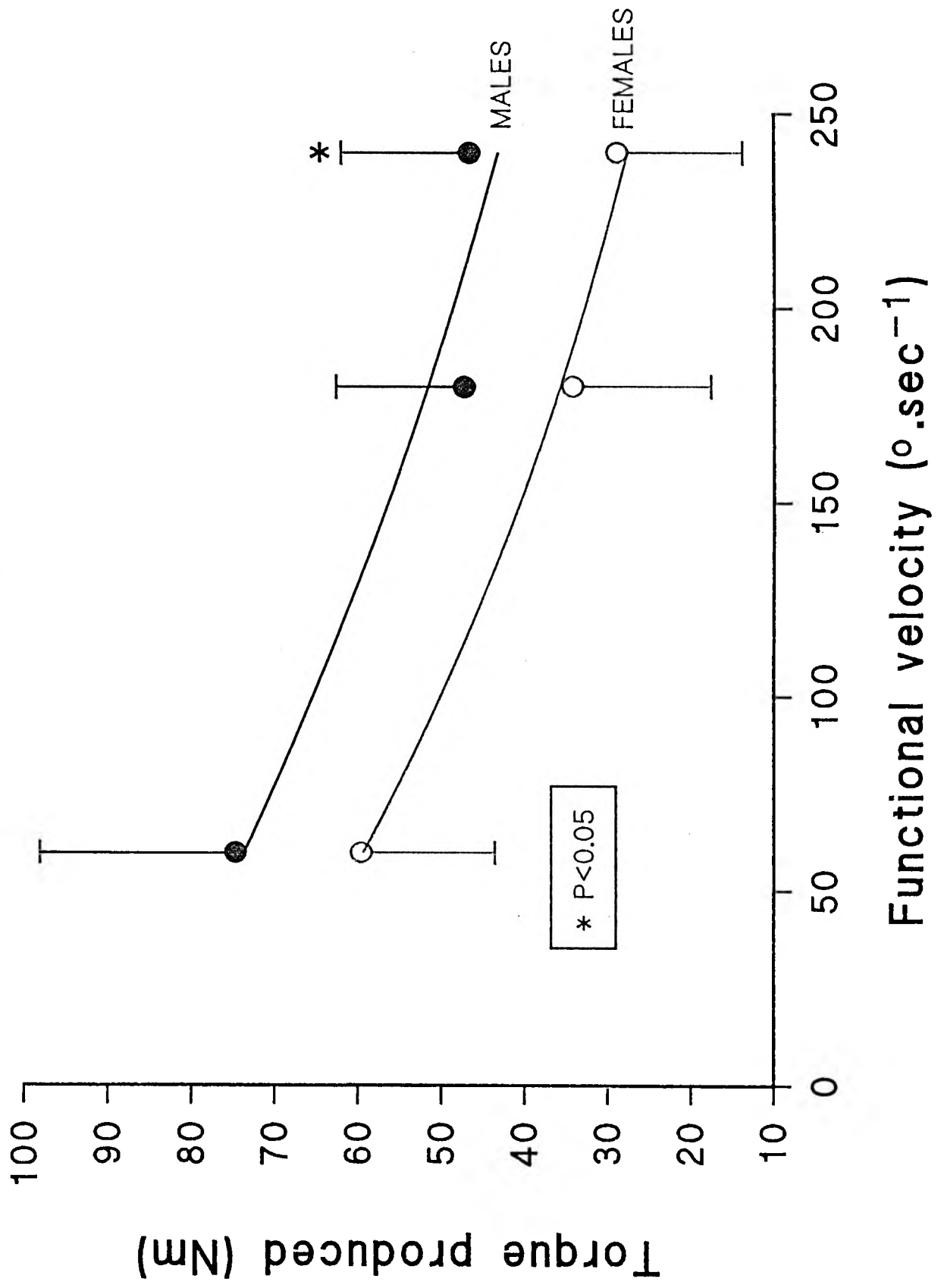


Fig 6. Absolute muscle function curves of bicep femoris.



to that produced by the males ($29.0 \pm 15.1\text{Nm}$ vs $46.6 \pm 15.3\text{Nm}$) but no significant differences were noted at both $60^\circ\cdot\text{sec}^{-1}$ and $180^\circ\cdot\text{sec}^{-1}$ (Fig 6).

The relative torques produced by the two muscle groups are shown in figures 7 and 8. No significant difference in the relative torque at an angular velocity of $60^\circ\cdot\text{sec}^{-1}$ existed between the males and the females in either quadriceps or hamstrings. There was a significant difference ($P<0.05$) between the relative torques produced by the quadriceps group of muscles in the females at $180^\circ\cdot\text{sec}^{-1}$ compared to that produced by the males ($12.19 \pm 4.75\text{Nm}\cdot\text{l}^{-1}$ vs $18.87 \pm 7.01\text{Nm}\cdot\text{l}^{-1}$). No significant differences were noted at $240^\circ\cdot\text{sec}^{-1}$ in either muscle groups.

Fig 7. Relative muscle function curves of the quadriceps.

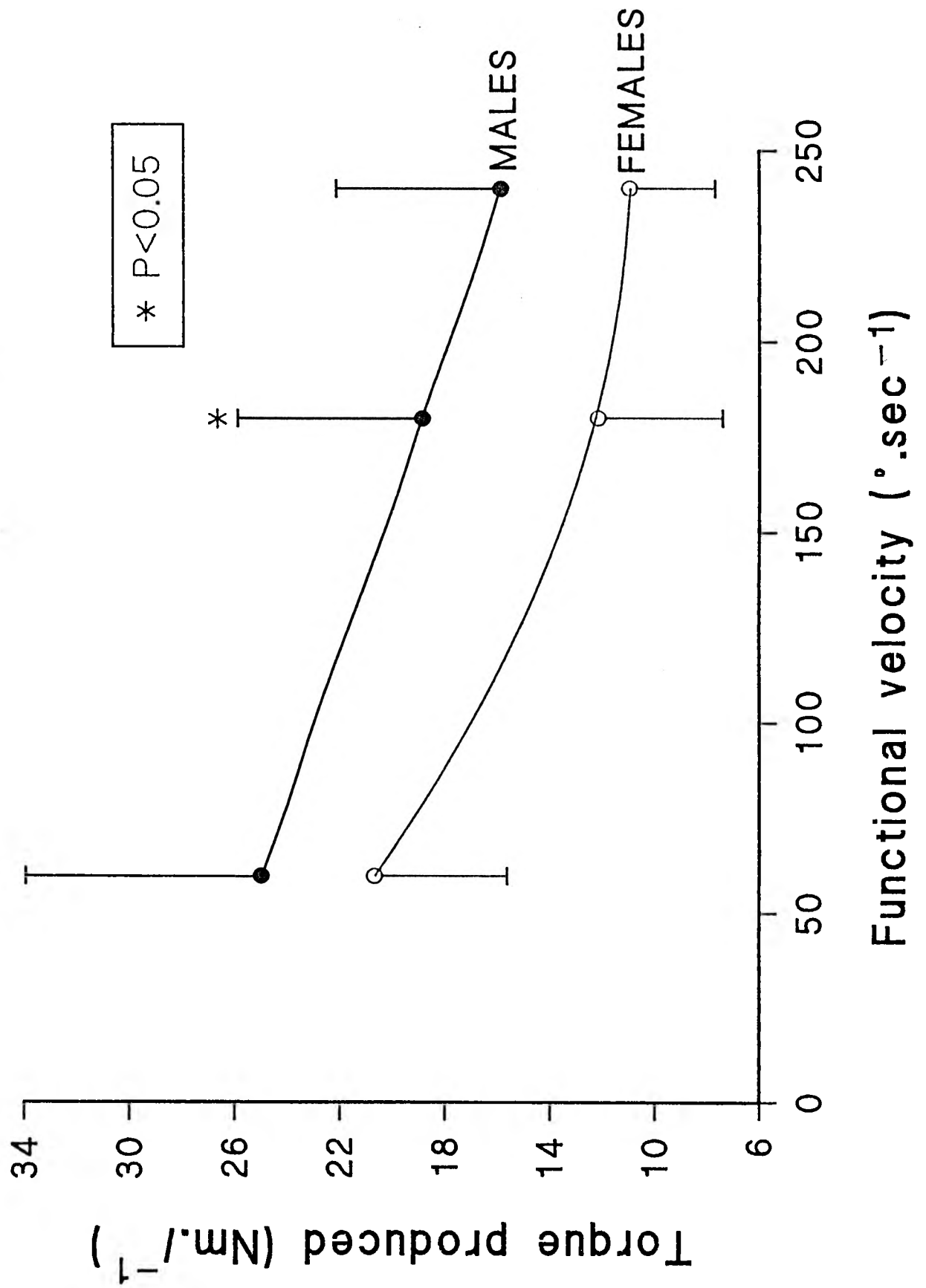
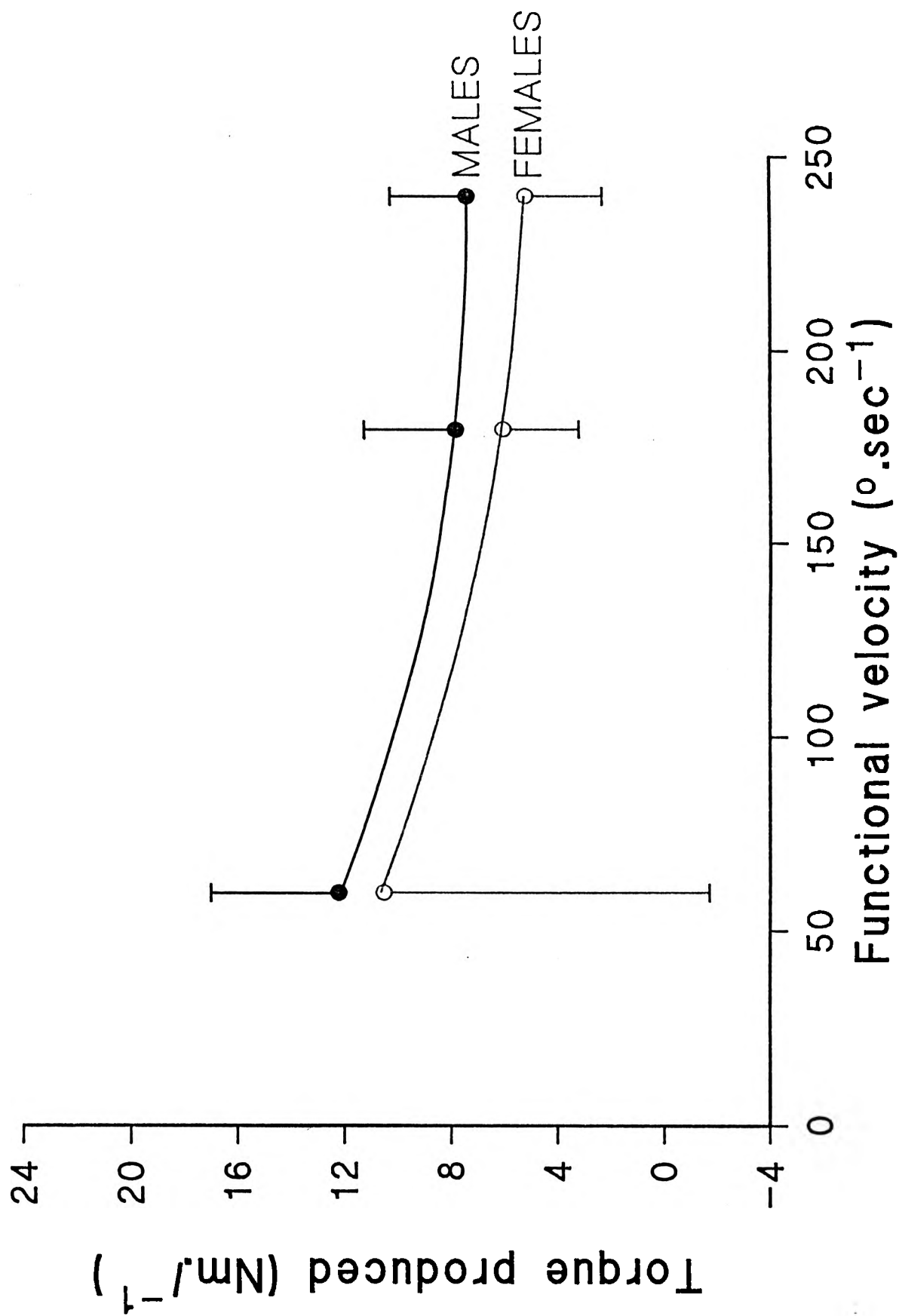


Fig 8. Relative muscle function curves of bicep femoris.



When the endurance ratios were compared (Table 4), no differences were apparent in the quadriceps muscles (0.926 ± 0.196 in the females compared to 0.864 ± 0.187 in the males) or in the hamstring muscles (0.848 ± 0.270 in the females compared to 1.028 ± 0.487 in the males).

Table 4. Ratio of average peak torques depicting endurance ratios in the quadriceps (leg extensions) and hamstrings (leg flexions) at an angular velocity of $240^\circ \cdot \text{sec}^{-1}$.

	FEMALES	MALES	P
Quadriceps ₂ :Quadriceps ₁	0.926 ± 0.20	0.864 ± 0.19	NS
Hamstrings ₂ :Hamstrings ₁	0.848 ± 0.27	1.028 ± 0.49	NS

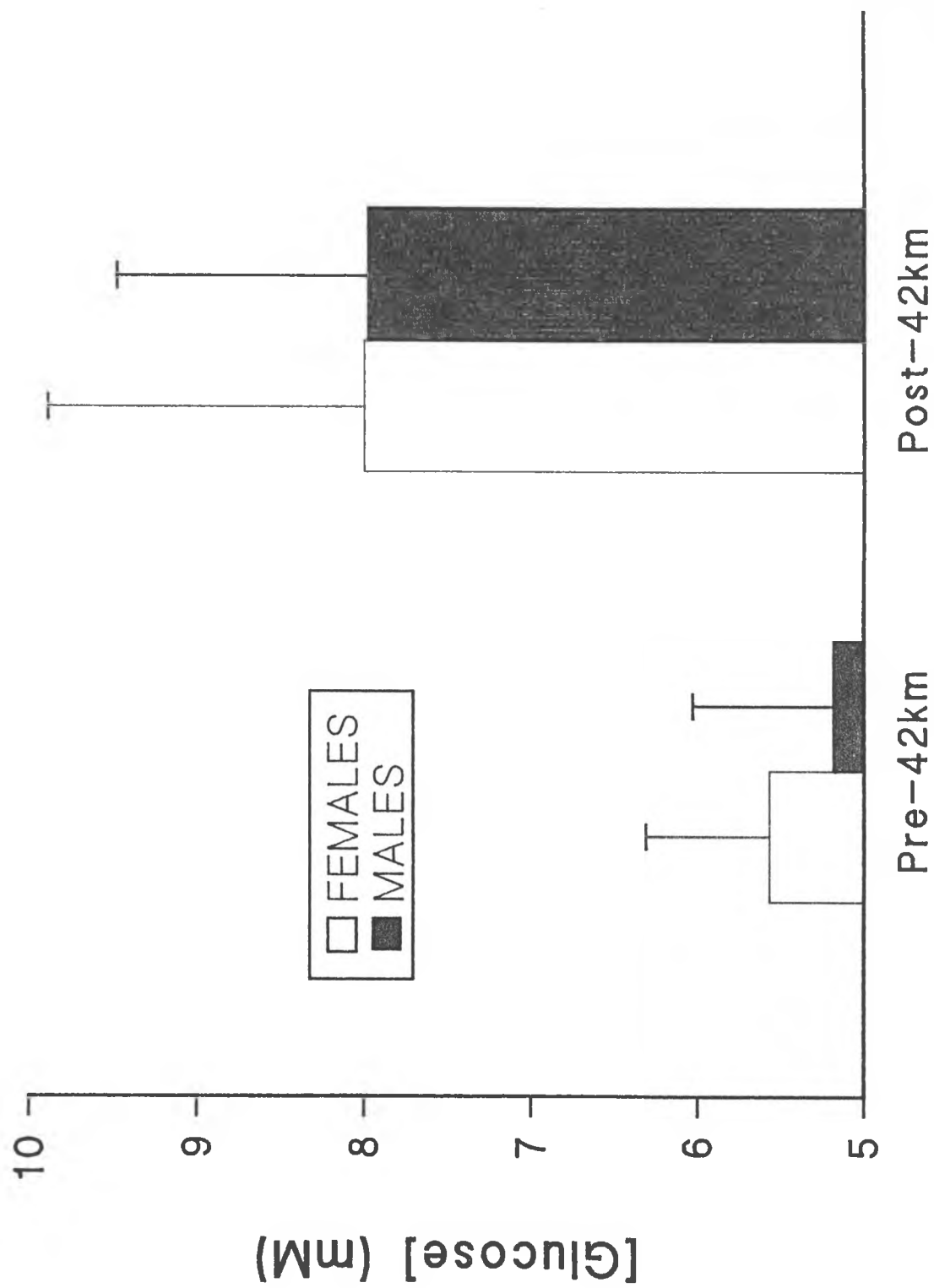
Values are means $\pm$ SD for 9 females and 9 males.

Where: ₂ is the average torque in the last five (of twenty) repetitions.

₁ is the average torque in the first five (of twenty) repetitions.

There was no significant gender-related difference in the concentration of glucose that occurred in the blood plasma as a result of running 42.2km (Fig 9). The initial resting values of glucose for both groups ($5.41 \pm 0.78\text{mM}$ in the females vs $5.18 \pm 0.85\text{mM}$ in the males) were within the normal resting range ($3.0 - 6.0\text{mM}$). Post exercise blood glucose concentrations show no gender-related difference with the females' levels at $8.09 \pm 1.74\text{mM}$ and the males' level at $7.98 \pm 1.50\text{mM}$.

Fig 9. The effects of running 42.2km on blood glucose concentration.



There were no significant differences in any of the personality traits (Fig 10), measured using the profile of mood states (POMS) test. There were also no gender-related differences in the personal motivation (PM) test, with the female group scoring 64.4 ± 8.0 versus the 57.5 ± 17.3 personal motivation units noted in the male group (Fig 11).

Fig 10. The resting personality profiles of the two gender groups.

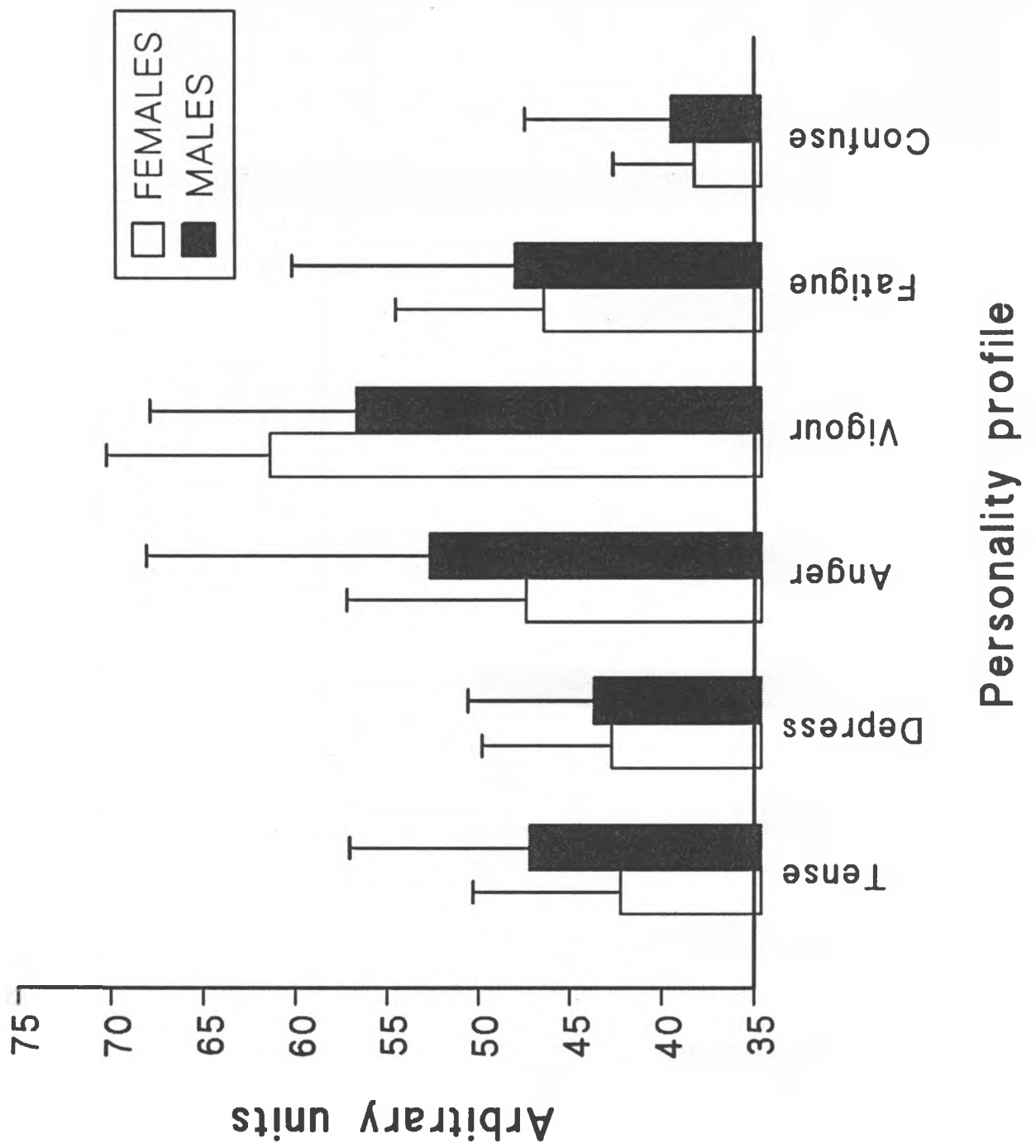
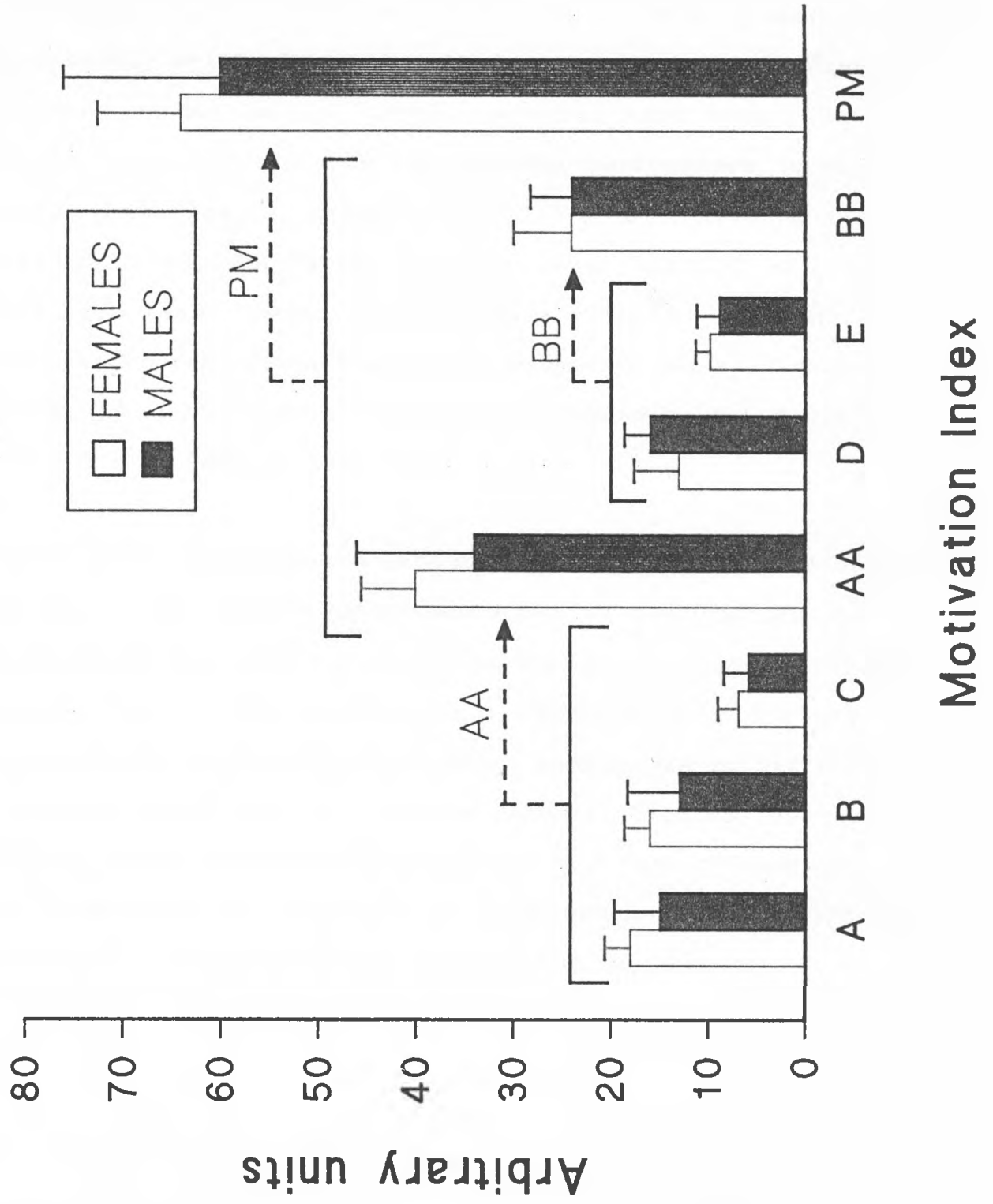


Fig 11. The Personal Motivation (PM) indices of the two gender groups.



2.4. DISCUSSION

Comparisons have indicated that top female runners are consistently 9-11% slower than their male counterparts over all distances raced (Noakes, 1992). Studies have shown that the champion male athlete owes this greater performance level to a greater physiological capacity (Costill et al., 1979; Cureton & Sparling, 1980; Hutchinson et al., 1991; Pate et al., 1985; Sparling, 1980; Wells & Plowman, 1983). However when performances were matched between the genders over a distance of 24.1km (ie half-marathon distances), physiological capacities were similar (Pate et al., 1985).

In this study, performances were matched at the marathon distance (42.2km). The female group performed as well as their male counterparts but with a significantly lower relative $\text{VO}_{2\text{peak}}$ ($\text{ml}_{\text{O}_2} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$). The lower maximal oxygen consumption was not compensated by differences in running economy nor by differences in fitness level (Fig 4). In the determination of the latter, care was taken to standardise the site and time of sampling and the intensities of exercise in both groups, when blood was collected to measure lactate levels (Jacobs, 1986).

The female group typically had a greater percentage body fat than the male group. It has been found that males have significantly less fat content compared to females (Brodie, 1988; Costill et al., 1979; Cureton & Sparling, 1980; Durnin & Womersley, 1974;

Fox & Mathews, 1981; Keys & Brozek, 1953; Noakes, 1992; Wells & Plowman, 1983). The percentage body fat values obtained in the present study fall within the average ranges of 12-16% for males, and 22-26% for females (Wells & Plowman, 1983). The implications of an increased body fat content on the females' performance may have a two-fold effect: there is less muscle to exert force, and the increased fat mass increases the metabolic cost of weight-bearing exercises (such as running is). This was the case in the present study where the females had smaller lean thigh volumes compared to the males (Table 2). In an attempt to eliminate the fat variable, Cureton & Sparling (1980) equated both males and females (on the basis of fat-, or "dead" weight) by artificially weighing down the males so that the excess weights comprised a similar composite of the whole weight. These authors found that in spite of having a 7.5% excess weight to carry, the males posted a 23% superior performance compared to their female counterparts.

In the present study, the effect of body fat may be interpreted through the VO_{2max} per unit lean body, or fat-free mass (FFM). Although the relative $VO_{2max}(FFM)$ was virtually identical between the two groups (Table 3), the greater percentage body fat content in the females would have been expected to lessen female performance compared to that of the male.

Strength comparisons (measured as Nm muscle torque developed) indicated that our females were on average 66% as strong as the men, which was similar to what others found (Andersen &

Henrikkson, 1977; Cureton & Sparling, 1980; Cureton et al., 1988; Laubach, 1976; Noakes, 1992; Wells et al., 1981; Wells & Plowman, 1983). However, after standardising torques for the volume of thigh muscle (ie $\text{Nm} \cdot \text{l}^{-1}$), the only difference that existed between the genders was a higher torque developed by the quadriceps muscle at $180^\circ \cdot \text{sec}^{-1}$ in the male group. Therefore, since relative muscle torque capacity was, if anything, higher in the male group at approximate functional velocities, muscle torque capacity was apparently not the reason why females managed to perform as well as their male counterparts over the 42.2km distance in this study. Costill et al., (1976) found the only gender-related difference in muscle function was that the males had larger fibre areas compared to females, which the results of the current study also suggest since the males had larger thigh volumes compared to the females. When the endurance, or fatigue ratios were compared, neither group had an advantage over the other (Table 4).

The greater body fat, lower aerobic capacity and lesser muscle torque capacity was also not compensated by a more resolute psychological profile. Previous studies have indicated that females are psychologically better equipped to cope with the stress of endurance exercise than are males (Black et al., 1979; Noakes, 1992; Scott & Gijssbers, 1981). However, the difficulty in assessing psychological disposition with endurance-running is the control over testing and the variability in testing conditions.

While male and female athletes who have been performance-matched over $\pm 25\text{km}$ have similar physiologies (Pate et al., 1985), those who were matched over 42.2km showed a differing physiological function. Females showed elevated body fat stores; lower body mass standardised $\text{VO}_{2\text{max}}$ values; and a lower standardised muscle power. Despite an apparently lower physiological capacity, they were able to perform as well as their male counterparts at 42km . We were not able to identify any factor able to compensate for these apparent disadvantages.

2.5. CONCLUSION

Therefore, in contrast to the finding that male and female athletes who have been matched on their performance over ± 25 km achieve the performance in physiologically similar fashions (Pate et al., 1985), the same cannot be said of athletes competing at the standard marathon (42.2km) distance. When male and female athletes were matched on their performances over 42.2km, the sexes showed a differing physiological function. Females showed less adaptive physical characteristics (elevated body fat stores); lower body mass standardised $\text{VO}_{2\text{max}}$ values; and a lower standardised muscle power. Despite an apparently lower physiological capacity, they are able to perform as well as their male counterparts at 42km. However, it may be postulated that the females achieved the similar performance level at this distance by exercising at a higher percentage of their $\text{VO}_{2\text{max}}$ values. The mechanism which allows them to achieve such status has not been ascertained the present study.

We wish to stress however, that there is no evidence to suggest that the elite female athlete can match or outperform the elite male athlete in the foreseeable future. The results shown by Whipp & Ward (1992) probably reflect the advantage the female athlete has enjoyed of using latter day advances in sports science, since full female participation in athletics only began in the 1960's compared to the turn of the century for males.

CHAPTER 3: Endurance exercise responses in performance-matched male and female athletes.

3.1. INTRODUCTION

A preliminary study (Lewis et al, 1988) conducted in this laboratory has suggested that females outperform males with matched aerobic capacities during ultra-endurance competition. Furthermore, the difference in performance between the matched groups of females and males appeared to widen as the race distance increased.

In a country where the premium road race is 90km long, and attracts a field of some 12 000 runners, an opportunity existed to compare running performance between females and males in running events up to 90km in distance. In the present study we chose to match the female and male runners on performances over a standard marathon distance (42.2km) and then compare the two groups at running distances of 10km, 21.1km, and 90km.

3.2. METHODS

Twenty runners, ten males and ten females, volunteered to participate in this study after providing informed consent. Each male runner was matched with a female runner according to the time taken to complete a given standard marathon (42.2km), as described in chapter 2. The female group ran an average of 3:36 $\pm$ 0:42 hours, and the male group an average of 3:39 $\pm$ 0:47 hours for a standard marathon.

A pre-requisite for subject participation was that each subject intended competing in a selected ultra-endurance event (the 90km Comrades Marathon), which is the major event on the South African running calendar. In addition, each subject pair was required to participate in the same 10km and 21.1km race prior to the ultra-endurance event.

Physical characteristics (height and weight) and percent body fat (Durnin & Womersley, 1974) were assessed, and aerobic characteristics ($\text{VO}_{2\text{max}}$, running economy (Conley et al., 1981b), and the onset of blood lactate accumulation (Jacobs, 1986)) were determined and are reproduced in table 2 in the previous chapter. The average fraction of the $\text{VO}_{2\text{max}}$ (F) of each athlete sustained at each of the four distances examined was estimated from:

$$F = v_s \cdot \text{RE} / \text{VO}_{2\text{max}} \quad (\text{di Prampero et al., 1986}).$$

where v_s is the average running speed (in $\text{m} \cdot \text{min}^{-1}$) at a given distance (s), RE is the running economy (in $\text{ml}_{\text{O}_2} \cdot \text{kg}^{-1} \cdot \text{km}^{-1}$), and $\text{VO}_{2\text{max}}$ is the maximal aerobic capacity of each athlete (in $\text{ml}_{\text{O}_2} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$). Maximal oxygen consumption ($\text{VO}_{2\text{max}}$) and running economy were measured in the laboratory (at an altitude of 1800m, and a barometric pressure of 625 Torr) using a motor-driven treadmill (Powerjog, E10, Sport Engineering Limited, Birmingham, England) and an on-line system to measure oxygen consumption (Oxycon 4, Mijnhardt, Bunnik, The Netherlands) (Wyndham et al., 1959).

Data from the 10km, 21.1km, and 42.2km distances were obtained from races run at an altitude of 1 800m (625 Torr). The 90km race, however, was run at sea-level (760 Torr) and thus a correction for $\text{VO}_{2\text{max}}$ was made for sea-level conditions which allowed a corrected calculation for the average F at the 90km distance. The running economy was assumed to remain unchanged between altitude and sea-level. This correction was achieved by

using the equation of Peronnet et al., (1991), and the corrected $\text{VO}_{2\text{max}}$ (at sea-level) values are given in table 3. The average fraction of the $\text{VO}_{2\text{max}}$ (F), and relative energy expenditures are depicted in figures 15, 16, and 17.

Blood samples were obtained before and after the 90km race (Comrades Marathon). The blood was used to measure plasma concentrations of glucose (Glucose GOD/PAP; colorimetric method with deproteinisation, Randox Laboratories, Antrim, N. Ireland), free fatty acids (gas chromatography with 50% v/v ortho-phosphoric acid preparation), and plasma osmolalities (5500 vapour pressure osmometer, Wescor Inc., Logan, Utah, USA). The subjects were also asked to complete the profile of mood states (POMS) questionnaire under normal resting conditions, and then again immediately after the ultra-endurance event. Student's t-statistic for independent data (Glantz, 1981) was used to analyse differences between groups. The null hypothesis was rejected at the 5.0% level. The data are presented as means $\pm$ SD.

3.3. RESULTS

The female group was lighter, had a larger percentage body fat, and a lower relative maximal aerobic capacity than their male counterparts as depicted in tables 2 and 3. After correcting for the change in altitude from 625 Torr to 760 Torr, the female group still had a significantly lower ($P < 0.05$) $\text{VO}_{2\text{max}}$ value ($51.5 \pm 3.0 \text{ml}_{\text{O}_2} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$) compared to their male counterparts ($54.6 \pm 3.5 \text{ml}_{\text{O}_2} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$).

Figure 12 shows the average running speeds over the four distances (performances were matched at 42.2km). The speeds at 10km, were $227.4 \pm 16.4 \text{m} \cdot \text{min}^{-1}$ in the female group vs $233.2 \pm 35.8 \text{m} \cdot \text{min}^{-1}$ in the male group. At the 21.1km distance, the female group ran an average speed of $211.8 \pm 13.7 \text{m} \cdot \text{min}^{-1}$ compared to the $213.8 \pm 21.9 \text{m} \cdot \text{min}^{-1}$ of the males. At 42.2km, the average speeds were similar ($194.8 \pm 12.9 \text{m} \cdot \text{min}^{-1}$ for the female group vs $192.6 \pm 16.3 \text{m} \cdot \text{min}^{-1}$ for the male group). The female group ran significantly faster ($171.0 \pm 11.7 \text{m} \cdot \text{min}^{-1}$) than the male group ($155.2 \pm 14.7 \text{m} \cdot \text{min}^{-1}$) over the 90km distance ($P < 0.05$).

Table 5. The running times for men and women over the 42.2km and 90km distances.

	FEMALES	MALES	P
Standard marathon (42.2km)	$3:36 \pm 0:42$	$3:39 \pm 0:47$	NS
Ultra-marathon (90km)	$8:46 \pm 0:37$	$9:40 \pm 0:43$	0.05

Fig 12. The changes in average running speeds as racing distance increases.

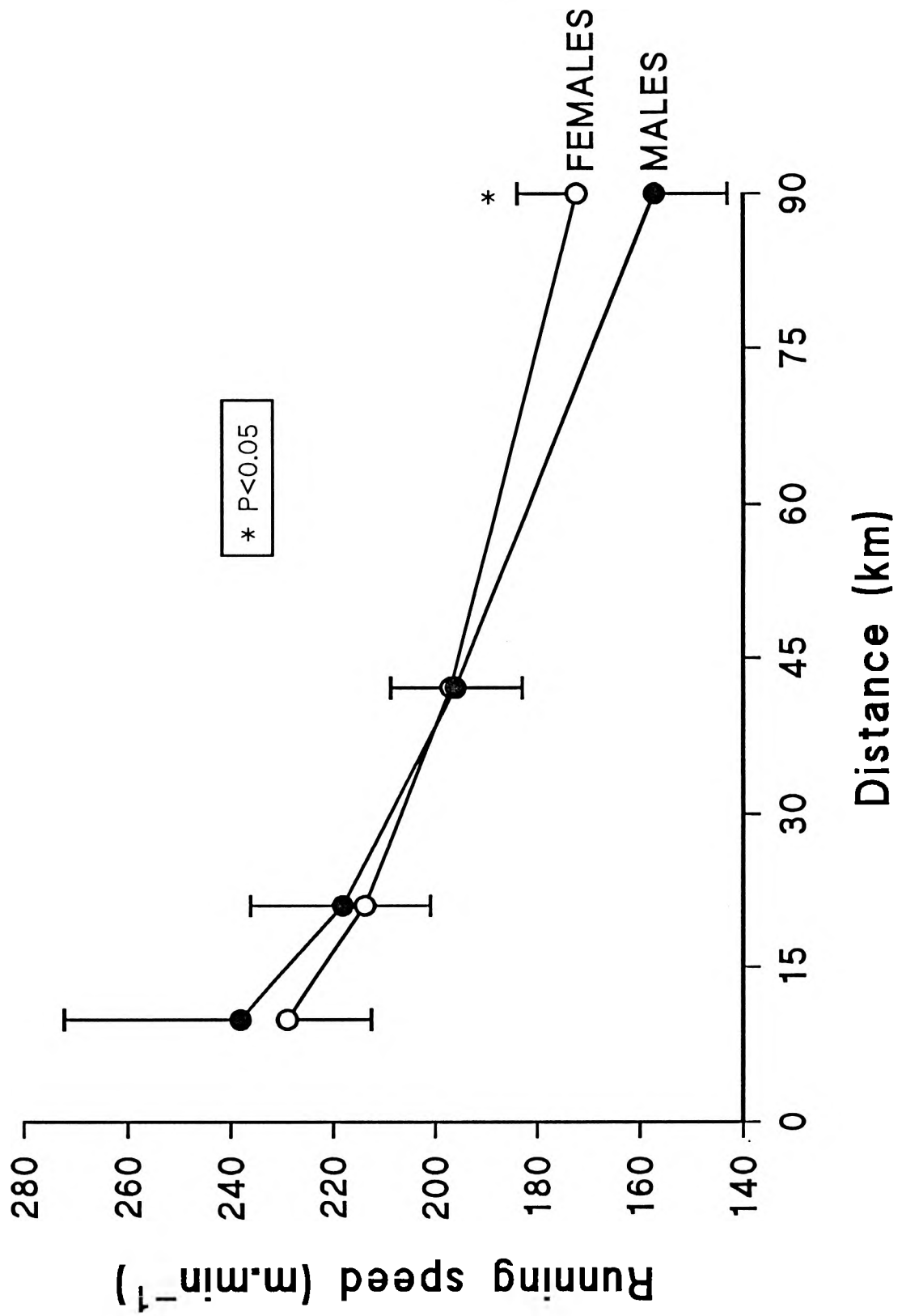


Figure 13 shows the absolute change ($\Delta v_s = v_s - v_{10}$) in the average running speeds at each distance (s) compared to the respective pace set at 10km (reference pace), and figure 14 the changes in running speed as a percentage change (expressed in parentheses). At Δv_{21} , the females ran $15.2 \pm 6.6 \text{ m} \cdot \text{min}^{-1}$ ($6.5 \pm 2.8\%$) slower vs $20.0 \pm 22.1 \text{ m} \cdot \text{min}^{-1}$ ($6.7 \pm 8.0\%$) slower by the males. At $\Delta v_{42.2}$, the females ran $32.1 \pm 11.0 \text{ m} \cdot \text{min}^{-1}$ ($13.9 \pm 4.4\%$) slower than their 10km time; the males ran $42.2 \pm 30.7 \text{ m} \cdot \text{min}^{-1}$ ($15.6 \pm 10.4\%$) slower than their 10km time. At Δv_{90} , the females ran $56.6 \pm 13.6 \text{ m} \cdot \text{min}^{-1}$ ($24.6 \pm 5.2\%$) slower than their 10km time; the males ran $80.9 \pm 27.0 \text{ m} \cdot \text{min}^{-1}$ ($32.5 \pm 7.4\%$) slower than their 10km time. There was a significant difference at Δv_{90} between the genders ($P < 0.05$), in addition to the slopes of the curves (ie the rates of decline, or deterioration in average running speed with increasing distance) also being significantly different ($P < 0.05$).

Fig 13. The absolute change (from 10km pace) in running speed with increasing distance.

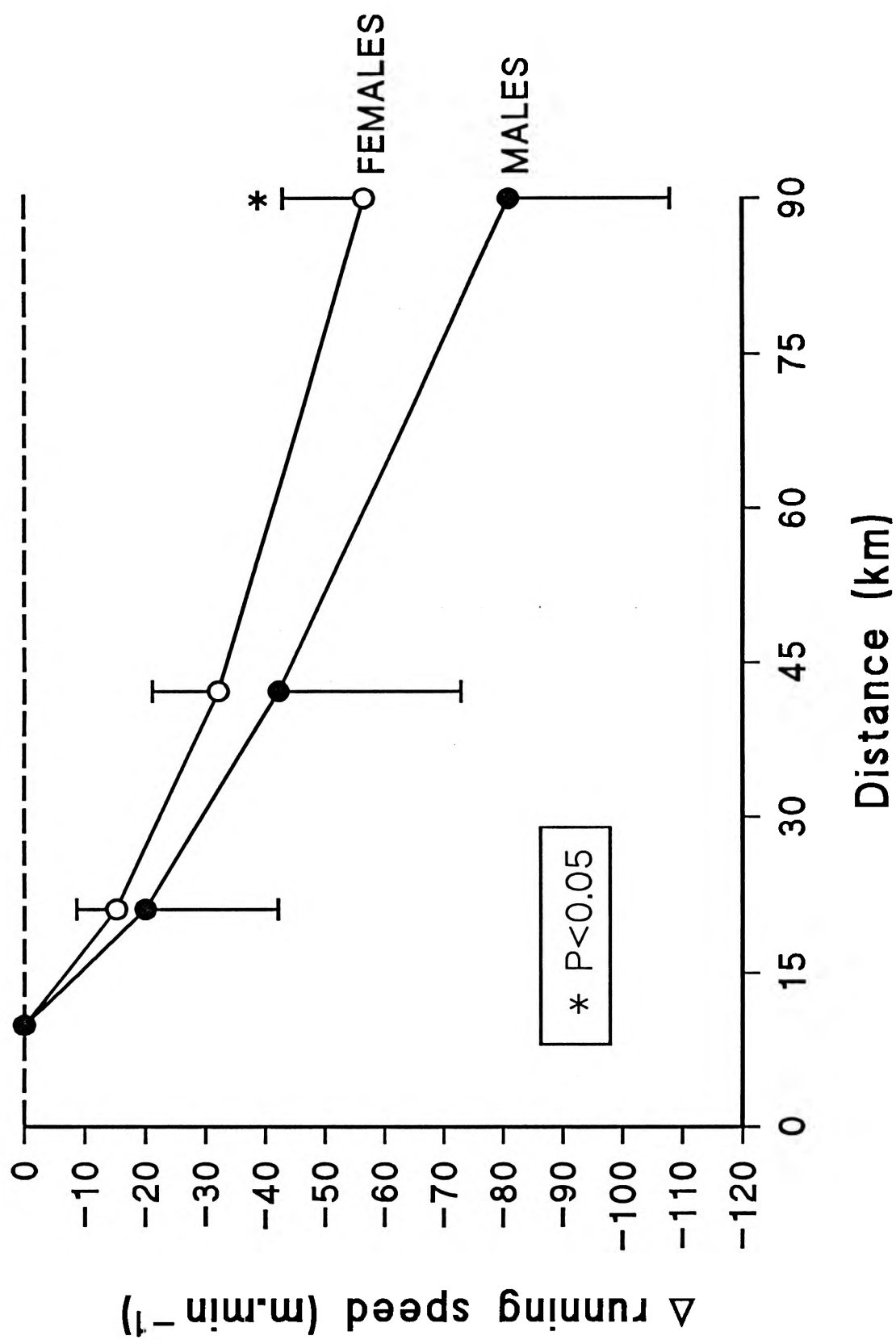
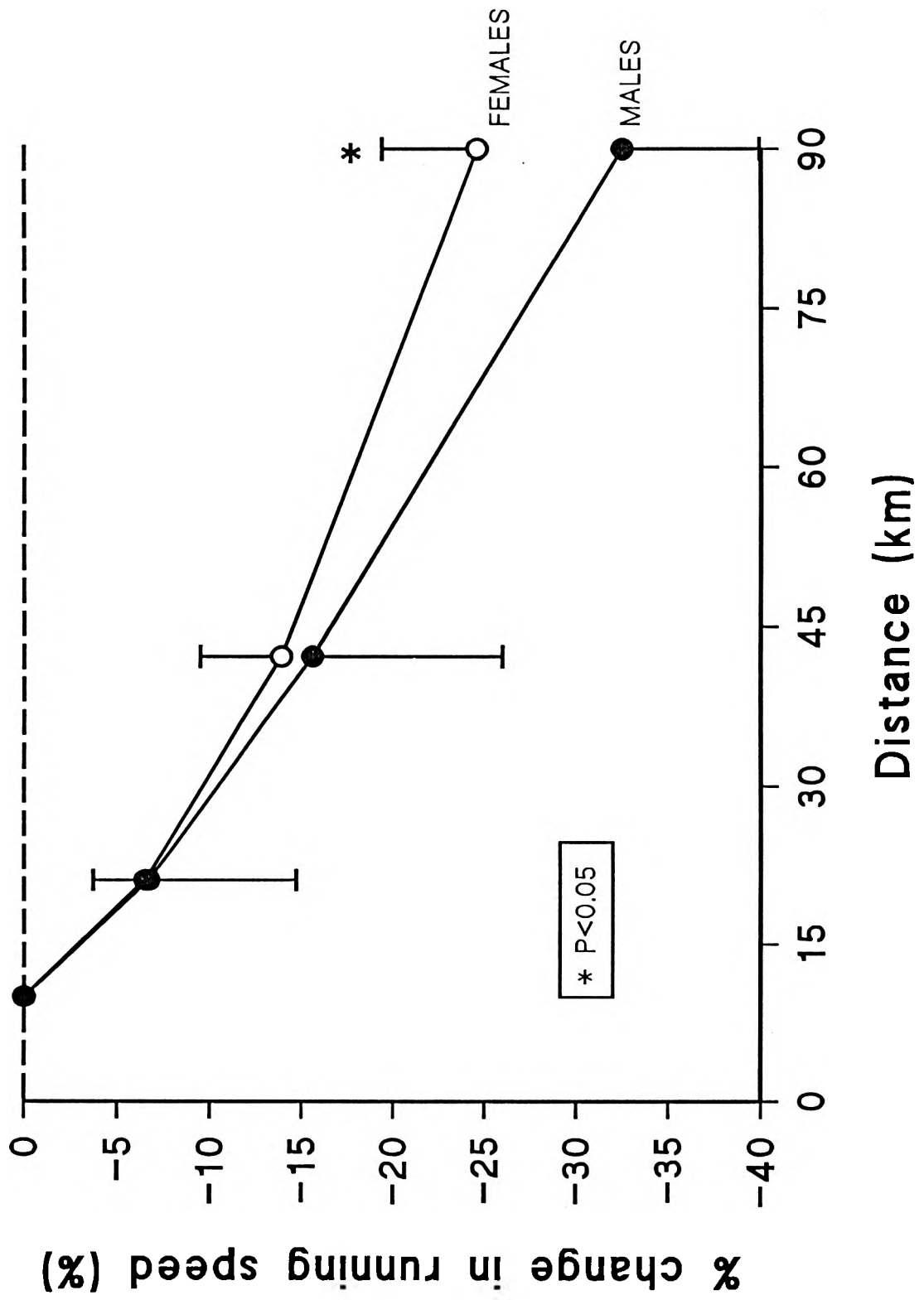


Fig 14. The percentage change in average running speeds (from 10km pace) with increasing distance.



The average fractions of VO_2max (F) that could be sustained at the respective distances (s) are depicted in figure 15. At 10km, F_{10} in the females is $84.4 \pm 7.5\%$ vs $79.9 \pm 7.1\%$ in the males. $F_{21.1}$ in the females is larger ($P < 0.05$) ($78.7 \pm 6.1\%$) than that observed in the males ($73.5 \pm 3.8\%$). The females exercise at a higher ($P < 0.01$) $F_{42.2}$ value (73.4 ± 5.5) compared to the males ($66.3 \pm 3.7\%$). At 90km, the females also exercised at a higher ($P < 0.01$) F_{90} value ($59.8 \pm 6.2\%$) compared to their male counterparts ($50.2 \pm 3.1\%$). The slope of the regression curve representing the average fraction of the VO_2max used for the females was significantly less ($P < 0.05$) than the corresponding curve for the males (Fig. 16). Figure 17 depicts the average work-rates (in $\text{watts} \cdot \text{kg}^{-1}$) at each distance studied. At 10km, the female group worked at $13.8 \pm 1.7 \text{W} \cdot \text{kg}^{-1}$ vs $13.9 \pm 1.9 \text{W} \cdot \text{kg}^{-1}$ in the males. The work-rate observed in the female group at 21.1km was $12.8 \pm 1.5 \text{W} \cdot \text{kg}^{-1}$ compared to $12.7 \pm 1.4 \text{W} \cdot \text{kg}^{-1}$ in the male group. At 42.2km, the females' work-rate was $11.8 \pm 1.4 \text{W} \cdot \text{kg}^{-1}$ vs $11.5 \pm 1.0 \text{W} \cdot \text{kg}^{-1}$ of the males. At 90km, the average energy expenditure of the females was greater ($P < 0.05$) ($10.4 \pm 1.3 \text{W} \cdot \text{kg}^{-1}$) than their male counterparts ($9.2 \pm 0.9 \text{W} \cdot \text{kg}^{-1}$). Over the 90km distance the females used on average $30.8 \pm 4.0 \text{mlO}_2 \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ ($P < 0.05$) compared to $27.4 \pm 2.8 \text{mlO}_2 \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ consumed by the males.

Fig 15. The difference in the sustainable fractions of VO_2 peak with increasing distance.

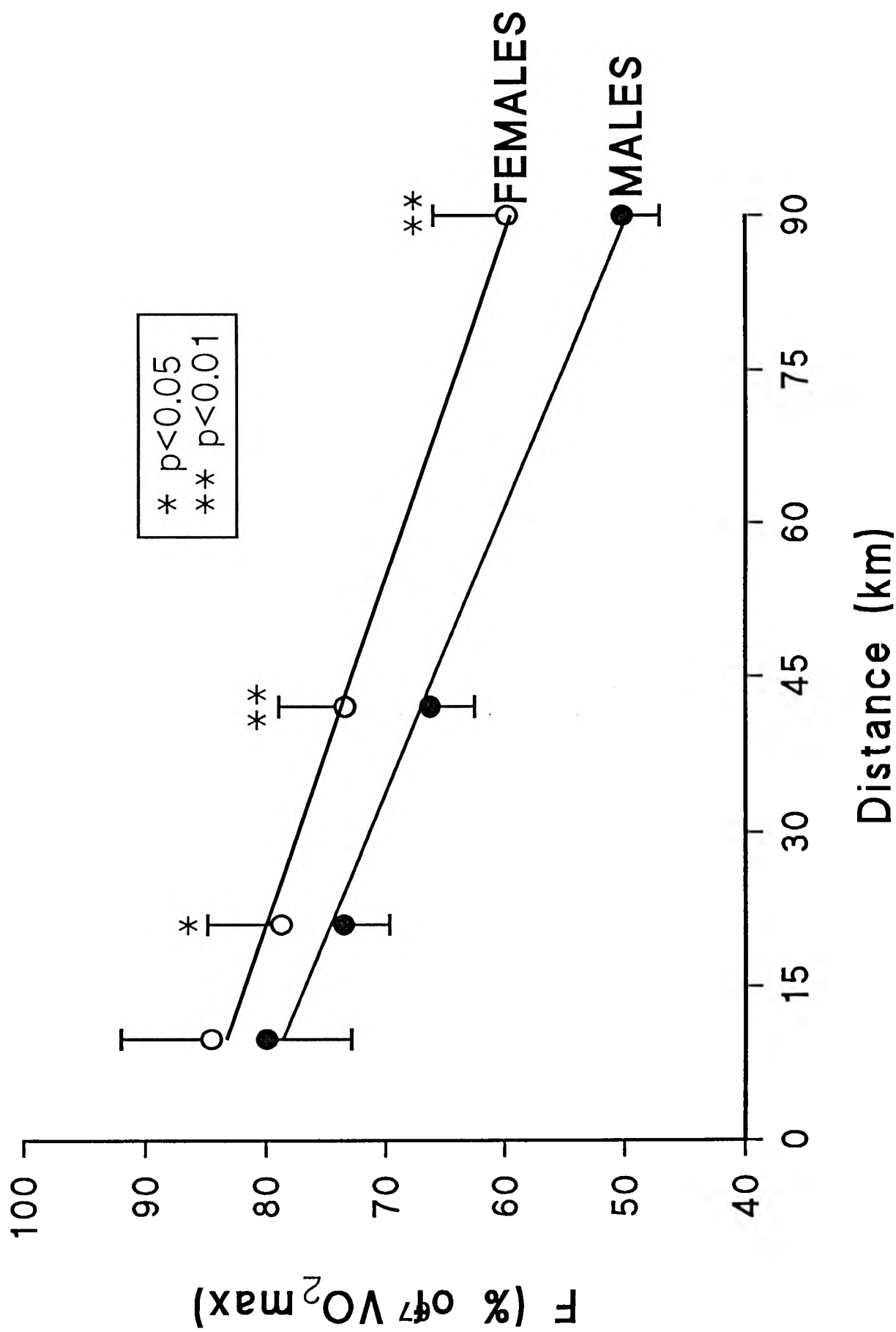


Fig 16. The difference in the average O_2 - consumption rates with increasing distance.

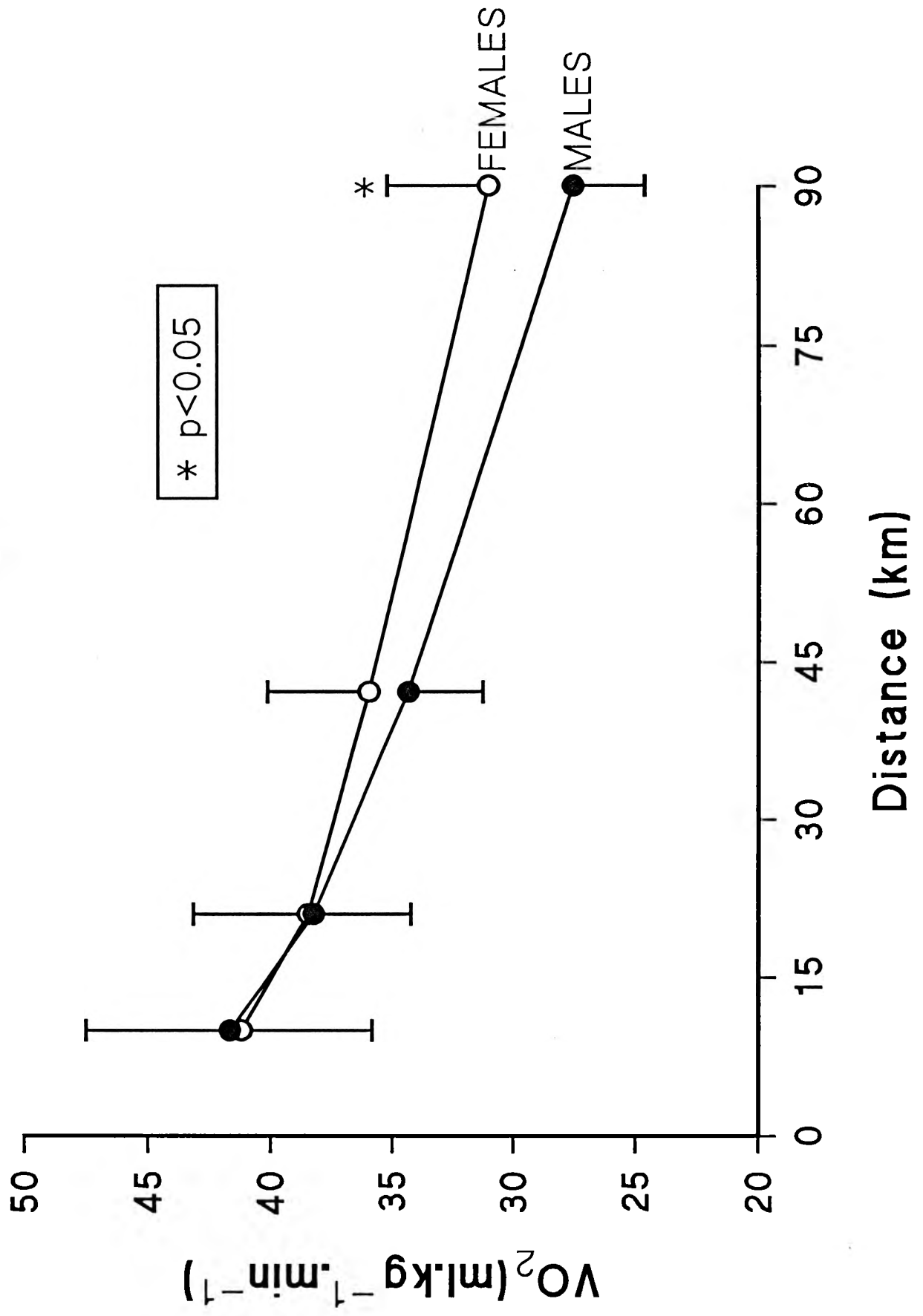
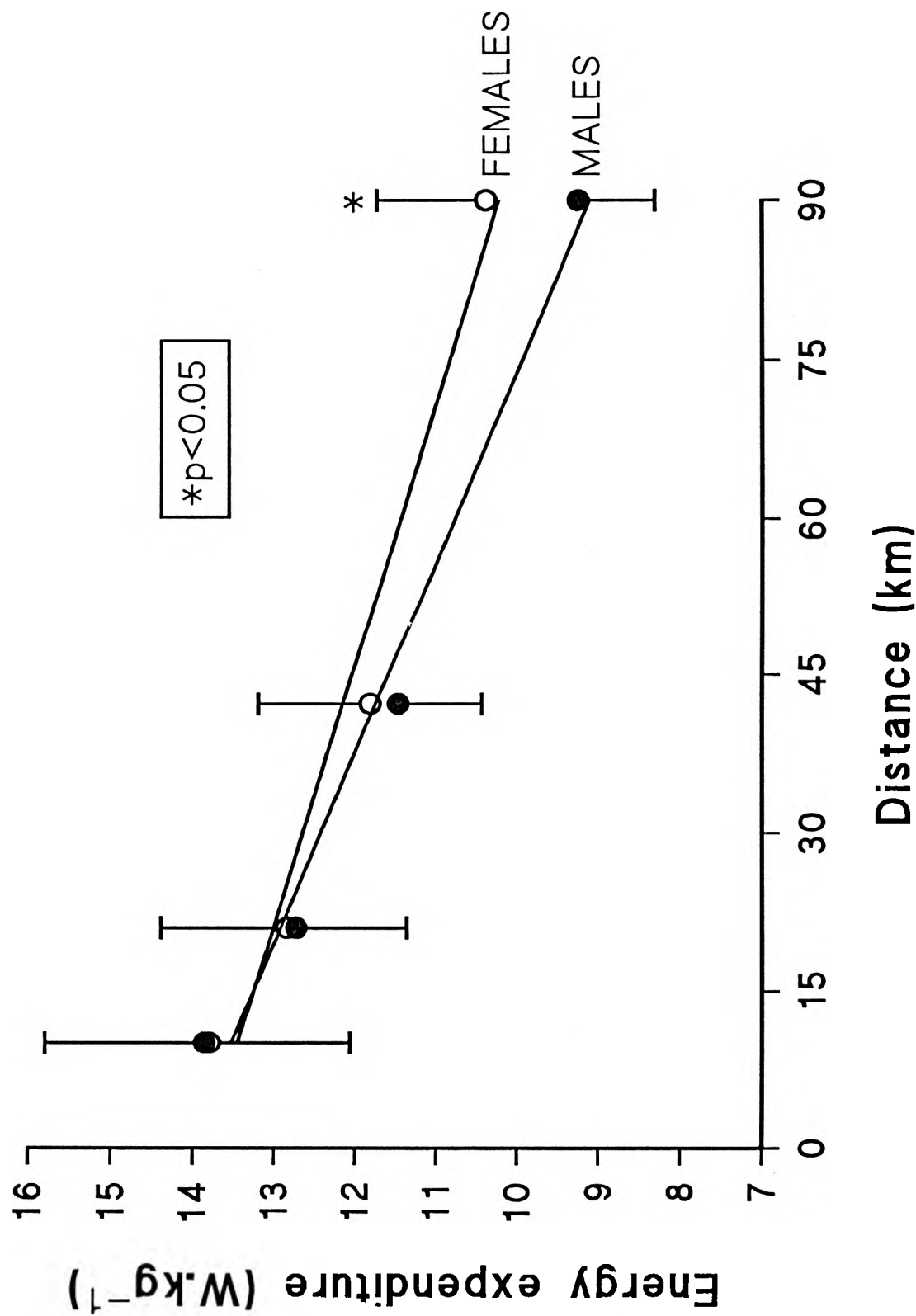


Fig 17. The difference in relative energy expenditure with increasing distance.



There was no significant gender-related difference in the concentration of glucose that occurred in the blood plasma as a result of running the Comrades Marathon (Fig. 18). The initial resting values of glucose for both groups ($5.3 \pm 0.97\text{mM}$ in the females vs $5.71 \pm 1.28\text{mM}$ in the males) were within the normal resting range (3.0 - 6.0mM). Resting FFA levels were $0.23 \pm 0.31\text{mM}$ for the females and $0.24 \pm 0.26\text{mM}$ for the males. Figure 19 shows a significantly lower ($P < 0.01$) plasma FFA concentration in the females upon completion of the Comrades Marathon. The female [FFA] was $0.370 \pm 0.28\text{mM}$ compared to $0.880 \pm 0.47\text{mM}$ noted in the male group (Fig. 19). The pre-90km osmolality samples were $299.0 \pm 23.2\text{mM} \cdot \text{kg}^{-1}$ vs $304.7 \pm 34.8\text{mM} \cdot \text{kg}^{-1}$, females vs males respectively. The post-90km osmolalities of $314.1 \pm 16.9\text{mM} \cdot \text{kg}^{-1}$ in the females vs $315.2 \pm 7.1\text{mM} \cdot \text{kg}^{-1}$ in the males were not significantly different (Fig. 20).

Fig 18. The Effects of running 90km on plasma glucose concentrations

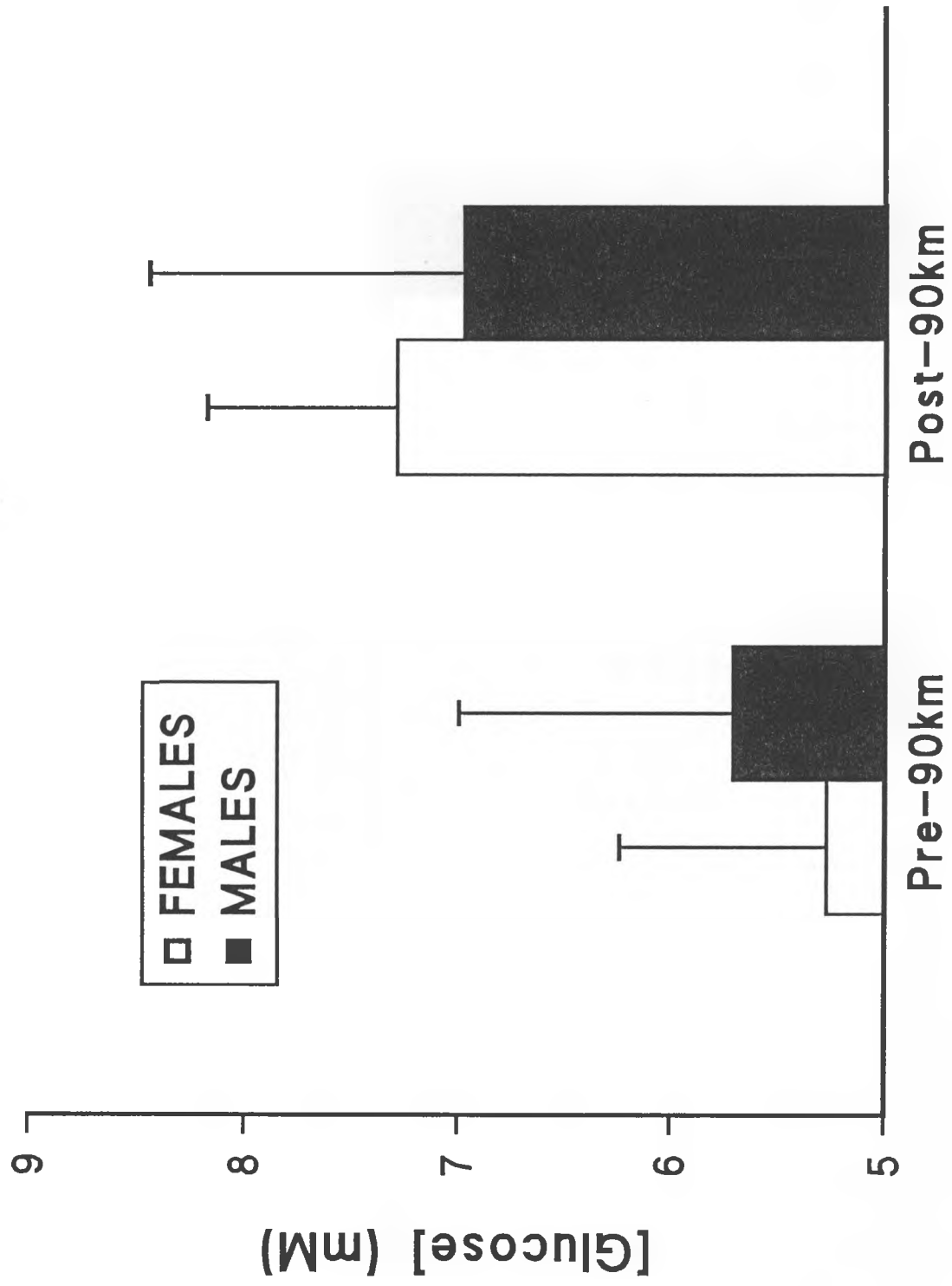


Fig 19. The Effect of running 90km on plasma FFA concentration

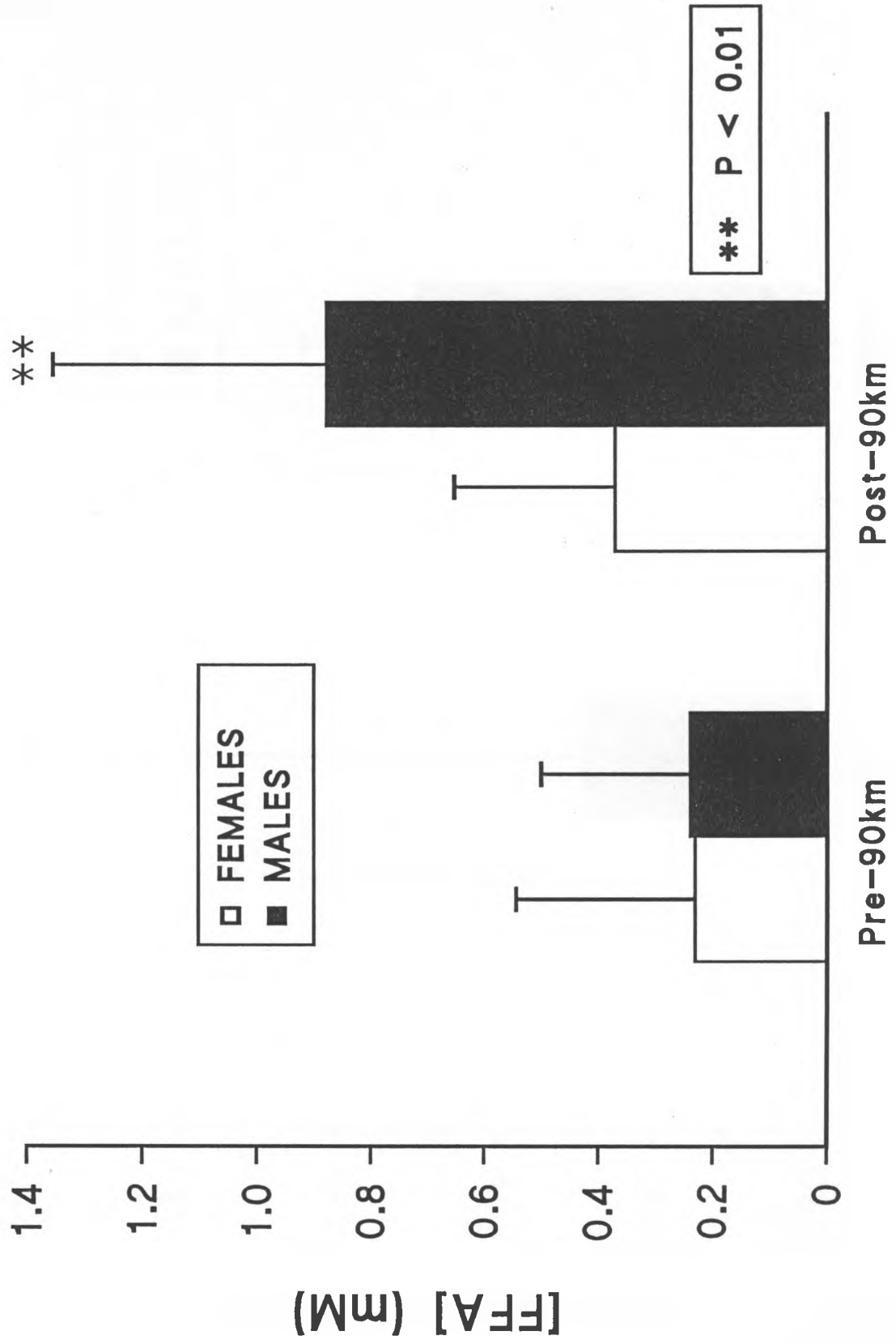


Fig 20. The effect of running 90km on plasma osmolality

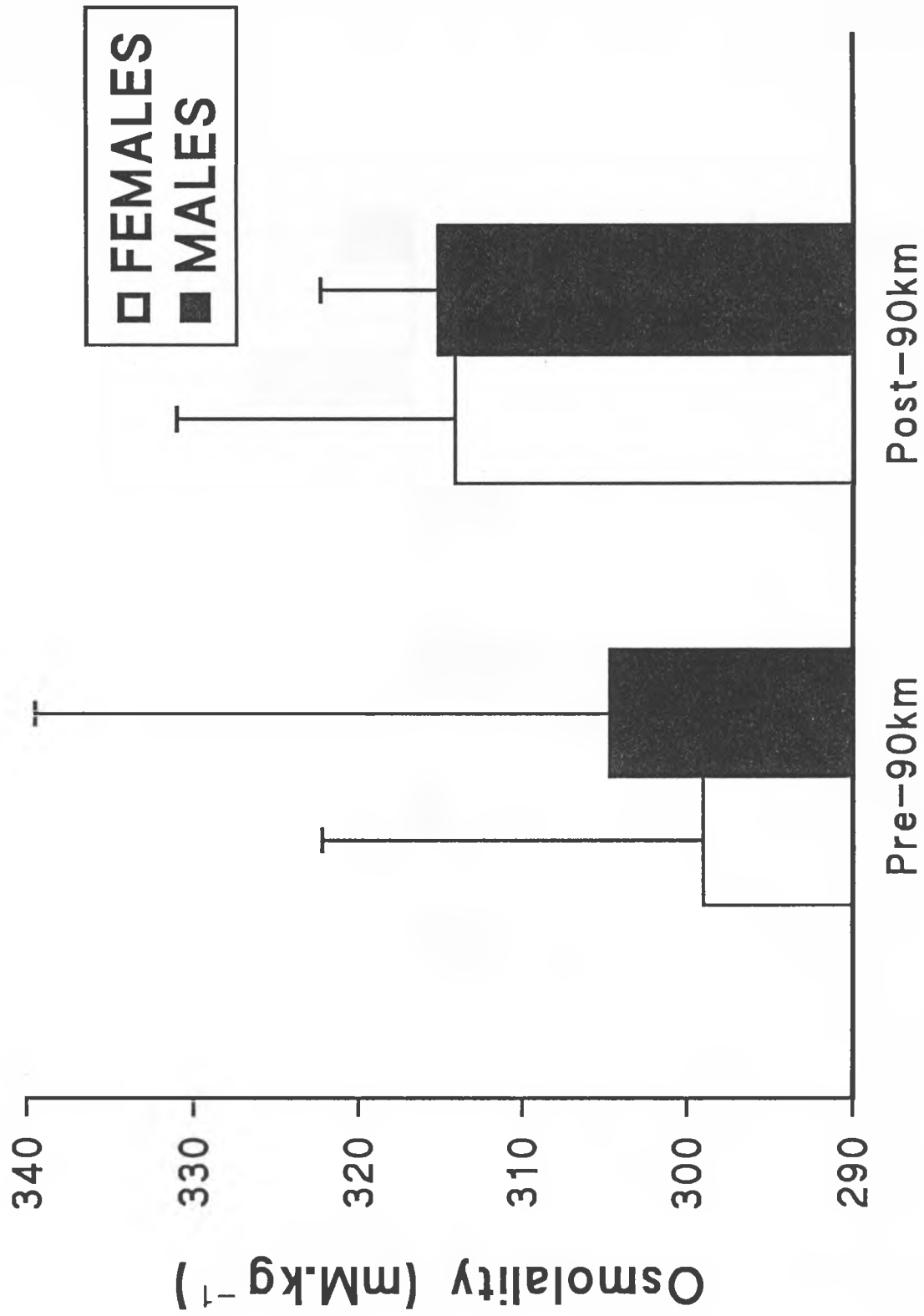
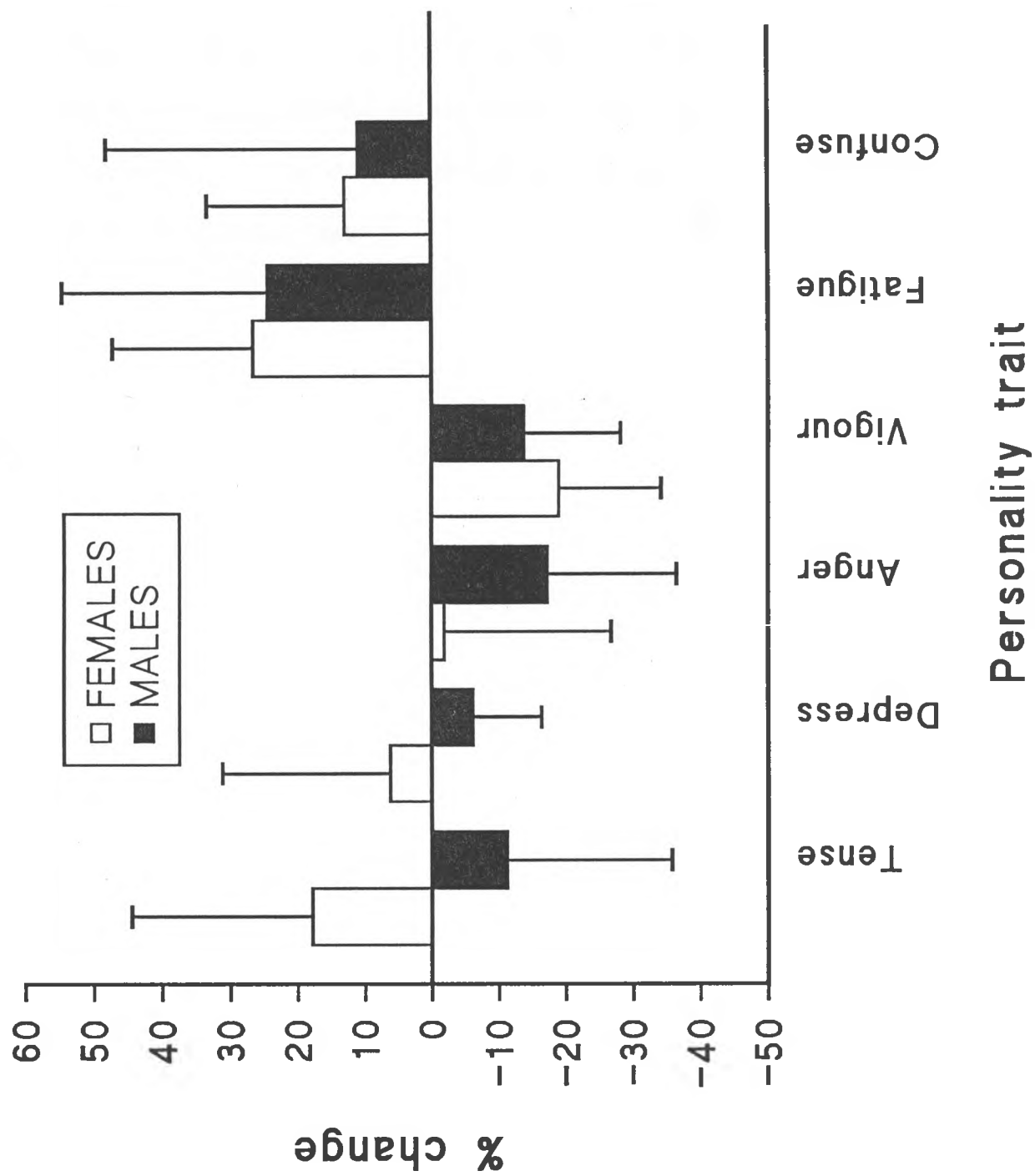


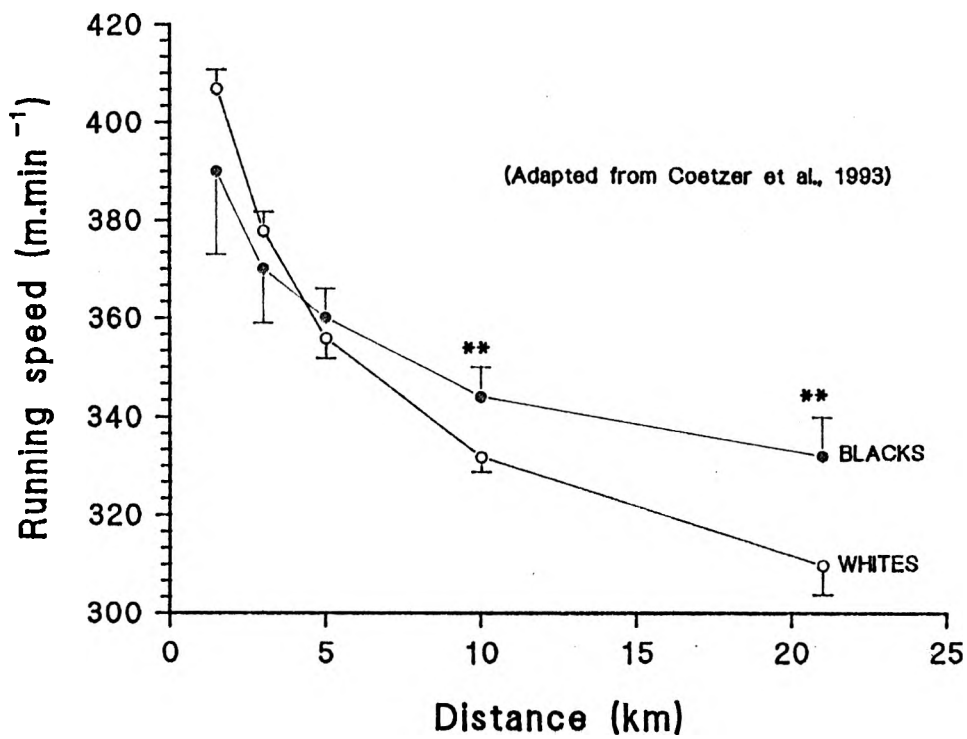
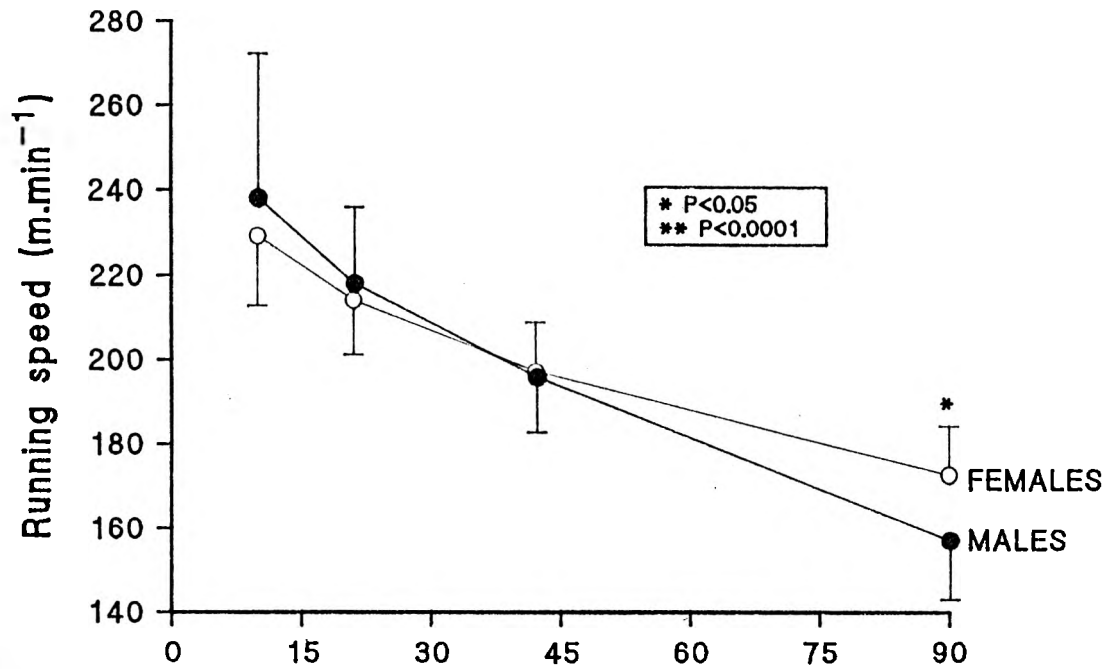
Fig 21. The psychological effects of running 90km



There were no significant differences between the genders in any of the personality traits after running the 90km distance (Fig 21).

Finally, figure 22 shows a comparison in gender- and racial-differences in running performances over varying distances: the exhibit similar trends in the rates of deterioration, with increasing distance of the race, on the parts of white and male athletes, compared to their black and female counterparts.

Fig 22. Comparison in the gender- and racial-differences in running performances over varying distances.



3.4. DISCUSSION

In spite of matching performances at 42.2km our female subjects outran their male counterparts over a distance of 90km. The greater performance by the females could not be ascribed to a higher maximal aerobic capacity or to a better running economy, or to an enhanced level of fitness.

However, the greater performance at 90km and an equal performance at 42.2km in spite of a lesser aerobic capacity by the females was related to a greater fraction of $\text{VO}_{2\text{max}}$ that could be sustained during each of these races (Fig. 15). Over 42.2km a greater $\dot{V}$ compensated for a lower $\text{VO}_{2\text{max}}$ in the female group so that the energy expended, and hence performances, were the same between the two groups. Over 90km, the difference in $\dot{V}$ between the two groups was sufficiently large to result in a significantly greater energy expenditure and hence better performance by the female group. In an attempt to identify how the female group were able to sustain exercise at a significantly greater fraction of $\text{VO}_{2\text{max}}$ than the males we measured plasma FFA.

Costill et al., (1979) found that when athletes ran at a pace of $\approx 60\%$ $\text{VO}_{2\text{max}}$, there were no gender-related differences in plasma FFA levels during at least the first 60 minutes of exercise. The latter study did however find that male athletes exhibited a greater muscle carnitine palmitoyl transferase (CPT) activity compared to female athletes, and it is muscle CPT which may in

part control the rate of FFA oxidation. Furthermore, they postulated that males should be capable of an enhanced level of β -oxidation merely as a result of their larger mitochondrial network being able to oxidise lipids more efficiently by way of their elevated muscle stores (Costill et al., 1987). These conclusions contradict the findings of Tarnopolsky et al., (1990) who presented evidence that females were able to utilise fat more efficiently than males and they speculated that as a result females should be expected to perform better (than males) in long distance exercise.

It has been shown previously that lipid oxidation during muscular activity is positively related to the concentration of circulating FFA (Andersen & Henriksson, 1977; Randle et al., 1963) and that the overall contribution of β -oxidation to the energy demands of the exercise is inversely related to the exercise intensity (Carlson et al., 1971). Thus, at 90km where plasma FFA levels were approximately half as high in the female group compared to the male group upon completion of the ultra-endurance event, and where the females were working at $\approx 60\%$ of VO_{2max} compared to $\approx 50\%$ of VO_{2max} of the males it is probable that the process of β -oxidation was not employed to the same degree as an energy supply in the females as in the males. Prevailing evidence (Anderson & Henriksson, 1977; Costill et al., 1977; Costill et al., 1979) therefore would favour the conclusion that in our study fat utilisation was greater in the male group and that the β -oxidation of fat therefore does not explain why the females outperformed their male counterparts.

Both plasma osmolality and blood glucose levels did not differ significantly between the two groups before and after the 90km race (Figs. 18 and 20) and therefore were not influencing factors in the respective performances.

The results of the psychological assessments used in this study also failed to supply the reason why the females outperformed the males during the ultra-endurance exercise. Previous studies have indicated that females are psychologically better equipped to cope with the stress of endurance exercise than were males (Black et al., 1979; Koltyn et al., 1990; Morgan, 1985; Noakes, 1992; Scott & Gijsbers; 1981). However, difference in psychological fortitude was apparently not a factor in this study (Figs 11 and 21).

When we compared F 's at each of the running distances studied, the degree of decline of F as the distance increased was significantly less in the female group compared to that in the male group (figure 15). While differences in performance were not detected at the shorter distances studied, the differences tended to become increasingly larger as running distance increased.

There was a tendency for running performance to be better in the males at distances less than 42.2km although these performances were not significantly different. However, an extrapolation of our results to running distances less than 10km did not exclude the possibility that our male subjects could have outperformed

the females over shorter endurance events (3km and 5km).

Interesting to note at this point is that when elite black and white South African runners (male middle distance runners) were compared, it was found that black athletes perform better with increasing distance, and that the black athletes were able to sustain a higher percentage of their VO_2max values with increasing distances (Coetzer et al., 1993). The reasons for this phenomenon in these performance-matched athletes could not be attributed to muscle fibre type composition, VO_2max , nor running economy. It seems that there may be a similar situation occurring across the racial line as it is across the gender line.

3.5. CONCLUSION

In conclusion, when male and female athletes were matched on their performance at a standard marathon (42.2km) level, males showed a tendency for larger performance decrements with increasing distance, and although the groups had been matched at 42.2km, the females outperformed the males at the 90km distance. The females exercised at higher levels of their $\text{VO}_{2\text{max}}$, but were apparently less reliant on β -oxidation for fuel than were the males. These data suggest that females are able to maintain a higher work rate for longer during ultra-endurance exercise.

When elite black and white South African runners (male middle distance runners) were compared, it was found that black athletes perform better with increasing distance, and that the black athletes were able to sustain a higher percentage of their $\text{VO}_{2\text{max}}$ values with increasing distance (Coetzer et al., 1993). The reasons for this phenomenon in these performance-matched athletes could not be attributed to muscle fibre type composition, $\text{VO}_{2\text{max}}$, or running economy. It seems that there may be a similar situation occurring across the gender-line as it is occurring across the racial-line.

CHAPTER 4. SUMMARY

When male and female athletes were matched on their performance at a standard marathon (42.2km) level, males showed larger performance decrements with increasing distance, and although the groups had been matched at 42.2km, the females outperformed the males at the 90km distance. At the 90km distance, the males had post-exercise blood-borne free fatty acid concentrations nearly twice that of the females. Since it is generally accepted that the concentration of FFA in the plasma is an indication of the rate of β -oxidation, it contradicts the theory governing ultra-endurance exercise in that in these events the better-performing athletes utilise β -oxidation as a means of obtaining their energy (thereby employing a more efficient method of glycogen-sparing) better than those athletes performing less well. However, we found via indirect measurements that the females were exercising at higher levels of their $\text{VO}_{2\text{max}}$, and may not have been as reliant on β -oxidation for fuel as were the males. Furthermore, it has been proposed from numerous studies that males have a more adapt mechanism of utilising fat compared to females. These data suggest that females are more able to maintain a higher work rate for longer compared to performance-matched males. The reason(s) for the occurrence of this phenomenon have not been explained in this study: it is not a function of the females $\text{VO}_{2\text{max}}$, nor is it

an advantageous metabolic adaptation, nor do they (females) have superior running economies and training adaptations.

We wish to emphasise however that there is no evidence to suggest that the elite female athlete can match or outperform the elite male athlete in the foreseeable future. The results shown by Whipp and Ward (1992) probably reflect, at least partly, the advantage the female athlete has enjoyed of using latter day advances in sports science, since full female participation in athletics only began around the 1950's and 1960's compared to the turn of the 20th century for males (Sparling et al., 1993).

APPENDIX A

1. ASSAY FOR LACTATE

Test-Combination: Lactate fully enzymatic.

UV-method.

Boehringer Mannheim, Cat. No: 256773 for 3 x 100ml.

Assay without deproteinisation

Additional reagent:

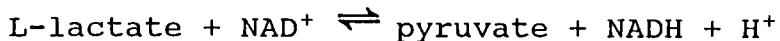
Fluoride/EDTA (Cat. No: 243710).

METHOD

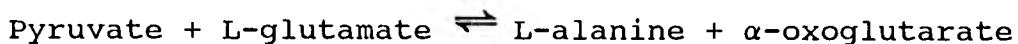
Model from Noll, F. (1974). L-(+)-Lactate. Determination with LDH, GPT and NAD. Page 1475 ff. in H.U. Bergmeyer, ed. Methods of Enzymatic analysis, 2nd edition (translated from 3rd German Edition) Verlag Chemie Weinheim and Academic Press, Inc., New York and London. 4 volumes.

TEST PRINCIPLE

LDH



LDH



2. ASSAY FOR GLUCOSE

Test-Combination: Glucose fully enzymatic

GOD-PAP assay

Randox Laboratories, Cat. No: GL 261 for 6 x 50ml

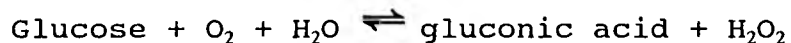
Assay without deproteinisation

METHOD

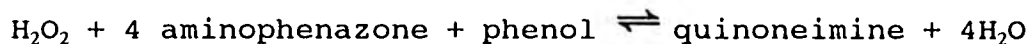
Glucose is determined after enzymatic oxidation in the presence of glucose oxidase. The formed hydrogen peroxide reacts under catalysis of peroxidase with phenol and 4-aminophenazone to form a red-violet quinoneimine dye as indicator.

REACTION PRINCIPLE

GOD



PAP



2. ASSAY FOR FREE FATTY ACIDS

Sample Preparation:

1. 0.5ml sample + 0.05ml 50% v/v ortho-phosphoric acid (Dilution factor: 1.1).
2. After 30 minutes, samples were centrifuged.
3. 0.25ml sample + 0.025 internal standard (No dilution factor: STD treated in the same way).

Calculations:

As calculated from the chromatograms attained by gas chromatography from the following equation:

$$\frac{PA(FFA)_{sample}}{PA(FFA)_{STD}} \times STD \text{ concentration (Ac)} \times \text{dilution factor (mmol/100ml}^3\text{)}$$

Where

PA	= peak area on chromatogram
FFA	= Free fatty acid
STD	= Free fatty acid standard

Correct for injection error by multiplying value calculated by the correction factor determined as follows:

$$\text{Correction factor} = \frac{PA \text{ of INT STD in the STD solution}}{PA \text{ of INT STD in the sample solution}}$$

REFERENCES

- Andersen P, and J. Henriksson. Capillary supply of the quadriceps femoris muscle in man: Adaptive response to exercise. *Journal of Physiology*, 1977; 270; 677-690.
- Bergstrom, J., Hermansen, L., Hultman, E., and Saltin, B. Diet, muscle glycogen and physical performance. *Acta Physiol Scand*, 71: 140-150, 1967.
- Black, J., G.B. Chester, and G.A. Starmer. The painlessness of the long-distance runner. *Medical Journal of Australia*, 1; 522-523, 1979.
- Brodie, D.A. Techniques of measurement of body composition, part I. *Sports Medicine*, 5; 11-40, 1988.
- Carlson, L., L.G. Ekelund, and S.O. Fröberg. Concentration of triglycerides; phospholipids, and glycogen in skeletal muscle and of free fatty acids and β -hydroxybutyric acid in blood in man in response to exercise. *Eur. J. Clin Invest.* 1: 248-254, 1971.
- Coetzer, P., T.D. Noakes, B. Sanders, M.I. Lambert, A.N. Bosch, T. Wiggins, and S. Dennis. Superior fatigue resistance of elite black South African runners. *J. Appl. Physiol.* 75(4): 1822-1827, 1993.
- Conley, D.L., G.S. Krahenbuhl, L.N. Burkett, and A.L. Millar. Physiological correlates of female road racing performance. *Research quarterly* 52, 441-448, 1981a.
- Conley, D.L., G.S. Krahenbuhl, and L.N. Burkett. Training for aerobic capacity and running economy. *Physician and Sportsmedicine* 9 (April), 107-115, 1981b.
- Costill, D.L., J. Daniels, W. Evans, W. Fink, G. Drahenbuhl, and Saltin, B. Skeletal muscle enzymes and fibre composition in male and female track athletes. *Journal of Applied Physiology* 40: 149-154, 1976.
- Costill, D.L., W.J. Fink, L.H. Getchell, J.L. Ivy, and F.A. Witzmann. Lipid metabolism in skeletal muscle of endurance trained males and females. *Journal of Applied Physiology* 47, 787-791, 1979.
- Costill, D.L., W.J. Fink, M. Flynn, and J. Kirwan. Muscle fibre composition and enzyme activities in elite female distance runners. *Int. J. Sports Med.* 8: 103-106, 1987.
- Cureton, K.J., and Sparling, P.B. Distance running performance and metabolic responses to running in men and women with excess weight experimentally equated. *Medicine and Science in Sports and Exercise* 12, 288-294, 1980.

Cureton, K.J., A.M. Collins, D.W. Hill, and F.M. McElhannon. Muscular hypertrophy in men and women. *Medicine and Science in Sports and Exercise*, 20(4); 338-344, 1988.

Daniels, J., and J. Gilbert. (1979). Oxygen Power. Performance Tables for Distance Runners', Oxygen Power, Tempe, Arizona.

Daniels J.T., R.A. Yarbough, and C. Foster. Changes in $\text{VO}_{2\text{max}}$ and running performance with training. *European Journal of Applied Physiology*, 39; 249-254, 1978a.

Davies, C.T.M., and M.W. Thompson. Aerobic performance of female marathon and male ultra-marathon athletes. *European Journal of Applied Physiology* 41, 233-245, 1979.

di Prampero, P.E., G. Atchou, J.-C. Bruckner, and C. Moia. The energetics of endurance running. *Eur. J. Appl. Physiol.* 55: 259-266, 1986.

Drinkwater, B. Training of Female Athletes. In: *The Olympic Book of Sports Medicine*, 309-327. Blackwell Scientific Publications, Oxford.

Durnin, J.V.G.A., and J. Womersley. Body fat assessed from the total body density and its estimation from skinfold thickness: measurements on 481 men and women aged 16 to 72 years. *Br. J. Nutr.* 32: 77-97, 1974.

Ekblom, B., and L. Hermansen. Cardiac output in athletes. *Journal of Applied Physiology*, 25; 619-625, 1968.

Fox, E.L., and D.K. Mathews. *The Physiological Basis of Physiological Education and Athletics*. Philadelphia, PA: Saunders, 1981, p. 528.

Glantz, S.A. *Primer of Biostatistics*. New York: McGraw-Hill, 1981, p. 63-93.

Gollnick, P.D., and B. Saltin. Hypothesis: Significance of skeletal muscle oxidative enzyme enhancement with endurance training. *Clinical Physiologist*, 2; 1-12, 1982.

Gollnick, P.D. Free fatty acid turnover and the availability of substrates as a limiting factor in prolonged exercise. In: *The Marathon: Physiological, Medical, Epidemiological, and Psychological Studies*. Ann. N.Y. Acad. Sci. 301:64-71, 1977.

Green, H.J., L.L. Jones, M.E. Houston, M.E. Ball-Burnett and B.W. Farrance. Muscle energetics during prolonged cycling after exercise hypervolemia, *Journal of Applied Physiology*, 66; 622-231, 1989.

Harries, M., Williams, C., Stanish, W.D., and Micheli, L.J. Oxford textbook of sports medicine. Oxford University Press, 1994.

Holloway, J.B., and T.R. Baechle. Strength Training for female athletes: A review of selected aspects. *Sports Medicine*, 9(4); 216-228, 1990.

Hopkins, P. and S.K. Powers. Oxygen uptake during submaximal running in highly trained men and women. *American Corrective Therapy Journal*, 36; 13-132, 1982.

Hultman, E. Physiological role of muscle glycogen in man with special reference to exercise. *Circulatory Research*, 20/21, Suppl 1:1199-1114, 1967.

Hurley, B.F., Nemeth, P.M., Martin, W.H., Dalsky, G.P., and Holoszy, J.O. Muscle triglyceride utilization during exercise: effect of training. *Journal of Applied Physiology*, 60: 562-567, 1986.

Hutchinson, P.L., K.J. Cureton, H. Outz, and G. Wilson. Relationship of cardiac size to maximal oxygen uptake and body size in men and women. *International Journal of Sports Medicine*, 12(4); 369-373, 1991.

Jacobs, I. Blood lactate: implications for training and sports performance. *Sports Medicine*, 3; 10-25, 1986.

Jacobs, I., Tesch, P.A., Bar-Or, O., Karlsson, J., and Dotson, R. Lactate in human skeletal muscle after 10s and 30s of supramaximal exercise. *Journal of Applied Physiology*, 55; 365-368, 1983b.

Johnson, R.H., J.L. Walton, H.A. Krebs, and R.H. Williamson. Metabolic fuels during and after severe exercise in athletes and non-athletes. *Lancet*. 2:452-455, 1969.

Kannus, P., Cook, L., and Alosa, D. Absolute and relative endurance parameters in isokinetic tests of muscular performance. *Journal of Sports Rehabilitation*, 1, 2-12, 1992.

Keys, A., and J. Brozek. Body fat in adult man. *Physiological Reviews*, 33; 245-325, 1953.

Lauerbach, L.L. Comparative muscular strength of men and women: a review of the literature. *Aviation, Space, and Environmental Medicine*, May; 534-542, 1976.

Lebrun, C.M. Effect of the different phases of the menstrual cycle and oral contraceptives on athletic performance. *Sports Medicine*, 16: 400-430, 1993.

Kirkwood, S.P., L. Packer, and G.A. Brooks. Effects of endurance training on a mitochondrial reticulum in limb skeletal muscle, *Archives of biochemistry and biophysics*, 255; 80-88, 1987.

Koltyn, K.F., P.J. O'Conner, and W.P. Morgan. Perception of effort in female and male competitive swimmers. *Int. J. Sports Med.* 12: 427-429, 1990.

Lewis, D.A., E. Kamon, and J.L. Hodgson. Physiological differences between genders: implications for sports conditioning. *Sports Medicine*, 3; 357-369, 1986.

Lewis, C. Physiological differences in physiologically-matched male and female athletes. *Unpublished manuscript*, 1988.

Louw, J. Predicting your Comrades Performance. *Comrades Marathon Update*, January, 12-13, 1989.

Lukaski, H.C. Methods for the assessment of human body composition: traditional and new. *American Journal of Clinical Nutrition*, 46; 537-556, 1987.

Maughan, R.J. and J.B. Leiper. Aerobic capacity and fractional utilisation of aerobic capacity in elite and non-elite male and female marathon runners. *European Journal of Applied Physiology*, 52; 80-87, 1983.

McConnell, T.R. Practical considerations in the testing of $\dot{V}O_{2\max}$ in runners. *Sports Medicine*, 5; 57-68, 1988.

Milroy, A. Is the female of the ultra species tougher than the male? *Unpublished manuscript*, 1992b. From T.D. Noakes, *Lore of Running*, p 615, 3rd edition. Cape Town, Oxford University Press.

Misner, J.E. B.H. Massey, S.B. Going, M.G. Bemben, and T.E. Ball. Sex differences in static strength and fatigability in three different muscle groups. *Research Quarterly in Exercise and Sport*, 67: 1843-1849, 1990.

Morgan, W.P. Affective beneficence of vigorous physical activity. *Medicine and Science in Sports and Exercise*, 17; 94-100, 1985.

Morton, R.H. The supreme runner: what evidence now? *Australian Journal of Sports Sciences*, 3: 7-10, 1983.

Newsholme ET, and T. Leech, (1983). *The Runner: Energy and Endurance*, Fitness Books, Oxford, Walter L. Meager.

Noakes, T.D. (1992). *Lore of Running*. 3rd edition. Cape Town, Oxford University Press.

Noakes, T.D. Implications for exercise testing for prediction of athletic performance: A contemporary perspective. *Medicine and Science in Sports and Exercise*, 20; 319-330, 1988b.

Pate, R.R., C. Barnes, and W. Miller. A physiological comparison of performance-matched female and male distance runners. *Research Quarterly for Exercise and Sport*, 56(3); 245-250, 1985.

Pate, R.R., and A. Kriska. Physiological basis of the sex difference in cardiorespiratory endurance. *Sports Medicine*, 1; 87-98, 1984.

Peronnet, F., and G. Thibault. Mathematical analysis of running performance and world running records. *Journal of Applied Physiology*, 67: 453-465, 1989.

Peronnet, F., G. Thibault, and D-L. Cousineau. A theoretical analysis of the effect of altitude on running performance. *Journal of Applied Physiology*, 70(1): 399-404, 1991.

Perrin, D.H. Reliability of isokinetic measures. *Athletic Training*. 10, 319-321, 1986.

Perrin, D.H. *Isokinetic Exercise and Assessment*. Chapter 4, p59-69, Human Kinetic Publishers, 1992.

Pottas, C.D., R. Erwee, A.B. Boshoff, and B.C. Lessing. *Manuel for the Achievement Motivation Questionnaire*. Pretoria; University of Pretoria; 1988, p. 1-43.

Prince, F.P., R.S. Hikida, and S.C. Hageramn. Muscle Fibre types in women athletes and non-athletes. *European Journal of Physiology*, 371; 161-165, 1977.

Randle, P.J., R.B. Garland, C.N. Hales, and E.A. Newsholme. The glucose fatty acid cycle its role in insulin sensitivity and the metabolic disturbances of diabetes mellitus. *Lancet*. 1: 785-789, 1963.

Ryder, H.W., H.J. Carr, and P. Herget. Future performance in footracing. *Scientific American*, 234; 108-119, 1976.

Saltin, B., J. Henriksson, E. Nygaard, and P. Anderson. Fibre types and metabolic potentials of skeletal muscle in sedentary man and endurance runners. In: *The Marathon: Physiological, Medical, Epidemiological, and Psychological Studies*. Ann. N.Y. Acad. Sci. 301:3-29, 1977.

Scheuer, J., and C.M. Tipton. Cardiovascular adaptations to physical training. *Ann Rev Physiol*, 39; 221-251, 1977.

- Scott, V., and K. Gijssbers. Pain perception in competitive swimmers. *British Medical Journal*, 283; 91-93, 1981.
- Sjodin, b., and Jacobs, I. Onset of blood lactate accumulation and marathon running performance. *International Journal of Sports Medicine*, 2: 23-26, 1981.
- Smith, S.S., Mayer, T.G., Gatchel, R.J., and Becker, T.J. Quantification of lumbar function. *Spine*. 10, 757-764, 1985
- Sparling, P.B. A meta-analysis of studies comparing maximal oxygen uptake in men and women. *Research Quarterly for Exercise and Sport*, 51(3); 542-552, 1980.
- Sparling, P.B., D.C. Nieman, and P.J. O'Connor. Selected Scientific Aspects of Marathon Racing: An update on fluid replacement, immune function, psychological factors and the gender difference. *Sports Medicine*, 15(2); 116-132, 1993.
- Stone, H.L. Cardiac function and exercise training in conscious dogs. *Journal of Applied Physiology* 42; 824-832, 1977.
- Tarnopolsky, L.J., J.D. Macdougall, S.A. Atkinson, M.A. Tarnopolsky, and J.R. Sutton. Gender Differences in substrate for endurance exercise. *J. Appl. Physiol.* 68: 302-308, 1990.
- Ullyot, J. (1976). Women's Secret Weapon. In E. Van Aaken. *Van Aaken Method*. World Publications. Mountain View, California.
- Washburn, R.A., and D.R. Seals. Peak oxygen uptake during arm cranking for men and women. *Journal of Applied Physiology* 56, 954-957, 1984.
- Wells, C.L., L.H. Hecht, and G.S. Krahenbuhl. Physical characteristics and oxygen utilisation of male and female marathon runners. *Research Quarterly* 52, 281-285, 1981.
- Wells, C.L., and S.A. Plowman. Sexual differences in athletic performance: biological or behavioral. *Physician and Sportsmedicine* 11 (August), 52-63, 1983.
- Whipp, B.J., and S.A. Ward. Will women soon outrun men? *Nature*. 355: 25, 1992.
- Wilmore, J.H. Alterations in strength, body composition and anthropometric measurements consequent to a 10-week weight training programme. *Med Sci Sports*, 6: 133-138, 1974.
- Wyndham C.H., N.B. Strydom, J.F. Morrison, J. Peter, and Z.U. Potgieter. Maximal oxygen intake at maximal heart rate during strenuous work. *J. Appl. Physiol.* 14: 927-936, 1959.

Yki-Jarvinen, H., Puhakainen, I., Saloranta, C., Groop, L., and Taskinen, M-R. Demonstration of a novel feedback mechanism between FFA oxidation from intracellular sources. *American Journal of Physiology*, 260: E680-689, 1991.