

The Effect of Fast and Slow Pace Training
on Running Economy

by


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ABSTRACT

Running economy is a measure of energy expenditure at a fixed load and is measured at submaximal velocities using steady state $\dot{V}O_2$ (SS $\dot{V}O_2$). If the principle of temporal specificity is applicable to running training, then changes in running economy should be specific to the pace used in training. The purpose of this experiment was to determine the effect of a fast pace and a slow pace training regimen on running economy at submaximal, threshold, and 3000m performance velocities. Sixteen well trained runners were separated into two groups ($N = 8$) and undertook similar training that differed only in the speed of their pace workouts. The Fast Pace group (FP; 21.4 yrs, 58.5kg, 59.8mL·kg⁻¹·min⁻¹) did pace workouts at 65 seconds per 400m or faster which was quicker than their 3000m performance pace; the Slow Pace group (SP; 20.8 yrs, 69.2kg, 69.1mL·kg⁻¹·min⁻¹) performed their pace workouts at 66 seconds per 400m or slower which was similar to their 3000m performance pace. Both groups were tested before the training program began (Pretest), after the pace training was completed, in 7-8 weeks (Track test), and after a four week period when both groups performed slow paced training (Transition test). Each testing session involved a $\dot{V}O_2$ max test and a test of running economy in which the runners ran for 5 minutes at each load. SS $\dot{V}O_2$, accumulated $\dot{V}O_2$ (Acc $\dot{V}O_2$), and heart rate (HR) were measured after the submaximal and threshold loads and after the 3000m pace load. The FP HR was lower from the pretest to the track and transition tests at the submaximal and threshold loads. There were no changes at the 3000m pace load. The SP SS $\dot{V}O_2$ was lower from the pretest to the track

pretest to the track test at the threshold and 3000m pace loads. The 3000m $SS\dot{V}O_2$ was still lower at the transition test. The SP training improved their running economy at the speeds nearest to their pace workout velocities, providing support for the presence of the temporal specificity principle in running training. The FP training improved metabolic efficiency at the submaximal and threshold velocities but did not affect running economy at any speed. The FP did significantly improve in 1500m performance from Pretest to Track test. In conclusion, running economy is more widely affected by slow paced training and there is evidence suggesting that running training is governed by the temporal specificity principle.

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INTRODUCTION

There are physiological measures which have been correlated to distance running performance (DRP): $\dot{V}O_2$ max (Costill, 1973; Astrand & Rodahl, 1986; Brandon & Boileau, 1987), anaerobic threshold (Farrell, Wilmore, Coyle, Billing & Costill, 1979; Tanaka & Matsuura, 1984; Cunningham, 1990) and running economy (Conley & Krahenbuhl, 1980; Cunningham, 1990). The aerobic cost of maintaining a specific running speed is referred to as running economy and it traditionally involved measures of steady state $\dot{V}O_2$ ($SS\dot{V}O_2$) at submaximal running velocities (Conley & Krahenbuhl, 1980; Conley, Krahenbuhl, Burkett, & Millar, 1984; Cunningham, 1990; Daniels & Daniels, 1992).

Below anaerobic threshold, there is an anaerobic component to the energy supplied during running (Brooks, 1985; Davis, 1985). The relatively low relationships ($r < .65$) which have been shown to exist between running economy and distance running performance (Farrell *et al.*, 1979) even in homogenous groups, could be due to the lack of a measure of the anaerobic contribution to energy metabolism (Gladden & Welch, 1978). Another reason may be that RE was measured at submaximal velocities while training to improve performance is often accomplished at or close to maximum speeds. Even though a substantial volume of training can occur at submaximal speeds, greater efficiency at these speeds may not transfer to performance at maximum velocities. Pollock (1977) showed marathoners being more efficient than middle distance runners but marathoners compete and train at a pace much closer to the testing speeds than do

middle distance runners. Though less economical than marathon runners at 268 metres per minute, middle distance runners become more economical at 370 metres per minute pace (Daniels & Daniels, 1992).

While being efficient at submaximal speeds may be relevant for certain conditions, when assessing the effect of a training program, measures of RE at the training and performance speeds may be more meaningful. Training does improve efficiency at submaximal work intensities (Conley *et al.*, 1981, 1984; Scrimgeour *et al.*, 1986), but little has been done to determine the effect of training on RE at maximal intensities. In more elite running groups, usually one to two workouts per week are performed at the planned competition race velocity and are termed pace training workouts. The intention is to improve the ability of the athlete to run comfortably at the race pace; in effect improve RE of the athlete at this running speed. This is similar to the resistance training principle that the speed of contraction in training should be similar to the speed of contraction during performance, temporal specificity of movement. This is done to train the neuromuscular system to work at the required rate (Sale, 1992; Schimdtbliecher, 1992). Whether this principle is demonstrated in running, *i.e.* train the leg muscles to work at the desired rate, is still equivocal. In addition, it has been reported (Davis, 1985; Kaneko, 1990) that fast twitch muscle fibres (FTF) are less aerobically efficient than slow twitch fibres. To improve FTF efficiency, training at an intensity high enough to recruit these fibres is necessary, according to the size principle (Noth, 1992). Pace training may stimulate improvements in RE by training the neuromuscular system and recruiting and training the less efficient FTF.

The difficulty in determining the effect of training on RE at a performance speed

is assessing the contribution of anaerobic energy sources (Cunningham & Faulkner, 1969; Morgan *et al.*, 1989). Oxygen debt has been used as a means of quantifying anaerobic input in any exercise. Originally oxygen debt (O_2 debt) was thought to be a measure of oxygen utilized to replace intramuscular high energy phosphates and metabolise lactate (Hill & Lupton, 1923; Margaria, Edwards, & Dill, 1933). Many believe that O_2 debt cannot accurately assess the anaerobic component of energy production because some of the factors contributing to the oxygen debt are not anaerobic; *i.e.* hormone levels, elevated body temperature (Welch *et al.*, 1970; Gaesser & Brooks, 1984). However, these alterations in metabolism result from meeting the energy demands of exercise. Any decrease in O_2 debt should be the result of reduced energy demands, whether by reducing the work done or increasing the utilization of energy produced. The former refers to improved running economy, the latter to increasing metabolic efficiency. Using O_2 debt in this way has been accepted by some researchers to be a gross indicator of anaerobic sources of energy (Cunningham & Faulkner, 1969).

In order to use O_2 debt, validity and reliability must be ensured and baseline resting $\dot{V}O_2$ must be established. True resting $\dot{V}O_2$ would require measuring the basal metabolic rate, which is affected by many factors and requires a post exercise collection period in excess of 24 hours (Stainsby & Barclay, 1970). The steady state $\dot{V}O_2$ achieved during a low work rate is an adequate baseline measure and is not as sensitive to external factors such as anticipation and day to day variation (Stainsby & Barclay, 1970). Tests of RE must control running speed, footwear, time of day, training activity, and length of treadmill accommodation, as all can affect $\dot{V}O_2$ (Gaesser & Brooks, 1984; Daniels,

1985).

At maximal speeds, O_2 deficit and accumulated $\dot{V}O_2$ together with O_2 debt should give a clearer picture of changes that may occur in RE or energy supply. By knowing if more O_2 is being utilized during a workload and if this additional accumulated O_2 represents a decline in O_2 deficit or more O_2 used because steady state $\dot{V}O_2$ has increased is important when interpreting changes in O_2 debt.

RE at 3000m performance speed has not been measured because of the lack of an accurate measure of energy supply at high intensities.

PURPOSE

The purpose of this experiment was therefore to determine the effect of fast pace training vs. slow pace training on submaximal and 3000m running economy.

HYPOTHESIS

Changes in RE would be temporally specific to training paces. The SP and FP groups will improve running economy at the velocities specific to their pace training.

METHODOLOGY

Subjects

The subjects were volunteers, 6 females and 10 males, from the Island Pacific Racing Team running club. A normal training year would see these athletes begin cross-country training in September after a one month rest at the end of the outdoor competitive season. They would build up their training volume and intensity through September and October in preparation for the month long competitive cross-country season. After the completion of their cross-country season, the athletes would spend the month of December performing high volume/low intensity training in transition before beginning their pre-competitive indoor pace training in January. Because of the de-emphasis of their indoor competitive season, "pre-competitive" training was followed throughout the indoor season with the only reduction in training volume coming before their final race in early March. They then would perform a month of transition training similar to December, high volume/low intensity, from mid March to mid April in preparation for the outdoor season. Pre-competitive training was done from mid April to the end of May followed by the outdoor competitive season which extends through June and July. August is used as a recovery month before the yearly cycle begins again. All subjects had been through this training cycle at least once, with 14 of the 16 subjects having performed it three times or more. The purpose and procedures were explained to the athletes and all subjects signed a consent form (Appendix B) before testing began.

Training

The subjects were separated into two groups based on the speed of their pace workouts; one group (5 females $\bar{X} \dot{V}O_2 \text{ max} = 52.6 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; 3 males $\bar{X} \dot{V}O_2 \text{ max} = 72.0 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) performed fast pace workouts; pace of 400m in 65s or faster (FP), the other group (1 female, $\dot{V}O_2 \text{ max} = 56.1 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; 7 males $\bar{X} \dot{V}O_2 \text{ max} = 71.0 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) performed slow pace workouts; pace of 400m in 66s or slower (SP). The weekly training routine for groups was similar:

1 long run, 70-90 min easy effort (6:30-8:00 minutes per mile);

1-2 pace workouts as above;

1 steady state workout 30-45 min continuous near AT or

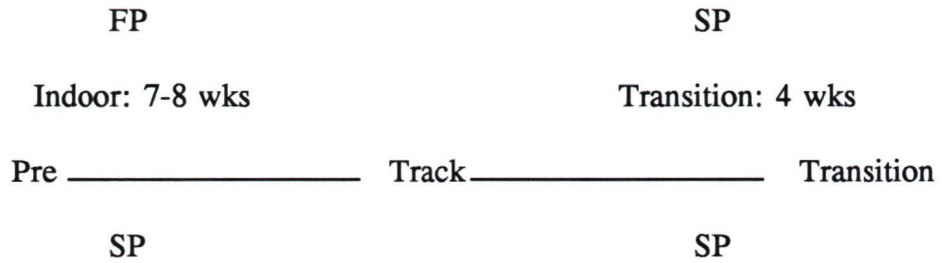
2-3 \times 10 min (5 min rest) AT;

3-4 easy runs 20-60 min easy effort (6:30-8:00 minutes per mile).

Weekly volume was similar between groups with the only difference being the velocity at which the pace workouts were performed.

This phase of training lasted for 7-8 weeks, until the end of the indoor season. Following this was a transition phase; a 4-week period when subjects in the FP group performed the same training as the SP group.

Fast pace group



Slow pace group

(FP = fast pace; SP = slow pace)

At each testing period (Pretest, Track test, Transition test) measures of RE and $\dot{V}O_2$ max were taken. The pretest was before any pace training on the track had begun. Prior to this, all subjects were finishing 2-4 weeks of high volume/low intensity training after the end of cross-country season. The track test was at the end of indoor season; the transition test after the FP group had performed 4 weeks of slow pace training.

Testing Protocol

Conditions for each RE test were controlled as follows: All subjects performed a low volume/low intensity training day on the day before testing. Subjects wore the same footwear for each test and subjects were only allowed to stretch for a warm-up before each test, no jogging was permitted. All testing speeds were identical for each subject for all three RE tests.

To begin the test, subjects sat quietly for three minutes while baseline $\dot{V}O_2$ was measured. Subjects then warmed up for two minutes at treadmill speeds below the first testing speed. Subjects ran for 5 min at the first three testing speeds with no rest

between each load. The first, second, and third stage speeds were determined from their AT- $\dot{V}O_2$ max test. The first speed was 2mph slower than AT, the second speed 1mph slower than AT and the third speed was their AT. The final stage speed was their 3000m pace (to the closest .5mph). At the end of the third stage, the subjects had a seated rest for three min during which a finger prick blood sample for lactate analysis was taken after 30 seconds of rest. At the end of the three minutes seated rest, subjects resumed running at the speed of the third stage. In 30 seconds the treadmill velocity was increased to their final speed at which they ran for 1:30 minutes. At the end of their final stage they had an additional three minutes seated rest. The dependent variables measured were accumulated VO_2 , steady state $\dot{V}O_2$, heart rate, blood lactate, O_2 debt, and O_2 deficit.

The AT- $\dot{V}O_2$ max test was conducted according to the standard UVic Sport and Fitness Testing Centre procedure. Subjects began at a self-selected "easy" speed and the treadmill velocity increased 0.5mph every two minutes until VT was detected (a nonlinear increase in VE concomitant with a decrease in VCO_2). VT was accepted as the subjects' Anaerobic Threshold (AT). Subsequently the treadmill grade was increased 2% every minute until volitional exhaustion. $\dot{V}O_2$ max was accepted if two of the following three criteria were met:

1. $R > 1.10$,
2. Plateau of $\dot{V}O_2$,
3. volitional exhaustion.

Fourteen of sixteen subjects met all three $\dot{V}O_2$ max criteria. Two subjects did not have $R > 1.10$ but did demonstrate a plateau in $\dot{V}O_2$. $\dot{V}O_2$, $\dot{V}CO_2$, and ventilation were measured via open circuit spirometry using a Beckman Horizon Metabolic Cart for analysis. Heart rate was measured telemetrically every 30 seconds on a Sport Tester 2000 heart rate monitor. The treadmill velocities were controlled continuously by using a counter to measure the speed and to ensure reliability.

Statistics

The dependent variables steady state $\dot{V}O_2$, accumulated VO_2 , O_2 debt, O_2 deficit, % $\dot{V}O_2$ max, steady state heart rate, and blood lactate were analyzed using a 2×3 ANOVA with repeated measures followed by correlated t -test to distinguish differences between means where appropriate. Level of significance was set at $p < .05$.

Operational Definitions

Accumulated VO_2 (litres)

The total VO_2 accumulated for each load minus the resting baseline. It gives an indication of the total metabolic work performed during a submaximal stage.

Steady State $\dot{V}O_2$ (mL·kg⁻¹·min⁻¹)

A measure of the steady state work being done aerobically (Pollock, 1977; Conley & Krahenbuhl, 1980; Cunningham, 1990; Daniels & Daniels, 1992). It reflects efficiency of running at a submaximal velocity (Daniels *et al.*, 1978).

Percent $\dot{V}O_2$ max

A measure of the steady state oxygen cost relative to the $\dot{V}O_2$ max. It is more sensitive to changes in both $\dot{V}O_2$ max and SS $\dot{V}O_2$ (Costill, Thomason, & Roberts, 1973; Conley, Krahenbuhl, Burkett, & Millar, 1981). It is a measure of metabolic efficiency.

Heart Rate

A measure of the cardiorespiratory work during steady state running. Changes in heart rate reflect alterations in the response of the cardiorespiratory system to the metabolic need in the working muscles at the same absolute workload (Burkett *et al.*, 1985; Astrand & Rodahl, 1986).

Oxygen Deficit

Oxygen deficit is a measure of how much energy is provided non-aerobically during the period $\dot{V}O_2$ is rising to meet the load imposed (Stainsby & Barclay, 1970).

It can be calculated by subtracting the estimated AccVO₂ for the load (SS $\dot{V}O_2$ multiplied by the time of exercise) and subtracting the actual AccVO₂ measured during each 5

minute load.

Oxygen Debt

Oxygen debt is the measured $\dot{V}O_2$ above resting $\dot{V}O_2$ after exercise has ceased. It was measured as the AccVO_2 during the three minute recovery after the submaximal-threshold load and the maximal load (Stainsby & Barclay, 1970). Changes in O_2 deficit or O_2 debt indicate alterations in the volume of energy supplied non-aerobically (Cunningham & Faulkner, 1969).

Running Economy

The energy required to perform at a fixed running speed. It was determined with measures of $SS\dot{V}O_2$, O_2 deficit, O_2 debt, and blood lactate at the submaximal, threshold, and sprint workloads.

Metabolic Efficiency

The amount of metabolic energy provided to run at a fixed submaximal velocity in relation to the amount of energy provided at $\dot{V}O_2$ max.

RESULTS

The mean age, weight, and $\dot{V}O_2$ max of the subjects in each group at the Pretest are presented in Table 1. $\dot{V}O_2$ max declined in both groups from Pretest to Track test and in the SP group from Pretest to Transition test (Fig. 1). There were no changes in body weight.

Because each subject ran at a load derived from their own VT, and 3000m pace, between group comparisons of SS $\dot{V}O_2$ and Acc $\dot{V}O_2$ are not considered.

There were no significant within group changes across training times in Acc $\dot{V}O_2$ (Table 2).

The FP group SS $\dot{V}O_2$ did not change significantly across the training times. The SP group SS $\dot{V}O_2$ did not change at the submaximal load but did decrease from pretest to track test in both the threshold and sprint loads. The transition test SS $\dot{V}O_2$ was still significantly lower than the pretest value in the sprint load but the threshold SS $\dot{V}O_2$ had returned to pretest value (Table 3).

Percent $\dot{V}O_2$ max at a fixed load can be used as a measure of running economy (Costill *et al.*, 1973) where between group comparisons are possible because the subjects are running at the same absolute speeds. The two groups were not different in % $\dot{V}O_2$ max at any load. At the transition test the FP group sprint percent $\dot{V}O_2$ max was higher

than the pretest value. There were no other within group changes in either group (Table 4).

SP heart rate was unchanged over the testing times at all speeds. FP heart rate decreased significantly from Pretest to Track test and Pretest to Transition test at the submaximal and threshold speeds. There was no change at the 3000m pace load (Table 5).

Oxygen deficit and oxygen debt were not compared between groups due to the difference in loads of each subject. Oxygen debt was unchanged in both groups across the training times at submaximal-threshold and sprint loads. The FP group submaximal-threshold O_2 deficit was elevated from pretest to transition test only, 8.2 - 9.2 L. FP group 3000m pace O_2 deficit was unchanged over the three testing times. SP group submaximal-threshold O_2 deficit did not change, but their 3000m pace O_2 deficit did become smaller from pretest to track test, 18.9 - 15.7 L. It returned to its Pretest value (19.4) by the transition test. (ns) (Fig. 2 and Fig. 3).

Blood lactate values were not different between groups at any test, nor were there any within group changes (Table 6).

At a common absolute running speed, $228\text{m}\cdot\text{min}^{-1}$, there was no difference in $SS\dot{V}O_2$ between SP and FP (Table 7).

Table 1: Fast Pace (FP) group and Slow Pace (SP) group age (yrs), weight (kg), and $\dot{V}O_2$ max ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $\text{L}\cdot\text{min}^{-1}$) at Pretest.

	Age (SE)	Weight (SE)	$\dot{V}O_2$ max (SE)	
FP Group	21.4 (1.4)	70.5 (3.6)	59.8 (3.8)	4.87 (.29)
SP Group	20.8 (0.8)	60.2 (1.6)	69.1 (2.2)	3.62 (.28)

Table 2: Fast Pace (FP) group and Slow Pace (SP) group AccVO₂ (L) at each load over the three testing times; Pretest (Pre), Track test (Track), and Transition test (Trans).

	Submaximal load			Threshold load			Sprint load		
	Pre (SEM)	Track (SEM)	Trans (SEM)	Pre (SEM)	Track (SEM)	Trans (SEM)	Pre (SEM)	Track (SEM)	Trans (SEM)
FP Group	193.6 11.9	187.7 12.3	188.5 9.0	215.6 13.2	214.8 13.5	243.1 9.8	62.3 4.2	63.7 4.0	66.5 3.6
SP Group	192.0 28.8	213.2 10.1	218.6 8.2	219.4 33.6	243.1 12.2	250.8 10.2	65.4 9.1	75.4 3.3	76.1 3.4

Table 3: Fast Pace (FP) group and Slow Pace (SP) group $SS\dot{V}O_2$ ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) at each load over the three testing times; Pretest (Pre), Track test (Track), and Transition test (Trans).

	Submaximal load			Threshold load			Sprint load		
	Pre (SEM)	Track (SEM)	Trans (SEM)	Pre (SEM)	Track (SEM)	Trans (SEM)	Pre (SEM)	Track (SEM)	Trans (SEM)
FP Group	44.6 2.8	43.6 2.8	43.2 2.0	49.2 2.9	49.2 3.0	48.7 2.2	53.0 3.4	53.5 3.4	53.3 2.9
SP Group	50.0 2.3	48.6 2.3	49.8 1.8	57.2a 2.5	55.0a 2.6	56.7 2.1	63.1bc 2.4	60.0b 2.8	62.0c 2.3

Within group differences denoted by matching letters, $p < .05$.

Table 4: Fast Pace (FP) group and Slow Pace (SP) group % $\dot{V}O_2$ at each load over the three testing times; Pretest (Pre), Track test (Track), and Transition test (Trans).

	Submaximal load			Threshold load			Sprint load		
	Pre (SEM)	Track (SEM)	Trans (SEM)	Pre (SEM)	Track (SEM)	Trans (SEM)	Pre (SEM)	Track (SEM)	Trans (SEM)
FP	74.8	77.1	78.9	82.6	87.0	88.8	88.8a	94.4	96.9a
Group	2.2	2.1	2.3	2.1	2.1	2.6	2.3	2.0	2.2
SP	72.2	72.2	74.6	82.5	81.7	85.0	91.2	89.1	92.9
Group	1.9	1.8	2.2	1.5	2.0	2.1	1.4	2.0	2.5

Within group differences denoted by matching letters, $p < .05$.

Table 5: Fast Pace (FP) group and Slow Pace (SP) group heart rates (b min^{-1}) at each load over the three testing times; Pretest (Pre), Track test (Track), and Transition test (Trans).

	Submaximal load			Threshold load			Sprint load		
	Pre (SEM)	Track (SEM)	Trans (SEM)	Pre (SEM)	Track (SEM)	Trans (SEM)	Pre (SEM)	Track (SEM)	Trans (SEM)
FP Group	176ab 2.6	170a 3.1	169b 3.5	186cd 2.6	182c 2.9	180d 3.4	189 3.2	186 3.4	185 3.6
SP Group	164 3.6	163 2.7	163 2.7	175 3.5	175 3.0	175 2.9	185 2.8	181 2.9	181 2.5

Within group differences denoted by matching letters, $p < .05$.

Table 6: Fast Pace (FP) group and Slow Pace (SP) group blood lactate (mmoles·L⁻¹) after the threshold load over the three testing times; Pretest, Tract test, and Transition test.

	Pretest (SEM)	Tract test (SEM)	Transition test (SEM)
FP Group	4.1 .6	4.4 .7	4.6 .7
SP Group	3.1 .4	3.3 .3	3.4 .4

Table 7: Fast Pace (FP) group and Slow Pace (SP) group $SS\dot{V}O_2$ ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) at $228\text{m}\cdot\text{min}^{-1}$ over the three testing times; Pretest, Tract test, and Transition test.

	Pretest (SEM)	Tract test (SEM)	Transition test (SEM)
FP Group	45.2 1.8	45.5 1.6	43.9 0.6
SP Group	45.3 1.1	44.3 1.2	45.2 1.2

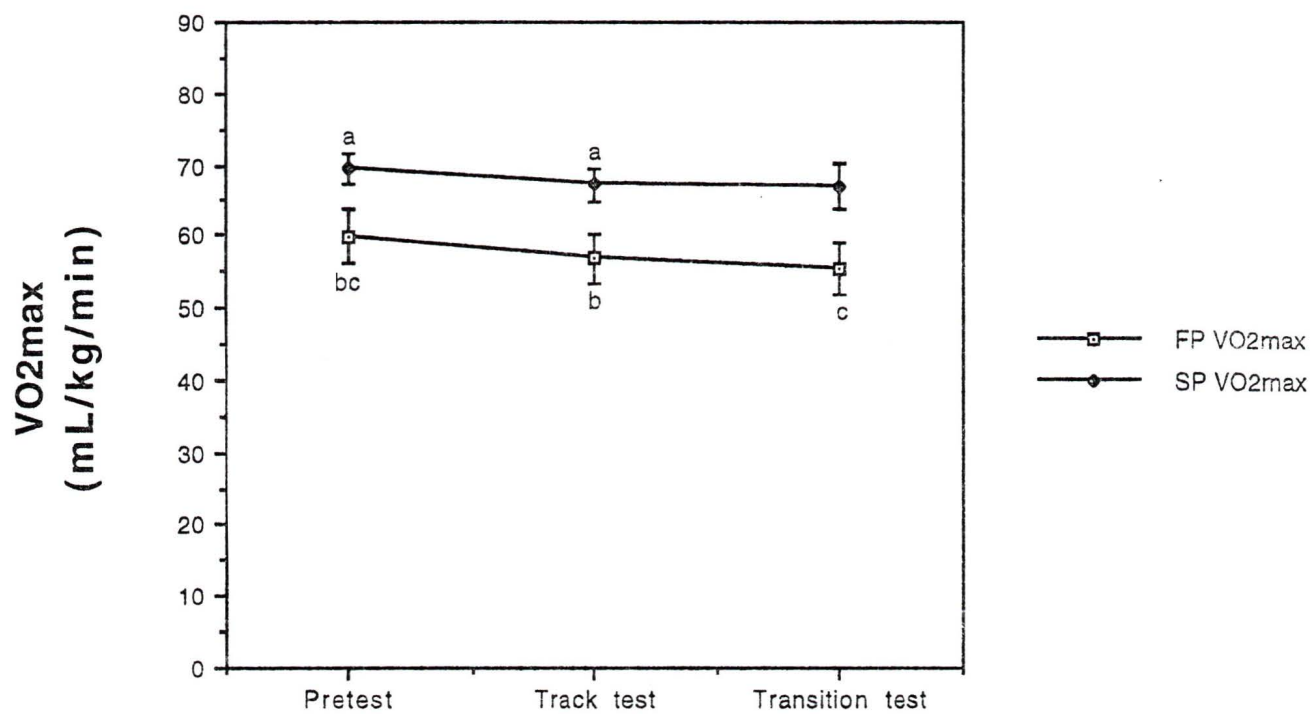


Figure 1: Fast Pace (FP) and Slow Pace (SP) VO₂max at the Pretest, Track test, and Transition test. Within group differences are denoted by matching letters, $p < .05$.

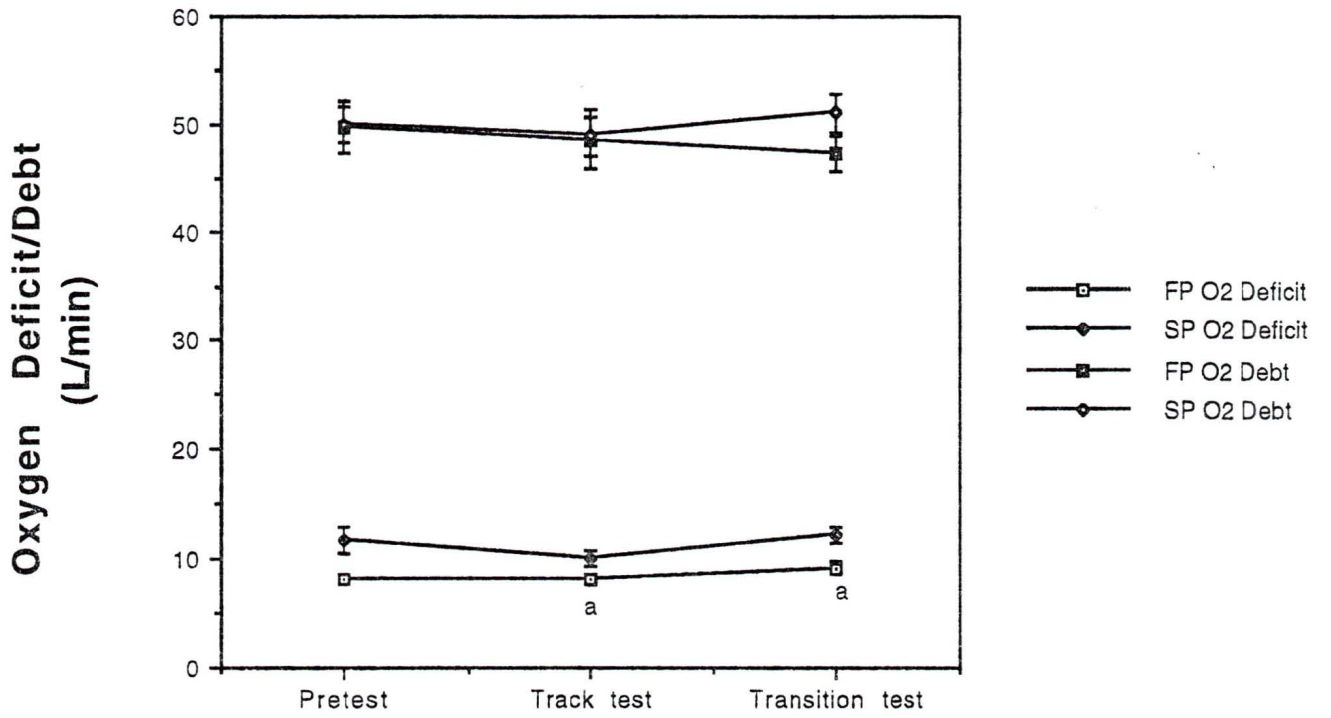


Figure 2: Fast Pace (FP) and Slow Pace (SP) O₂ deficit/debt at the submaximal-threshold load at the Pretest, Track test, and Transition test. Within group differences denoted by matching letters, $p < .05$.

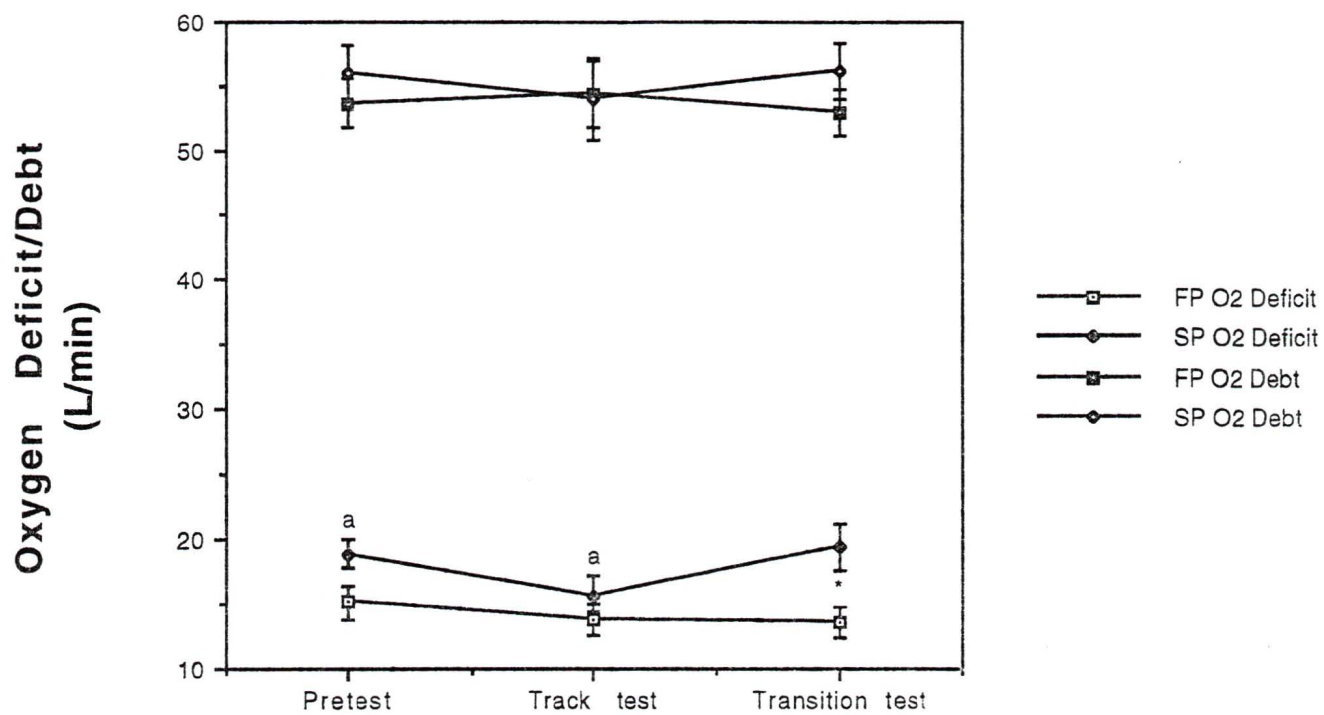


Figure 3: Fast Pace (FP) and Slow Pace (SP) O₂ Deficit/Debt at the 3000m Pace load at the Pretest, Track test, and Transition test. Within group differences denoted by matching letters, between group differences denoted by * , $p < .05$.

DISCUSSION

Interpretation of the data depends on the definition of running economy and metabolic efficiency. Improvements due to training usually are agreed to be: lower $SS\dot{V}O_2$ at a constant load (Daniels, Yarborough, & Foster, 1978; Conley, Krahenbuhl, Burkett, 1981; Conley *et al.*, 1984); lower HR at a fixed workload (Morgan & Craib, 1992); using a lower percent $\dot{V}O_2$ max at submaximal loads (Conley, Krahenbuhl, Burkett, 1981; Conley *et al.*, 1984; Scrimgeour *et al.*, 1986); or performing at a higher percent $\dot{V}O_2$ max (Costill, Thomason, Roberts, 1973; Scrimgeour *et al.*, 1986). With the exception of performing at a higher percent $\dot{V}O_2$ max these changes all reflect the workload being relatively less metabolically demanding. Reducing your $SS\dot{V}O_2$ at a common load means performing the same amount of work at a lower aerobic energy cost. A reduction in percent $\dot{V}O_2$ max at a common load translates into lower cost relative to maximal aerobic power for the same work, thus better running economy. A lower HR at the same load (without changes in other variables) indicates that the subject is better able to meet the O_2 demands through an enhanced transport of oxygen by the cardiovascular system. Improved O_2 extraction in the muscles means the O_2 demand can be met with a smaller volume of blood and so heart rate drops.

The runner may not have changed running economy, but would be more efficient in providing and using the energy required to do the work. This should mean the runner could perform continuously at a higher percent $\dot{V}O_2$ max. So an elevation in percent

$\dot{V}O_2$ max at performance velocities can indicate enhanced metabolic efficiency, and not necessarily better running economy.

Pretest to Track Test

Submaximal measures do not necessarily reflect responses at performance intensities. It has been demonstrated that better trained runners are more economical at submaximal velocities than their lesser trained counterparts (Costill *et al.*, 1973, Pollock, 1977; Bransford & Howley, 1977; Scrimgeour *et al.*, 1986). Athletes less economical at submaximal loads but able to perform in competition at a higher percent $\dot{V}O_2$ max could have a performance advantage in competition if $\dot{V}O_2$ max's are similar. Long distance runners are more economical than middle distance runners at lower intensities but this is reversed at high intensities (Daniels & Daniels, 1992). The lack of significant $\dot{V}O_2$ changes in the FP group at the submaximal and threshold loads (Table 3) while performing above threshold intervals from 100m to 500m together with the improved running economy of the SP group at the threshold load when they performed threshold pace or slower intervals 400m to 2000m long from pretest to track test were similar to those reported for the type of training each group was doing (Conley *et al.*, 1984). The decline in SP group $\dot{V}O_2$ max despite improvement in running economy may be due to decreased training intensity but this is not seen in the literature.

The lack of changes at the sprint (3000m pace) load in the FP group was originally unexpected (Schmidtbleicher, 1992; Sale, 1992). The decline in $\dot{V}O_2$ max for

the FP group indicates that the training regimen was not adequate to maintain aerobic power or to improve RE. The runners were tested at the completion of their cross country season, so it is probable their fast pace training, in conjunction with the slower paces described in the methodology, was unable to sustain their aerobic power but sufficient to maintain RE at the submaximal and threshold workloads that they had achieved during the cross country season.

The FP group's FP workouts were faster than their 3000m testing speed. The SP group's 3000m and threshold testing speeds matched the running speed of their pace workouts and this is where their improvements in RE occurred. Evidence of temporal specificity is present in the SP group's results and although not apparent in the FP group this may be because they were tested at a slower speed than at which they performed their FP training. Supporting this temporal specificity effect are the FP group's results from their indoor season. Though there was no measured change in RE or metabolic efficiency at the sprint load and maximum aerobic power declined from Pretest to Track test, mean 1500m performance did improve (Table 8 Appendix A).

At the submaximal and threshold loads, FP group HR was lower from Pretest to Track and Transition tests (Table 5). A reduction in HR is an indication that the extraction of O_2 is enhanced permitting lower muscle blood flow and a lower heart rate (Astrand & Rodahl, 1986). Because neither the external load, relative load, or $SS\dot{V}O_2$ were changed this would seem to suggest that they are more efficiently supplying the O_2 demand through the cardiovascular system. At the sprint load, despite a loss of aerobic power, there was no increase in physiological strain (increase in HR, $SS\dot{V}O_2$, or O_2

debt). The increase in metabolic efficiency at the submaximal and threshold loads may compensate for this reduction in aerobic power and allow the FP group to maintain the same absolute submaximal and threshold loads at a lower heart rate.

The SP group became more economical at the sprint load, as evidenced by a lower $SS\dot{V}O_2$. An argument could be made that a lower $SS\dot{V}O_2$ at a maximal load may indicate a lessened ability to perform at this load, because the energy not provided by aerobic sources must then be provided by non-aerobic, lactic or alactic anaerobic sources. If this was the case, then it should be reflected in an elevation of the O_2 debt to recover from the increase alactic and lactic energy supply (Piiper & Spiller, 1970). That the O_2 debt is not higher suggests the SP group has become more economical. The decrease in O_2 deficit suggests they were able to supply more energy aerobically and the increase in $AccVO_2$, though non-significant, would support this conclusion. In fact, despite a lower $SS\dot{V}O_2$, $AccVO_2$ rose non-significantly but did not decrease in unison with $SS\dot{V}O_2$ as would be expected if there was no change in the ratio of aerobic-anaerobic energy contribution.

Track Test to Transition Test

The changes that indicated the improvement in FP metabolic efficiency *i.e.* the lower HR at the submaximal and threshold loads, did not continue with the slow-paced training performed during the transition phase. This suggests these improvements in metabolic efficiency were due to the fast-paced training performed during the indoor track phase. The increase in O_2 deficit from the pretest value, without a change in

AccVO_2 or $\text{SS}\dot{\text{V}}\text{O}_2$ could mean that while adjusting to the submaximal and threshold loads, more energy is being supplied from non-aerobic sources. This would suggest that energy is being used less efficiently and that some of the gains in efficiency from the fast pace training may have been lost. The absence of changes in submaximal-threshold O_2 debt or AccVO_2 and $\text{SS}\dot{\text{V}}\text{O}_2$ at the sprint load makes it hard to discern with certainty if this occurred.

There were no further improvements during this phase in the SP group's running economy. The improved running economy at the threshold load demonstrated over the first training period was no longer evident. Their transition $\text{SS}\dot{\text{V}}\text{O}_2$, though not different from the track test was no longer different from the pretest $\text{SS}\dot{\text{V}}\text{O}_2$ due to a reduction in within group variability. Their running economy at the 3000m pace load was unchanged.

In conclusion, fast-pace training may improve metabolic efficiency and should allow the athlete to perform at a higher percent $\dot{\text{V}}\text{O}_2$ max. SP training improved running economy at threshold and supramaximal loads but was not able to maintain $\dot{\text{V}}\text{O}_2$ max. It should therefore allow the athlete to perform at faster submaximal running speeds but at the same percent $\dot{\text{V}}\text{O}_2$ max. O_2 debt should be used in conjunction with O_2 deficit and AccVO_2 when measuring changes in RE in order to gain an overall picture of the alterations in the energy supply. There is some evidence for temporal specificity in training as there were improvements in SP RE at the pace closest to their pace workouts,

the threshold and sprint workloads. There was no evidence of temporal specificity in the FP group at the sprint workload but this may be due to their being tested at a speed that was slower than their pace workouts in training. It might also be an indication that at higher intensities, a higher volume of training or a longer period of time than eight weeks is needed before the temporal specificity effect results, or that two pace sessions per week are not sufficient to elicit significant changes in RE. Running intervals at speeds slower than 65 seconds for 400m twice a week over eight weeks should be sufficient to see improvements in RE at these training velocities.

Practical Recommendations

- Pace training should be done as close to the performance pace as possible to maximize the benefits of changes in running economy. The minimum training requirements are two sessions at performance speeds per week for eight weeks.
- Training to maximize aerobic power should be undertaken immediately preceding the pace training phase. Training to maintain maximum aerobic power during the pace training phase should also be performed.

Future Research

To further pursue the concept of temporal specificity of movement in running, an attempt should be made to duplicate the intentions of this study with three groups, one group performing no pace training, one group performing slow pace training, and one group performing fast pace training. Subjects from the three groups would be tested at the training pace of each group and, if possible, a competition at each pace would be set

up so a correlation between running economy at each pace can be performed for each competition.

REFERENCES

- Astrand, P.O., & Rodahl, K. (1986). *Textbook of Work Physiology*. New York: McGraw-Hill.
- Barnard, R., & Foss, M. (1969). Oxygen debt: effect of beta-adrenergic blockade on the lactic acid and alactic acid components. *Journal of Applied Physiology*, **27**(6), 813-816.
- Bransford, D., & Howley, E. (1977). Oxygen cost of running in trained and untrained men and women. *Medicine and Science in Sports and Exercise*, **9**, 41-44.
- Brooks, G.A. (1985). Anaerobic threshold: review of the concept and directions for future research. *Medicine and Science in Sports and Exercise*, **17**, 22-31.
- Brooks, G., Hittelman, K., Faulkner, J., & Beyer, R. (1971). Tissue temperatures and whole-animal oxygen consumption after exercise. *American Journal of Physiology*, **221**, 427-431.
- Burkett, L., Fernhall, B., & Walters, S. (1985). Physiologic effects of distance running training on teenage females. *Research Quarterly for Exercise and Sport*, **56**, 215-220.
- Caiozzo, V., Davis, J., Ellis, J., Azus, J., Vandagriff, R., Prietto, C., & McMaster, W. (1982). A comparison of gas exchange indices used to detect the anaerobic threshold. *Journal of Applied Physiology*, **53**, 1184-1189.
- Cavanagh, P., & Williams, K. (1982). The effect of stride length variation on oxygen uptake during distance running. *Medicine and Science in Sports and Exercise*, **14**, 30-35.
- Cavanagh, P., Andrew, G., Kram, R., Rodgers, M., Sanderson, D., & Hennig, E. (1985). An approach to biomechanical profiling of elite distance runners. *International Journal of Sports Medicine*, **1**, 36-62.
- Conley, D., & Krahenbuhl, G. (1980). Running economy and distance running performance of highly trained athletes. *Medicine and Science in Sports and Exercise*, **12**, 357-360.
- Conley, D., Krahenbuhl, G., & Burkett, L. (1981). Training for aerobic capacity and running economy. *The Physician and Sportsmedicine*, **9**, 107-115.

- Conley, D., Krahenbuhl, G., Burkett, L., & Millar, L. (1984). Following Steve Scott: physiological changes accompanying training. *The Physician and Sportsmedicine*, **12**, 103-106.
- Conley, D., Krahenbuhl, G., Burkett, L., Millar, L. (1981). Physiological correlates of female road racing performance. *Research Quarterly for Exercise and Sport*, **52**, 441-448.
- Costill, D., Thomason, H., & Roberts, E. (1973). Fractional utilization of the aerobic capacity during distance running. *Medicine and Science in Sports*, **5**, 248-252.
- Cunningham, D., & Faulkner, J. (1969). The effect of training aerobic and anaerobic metabolism during a short exhaustive run. *Medicine and Science in Sports*, **1**, 65-69.
- Cunningham, L. (1990). Relationship of running economy, ventilatory threshold, and maximal oxygen consumption to running performance in high school females. *Research Quarterly for Exercise and Sport*, **61**, 369-374.
- Daniels, J. (1985). A physiologist's view of running economy. *Medicine and Science in Sports and Exercise*, **17**, 332-338.
- Daniels, J., & Daniels, N. (1992). Running economy of elite male and elite female runners. *Medicine and Science in Sports and Exercise*, **24**, 483-489.
- Daniels, J., Krahenbuhl, G., Foster, C., Gilbert, J., & Daniels, S. (1977). Aerobic responses of female distance runners to submaximal and maximal exercise. *Annals New York Academy of Sciences*, **301**, 726-733.
- Daniels, J., Oldridge, M., Mable, F., & White, B. (1978). Differences and changes in VO_2 among young runners 10 to 18 years of age. *Medicine and Science in Sports*, **10**, 200-203.
- Daniels, J., Yarbrough, R., & Foster, C. (1978). Changes in VO_2 max and running performance with training. *European Journal of Applied Physiology*, **39**, 249-254.
- Davis, J. (1985). Anaerobic threshold: review of the concept and directions for future research. *Medicine and Science in Sports and Exercise*, **17**, 6-18.
- Davis, J., Vodak, P., Wilmore, H., Vodak, J., & Kurtz, P. (1976). Anaerobic threshold and maximal aerobic power for three modes of exercise. *Journal of Applied Physiology*, **41**(4), 544-550.

- Farrell, P., Wilmore, J., Coyle, E., Billing, J., Costill, D. (1979). Plasma lactate accumulation and distance running performance. *Medicine and Science in Sports*, **11**, 338-344.
- Gaesser, G., & Brooks, G. (1984). Metabolic bases of excess post-exercise oxygen consumption: a review. *Medicine and Science in Sports and Exercise*, **16**, 29-43.
- Gladden, L., & Welch, H. (1978). Efficiency of anaerobic work. *Journal of Applied Physiology*, **44**, 564-570.
- Hagberg, J., Mullin, P., & Nagle, F. (1980). Effect of work intensity and duration on recovery O₂. *Journal of Applied Physiology*, **48**, 540-544.
- Hill, A., & Lupton, H. (1923). Muscular exercise, lactic acid, and the supply and utilization of oxygen. *Quarterly Journal of Medicine*, **16**, 135-171.
- Kaneko, M. (1990). Mechanics and energetics in running with special reference to efficiency. *Journal of Biomechanics*, **23**, 57-63.
- Knuttgen, H.G. (1970). Oxygen debt after submaximal physical exercise. *Journal of Applied Physiology*, **29**, 651-657.
- Londeree, B. (1986). The use of laboratory test results with long distance runners. *Sports Medicine*, **3**, 201-213.
- Noth, J. (1992). Motor units. In Komi; (ed.) *Strength and Power in Sport*, 21-28, Blackweel Scientific, London.
- MacDougall, D., Reddan, W., Layton, C., & Dempsey, J. (1974). Effects of metabolic hyperthermia on performance during heavy prolonged exercise. *Journal of Applied Physiology*, **36**, 538-544.
- Margaria, R., Edward, R.H., & Dill, D. (1933). The possible mechanisms of contracting and paying the oxygen debt and the role of lactic acid in muscular contraction. *American Journal of Physiology*, **106**, 689-715.
- Morgan, D., & Craib, M. (1992). Physiological aspects of running economy. *Medicine and Science in Sports and Exercise*, **24**, 456-461.
- Morgan, D., Krahenbuhl, G., Woodall, K., Jordan, S., Filarski, K., & Williams, T. (1990). Daily variability in running economy among well-trained runners. *Medicine and Science in Sports and Exercise*, **22**, S134.
- Morgan, D., Martin, P., & Krahenbuhl, G. (1989). Factors affecting running economy. *Sports Medicine*, **7**, 310-330.

- Morgan, D., Martin, P., Krahenbuhl, G., & Baldini, F. (1991). Variability in running economy and mechanics among trained male runners. *Medicine and Science in Sports and Exercise*, **23**, 378-383.
- Piiper, J., Di Prampero, P., & Cerretelli, P. (1968). Oxygen debt and high-energy phosphates in gastrocnemius muscle of the dog. *American Journal of Physiology*, **215**, 523-531.
- Piiper, J., & Spiller, P. (1970). Repayment of O₂ debt and resynthesis of high-energy phosphates in gastrocnemius muscle of the dog. *Journal of Applied Physiology*, **28**, 657-662.
- Pollock, M.L. (1977). Submaximal and maximal working capacity of elite distance runners. Part I: Cardiorespiratory aspects. *Annals New York Academy of Sciences*, **301**, 310-322.
- Sale, D. (1992). Neural adaptation to strength training. In Komi; (ed.) *Strength and Power in Sport*, 249-265. Blackweel Scientific, London.
- Schmidtbleicher, D. (1992). Training for Power Events. In Komi; (ed.) *Strength and Power in Sport*, 381-395. Blackweel Scientific, London.
- Scrimgeour, A., Noakes, T., Adams, B., & Myburgh, K. (1986). The influence of weekly training distance on fractional utilization of maximum aerobic capacity in marathon and ultramarathon runners. *European Journal of Applied Physiology*, **55**, 202-209.
- Sidney, K., & Shephard, R. (1977). Maximum and submaximum exercise tests in men and women in the seventh, eighth, and ninth decades of life. *Journal of Applied Physiology*, **43**, 280-287.
- Sparling, P., & Cureton, K. (1983). Biological determinants of the sex difference in 12-minute run performance. *Medicine and Science in Sports and Exercise*, **15**, 218-223.
- Stainsby, W., & Barclay, J. (1970). Exercise metabolism: O₂ deficit, steady level O₂ uptake and O₂ uptake for recovery. *Medicine and Science in Sports*, **2**, 177-181.
- Tanaka, K., & Matsuura, Y. (1984). Marathon performance, anaerobic threshold and onset of blood lactate accumulation. *Journal of Applied Physiology*, **57**, 640-643.
- Wasserman, K., Whipp, B., Koyal, S., & Beaver, W. (1972). Anaerobic threshold and respiratory gas exchange during exercise. *Journal of Applied Physiology*, **35**, 236-243.

- Welch, H., Faulkner, J., Barclay, J., & Brooks, G. (1970). Ventilatory response during recovery from muscular work and its relation with O₂ debt. *Medicine and Science in Sports*, **2**, 15-19.
- Yoshida, T. (1986). A comparison of lactate threshold and onset of blood lactate accumulation during two kinds of duration of incremental exercises. *Annals of Physiology and Anthropology*, **5**, 211-216.

APPENDIX A

Table 8: Fast Pace group 1500m performances at the Pretest and Track test

Pretest (SEM)	Track test (SEM)
4.82a (.19)	4.70a (.21)

Within group differences denoted by matching letters, $p < .05$.

APPENDIX B

UNIVERSITY OF VICTORIA SPORTS AND FITNESS CENTRE
INFORMED CONSENT OF PHYSIOLOGICAL ASSESSMENTS

In order to assess physiological function(s) the following laboratory tests will be performed:

Lab Initial	Subject Initial	
_____	_____	<p style="text-align: center;"><u>Submaximal Cardio-Respiratory Function</u></p> <p>You will exercise on an ergometer up to 75% of predicted maximum heart rate. The following indicated variables will be measured:</p> <p>a) ventilatory responses ___ c) thermoregulatory responses ___</p> <p>b) heart rate responses ___ d) other ___</p>
_____	_____	<p style="text-align: center;"><u>Maximal Cardio-Respiratory Function</u></p> <p>You will exercise on an ergometer with progressively increasing loads to elicit maximal responses in the following indicated variables:</p> <p>a) oxygen consumption ___ c) ventilation ___</p> <p>b) heart rate ___ d) other ___</p>
_____	_____	<p style="text-align: center;"><u>Submaximal and/or Maximal Muscular Contractions</u></p> <p>You will perform submaximal or maximal muscular contractions in the following modes:</p> <p>isometric ___ isotonic ___ isokinetic ___ eccentric ___</p>
_____	_____	<p style="text-align: center;"><u>Maximal Anaerobic Function</u></p> <p>You will exercise maximally on an ergometer for a period of ___ seconds to elicit responses in the following indicated variables:</p> <p>a) heart rate ___ b) blood lactate ___ c) other ___</p>
_____	_____	<p style="text-align: center;"><u>Blood Chemistry</u></p> <p>Blood samples will be taken prior to, during, or post-exercise by:</p> <p>a) venipuncture ___ b) finger tip prick ___</p>
_____	_____	<p style="text-align: center;"><u>Body Composition</u></p> <p>Lean body mass and percent body fat may be assessed by:</p> <p>a) anthropometric measures ___ b) body densitometry ___</p>

Lab Initial	Subject Initial	
_____	_____	Tests will be administered by qualified personnel under the direct supervision of the investigator(s).
_____	_____	Blood samples will be taken by a qualified laboratory technician or registered nurse.
_____	_____	Test and/or training data/results will be treated in a confidential manner and used only to describe group responses unless specific approval has been given to other use of the material by each subject, or guardian where necessary.
_____	_____	While it is highly unlikely that a subject should be injured or taken ill during a test or training session, lab personnel are trained in emergency procedures and emergency equipment is on-site at all times.
_____	_____	All laboratory activity will be completed proximal to medical and/or paramedical assistance.
_____	_____	The maximal exercise loads imposed will not exceed those which might be expected of an athlete during sports performance.
_____	_____	If a record is achieved; athletes name, sport, record value and date of testing may be posted on the U.Vic Sport and Fitness Centre Records Board.

I have read the above and agree to participate in this research project/fitness appraisal at my own risk. I regularly take part in strenuous physical activity at least as intense as these tests. I realize that I may expect a thorough explanation and/or demonstration of any procedures and that I may terminate participation at any time in any or all procedures of my own volition.

Having voluntarily assumed participation and the risks thereof, in the project, I hereby disclaim and release the University of Victoria, its agents, servants or employees, including all personnel involved in the research project/fitness appraisal from any and all liability that might otherwise arise as a result of my participation as a research subject in this study/or fitness appraisal.

NAME: _____ DATE: _____
(please print)

SIGNATURE: _____

APPENDIX C

LITERATURE REVIEW

The use of $\dot{V}O_2$ max as a predictor of performance in sport and exercise began in the early 20th century (Hill & Lupton, 1923). Since then the relationship between performance and other variables such as ventilatory threshold (Wasserman *et al.*, 1973; Davis *et al.*, 1976; Caiozzo *et al.*, 1982), onset of blood lactate accumulation (Tanaka & Matsuura, 1984; Yoshida, 1986) and running economy (Costill *et al.*, 1973; Bransford & Howley, 1977; Pollock, 1977; Conley *et al.*, 1981) have been identified as predictors. Running economy (RE) has been defined as the $\dot{V}O_2$ required per unit of body weight to perform at a fixed submaximal running velocity (Cunningham, 1990).

RE has been highly correlated, $r = -.94$ (Costill *et al.*, 1973) and poorly correlated, $r = .05-.49$ (Sparling & Cureton, 1983; Cunningham, 1990) with distance running performance (DRP). It was postulated that group makeup impacts the correlation. In groups homogeneous in DRP, RE is strongly associated with DRP, $r = .79-.81$ (Conley & Krahenbuhl, 1980), whereas in groups heterogeneous in DRP, this association is weak, $r = .14-.16$ (Conley *et al.*, 1981). This is contrary to how $\dot{V}O_{2,max}$ predicts DRP; very well in heterogeneous groups, $r = .91$ (Costill *et al.*, 1973) but poorly in homogeneous groups, $r = .58-.12$ (Pollock, 1977; Conley & Krahenbuhl, 1980). Being economical is not a precursor to having a high $\dot{V}O_2$ or *vice versa*. It has been suggested that it is more relevant to look at RE in terms of relative effort (Daniels & Daniels, 1992); dividing the submaximal $SS\dot{V}O_2$ by $\dot{V}O_2$ max which

give percent $\dot{V}O_2$ max at which the athlete is working. This explains the difference in performance between two runners with similar $\dot{V}O_2$ max's but different DRP. The athlete with the lower SS $\dot{V}O_2$ max at a common running velocity would be working at a lower percent $\dot{V}O_2$ max and would be expected to be able to hold this pace longer than an athlete working at a higher percent $\dot{V}O_2$ max (Daniels & Daniels, 1992; Daniels, 1985). Improvement in RE can take two forms; a lower SS $\dot{V}O_2$ at the same submaximal load or a lower percent $\dot{V}O_2$ max at a submaximal load.

Also important for performance is at what percent $\dot{V}O_2$ max the runner can compete. If two runners have similar $\dot{V}O_2$ max's, the runner who can perform at the higher percent $\dot{V}O_2$ max should have the performance advantage (Costill *et al.*, 1973; Daniels & Daniels, 1992). This aspect of RE is most important for performance, being able to work at the highest percent $\dot{V}O_2$ max possible. An improvement, without changes in any other variable (*i.e.* SS $\dot{V}O_2$ at a fixed load or $\dot{V}O_2$ max) suggests the runner is more metabolically efficient in supplying energy aerobically. The same quantity of energy is being supplied through SS $\dot{V}O_2$ at the same percent $\dot{V}O_2$ max at a fixed load but it is used more efficiently and the athlete is able to perform at a higher load.

Regular measures of $\dot{V}O_2$ max and RE can establish the effect a training program

has on fitness, as determined by these variables, and may be of use in identifying what should be the goal of further training (Conley, Krahenbuhl, & Burkett, 1981; Londeree, 1986). By knowing these physiological measures it may be useful to know if training should focus on improving $\dot{V}O_2$ max or RE. Although inappropriate for interindividual comparison, RE and $\dot{V}O_2$ max may aid an individual in discerning their running and metabolic economy. RE may be more useful for marathoners who wish to know the approximate pace at which they should compete (Londeree, 1986). A marathoner who has been tested repeatedly may know that he/she can begin their race at as close to 80% $\dot{V}O_2$ max as possible to avoid late race fatigue.

Many factors have been shown to affect RE and should be controlled to reduce intraindividual variability and ensure reliability of the RE measure:

Fatigue - Workouts of high intensity (downhill running) can cause an elevation in $\dot{V}O_2$ submax, thus disturbing RE (Cavanagh *et al.*, 1985);

Temperature - Elevated temperatures reduce metabolic efficiency through an increase respiration, circulation, and sweating (MacDougall *et al.*, 1974);

Stride length - Changes in optimal stride length can lead to an increase in $\dot{V}O_2$, though most runners select a stride length very near their optimal length (Cavanagh & Williams, 1982);

External Weight - The addition of extra weight increases $\dot{V}O_2$, especially weight added at the limb extremities, so care must be taken to ensure that clothing, shoes, and any other equipment worn during the test remain constant (Frederick *et al.*, 1984);

Testing Time - Circadian rhythms can cause fluctuations in $\dot{V}O_2$ if measured at different times of the day (Morgan *et al.*, 1990) so when possible testing should always be done at a similar time of the day for each subject;

Treadmill Accommodation - It is important that runners be comfortable running on the treadmill so their running style will mimic that of overground running. As runners become more comfortable with running on the treadmill, RE values will change so the tester must be certain that each subject is fully accommodated to treadmill running to ensure reliability of each measure (Morgan *et al.*, 1991).

Factors that affect interindividual comparisons of RE should be recognized, as they will affect within and between group comparisons:

Age - Younger athletes (pre-pubescent) have been shown to be less economical at common submaximal intensities than their older counterparts (Daniels, 1978). Loss of flexibility that occurs with aging has been identified as a possible reason older athletes are less economical than young adults (Sidney & Shepard, 1977);

Gender - There is no clear position on the influence of gender on RE. There has been evidence that contends there is no difference in RE between men and women (Sparling & Cureton, 1983) and evidence that supports the contention that there is a difference (Bransford & Howley, 1977). Daniels has, in two different studies, concluded that there is and there is not a difference in RE of men and women (Daniels *et al.* 1977; Daniels & Daniels, 1992);

Training - Most of the RE research suggests that better trained runners are more

economical than lesser trained runners (Daniels & Daniels, 1992; Bransford & Howley, 1977; Conley, Krahenbuhl, & Burkett, 1981; Pollock, 1977; Costill *et al.*, 1973; Scrimgeour *et al.*, 1986).

RE at submaximal running speeds has been measured using $SS \dot{V}O_2$ but there have been no attempts to measure RE at supramaximal running speeds, speeds closer to performance velocities. Because these running velocities are frequently above anaerobic threshold, a substantial portion of energy is provided anaerobically and measuring RE with $SS \dot{V}O_2$ would not provide an accurate measure of energy supply. It has been suggested that O_2 debt can provide an estimate of the energy provided non-aerobically (Cunningham & Faulkner, 1969) and may be a method of determining RE at supramaximal speeds.

Oxygen deficit is the term that describes the difference between estimated O_2 used during exercise at a particular workload and the actual O_2 measured at steady state. Before exercise begins $\dot{V}O_2$ is at a resting level. When exercise begins, $\dot{V}O_2$ gradually increases until it reaches the steady state level (for a submaximal workload) that satisfies the energy requirement. During this period, as $\dot{V}O_2$ is gradually increasing, the energy demand for the workload is assumed to be equal to that provided by the steady state $\dot{V}O_2$. This difference between $\dot{V}O_2$ estimated and $\dot{V}O_2$ measured is known as the O_2 deficit (Stainsby & Barclay, 1970). When exercise ceases, energy requirements are equal to those of the resting $\dot{V}O_2$, but $\dot{V}O_2$ does not immediately assume this resting value.

Rather, it gradually declines over a time period that depends on the length and intensity of the exercise (Hagberg, Mullin, & Nagle, 1980). This elevation of $\dot{V}O_2$ after the cessation of exercise is termed O_2 debt (Brooks *et al.*, (1971).

Though O_2 debt was initially reported to be the O_2 cost of metabolizing lactate created during the exercise, plus replacing stored O_2 and high energy phosphates utilized during the O_2 deficit (Hill & Lupton, 1923; Margaria *et al.*, 1933), other factors are recognized as affecting the volume of O_2 debt; tissue temperature (Brooks *et al.*, 1971) hormone levels (Barnard & Foss, 1969) exercise intensity and duration (Hagberg *et al.*, 1980) metabolite turnover (Stainsby & Barclay, 1970) and ventilatory work being performed during the post exercise period (Welch *et al.*, 1970).

The O_2 debt has been divided into two parts; the fast alactid recovery and the slow lactic recovery (Piiper, DiPrampo & Ceretelli, 1968). The magnitude of the fast recovery which lasts from 60-90 seconds has been directly linked to the size of the O_2 deficit and reflects the magnitude of stored O_2 and high energy phosphates utilized during this period of $\dot{V}O_2$ acclimatization at the beginning of exercise (Piiper, DiPrampo, & Ceretelli, 1968; Piiper & Spiller, 1970; Hagberg *et al.*, 1980). Exercise intensity affects this portion of the O_2 debt (Hagberg *et al.*, 1980). Intensity is positively related to the portion of O_2 stores that must be utilized and the quantity of high energy phosphate bonds that are broken while incurring the O_2 deficit. Exercise duration has no effect on these factors and does not affect this part of the O_2 debt. The effect of lactate levels in the muscle or blood on this part of the debt have not been elucidated. The slow recovery which is the remainder of O_2 debt represents lactate metabolism, and the processes

involved in restoring equilibrium in the working muscles; re-establishment of temperature, metabolite cycling and the lingering effects and processing of hormones (Knuttgen, 1970).

Submaximal energy production can be determined directly by measuring $SS\dot{V}O_2$ because most of the energy is being supplied through aerobic metabolism. Supramaximal energy production can only be measured indirectly by either blood or muscle lactate, O_2 debt, or both. Though the use of O_2 debt to indicate anaerobic energy production is imprecise because of the number of factors affecting it, within subject comparisons are possible to give an indication of change in energy production by anaerobic means (Cunningham & Faulkner, 1969).

In summary, RE is a measure of energy provided at a fixed workload that has been measured at submaximal running speeds by $SS\dot{V}O_2$. Determining RE at speeds closer to performance speeds may be more meaningful because changes may not take place at submaximal workloads but at supramaximal intensities. By using O_2 deficit, O_2 debt, and $SS\dot{V}O_2$ to measure RE at submaximal and 3000m running speeds, the effect of high speed and low speed training on RE at these different velocities should be better understood.

REFERENCES

- Barnard, R., & Foss, M. (1969). Oxygen debt: effect of beta-adrenergic blockade on the lactic acid and alactic acid components. *Journal of Applied Physiology*, **27**(6), 813-816.
- Bransford, D., & Howley, E. (1977). Oxygen cost of running in trained and untrained men and women. *Medicine and Science in Sports and Exercise*, **9**, 41-44.
- Brooks, G., Hittelman, K., Faulkner, J., & Beyer, R. (1971). Tissue temperatures and whole-animal oxygen consumption after exercise. *American Journal of Physiology*, **221**, 427-431.
- Caiozzo, V., Davis, J., Ellis, J., Azus, J., Vandagriff, R., Prietto, C., & McMaster, W. (1982). A comparison of gas exchange indices used to detect the anaerobic threshold. *Journal of Applied Physiology*, **53**, 1184-1189.
- Cavanagh, P., & Williams, K. (1982). The effect of stride length variation on oxygen uptake during distance running. *Medicine and Science in Sports and Exercise*, **14**, 30-35.
- Cavanagh, P., Andrew, G., Kram, R., Rodgers, M., Sanderson, D., & Hennig, E. (1985). An approach to biomechanical profiling of elite distance runners. *International Journal of Sports Medicine*, **1**, 36-62.
- Conley, D., & Krahenbuhl, G. (1980). Running economy and distance running performance of highly trained athletes. *Medicine and Science in Sports and Exercise*, **12**, 357-360.
- Conley, D., Krahenbuhl, G., & Burkett, L. (1981). Training for aerobic capacity and running economy. *The Physician and Sportsmedicine*, **9**, 107-115.
- Conley, D., Krahenbuhl, G., Burkett, L., Millar, L. (1981). Physiological correlates of female road racing performance. *Research Quarterly for Exercise and Sport*, **52**, 441-448.
- Costill, D., Thomason, H., & Roberts, E. (1973). Fractional utilization of the aerobic capacity during distance running. *Medicine and Science in Sports*, **5**, 248-252.
- Cunningham, D., & Faulkner, J. (1969). The effect of training on aerobic and anaerobic metabolism during a short exhaustive run. *Medicine and Science in Sports*, **1**, 65-69.

- Cunningham, L. (1990). Relationship of running economy, ventilatory threshold, and maximal oxygen consumption to running performance in high school females. *Research Quarterly for Exercise and Sport*, **61**, 369-374.
- Daniels, J. (1985). A physiologist's view of running economy. *Medicine and Science in Sports and Exercise*, **17**, 332-338.
- Daniels, J., & Daniels, N. (1992). Running economy of elite male and elite female runners. *Medicine and Science in Sports and Exercise*, **24**, 483-489.
- Daniels, J., Krahenbuhl, G., Foster, C., Gilbert, J., & Daniels, S. (1977). Aerobic responses of female distance runners to submaximal and maximal exercise. *Annals New York Academy of Sciences*, **301**, 726-733.
- Daniels, J., Oldridge, M., Mable, F., & White, B. (1978). Differences and changes in $\dot{V}O_2$ among young runners 10 to 18 years of age. *Medicine and Science in Sports*, **10**, 200-203.
- Daniels, J., Yarbrough, R., & Foster, C. (1978). Changes in $\dot{V}O_2$ max and running performance with training. *European Journal of Applied Physiology*, **39**, 249-254.
- Davis, J., Vodak, P., Wilmore, H., Vodak, J., & Kurtz, P. (1976). Anaerobic threshold and maximal aerobic power for three modes of exercise. *Journal of Applied Physiology*, **41**(4), 544-550.
- Frederick, E., Daniels, J., & Hayes, J. (1984). The effect of shoe weight on the aerobic demands of running, 616-625. In Bachl, N., Prokop, L., & Suckert, R. (eds.) *Proceedings of the World Congress on Sports Medicine*, Vienna, Urban & Schwarzenberg.
- Hagberg, J., Mullin, P., & Nagle, F. (1980). Effect of work intensity and duration on recovery O_2 . *Journal of Applied Physiology*, **48**, 540-544.
- Hill, A., & Lupton, H. (1923). Muscular exercise, lactic acid, and the supply and utilization of oxygen. *Quarterly Journal of Medicine*, **16**, 135-171.
- Knuttggen, H.G. (1970). Oxygen debt after submaximal physical exercise. *Journal of Applied Physiology*, **29**, 651-657.
- Londeree, B. (1986). The use of laboratory test results with long distance runners. *Sports Medicine*, **3**, 201-213.

- MacDougall, D., Reddan, W., Layton, C., & Dempsey, J. (1974). Effects of metabolic hyperthermia on performance during heavy prolonged exercise. *Journal of Applied Physiology*, **36**, 538-544.
- Margaria, R., Edwards, R.H., & Dill, D. (1933). The possible mechanisms of contracting and pay oxygen debt and the role of lactic acid in muscular contraction. *American Journal of Physiology*, **106**, 689-715.
- Morgan, D., Krahenbuhl, G., Woodall, K., Jordan, S., Filarski, K., & Williams, T. (1990). Daily variability in running economy among well-trained runners. *Medicine and Science in Sports and Exercise*, **22**, S134.
- Morgan, D., Martin, P., Krahenbuhl, G., & Baldini, F. (1991). Variability in running economy and mechanics among trained male runners. *Medicine and Science in Sports and Exercise*, **23**, 378-383.
- Piiper, J., Di Prampero, P., & Cerretelli, P. (1968). Oxygen debt and high-energy phosphates in gastrocnemius muscle of the dog. *American Journal of Physiology*, **215**, 523-531.
- Piiper, J., & Spiller, P. (1970). Repayment of O₂ debt and resynthesis of high-energy phosphates in gastrocnemius muscle of the dog. *Journal of Applied Physiology*, **28**, 657-662.
- Pollock, M.L. (1977). Submaximal and maximal working capacity of elite distance runners. Part I: Cardiorespiratory aspects. *Annals New York Academy of Sciences*, **301**, 310-322.
- Scrimgeour, A., Moakes, T., Adams, B., & Myburgh, K. (1986). The influence of weekly training distance on fractional utilization of maximum aerobic capacity in marathon and ultramarathon runners. *European Journal of Applied Physiology*, **55**, 202-209.
- Sidney, K., & Shephard, R. (1977). Maximum and submaximum exercise tests in men and women in the seventh, eighth, and ninth decades of life. *Journal of Applied Physiology*, **43**, 280-287.
- Sparling, P., & Cureton, K. (1983). Biological determinants of the sex difference in 12-min run performance. *Medicine and Science in Sports and Exercise*, **15**, 218-223.
- Stainsby, W., & Barclay J. (1970). Exercise metabolism: O₂ deficit, steady level O₂ uptake and O₂ uptake for recovery. *Medicine and Science in Sports*, **2**, 177-181.
- Tanaka, K., & Matsuura, Y. (1984). Marathon performance, anaerobic threshold and onset of blood lactate accumulation. *Journal of Applied Physiology*, **57**, 640-643.

- Wasserman, K., Whipp, B., Koyal, S., & Beaver, W. Anaerobic threshold and respiratory gas exchange during exercise. *Journal of Applied Physiology*, **35**, 236-243.
- Welch, H., Faulkner, J., Barclay, J., & Brooks, G. (1970). Ventilatory response during recovery from muscular work and its relation with O₂ debt. *Medicine and Science in Sports*, **2**, 15-19.
- Yoshida, T. (1986). A comparison of lactate threshold and onset of blood lactate accumulation during two kinds of duration of incremental exercises. *Annals of Physiology and Anthropology*, **5**, 211-216.

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