The Transient Oxygen Uptake Response as an Indicator of Sports Specific Adaptation

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ABSTRACT

Title of Thesis: The Transient Oxygen Uptake Response as an Indicator of Sports Specific Adaptation.

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A cross-sectional design examined aerobic power and transient oxygen uptake responses of four male sports groups (cyclists, runners, swimmers, and cross-country skiers). Data was collected via three modes of ergometry (treadmill running, cycling, and arm cranking), with the transient oxygen uptake responses being described via the 'half-time' ($t1/2\ \dot{V}O_2on$) and 'Mean Response Time' (MRT) values. The transient $\dot{V}O_2on$ responses were quantified via a single exponential process given as $\Delta\dot{V}O_2(t) = \Delta\dot{V}O_2ss\,(1-e^{-\frac{(t-TD)}{\tau}})$, where Δ reflects the increment above the previous (rest or exercise) steady state level, ss represents the steady state or asymptotic value, TD is the time delay parameter, and τ is the

time constant. Higher relative $\dot{V}O_2max$ scores for cyclists, runners, and cross-country skiers than the swimmers were found for treadmill running (significantly so for the runners and cross-country skiers versus the swimmers; $p<0.01$). For cycle ergometry, the runners had significantly higher ($p<0.01$) relative $\dot{V}O_2max$ scores than the swimmers and the cross-country skiers. Arm cranking produced significantly higher ($p<0.01$) relative $\dot{V}O_2max$ scores for the runners, swimmers, and cross-country skiers than the cyclists, with the swimmers producing the highest $\dot{V}O_2max$ scores. Analysis of ventilatory kinetics showed that the runners had the fastest maximal MRT on the treadmill, the cyclists on the cycle ergometer, and the swimmers on the arm crank ergometer. A significant relationship ($p<0.01$) was seen between $\dot{V}O_2max$ and submaximal t1/2 $\dot{V}O_2on$ response time ($r = -0.887$). It was concluded that 1) sports specific adaptation was responsible to a large extent for the differences between the groups, 2) the $\dot{V}O_2max$/t1/2$\dot{V}O_2on$ relationship has been clearly established, 3) a tentative link between the transient oxygen uptake response and blood lactate accumulation seems to be suggested through current ventilatory kinetic analysis and physiological theory, 4) more responsive evaluation of ventilatory kinetics is required, including the recognition of the importance of the actual magnitude of change in $\dot{V}O_2$, and 5) the transient oxygen uptake response does seem to have a role in describing the sports specific adaptation of athletes at the peripheral level.

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CHAPTER I

INTRODUCTION

Statement of the problem

The major concern of this investigation was to describe the transient oxygen uptake responses, and the possible occurrence of regional variations in these responses, of male subjects from four different sports disciplines. The investigation established such data via given modes of ergometry utilising both incremental and constant load work tasks. The dependent variables examined were maximum oxygen uptake ($\dot{V}O_2max$), peak volume of oxygen uptake ($P\dot{V}O_2$), the transient oxygen response to maximal exercise ($\dot{V}O_2on$), and the half-time of the transient oxygen response to submaximal exercise ($t1/2\dot{V}O_2$).

Significance of the study

An aspect of current interest in the field of exercise physiology concerns the nature and implications of transient oxygen uptake responses, particularly at the onset of exercise ($\dot{V}O_2on$). These responses have been the subject of several studies (Cerretelli, Shindell, Pendergast, Di Prampero, & Rennie, 1979; Cerretelli, Pendergast, Paganelli, & Rennie, 1979; Cerretelli, Rennie, & Pendergast, 1980; Hagberg, Nagle, & Carlson, 1978), however, there is some controversy as to the exact contribution of these 'transients' to the understanding of human physiological performance. Early researchers (Di Prampero, Davies, Cerretelli, Margaria, 1970; Henry, 1951) suggested that at any given work-load the time course of oxygen consumption at the onset of exercise is exponential, with a half-time (t1/2$\dot{V}O_2$on) of 30 seconds. However, later investigators (Hagberg, et al., 1978; Hickson, Bomze, & Holloszy, 1978; Hagberg, Hickson, Eshani, & Holloszy, 1980) have reported that the t1/2$\dot{V}O_2$on is variable and dependent upon the work-load required and the degree of training of the subjects tested.

In contrast to the notion that training influences the $\dot{V}O_2$on response time, Armstrong, Davies, and Mulhall (1982) stated that their study of age-group swimmers did not find faster adjustments of the the $\dot{V}O_2$on transient. Armstrong et al., (1982) concluded that their data illustrated no difference between the $\dot{V}O_2$on transient at the onset of exercise for trained and untrained muscles. Conversely, Macek and Vavra (1980) reported faster t1/2$\dot{V}O_2$ transients in their study using children in comparison with adults utilising a constant load maximum exercise protocol.

Recent research (T. Mercer, personal communication, December 1985) has shown that training clearly decreases the $\dot{V}O_2$on response time. T. Mercer (personal communication, December 1985) also stated that the level of habitual physical activity affects the $\dot{V}O_2$on response and that specific endurance training enhanced the $\dot{V}O_2$on transient. Also, the P$\dot{V}O_2$ parameter seems to be a less sensitive indicator, than the submaximal t1/2$\dot{V}O_2$on and MEP ('Maximal Endurance Performance' test), of peripheral adaptations brought about through endurance training. Thus, T. Mercer (personal communication, December 1985) recommends the use of the submaximal $\dot{V}O_2$on, maximal $\dot{V}O_2$on, and MEP as determinants of the extent to which peripheral adaptations have occurred following sports-specific tranining regimes and, further, that the $\dot{V}O_2$on response and MEP be used as monitoring agents with which to identify adaptation plateaus in response to the training stimulus. Thus, this recent finding suggests that the $\dot{V}O_2$on response could be an important tool with which the sports coach and exercise physiologist might evaluate the muscle condition, and hence the training state, of a group of athletes. A programme to regularly assess the $\dot{V}O_2$on or $t1/2\dot{V}O_2$on responses of athletes by a coach could, therefore, provide accurate and up-to-date information concerning each athlete's trained state, particularly for those sports in which athletes embark on intensive training programmes (Cerretelli et al., 1980), such as competitive swimming and distance running.

Previous research (Pendergast, Shindell, Cerretelli, & Rennie, 1980) has hinted that there may be regional variations, that is, central and peripheral differences, in the transient oxygen uptake responses of athletes dependent upon their sports activity. Therefore, it may be the case that swimmers, for example, have faster $t1/2\dot{V}O_2$on responses when compared to athletes from other sports disciplines as a central physiological characteristic and, or, as a peripheral physiological characteristic.

The aim of this study was to examine the regional variation in the transient oxygen uptake response both within a particular sports group and between sports groups. The results of this study should provide a step towards answering the question of the exact nature and implications of the transient oxygen uptake response, particularly with reference to sports-related performance.

Delimitations

The subjects for this study were males ranging in age from 14-27 years old. The subjects were selected on the grounds of being 'good' representatives of their sports groups, with indentification of 'good' being sports performance and a $\dot{V}O_2max$ in excess of $55ml \cdot kg^{-1} \cdot min^{-1}$ (Astrand & Rodahl, 1977; Watson, 1978; McArdle, Katch, & Katch, 1981) established via a treadmill run to 'exhaustion'. The subjects were drawn from four sports groups, the Thunder Bay Thunderbolts Swimming Club, Team Fresh Air Experience Cycling and Team Petries Cycling, local national calibre distance runners and cross-country skiers.

The period of investigation was September 1986 for the cyclists, November 1986 for the runners, December 1986 for the swimmers and January 1987 for the skiers. The study utilised a Monark cycle ergometer for both the leg exercise tests and the arm exercise test, whilst the treadmill runs were performed on a Quinton treadmill ergometer. Measures were taken to minimise any diurnal variations by testing the subjects at the same time of day for all tests.

Limitations

The subjects took part in this investigation on a voluntary basis and completed all tests as requested. It was assumed that the subjects exerted maximum effort during all tests and that these test protocols were of sufficient specificity to examine the experimental hypotheses. Additionally, it was assumed that the dependent variables $\dot{V}O_2max$, $P\dot{V}O_2$, $\dot{V}O_2on$, and $t1/2\dot{V}O_2on$ would accurately detect and describe any variations in the performances of the subjects. Any variations in the performances of the subjects were then attributed to the specific nature of their sports involvement.

It was recognised that the modes of ergometry themselves are limiting factors, particularly for those subjects of the 'swimmers' group'. A period of habituation by the subjects of the various protocols was incorporated prior to all testing sessions.

The use of a 'non-linear curve' computer programme to plot the data collected graphically was assumed to adequately describe significant occurrences in the respiratory kinetics of the subjects.

Definitions

Maximum oxygen uptake ($\dot{V}O_2max$). The highest oxygen uptake the individual can attain during physical work whilst breathing air at sea level. During exercise this is the point at which oxygen consumption asymptotes and fails to show any further increase with an increased work-load. In this study $\dot{V}O_2max$ was determined via treadmill running, ($\dot{V}O_2max$ tm).

Peak volume of oxygen uptake ($P\dot{V}O_2$). During cycle ergometry or arm cranking, this is the point at which oxygen consumption peaks and then plateaus, despite further increases in work-load.

$P\dot{V}O_2$ arms ....arms cranking $P\dot{V}O_2$

$P\dot{V}O_2$ legs ......cycle ergometry $P\dot{V}O_2$

$\dot{V}O_2on$. The time, in seconds, required to bring about $\dot{V}O_2max$ or $P\dot{V}O_2$ from pre-exercise to maximal levels.

$\dot{V}O_2on$ tm ....established by treadmill running

$\dot{V}O_2$on arms ...established by arm cranking

$\dot{V}O_2$on legs .....established by cycle ergometry

t1/2$\dot{V}O_2$on. The time, in seconds, required to bring about a 50% change in $\dot{V}O_2$ from pre-exercise to steady state exercise levels.

t1/2$\dot{V}O_2$ tm .....t1/2$\dot{V}O_2$on for treadmill running

t1/2$\dot{V}O_2$on arms ...t1/2$\dot{V}O_2$on for arm cranking

t1/2$\dot{V}O_2$on legs .....t1/2$\dot{V}O_2$on for cycle ergometry

Single exponential process. $\Delta\dot{V}O_2(t) = \Delta\dot{V}O_2ss\ (1-e^{-(\frac{t-TD}{\tau})})$, where Δ reflects the increment above the previous (rest or exercise) steady state level, and ss represents the steady state or asymptotic value.

τ. The time constant of the transient oxygen uptake response.

TD. The time delay parameter. This allows the single exponential process to produce the best possible value for the time constant (τ) of the response without artificially constraining the regression to pass through the origin.

MRT. The overall rate of change of the response is obtained from the sum of τ + TD. This is known as the 'mean response time' (MRT = τ + TD).

Steady state. A steady state condition denotes a work situation where oxygen uptake equals the oxygen requirement of the tissues.

Constant load work regime. A work period during which the load imposed upon the subject remains constant. The product of a constant frictional resistance and pedal cadence.

Incremental load work regime. A work period during which the load imposed upon the subject increases as the period of exercise continues. The product of an increasing frictional resistance and a fixed pedal cadence in the case of cycle or arm cranking ergometry. In the case of treadmill running, the product of an increased slope angle and a fixed pace.

CHAPTER II

LITERATURE REVIEW

Aerobic Power

Maximal aerobic power ($\dot{V}O_2max$) has for some time been considered to be the definitive measure of cardiorespiratory efficiency and endurance (Hill & Lupton, 1923; Saltin & Astrand, 1967). $\dot{V}O_2max$ is normally quantified with the addition of 'unit time', such that it is expressed as $\dot{V}O_2max$ in litres per minute ($\dot{V}O_2max$ $1 \cdot min^{-1}$) for activities where total power output is critical and bodyweight is supported, and as $\dot{V}O_2max$ in millilitres per kilogramme bodyweight per minute ($\dot{V}O_2max$ $ml \cdot kg^{-1} \cdot min^{-1}$) for activities where the individual has to support his own bodyweight.

Various modes of ergometry have been used to elicit $\dot{V}O_2max$, however, it has been shown that cycle ergometry normally produces lower $\dot{V}O_2max$ values (generally 7-8% lower) than does treadmill running (Newton, 1973; Smodlaka, 1982). However, more recent work (LaVoie, Mahoney, & Marmelic, 1978; King, Brodowicz, & Ribisi, 1982) has indicated that the use of toe-stirrups on the pedals would significantly reduce the differences in the $\dot{V}O_2$max values obtained when using cycle ergometry and treadmill running.

Shephard, Allen, Benade, Davies, Di Prampero, Hedman, Merriman, Myhre, & Simmons (1968) and Astrand & Rodahl (1977) reported that $\dot{V}O_2$max is achieved when $\dot{V}O_2$ increases by less than $2 ml \cdot kg^{-1} \cdot min^{-1}$ with a further increase in workload. Additionally, other criteria such as certain blood lactate concentrations (Fox & Mathews, 1976; Astrand & Rodahl, 1977) and the Respiratory Exchange Ratio (RER) (Thomas, Cunningham, Plyley, Boughner, & Cook; 1981) have been cited as having been used in the determination of $\dot{V}O_2$max. Reported values of $\dot{V}O_2$max in males range from approximately $45 ml \cdot kg^{-1} \cdot min^{-1}$ for young sedentary individuals to values in excess of $80 ml \cdot kg^{-1} \cdot min^{-1}$ for cross-country skiers (Saltin & Astand, 1967).

Peak aerobic power ($P\dot{V}O_2$) is directly influenced by the muscle mass actually involved in the physical work being undertaken (Shephard, 1984). Thus, when investigating oxygen uptake in experiments requiring the use of small muscle groups (e.g., arms), it has been deemed necessary by certain researchers to report $P\dot{V}O_2$ values in place of $\dot{V}O_2max$ figures (Shephard, 1971; Washburn & Seals, 1983) due mainly to the repeated failure of such experimental conditions to determine $\dot{V}O_2max$ using traditional methods. The criteria used to establish $P\dot{V}O_2$ are essentially the same as those used to determine $\dot{V}O_2max$.

Adaptation to sports-specific training

Maximum aerobic power ($\dot{V}O_2max$ $l \cdot min^{-1}$) has previously been discussed, however, an important aspect was deliberately omitted so that it could be introduced at this stage. This aspect concerns the maximum rate at which energy may be released purely via the oxidative process. According to Thoden, Wilson, & MacDougall (1982):

> The rate at which this process can occur is dependent upon two factors: the chemical ability of tissues to use oxygen in breaking down fuels (peripheral component), and the combined abilities of the pulmonary, cardiac, blood, vascular, and cellular mechanisms to transport oxygen to the aerobic machinery of muscle (central component). (p. 39)

Usually these two aspects, transport and utilisation, are simplified by being treated as a single entity with $\dot{V}O_2max$ ($l \cdot min^{-1}$ or $ml \cdot kg^{-1} \cdot min^{-1}$) being used as the quantitative description. However, these two aspects, the peripheral and central components, should not be dismissed quite so easily since they are actually of extreme importance.

Central and peripheral adaptations to endurance training, generally signified by the increased ability to take up oxygen, have long been recognized. Central adaptations concern aspects such as increased efficiency in heart rate (fH), stroke volume (SV), and blood pressure (Brooks & Fahey, 1984). Thus increases in maximum cardiac output ($\dot{Q}$ = fH x SV), stroke volume, and blood volume, and decreases in resting and sub-maximal exercise heart rates are usually seen after endurance training.

Peripheral adaptations are concerned with those changes occurring primarily within the trained muscle. Holloszy (1967) has been credited with the discovery of increased levels of oxidative enzymes in trained muscle, together with increased mitochondrial numbers and densities, and increased skeletal muscle myoglobin content. Holloszy, Oscai, Mule, & Don (1971) found that skeletal muscle that had adapted to a 'strenuous endurance exercise' programme contained approximately twice as many mitochondrial cristae per gramme as untrained muscle. Gollnick, Ianuzzo, & King (1971) in their work with rats found similar findings as Holloszy et al. (1971), with 'significant' increases in mitochondrial concentration after training. Morgan, Cobb, Short, Ross, & Gunn (1971) presented further evidence that exercise training in man brings about mitochondrial growth, increased oxidative capacity, and extended ability for the synthesis of glycogen and lipid. Morgan et al. (1971) more specifically said that muscle hexokinase and glycogen synthetase activities were stimulated after exercise conditioning, and that the increased oxidative capacity of trained muscle was accompanied by an increase in capacity to synthesize 'two potential intracellular stores', glycogen and triglyceride. According to Kiessling, Piehl, & Lundquist (1971), there are at least two advantages of an increased mitochondrial activity level. Initially, the increase in capacity to form adenosinetriphosphate (ATP) is the most important. Secondly, they cite that the balance between the mitochondrial function and lactate level has importance since metabolic changes (brought about due to endurance training) that could negate rises in lactate level would aid increased submaximal work capacity. That is, an increase in the ability to utilise free fatty acids (FFA) would reduce the rate of glycolysis and, thus, the formation of pyruvate and extramitochondrial NADH ('reduced nicotinamide adenine dinucleotide), resulting in reduced lactate levels and the ability to sustain submaximal work at a higher relative level.

Thus, improvements in $\dot{V}O_2max$ with training are well documented (Saltin, Blomquist, Mitchell, Johnson, Jnr., Wildenthal & Chapman, 1968; Pollock, 1973). Such improvements are linked directly with the intensity, duration, and frequency of the training bouts, with increases of 5-25% being possible, according to the American College of Sports Medicine (1978).

In recognition of the obvious importance of $\dot{V}O_2max$ for athletic performance, many investigators have studied the factors that limit $\dot{V}O_2max$ and the effect that $\dot{V}O_2max$ has on physical performance, although there has been a preoccupation by researchers with the 'central' component (O_2 transport, cardiac output and arterial O_2 content) at the expense of the 'peripheral' aspect (O_2 utilization by the contracting muscles). However, recently there has been a growth in the quantity of information regarding ventilatory and respiratory kinetics at the peripheral level.

Essentially, the key element is to recognise that whilst all endurance-trained athletes may exhibit a common 'central' adaptation, their respective peripheral adaptations will reflect the specific nature of their sports involvement. Thus, it is unlikely that a runner, for example, would display similar peripheral adaptive traits as a swimmer, although at the central level their $\dot{V}O_2max$ scores could be similar. That is, the runner is likely to show a marked peripheral efficiency in the legs, whilst the swimmer may show superiority in the arms and shoulders. The important factor, then concerns the actual muscle mass predominantly in use by a given athlete in a given sports activity.

Obviously, the testing of such elements relies heavily on the modes of ergometry and the protocols chosen by the investigator. Also the sensitivity of $\dot{V}O_2max$ or $P\dot{V}O_2$ values for the objective evaluation of the trained individuals who may be close to, or at, their genetically determined upper limit for O_2 uptake. Thus, an additional parameter (or parameters) is required for sports scientists to be able to provide relevant and up-to-the-minute feedback concerning the trained state of an athlete. To date, and despite the widespread controversy surrounding it, the notion of 'Anaerobic Threshold' (AT), described as a percentage of the individual's $\dot{V}O_2max$ (%$\dot{V}O_2max$), has been used as a guide to the efficacy of an athlete's training programme. MacDougall (1977), after comparing athletes with non-athletes, remarked that AT could be useful in predicting the performance capacity of athletes, since athletes were found to have ATs occurring at a higher %$\dot{V}O_2max$ than non-athletes. Several investigators (Cummingham & Faulkner, 1969; Londeree & Ames, 1975; Donovan & Brooks, 1983) have shown that fatiguing levels of lactate accumulate later in trained athletes than in sedentary individuals. Donovan & Brooks (1983) are quick to point out that lactate production is still occurring in trained muscle at a given work level, but that it is the ability of the trained muscle to bring about lactate clearance to meet this lactate production that is the critical factor. Despite the vast quantities of published material regarding AT, controversy surrounds it's actual existence and determination. At the non-invasive level, Wasserman, Whipp, Koyal, & Beaver (1973) and Skinner & McLellan (1980) have stated that ventilatory AT may be determined by a respiratory inflection point, that is, non-linear increases in $\dot{V}E$ and $\dot{V}CO_2$, coupled with an increase in the fraction of expired O_2 (FeO_2) and a decrease in the fraction of expired CO_2 ($FeCO_2$).

The study by Weltman, Katch, Sandy, & Freedson (1978) found that individuals with high ATs attained steady state $\dot{V}O_2$ levels significantly faster than those individuals with low ATs. This occurrence hints strongly at a tangible link between AT and the transient oxygen uptake response. In view of the uncertainties surrounding the concept of AT, the identification of an easily discernible physiological parameter which can describe an athlete's physical condition, such as the transient oxygen uptake response, has an important contribution to make to exercise physiologists, coaches, and athletes alike.

<u>Studies concerned with the nature of the transient oxygen uptake response</u>

It is well established that O_2 consumption increases rapidly and then plateaus towards a steady state, or maximal value with the onset of exercise. Margaria, Edwards, & Dill (1933) found that the transient $\dot{V}O_2$on response during and following sudden changes in the intensity of physical work followed an exponential pattern. These findings have been confirmed by Henry (1951), Di Prampero et al., (1970), Whipp & Wasserman (1972), and Whipp & Casaburi (1982).

Henry & DeMoor (1956) and Wasserman, Van Kessel, & Burton (1967) reported that the time to reach a steady state in O_2 consumption increased as work rate increased. Whipp & Wasserman (1972) found that the transient oxygen uptake pattern during the non-steady state phase $\dot{V}O_2$ was dependent upon the work rate demanded and the physical fitness of the subject.

Cerretelli et al. (1980) have defined the $\dot{V}O_2$on transient as being the indicator of a recovery process aimed at re-establishing a steady state condition as determined by the stimulus. That is, the rate of increase in $\dot{V}O_2$, as a response to the imposed physical work level, may be an indication of the circulatory capacity to deliver oxygen and for this oxygen to be utilized by the appropriate tissues (de Vries, Wiswell, Romero, Moritani, & Bulbulian, 1982). Other studies have suggested that these mechanisms, the oxygen transient (Hughson & Morrissey, 1983) and the oxygen utilization (Pendergast, Shindell, Cerretelli, & Rennie, 1980), act as the rate-limiting component in the $\dot{V}O_2$on response to the stimulus of a constant load exercise.

The efficiency of such mechanisms has been determined by estimating their 'half-time' values, $t1/2\dot{V}O_2$on, described simply as the time required to achieve 50% of the difference between rest and steady state $\dot{V}O_2$ (Henry, 1951; Whipp & Wasserman, 1972; Pendergast et al., 1980). Although some investigators (Diamond, Casburi, Wasserman, & Whipp, 1977; Hagberg, Nagle, & Carlson, 1978) quantified the $\dot{V}O_2$on response using the rate constant K, Linnarsson (1974) had earlier used a mono-exponential function using a time constant (τ) and incorporating a time delay (TD). More recent studies have followed Linnarsson's lead by using a time constant and time delay in their calculations in order to achieve 'closer-fit' data lines (Hughson & Morrissey, 1982; Hughson & Morrissey, 1983; Cooper, Berry, Lamarra, & Wasserman, 1985; Powers, Dodd, Woodyard, & Mangum, 1985). Despite the actual method preferred, these studies all relate to $T = 1/k = t1/2/0.693$. These $t1/2\dot{V}O_2$on responses have been both directly assessed, via sophisticated 'breath-by-breath' analysis (Hickson et al., 1978; Cerretelli et al., 1979; Cooper et al., 1985), and indirectly determined by a single first order exponential model (Whipp, Ward, Lamarra, Davis, & Wasserman, 1982). Open circuit spirometry has also been used to determine the $\dot{V}O_2$on response (Hughson & Morrissey, 1982; de Vries et at., 1982; Convertino, Goldwater, & Sandler, 1984).

Whilst initial researach suggested that t1/2$\dot{V}O_2$on was 30 seconds whatever the workload (Henry, 1951; Margaria, Mangili, Cuttica, & Cerretelli, 1965; Di Prampero et al., 1970), later work has shown that t1/2$\dot{V}O_2$on will vary depending upon a number of factors. The $\dot{V}O_2$max of individuals has been shown to significantly affect the t1/2$\dot{V}O_2$on, for example, in adults a strong negative relationship was found to exist between t1/2$\dot{V}O_2$on and $\dot{V}O_2$max by Hagberg et al. (1978). That is, faster t1/2$\dot{V}O_2$on times have been found for subjects with high $\dot{V}O_2$max values. More recently, Powers, Dodd, and Beadle (1985) found a negative correlation of $r = -0.80$ ($p<0.05$) between $\dot{V}O_2$max and t1/2$\dot{V}O_2$on, and concluded that in individuals with 'similar training habits', those athletes with greater $\dot{V}O_2max$ scores also have faster $t1/2\dot{V}O_2on$ responses at the onset of work. However, Lake, Nute, Kerwin, and Williams (1986) have actually stated that the 'magnitude of $\dot{V}O_2max$ does not appear to dictate the rate at which a steady-state in $\dot{V}O_2$ is attained'. Cerretelli et al. (1979) and Hickson et al. (1978) have shown that $t1/2\dot{V}O_2on$ times become faster for subjects whose $\dot{V}O_2max$ was increased through physical training. This aspect adds more support to the notion that the $t1/2\dot{V}O_2on$ response time has the potential to establish itself as an indicator of the efficiency of an individual's $\dot{V}O_2$ adjustment process and the individual's adaptation to physical conditioning.

Although Macek and Vavra (1980) found in their study that prepubescent boys had significantly faster $\dot{V}O_2on$ responses than adults, Armstrong, Davies, & Mulhall (1982) do not support this view following their investigation of post-pubescent age-group swimmers. Other findings (Freedson, Billiam, Sady, & Katch, 1981; de Vries et al., 1982; Cooper et al., 1985) have tended to support the idea that no differences exist between the $\dot{V}O_2$on responses of children and adults, although younger children have been reported to have faster t1/2$\dot{V}O_2$on times than older children (Freedson et al., 1981; Cooper et al., 1985).

Cerretelli et al. (1979) and Convertino et al. (1984) both report slower t1/2$\dot{V}O_2$on responses for supine exercise as opposed to upright exercise. Although Cerretelli et al. (1980) found that non-trained male subjects exhibited slower t1/2$\dot{V}O_2$on times for arm work versus leg work, they found that for individuals involved in activities requiring considerable arm work the $\dot{V}O_2$on response was quicker for arm exercise than for leg exercise at an 'equivalent' load. However, Armstrong et al. (1982) examined 'trained' subjects during maximal arm and leg exercise and found no significant differences.

Thus, these later studies have demonstrated that $\dot{V}O_2$on kinetics may be affected by elements such as the $\dot{V}O_2$max of the subjects, exercise intensity, the age of the subjects, the state of training of the subjects, the limbs used in the study, the posture used and the actual mode of ergometry, all of which were originally hypothesised by Fujihara, Hildebrandt, & Hildebrandt (1973). $\dot{V}O_2$on 'half-times' (t1/2$\dot{V}O_2$on) have been reported to vary between 15-90 seconds depending upon such influences (Davies, Di Prampero, & Cerretelli, 1972; Cerretelli et al., 1980).

<u>Areas requiring further attention with regard to the transient oxygen uptake response</u>

The literature to date illustrates the need for a number of areas to be investigated with regard to $\dot{V}O_2$on and t1/2$\dot{V}O_2$on. Obviously, the aspect of 'cause-effect' needs examining, that is, to what degree is the transient oxygen uptake response in an individual due to genetic endowment (e.g., muscle fibre-type composition per se) and what is the exact influence of physical conditioning? Secondly, cross-sectional analysis of various sports groups in order to ascertain the existence of sports-related peripheral adaptation should be undertaken, particularly in view of the conflicting literature (Cerretelli et al., 1980; Armstrong et al., 1982). Finally, there is a lack of longitudinal investigation examining the actual transient oxygen uptake responses over long-term training periods as followed by most elite athletes. Positive information emanating from such study could provide invaluable data of a practical nature to those engaged in the pursuit of èlite athletic performance.

Aspects of concern for the current investigation

This investigation addressed itself to the aspect of peripheral variations in the $\dot{V}O_2$on response of certain elite athlete groups, namely swimmers, cyclists, runners, and cross-country skiers. This was achieved by examining the ventilatory kinetics of the central and peripheral components of the subjects via three modes of ergometry; treadmill running, cycle ergometry, and arm cranking.

Saltin & Astrand (1967) found that elite male cross-country skiers and cyclists had relative $\dot{V}O_2$max values of greater than $80 ml \cdot kg^{-1} \cdot min^{-1}$ and $75 ml \cdot kg^{-1} \cdot min^{-1}$ respectively. They also described elite male middle-distance runners to have relative maximal oxygen consumption values of approximately $80 ml \cdot kg^{-1} \cdot min^{-1}$, and male swimmers produced a mean value of $67 ml \cdot kg^{-1} \cdot min^{-1}$. McKay, Braund, Chalmers, & Williams (1983) found that male Scottish international swimmers had a mean $\dot{V}O_2$max of $68.6 ml \cdot kg^{-1} \cdot min^{-1}$.

Franklin (1985) remarks that 'limb-specific' training effects suggest that a considerable segment of the training adaptation is concerned with 'extracardiac' or peripheral factors, such as blood flow alterations and cellular and enzymatic alterations in the specifically conditioned limbs.

This study is an attempt to quantify the magnitude of such peripheral variations, should they be found to exist, via parameters such as the $\dot{V}O_2$on and t1/2$\dot{V}O_2$on responses.

CHAPTER III

METHODOLOGY

Purpose

This investigation was undertaken to examine the transient oxygen uptake responses of four groups of athletes, with each group representing a different sports activity, and to determine the existence of possible peripheral adaptations in these responses.

Research Design

Cross-sectional Investigation; The transient oxygen uptake response as an indicator of sports specific adaptation

Subjects

Twenty male athletes representing four different sports disciplines were used for this investigation. Each group had an 'n' of five, with all subjects having been selected on the basis of being 'good' representatives of their sports groups, (determined by previous sports performance and a $\dot{V}O_2max$ in excess of $55 ml \cdot kg^{-1} min^{-1}$, established via a treadmill run to 'exhaustion'). The age range of the subjects was 14-27 years and they were drawn from the sports of competitive swimming, cycling, distance running, and cross-country skiing.

<u>Investigative periods</u>

The investigation period was September 1986 for the cyclists, November 1986 for the runners, December 1986 for the swimmers, and January 1987 for the skiers. Each period coincided with a major performance peak and, or, the end of the competitive season.

<u>Testing schedule</u>

An intergroup matrix design was used to encompass a non-manipulative aspect, that is, the investigator did not interfere with the training regimes of the sports groups, and a manipulative component, namely three different modes of ergometry. Essentially then, a cross-sectional, single observation study occured whereby four sports groups were examined for possible regional variations in oxygen uptake both between and within groups. All subjects were habituated to the ergometers and the test procedures.

Initially, all subjects performed a $\dot{V}O_2max$ test on a treadmill device ($\dot{V}O_2max$ tm) to establish an acceptable record of $\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$).

The subjects then performed PVO_2 tests, allocated randomly, for arms and legs ($P\dot{V}O_2$arms and $P\dot{V}O_2$legs) using an adapted Monark cycle ergometer and an ordinary Monark ergometer respectively. Each test was performed at least 24 hours after the previous performance so as to allow adequate rest and to minimise diurnal influences.

The remaining tests were then assigned in a randomised fashion so as to balance out any possible experimental inferences or confounding aspects caused by the experimental prodecures. These tests were as follows:-

$t1/2\dot{V}O_2$on tm x 2	$\dot{V}O_2$on tm
$t1/2\dot{V}O_2$on arms x 2	$\dot{V}O_2$on arms
$t1/2\dot{V}O_2$on legs x 2	$\dot{V}O_2$on legs

The $t1/2\dot{V}O_2$on tests were submaximal with each subject working at a work load corresponding to approximately 45% of each subject's $\dot{V}O_2$max for that particular mode of ergometry. That is, the $t1/2\dot{V}O_2$on tm test was performed at the work load that brought about 45% of $\dot{V}O_2max$ for a given subject on the treadmill, and so forth. These t1/2$\dot{V}O_2on$ tests were performed twice or where necessary three times, with a suitable rest period between each test, so as to achieve a level of reliability. The mean score of these 'half-times' was taken to represent the t1/2$\dot{V}O_2on$ for a given subject and mode ergometry when engaged in submaximal work. MRT values were established in a similar fashion.

The $\dot{V}O_2on$ tests were performed after the t1/2$\dot{V}O_2on$ tests once the subjects had had a suitable period of rest. The subject for these tests, however, had to work at the work load that elicited $\dot{V}O_2max$ for the particular mode being performed (treadmill, arm cranking, or cycle ergometry).

Gas analysis was carried out using a pre-calibrated computerized Beckman Metabolic Cart (MMC Horizon II System) programmed for 15 second interval probes. Heart rate (fH) was continuously monitored via a three lead (Cambridge VS4 model) electrocardiograph, intergrated by digital analogue to the Beckman Metabolic Cart.

Maximal Oxygen Uptake ($\dot{V}O_2max$)

A Quinton treadmill ergometer was used to bring about each subject's $\dot{V}O_2max$. The protocol use required each subject to move through a warm-up period at a comfortable pace (approximately five miles per hour) and at zero % grade for a minimum of three minutes. After completing the warm-up phase, the subject started the actual test at between seven and eight miles per hour, depending upon individual ability levels, with 2 1/2% grade. On completion of two minutes at this grade, the angle of slope was increased by 2 1/2%. This procedure was continued with 2 1/2% grade increases every two minutes until the subject could no longer sustain the required pace, finished the test of his own volition, and, or, $\dot{V}O_2max$ criteria were seen by the investigator. It should be noted that strong verbal encouragement was given to each subject.

Criteria for the determination of achievement of $\dot{V}O_2max$

$\dot{V}O_2max$ was acknowledged as having occurred when $\dot{V}O_2$ failed to increase with a further increase in work load. An increase in $\dot{V}O_2$ of $2 ml \cdot kg^{-1} \cdot min^{-1}$ or less above the previous value was taken as the indication of the $\dot{V}O_2$ asymptote.

2. Additionally, a Respiratory Exchange Ratio (RER) value of greater than 1.00 and a heart rate (fH) close to the age anticipated maximum for the subject was also used to reinforce the decision regarding the $\dot{V}O_2$ 'plateau'.

Peak Oxygen Uptake ($P\dot{V}O_2$)

1. $P\dot{V}O_2$ arm cranking ($P\dot{V}O_2$ arms)

An adapted Monark cycle ergometer was used to establish $P\dot{V}O_2$ for each subject's arms component. The testing procedure followed established formats concerning ergometer positioning and work load determination.

A warm-up phase took place at a 0.25 kiloponds (kp) resistance with a cranking cadence of 60 revolutions per minute (rpm), determined by a metronome providing an audio-visual signal, for three minutes. The initial work load was individually determined, but did not exceed 720 kpm·min^{-1} (2kp x 6m x 60rpm). Each work load was performed at for two minutes with increments of 90 kpm·min^{-1} (0.25kp x 6m x 60rpm) occurring at that time interval. As with the $\dot{V}O_2$max test, strong verbal encouragement was given to each subject, the test at the individual level being stopped once the subject could no longer maintain the required pace, the subject indicated his wish to finish, and, or, $P\dot{V}O_2$ criteria were seen to have occurred.

2. $P\dot{V}O_2$ leg cycling ($P\dot{V}O_2$ legs)

$P\dot{V}O_2$ legs was brought about using a Monark cycle ergometer equipped with toe stirrups and ankle straps. Subjects were positioned on the cycle ergometer following accepted procedure regarding such factors as seat height, habituation, and warm-up. The warm-up period lasted three minutes, with each subject pedalling against a low resistance at 60rpm. On completion of the warm-up, an initial work load was set (individually determined) and each subject then followed a 'continuous incremental' protocol with 180 kpm·min^{-1} (0.5kp x 6m x 60rpm) increases at two minute intervals until completion of the test.

Criteria for the determination of achievement of $P\dot{V}O_2$

1. $P\dot{V}O_2$ was deemed to have occurred when $\dot{V}O_2$ failed to increase with a further increase in work load. An increase in $\dot{V}O_2$ of less than $2 ml \cdot kg^{-1} \cdot min^{-1}$ (relative) or $0.15\ l \cdot min^{-1}$ (absolute) for a complete work load were taken as the indications of the $\dot{V}O_2$ asymptote.
2. An RER value greater than 1.00 and an fH close to the subject's age-predicted maximum were also used as supplementary criteria in the determination of maximum effort.

Transient Oxygen Uptake

The response to constant load submaximal exercise

The $t1/2\dot{V}O_2on$ and MRT responses for each mode of ergometry for each subject were determined and, as with the previous tests, metabolic data was monitored throughout. Despite the three ergometric modes, the protocols followed essentially the same format for each mode. The subject was instructed to begin the test once $\dot{V}O_2$ and fH had established 'stabilised' starting levels. The work load was predetermined from the subject's previous test results and was designed to bring about a $\dot{V}O_2$ of approximately 45% of the subject's previously determined $\dot{V}O_2max$ tm, $P\dot{V}O_2arms$, or $P\dot{V}O_2legs$. The subject worked at this intensity for five minutes after which time the subject was instructed to stop. Each subject performed at least two 'rest-to-work' transitions for each mode of ergometry, although the three modes were performed on different days. A period of rest with the subjects totally relaxed was required between repeat tests with pre-exercise $\dot{V}O_2$ and fH values having returned to within +/-5% of those values seen prior to the initial test.

The Beckman MMC Horizon II System allowed 15 second observation periods for $\dot{V}O_2$ and these readings were noted for the five minutes preceding and during each test. On the basis of this information, 15 second interval data points were established for each performance, with one mean value taken to represent the pre-exercise level (control/rest).

Transient Oxygen Uptake

The response to constant load maximal exercise

As previously describe for the 'submaximal' tests, a similar format was followed for the $\dot{V}O_2$on transient exercises. However, for these tests the subject had to work against those resistances which had previously elicited the subject's $\dot{V}O_2$max tm, $P\dot{V}O_2$arms, and $P\dot{V}O_2$legs. Once $\dot{V}O_2$ and fH values had stabilised, the subject was instructed to begin the exercise. The pre-set resistance pendulum was initially supported at zero resistance so as to reduce the effort required by the subject to overcome the inertia at the start of each test when the Monark ergometer was in use. An audiovisual signal was provided by a metronome to help subjects maintain a cadence of 60rpm for the cycling and arm cranking exercises.

The test was concluded once the subject was unable to maintain the 60rpm cadence, when using the Monark ergometer, or the required pace, when using the Quinton treadmill.

As with the t1/2$\dot{V}O_2$on, the 15 second interval data points were used to describe the oxygen transient, $\dot{V}O_2$on.

<u>Data Analysis: Transient Oxygen Uptake</u>

The transient $\dot{V}O_2$on response was described as the time, in seconds, required to bring about $\dot{V}O_2$max or $P\dot{V}O_2$ from pre-exercise to a maximal, or submaximal, asymptote. Recent studies (Hughson & Morrissey, 1982; Hughson & Morrissey, 1983; Cooper et al., 1985) have quantified the $\dot{V}O_2$on response using the time constant from a single exponential process given as $\Delta\dot{V}O_2\,(t) = \Delta\dot{V}O_2ss\,(1-e^{-\frac{(t-TD)}{\tau}})$, where Δ reflects the increment above the previous (rest or exercise) steady state level, and ss represents the steady state or asymptotic value. This process was carried out by an Apple II personal computer. TD represents the time delay parameter and this allowed the computer to fit the best possible value for the time constant (τ) of the response without artificially constraining the regression to pass through the origin. The overall rate of change of the response was then obtained from the sum of τ + TD. This is known as the 'mean response time' (MRT = τ + TD).

The half time of the $\dot{V}O_2$on response, t1/2$\dot{V}O_2$on, is simply put as the time, in seconds, required to bring about a 50% change in $\dot{V}O_2$ from pre-exercise to steady state exercise levels.

Basically, analysis of the response kinetics involved calculating the exercise steady state phase (maximal or submaximal) and using the 15 second interval data points in conjunction with the single exponential computer-run formula to determine $\dot{V}O_2$on for the maximal and submaximal performances and, hence, the MRT and t1/2$\dot{V}O_2$on responses.

Statistical Analysis

Traditional statistical methods were applied to evaluate the results obtained from the investigation. This involved one-way Analysis of Variance methodology using the "Minitab" statistical computer software package run on a VAX 11/780 system.

CHAPTER IV

RESULTS

Original Data and Analysis

Physical characteristics of the groups

Tables 1 to 4 show the physical characteristics of the subjects used in this investigation, whilst Table 5 gives the 'F-ratios' derived from an 'Analysis of Variance' statistical process. Immediately, it can be seen that the swimmers were the 'youngest' of the four groups with a mean age of 16 years, and this was significant ($p<0.05$) as compared to the cyclists (19.2 years), and the other two groups ($p<0.01$); the runners (21.8 years) and the cross-country skiers (21.4 years).

Despite being the youngest group overall, the swimmers were also the tallest group (mean = 182.4 cms) and the heaviest (mean = 72.8 kgs), although neither of these elements were at a significantly different level from the other groups.

Aerobic power; Incremental max tests

Figures 1 to 6 provide a graphical summary of the oxygen uptake characteristics of the four sports groups at the 'absolute' and 'relative' levels, whilst Tables 6 to 9 provide this information numerically. Analysis

Table 1

Subject Data

Cyclists

Subject	Age yr	Height cm	Weight kg
DZ	22	188.2	81.9
AN	16	172.0	59.8
GM	21	176.6	70.9
PT	16	164.0	59.25
EW	21	170.3	67.6
Mean	19.2	174.22	67.89
SD+/-	2.950	9.03	9.294

Table 2

Subject Data

Runners

Subject	Age yr	Height cm	Weight kg
BG	22	171.5	63.7
TH	19	175.0	60.0
MH	19	195.0	86.25
RM	22	177.5	70.8
ED	27	180.0	74.7
Mean	21.8	179.8	71.09
SD+/-	3.271	9.06	10.254

Table 3

Subject Data

Swimmers

Subject	Age yr	Height cm	Weight kg
MD	16	186.2	73.5
AF	14	179.7	71.1
KB	14	178.9	65.5
SL	16	175.2	67.8
JB	20	192.0	86.1
Mean	16	182.4	72.8
SD+/-	2.449	6.67	8.04

Table 4

Subject Data

Cross-country skiers

Subject	Age yr	Height cm	Weight kg
PM	20	175.3	61.7
MS	20	181.2	79.1
DB	22	188.7	75.8
KT	22	168.4	60.55
SP	23	165.4	68.9
Mean	21.4	175.8	69.21
SD+/-	1.342	9.47	8.257

Table 5

Subject Data; Analysis of Variance, (F-Ratios)

Age

	Cyclists	Runners	Swimmers
Runners	1.74		
Swimmers	3.48*	10.07**	
Skiers	2.30	0.06	18.67**

Height

	Cyclists	Runners	Swimmers
Runners	0.95		
Swimmers	2.66	0.27	
Skiers	0.07	0.47	0.49

Weight

	Cyclists	Runners	Swimmers
Runners	0.27		
Swimmers	0.80	0.09	
Skiers	0.06	0.10	0.49

* = $p<0.05$ ** = $p<0.01$

All other F-Ratios are not significant ($p>0.05$).

Figure 1

Incremental Max Test Data; Group means and SD+/-

Treadmill (absolute)

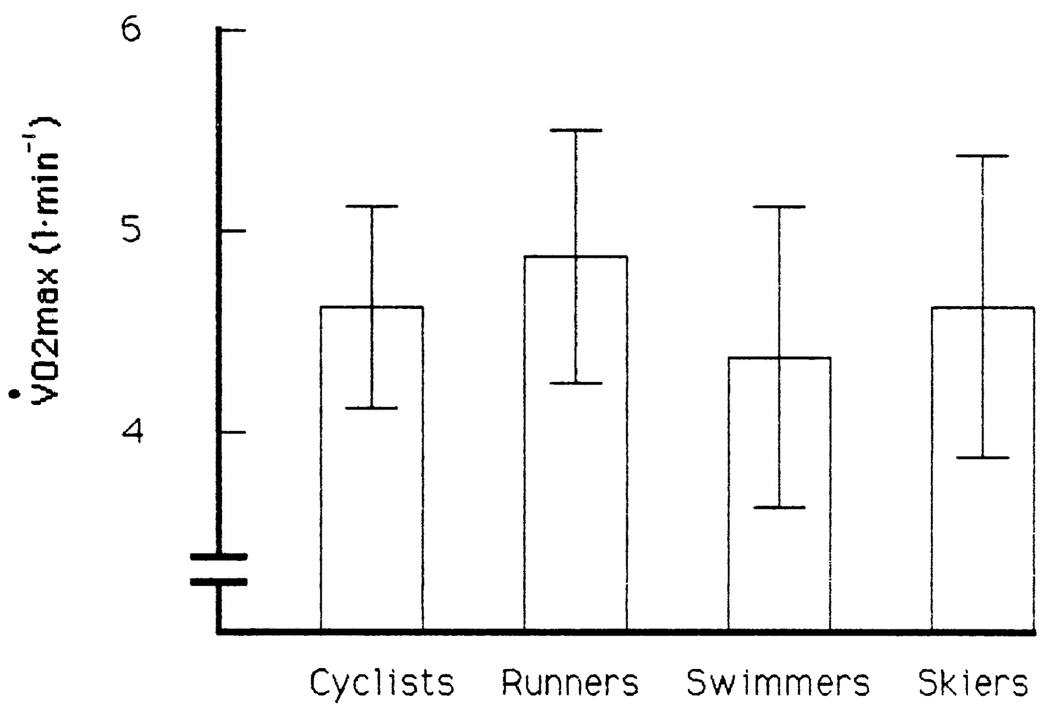


Figure 2

Incremental Max Test Data; Group means and SD+/-

Cycle ergometer (absolute)

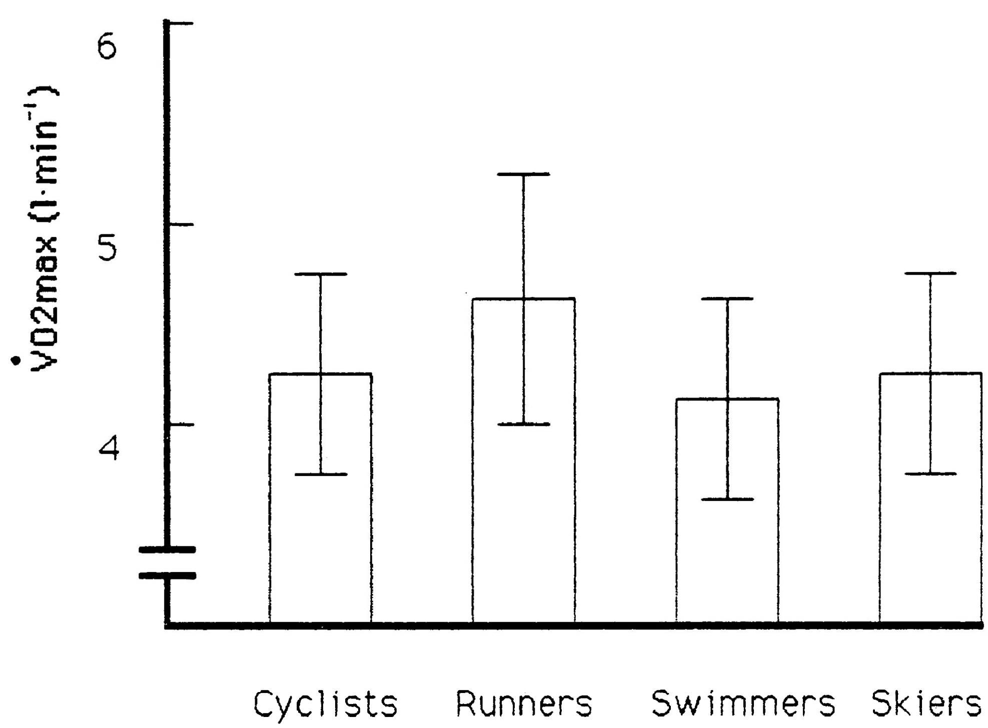


Figure 3

Incremental Max Test Data; Group means and SD+/-

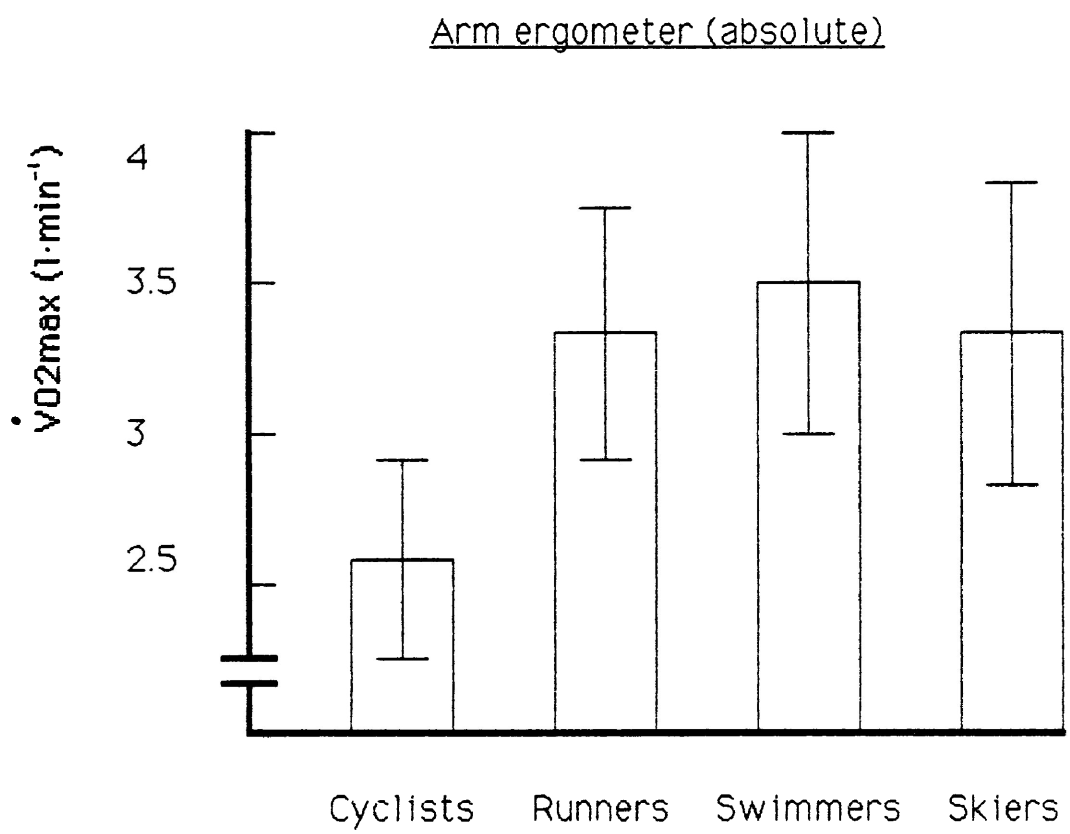


Figure 4

Incremental Max Test Data; Group means and SD+/-

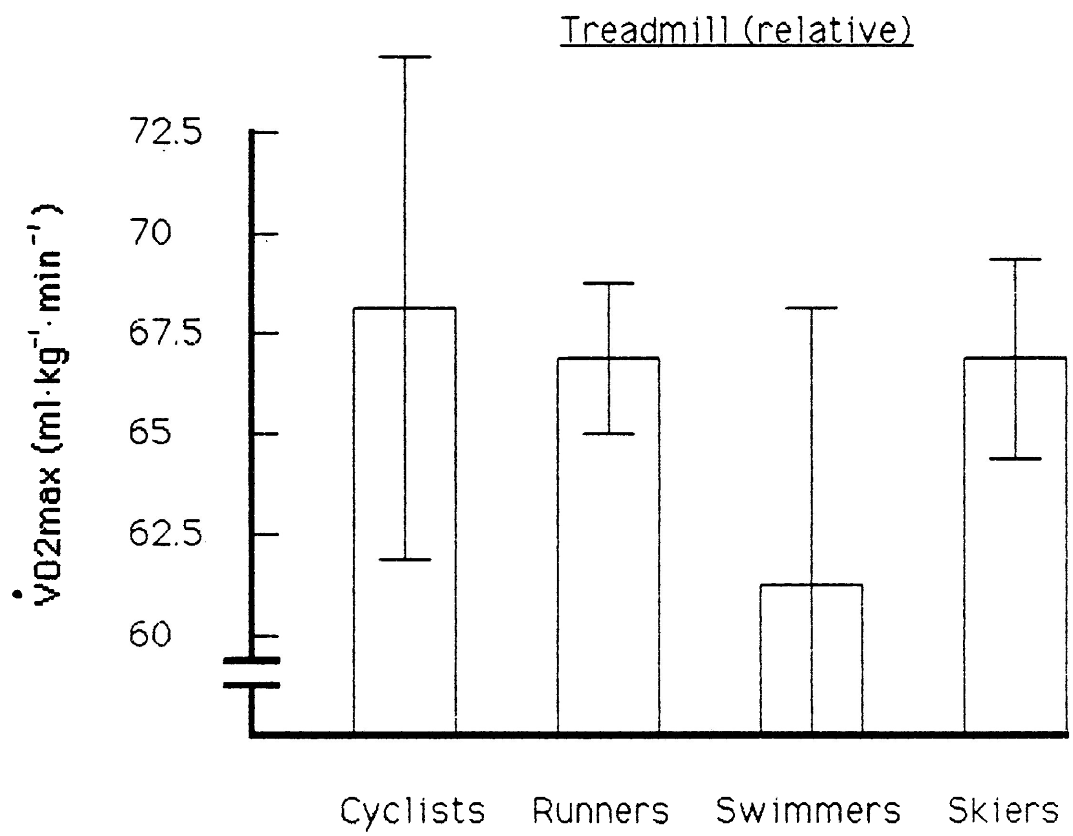


Figure 5

Incremental Max Test Data; Group means and SD+/-

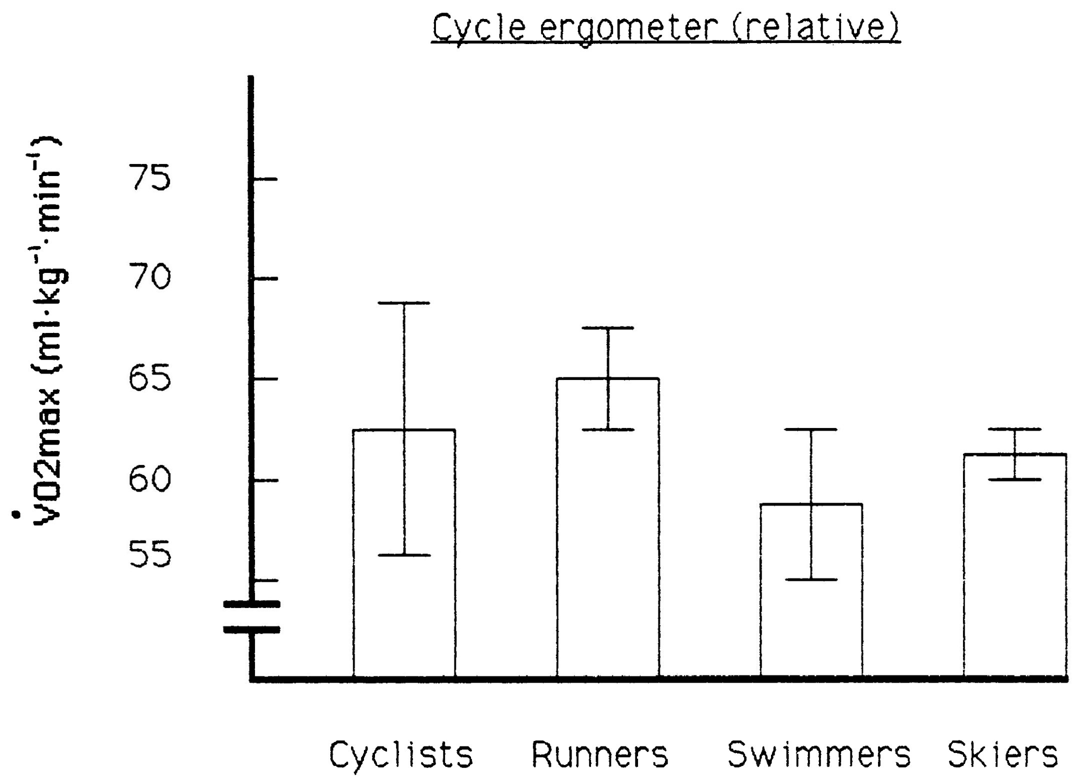


Figure 6

Incremental Max Test Data; Group means and SD+/-

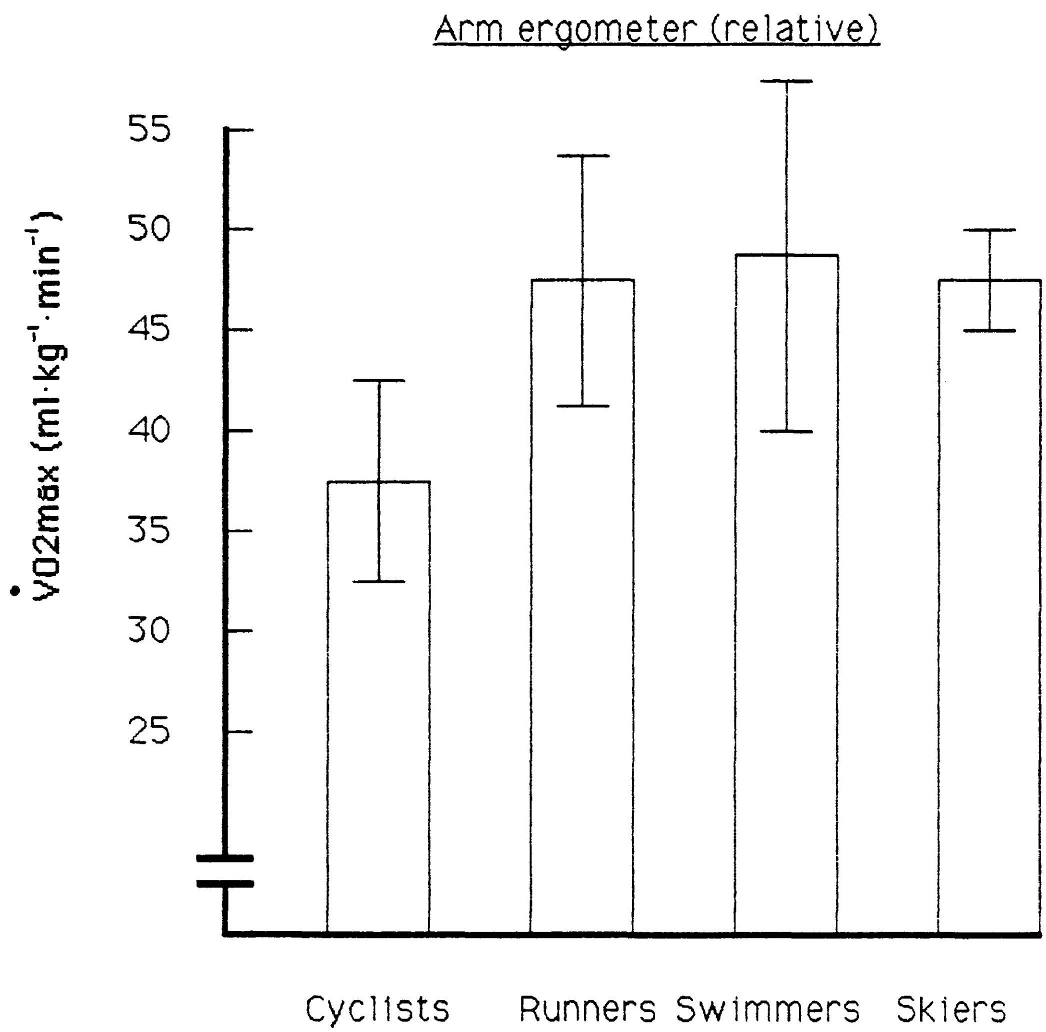


Table 6

Cyclists: Aerobic Power

	Treadmill		Cycle		Arm	
	$\dot{V}O_2max$		$P\dot{V}O_2$		$P\dot{V}O_2$	
Subject	$l \cdot min^{-1}$	$ml \cdot kg^{-1} \cdot min^{-1}$	$l \cdot min^{-1}$	$ml \cdot kg^{-1} \cdot min^{-1}$	$l \cdot min^{-1}$	$ml \cdot kg^{-1} \cdot min^{-1}$
DZ	4.676	57.0	4.448	54.2	2.765	33.7
AN	4.123	68.8	3.824	63.8	2.358	39.3
GM	5.226	73.6	4.826	67.9	2.712	38.2
PT	4.109	69.2	3.844	64.7	2.138	36.0
EW	4.773	70.5	4.541	66.2	3.081	44.9
Mean	4.5814	67.82	4.2966	63.36	2.6108	38.42
SD+/-	0.4729	6.335	0.4447	5.352	0.3683	4.212

Table 7

Runners; Aerobic Power

	Treadmill $\dot{V}O_2max$		Cycle $P\dot{V}O_2$		Arm $P\dot{V}O_2$	
Subject	$l \cdot min^{-1}$	$ml \cdot kg^{-1} \cdot min^{-1}$	$l \cdot min^{-1}$	$ml \cdot kg^{-1} \cdot min^{-1}$	$l \cdot min^{-1}$	$ml \cdot kg^{-1} \cdot min^{-1}$
BG	4.307	67.5	4.411	69.1	3.557	55.7
TH	3.903	64.4	3.795	63.1	2.751	45.8
MH	5.697	65.9	5.324	61.6	4.029	46.6
RM	4.773	67.3	4.802	67.7	3.100	43.7
ED	5.264	70.3	4.800	64.1	3.293	44.0
MEAN	4.7888	67.08	4.6264	65.12	3.346	47.16
SD+/-	0.7190	2.189	0.5668	3.163	0.4818	4.926

Table 8

Swimmers: Aerobic Power

	Treadmill $\dot{V}O_2max$		Cycle $P\dot{V}O_2$		Arm $P\dot{V}O_2$	
Subject	$l{\cdot}min^{-1}$	$ml{\cdot}kg^{-1}{\cdot}min^{-1}$	$l{\cdot}min^{-1}$	$ml{\cdot}kg^{-1}{\cdot}min^{-1}$	$l{\cdot}min^{-1}$	$ml{\cdot}kg^{-1}{\cdot}min^{-1}$
MD	4.023	54.6	3.737	50.7	2.785	37.8
AF	3.839	53.9	4.624	64.9	3.206	45.0
KB	4.502	68.6	3.721	56.7	4.161	63.4
SL	4.144	61.0	4.052	59.6	3.518	51.8
JB	5.797	67.2	4.807	55.7	4.140	48.0
MEAN	4.461	61.06	4.1882	57.52	3.562	49.2
SD+/-	0.7851	6.847	0.5033	5.227	0.5969	9.453

Table 9

Cross-country skiers; Aerobic Power

	Treadmill $\dot{V}O_2max$		Cycle $P\dot{V}O_2$		Arm $P\dot{V}O_2$	
Subject	$l \cdot min^{-1}$	$ml \cdot kg^{-1} \cdot min^{-1}$	$l \cdot min^{-1}$	$ml \cdot kg^{-1} \cdot min^{-1}$	$l \cdot min^{-1}$	$ml \cdot kg^{-1} \cdot min^{-1}$
PM	3.981	64.4	3.810	61.6	2.858	46.2
MS	5.566	69.5	4.761	60.1	3.979	50.2
DB	5.148	67.8	4.662	61.4	3.775	49.7
KT	3.992	64.6	3.685	60.7	2.840	46.8
SP	4.752	68.8	4.268	61.8	3.458	50.1
MEAN	4.6738	67.02	4.2372	61.12	3.382	48.6
SD+/-	0.7198	2.379	0.4856	0.705	0.5208	1.938

of variance performed on this data, and shown by Tables 10 and 11, highlighted a significant difference ($p<0.01$) between the arm cranking $P\dot{V}O_2$ responses of the cyclists as compared to the other three groups, with the cyclists producing lower oxygen consumption values (absolute and relative). No significant differences were established between the groups for treadmill running or cycle ergometry in absolute terms. However, in relative terms, variations in oxygen uptake were noted (Table 11). The treadmill $\dot{V}O_2max$ responses were higher and produced significant differences ($p<0.01$) for the runners and cross-country skiers when compared to the swimmers. The mean value for the cyclists was also higher than the swimmers, however, a large standard deviation ruled out the possibility of statistical significance. This was again true for the cyclists and swimmers when concerned with the cycle ergometer $P\dot{V}O_2$ responses. The runners produced significantly higher values ($p<0.01$) for this test than either the swimmers or the cross-country skiers. The runners, swimmers, and cross-country skiers were all significantly higher ($p<0.01$) than the cyclists for the arm cranking $P\dot{V}O_2$ tests.

Additionally, the percentage differences between the cycle ergometer

Table 10

Aerobic Power: Absolute: Analysis of Variance

Treadmill data: ($\dot{V}O_2max$; $l \cdot min^{-1}$)

No significance ($p>0.05$) between groups

Cycle ergometry data: ($P\dot{V}O_2$; $l \cdot min^{-1}$)

No significance ($p>0.05$) between groups

Arm cranking data: ($P\dot{V}O_2$; $l \cdot min^{-1}$)

	Cyclists	Runners	Swimmers
Runners	7.35*		
Swimmers	9.20*	NS	
Skiers	7.31*	NS	NS

* = $p<0.01$

NS = Not Significant ($p>0.05$)

Table 11

Aerobic Power: Relative: Analysis of Variance

Treadmill data: ($\dot{V}O_2max$; $ml \cdot kg^{-1} \cdot min^{-1}$)

	Cyclists	Runners	Swimmers
Runners	NS		
Swimmers	NS	7.74*	
Skiers	NS	NS	7.62*

Cycle ergometry data: ($P\dot{V}O_2$; $ml \cdot kg^{-1} \cdot min^{-1}$)

	Cyclists	Runners	Swimmers
Runners	NS		
Swimmers	NS	7.74*	
Skiers	NS	7.62*	NS

Arm cranking data: ($P\dot{V}O_2$; $ml \cdot kg^{-1} \cdot min^{-1}$)

	Cyclists	Runners	Swimmers
Runners	9.09*		
Swimmers	5.43*	NS	
Skiers	24.11*	NS	NS

* = $p<0.01$ NS = Not Significant ($p>0.05$)

and the arm cranking $P\dot{V}O_2$ responses when compared to the treadmill $\dot{V}O_2max$ results ($\dot{V}O_2max$ response = 100%) were analysed, (Tables 12 and 13). The mean percent values for each group show that no group achieved as high a score on the cycle ergometer as on the treadmill, with the runners achieving the highest percentage (96.98%) and the cross-country skiers the lowest (91.32%). Indeed, these particular values were significantly different ($p<0.05$).

The percentage difference for arm cranking versus treadmill produced highly visible results with the swimmers highest at 80.28%, the cross-country skiers next at 72.52%, the runners at 70.26%, and the cyclists lowest at 56.96%, (Figure 7). In terms of statistical variation, with the exception of the swimmers versus the cross-country skiers (due to a large standard deviation for swimmers), these values were all significantly different ($p<0.01$) from each other.

Submaximal MRT and $t1/2\dot{V}O_2on$

The submaximal MRT (Figure 8, Tables 14 and 15) for the treadmill revealed the following times, in seconds, for each group; 34.05, 29.36, 34.81, 34.41, (cyclists, runners, swimmers, and cross-country skiers

Table 12

<u>Percentage variation from Treadmill scores; Raw data</u>

(Treadmill $\dot{V}O_2max$ = 100%)

	$P\dot{V}O_2$legs		$P\dot{V}O_2$arms	
	% to Tm	SD+/-	% to Tm	SD+/-
Cyclists	93.76	1.31	56.96	5.32
Runners	96.98	4.69	70.92	7.745
Swimmers	95.34	15.45	80.28	9.750
Skiers	91.32	3.62	72.52	0.563

Tm = Treadmill

Table 13

Percentage variation from Treadmill scores; Analysis of Variance

$P\dot{V}O_2$legs

	Cyclists	Runners	Swimmers
Runners	NS		
Swimmers	NS	NS	
Skiers	NS	4.56	NS

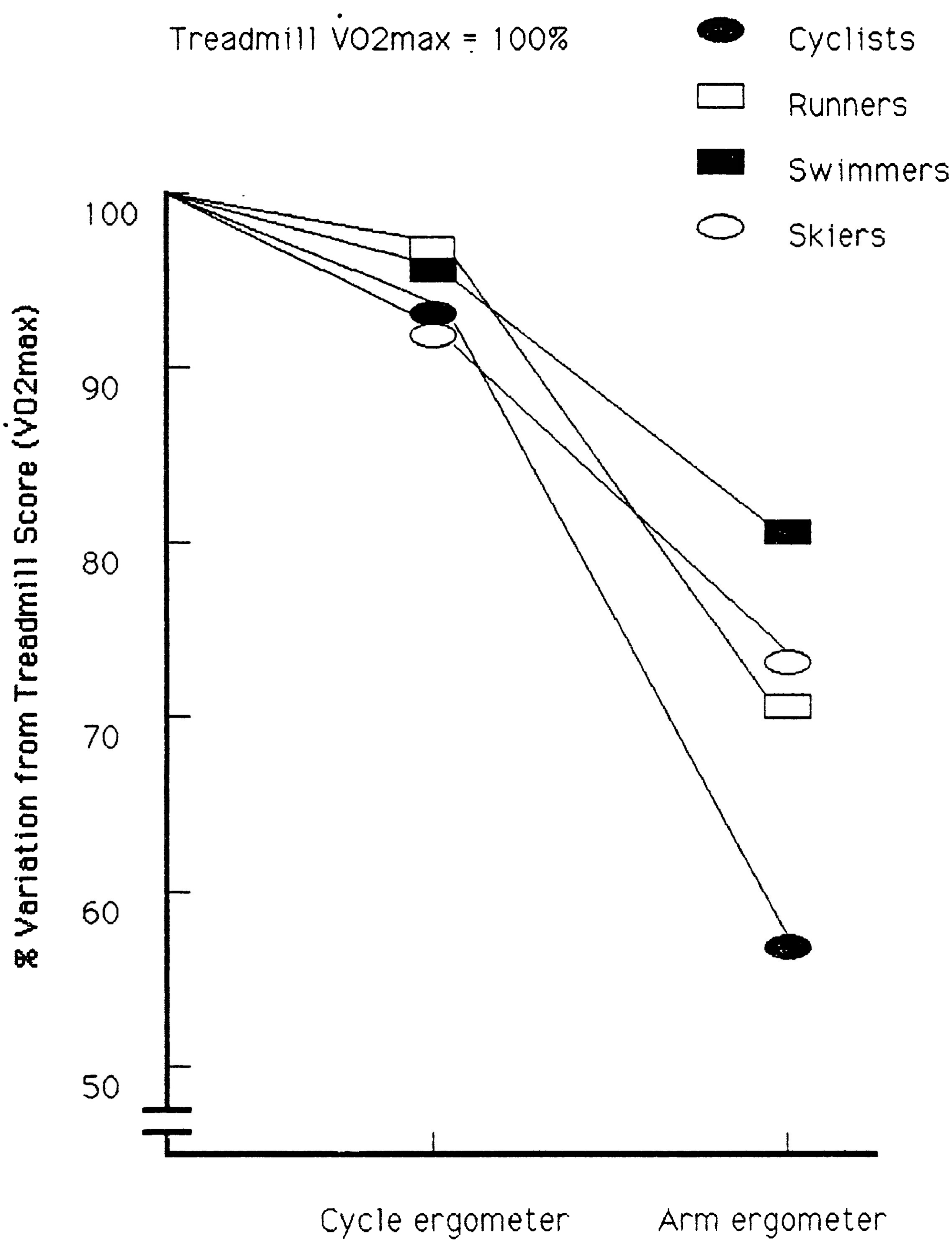
$P\dot{V}O_2$arms

	Cyclists	Runners	Swimmers
Runners	10.02**		
Swimmers	22.04**	3.24**	
Skiers	42.30**	NS	NS

* = p<0.05 ** = p<0.01

Figure 7

Percentage Variation from Treadmill scores



respectively). The runners produced significantly faster times ($p<0.05$) than the swimmers and cross-country skiers and, whilst similarly faster than the cyclists, a large cyclist standard deviation reduced significance to an intolerable level. The results for the cycle ergometer (Figure 9, Tables 14 and 16) did not produce any information of statistical significance. However, the responses for the arm cranking produced significantly faster times ($p<0.01$) for the runners (47.03 secs), swimmers (46.03 secs), and the cross-country skiers (42.19 secs) when compared to the cyclists (59.40 secs); see Figure 10, Tables 14 and 17.

The submaximal $t1/2\dot{V}O_2on$ response data produced similar information to the submaximal MRT results, with the $t1/2\dot{V}O_2on$ responses for the treadmill showing the runners to have faster times than the other three groups, plus statistical significance ($p<0.05$) when compared with the swimmers and cross-country skiers (Figure 11, Tables 14 and 18). Again a wide standard deviation for both the runners and the cyclists reduced the possibility of significance between these groups' results.

The submaximal $t1/2\dot{V}O_2on$ response times for the cycle ergometer were very closely grouped and did not yield any significant differences;

Table 14

Group Means (in seconds): Submaximal MRT and $t1/2\dot{V}O_2on$

	Mode	Cyclists X	Cyclists SD+/-	Runners X	Runners SD+/-	Swimmers X	Swimmers SD+/-	Skiers X	Skiers SD+/-
Submax	TM	34.05	5.746	29.36	3.878	34.81	4.092	34.41	4.595
MRT	LG	38.70	3.680	40.41	5.369	39.54	3.581	38.12	4.935
	AR	59.40	9.761	47.03	7.030	46.03	7.557	42.19	4.501
Submax	TM	24.23	3.531	20.35	3.465	24.63	3.003	24.42	2.611
$t1/2VO_2on$	LG	28.04	2.809	28.42	4.275	28.51	3.215	27.90	3.840
	AR	38.55	5.619	31.33	4.489	33.04	6.957	29.04	3.543

TM = Treadmill LG = Cycle ergometer AR = Arm crank

Figure 8

Submaximal MRT: Treadmill

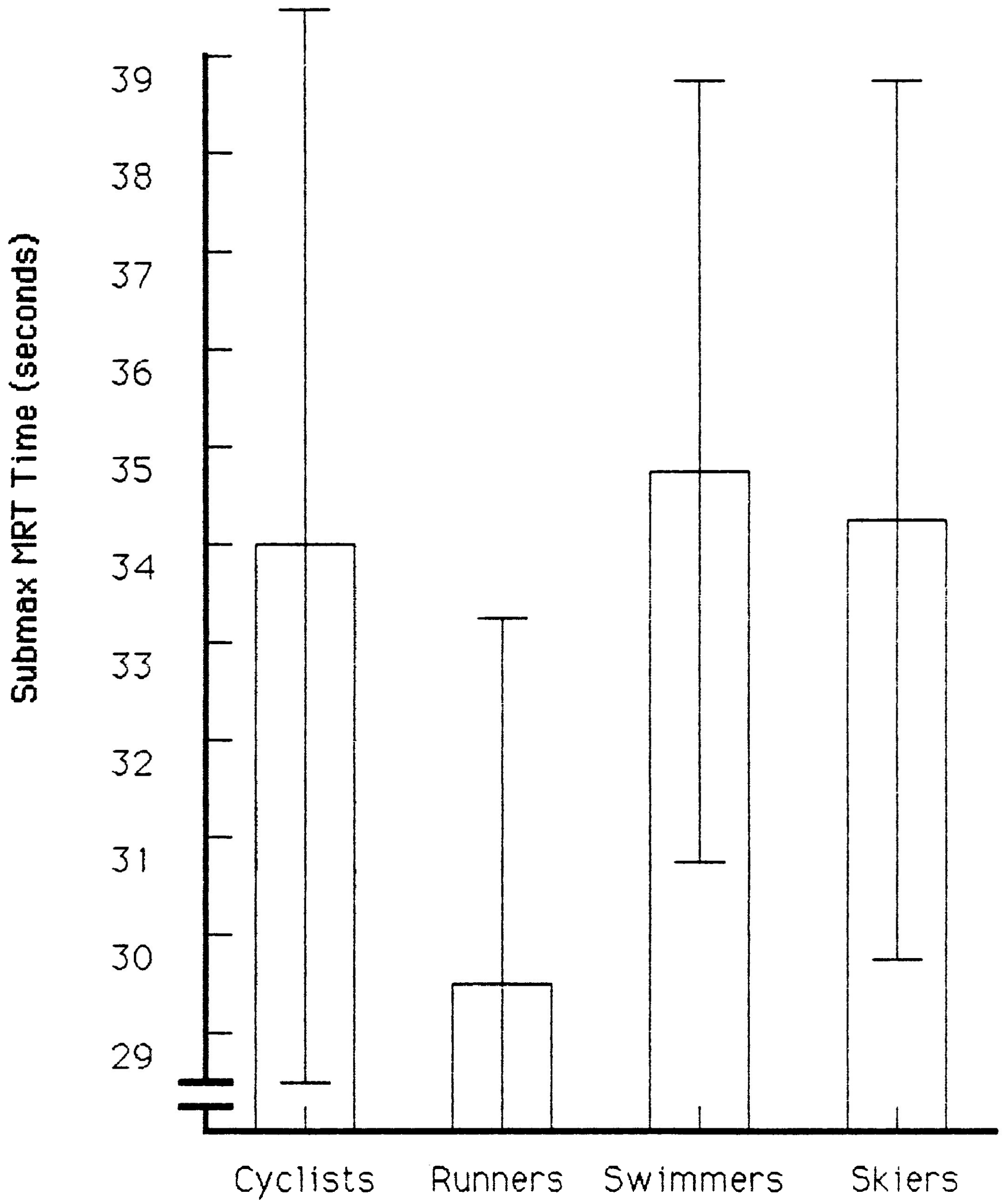


Figure 9

Submaximal MRT: Cycle ergometer

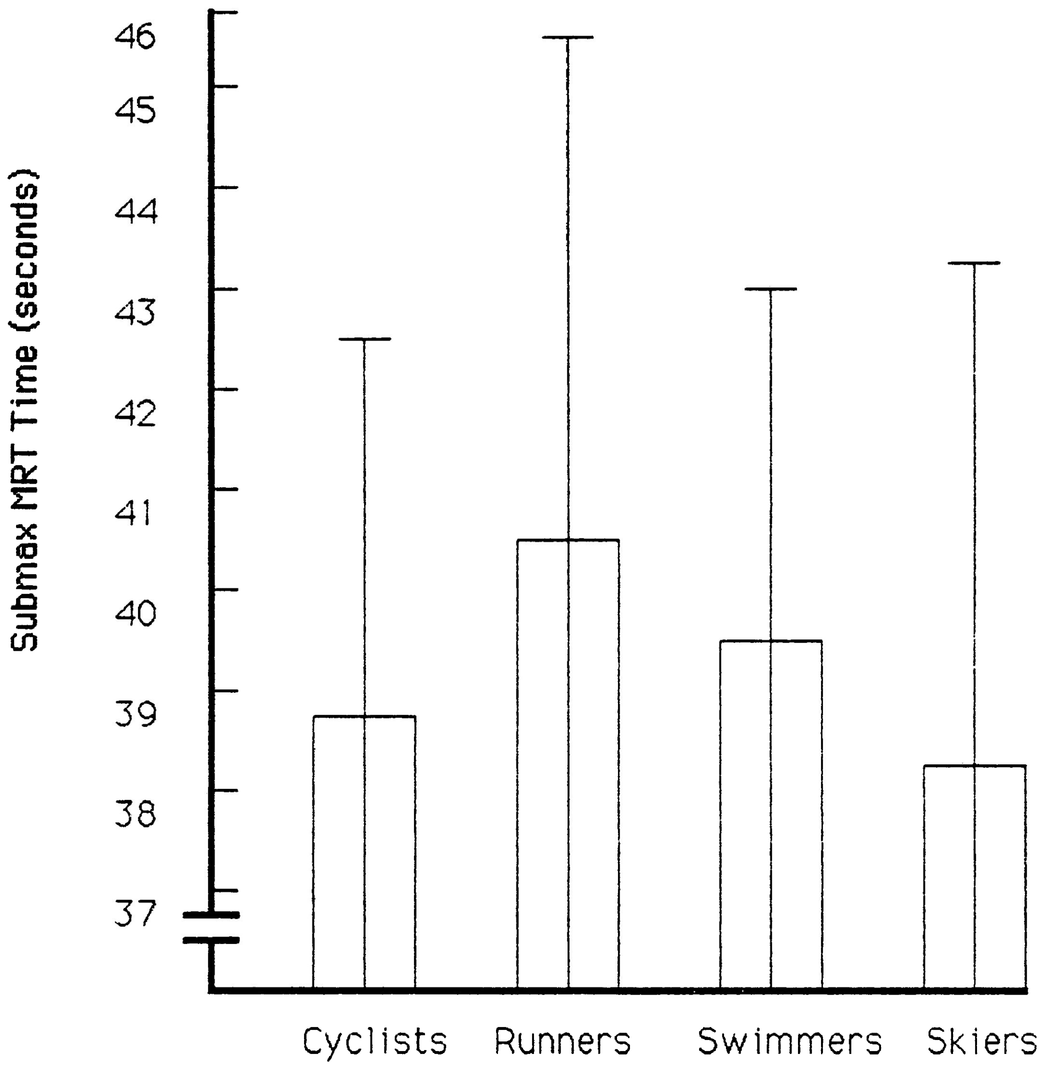


Figure 10

Submaximal MRT; Arm ergometer

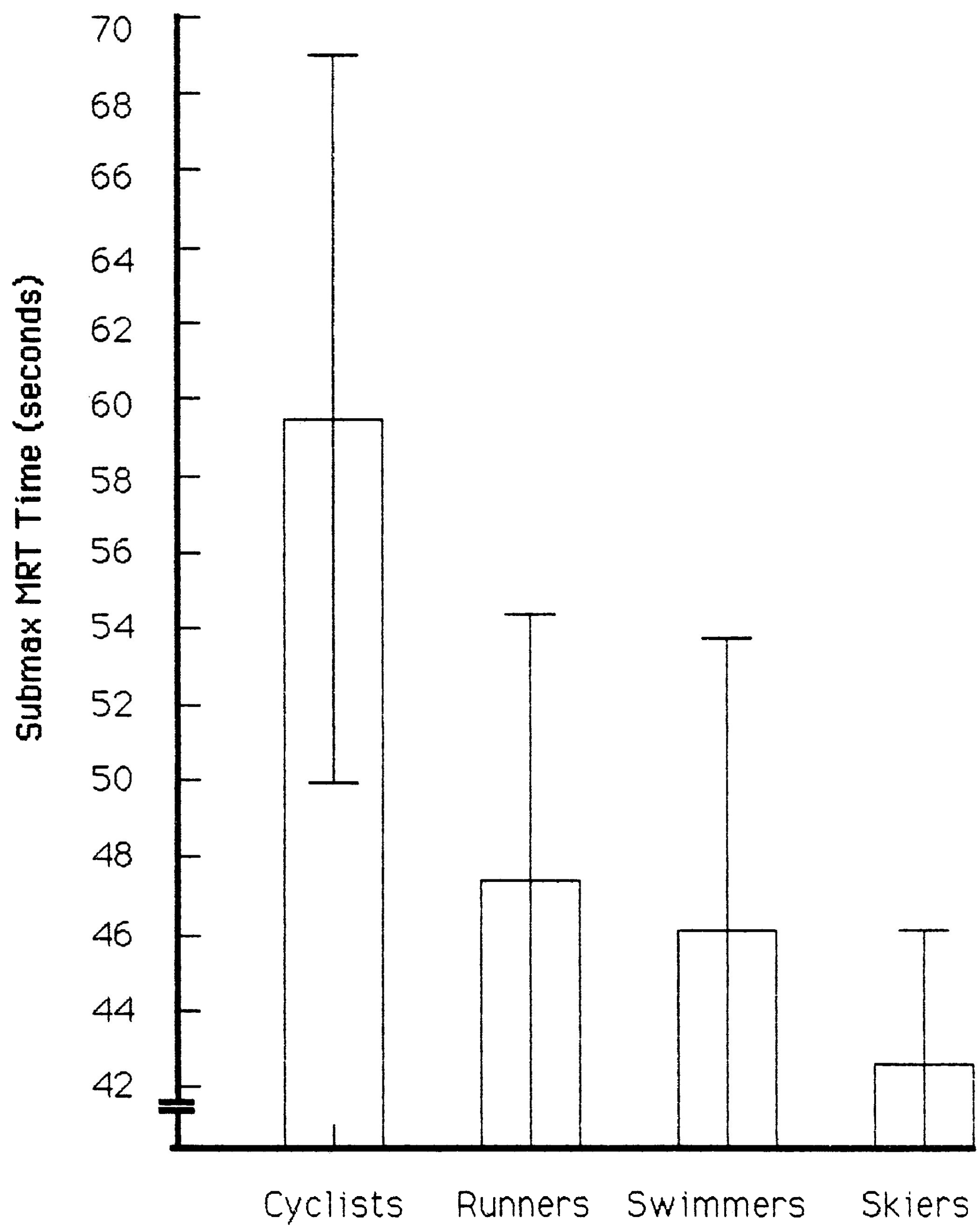


Table 15

Submaximal MRT; Treadmill: Analysis of Variance

Group	X	SD+/-	F-Ratios			
Cyclists	34.05	5.746		Cyclists	Runners	Swimmers
Runners	29.36	3.878	Runners	NS		
Swimmers	34.81	3.878	Swimmers	NS	4.66*	
Skiers	34.41	4.595	Skiers	NS	3.51*	NS

* = p<0.05

Table 16

Submaximal MRT; Cycle ergometer: Analysis of Variance

Group	X	SD+/-	F-Ratios			
Cyclists	38.70	3.680		Cyclists	Runners	Swimmers
Runners	40.41	5.369	Runners	NS		
Swimmers	39.54	3.581	Swimmers	NS	NS	
Skiers	38.12	4.935	Skiers	NS	NS	NS

NS = No significance (p>0.05) between groups

Table 17

Submaximal MRT; Arm crank; Analysis of Variance

Group	X	SD+/-	F-Ratios	Cyclists	Runners	Swimmers
Cyclists	59.40	9.761				
Runners	47.03	7.030	Runners	5.29*		
Swimmers	46.03	7.557	Swimmers	5.87*	NS	
Skiers	42.19	4.501	Skiers	12.82*	NS	NS

* = p<0.01

NS = No significance (p>0.05) between groups

Figure 11

Submaximal t1/2 $\dot{V}O2on$; Treadmill

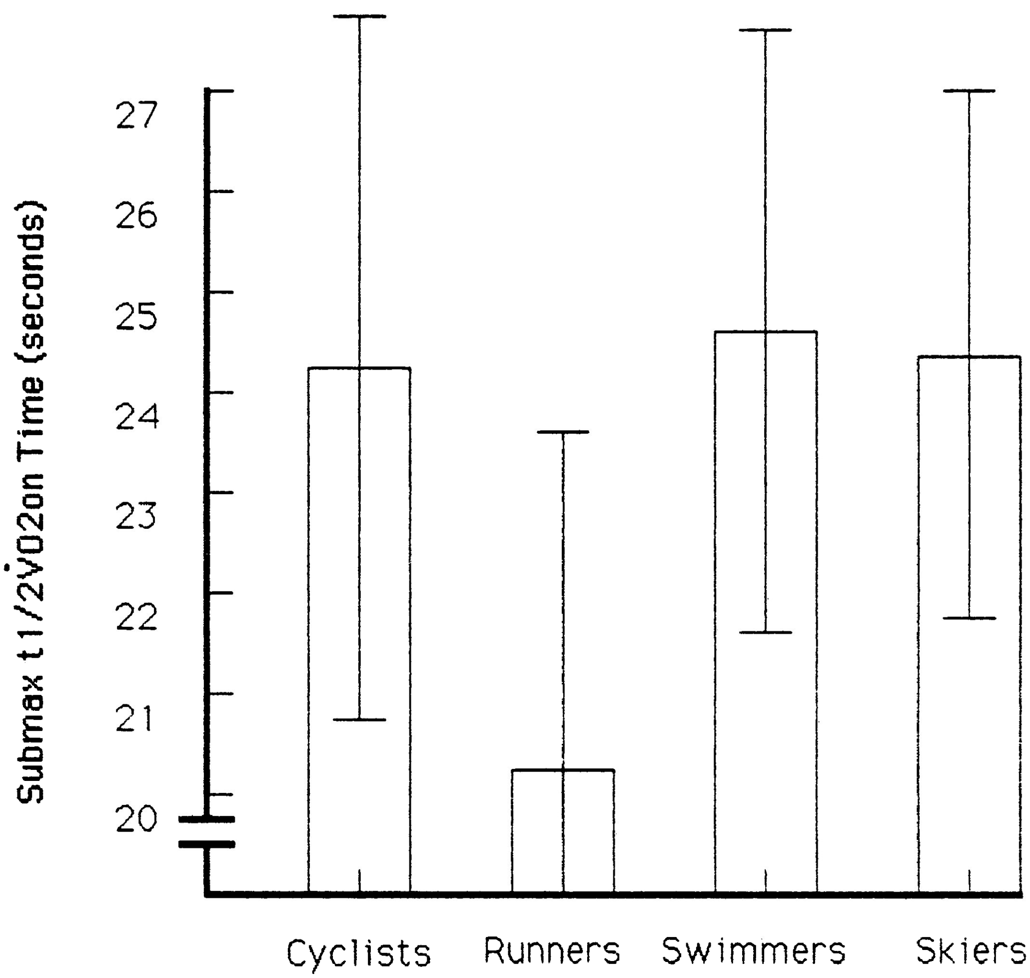


Figure 12

Submaximal t1/2V̇O2on: Cycle ergometer

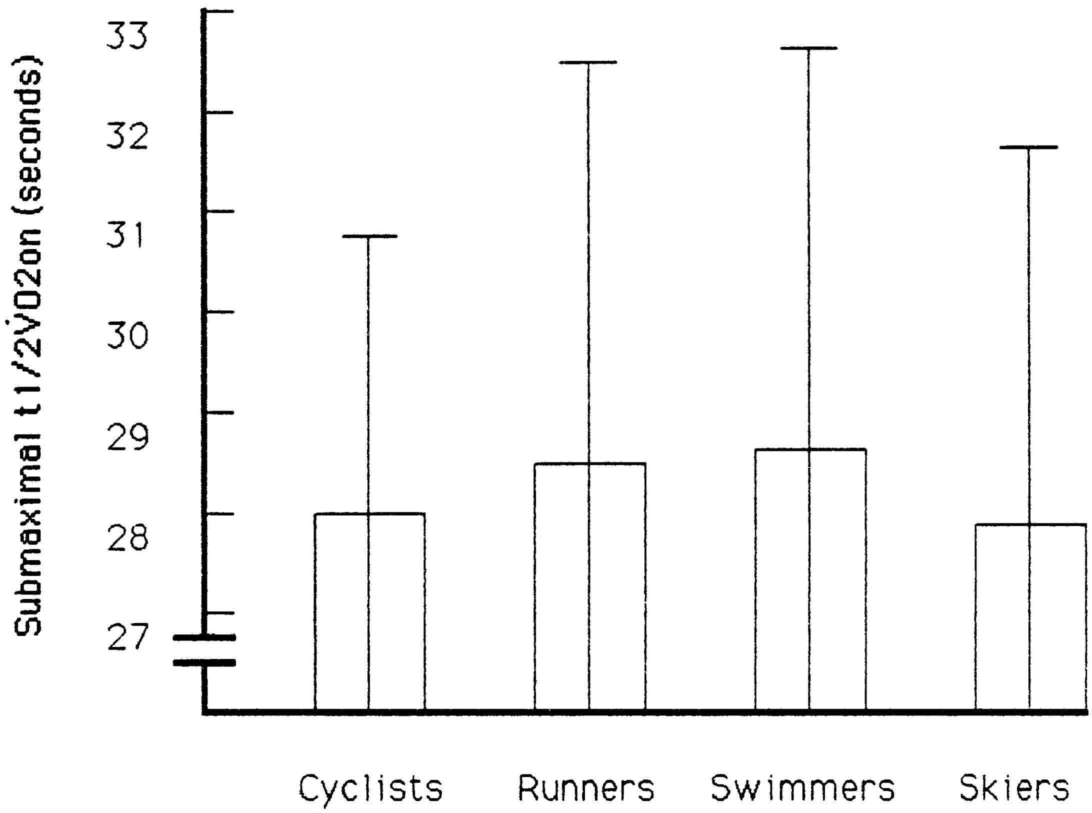


Figure 13

Submaximal t1/2V̇O2on; Arm ergometer

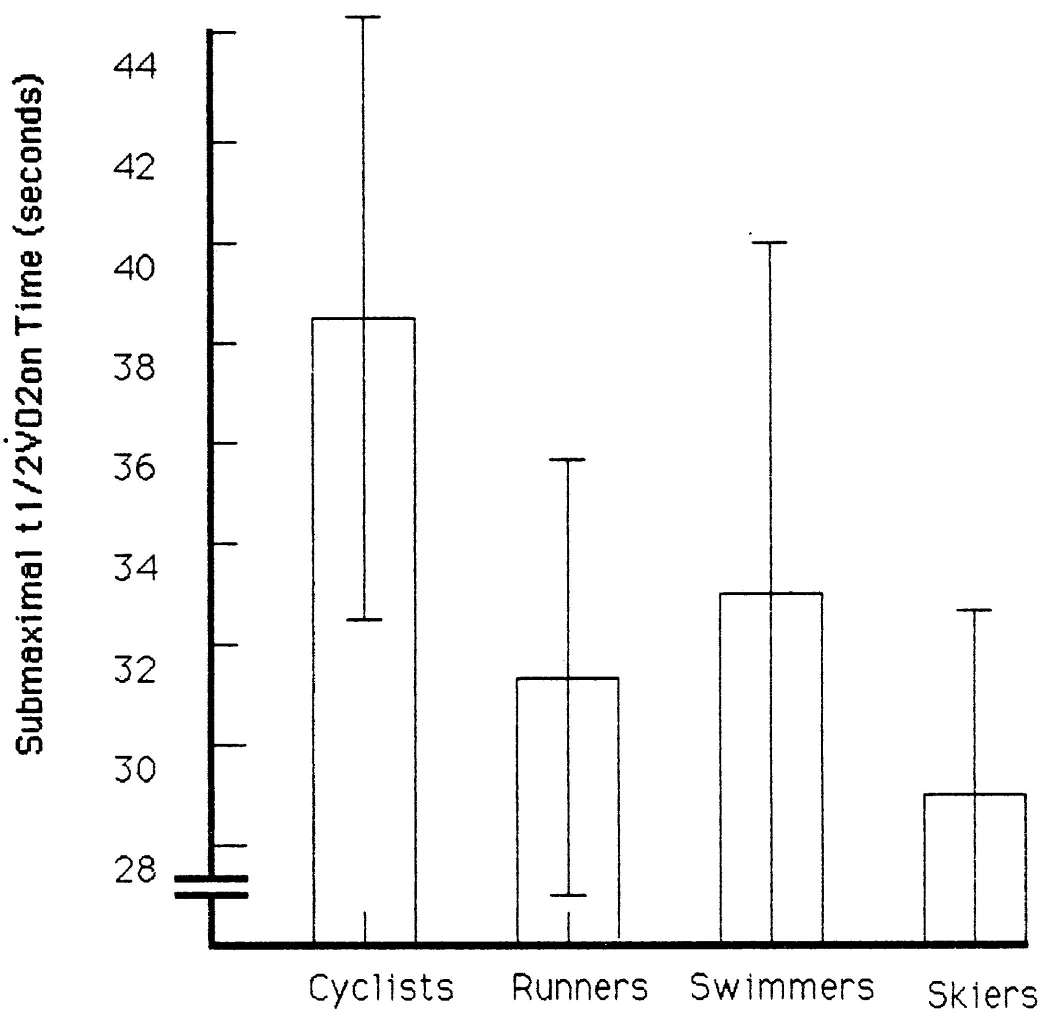


Table 18

Submaximal t1/2 $\dot{V}O_2$on; Treadmill: Analysis of Variance

Group	X	SD+/-	F-Ratios			
Cyclists	24.23	3.531		Cyclists	Runners	Swimmers
Runners	20.35	3.465	Runners	NS		
Swimmers	24.63	3.003	Swimmers	NS	4.36*	
Skiers	24.42	2.611	Skiers	NS	4.41*	NS

* = $p<0.05$

Table 19

Submaximal t1/2 $\dot{V}O_2$on; Cycle ergometer: Analysis of Variance

Group	X	SD+/-	F-Ratios			
Cyclists	28.04	2.809		Cyclists	Runners	Swimmers
Runners	28.42	4.275	Runners	NS		
Swimmers	28.51	3.215	Swimmers	NS	NS	
Skiers	27.90	3.840	Skiers	NS	NS	NS

NS = No significance ($p>0.05$) between groups

Table 20

Submaximal t1/2$\dot{V}O_2$on; Arm crank: Analysis of Variance

Group	X	SD+/-	F-Ratios	Cyclists	Runners	Swimmers
Cyclists	38.55	5.619				
Runners	31.33	4.489	Runners	5.04*		
Swimmers	33.04	6.957	Swimmers	NS	NS	
Skiers	29.04	3.543	Skiers	10.24**	NS	NS

* = p<0.05 ** = p<0.01

NS = No significance (p>0.05) between groups

Figure 12, Tables 14 and 19. The arm cranking submaximal t1/2$\dot{V}O_2$on results saw the cyclists with the slowest time (38.55 secs), compared to the runners (31.3 secs), the swimmers (33.04secs), and the cross-country skiers (29.04secs). These results were significant for the cyclists versus the runners ($p<0.05$), and for the cyclists versus the cross-country skiers ($p<0.01$), however, large standard deviations for the cyclists and the swimmers did not allow a significant result between these two groups; see Figure 9, Tables 11 and 18.

Maximal MRT and t1/2$\dot{V}O_2$on

The results for these tests revealed similar trends to those found for the submaximal tests, however, despite considerable time differences, in seconds, analysis of variance found there to be no significant difference between the groups for each form of ergometry due to large standard deviations within each group and the small 'n' (sample) involved in this study. The overall results for these tests are shown by Table 21.

The runners produced the fastest times for the treadmill maximal MRT (Figure 14 and Table 22) and maximal t1/2$\dot{V}O_2$on (Figure 17 and Table 25). The cycle ergometer maximal results were relatively close for all four groups, both for the MRT test (Figure 15 and Table 23) and the $t1/2\dot{V}O_2on$ test, (Figure 18 and Table 26). In contrast, the maximal MRT results for arm cranking showed the swimmers to be considerably faster (67.19 secs) than the cyclists, runners, and cross-country skiers with times of 78.97, 76.31, and 78.28 seconds respectively; Figure 16 and Table 24. The maximal $t1/2\dot{V}O_2on$ results for arm cranking (Figure 19 and Table 27) were more closely grouped, particularly in the case of the runners (48.83) and the swimmers (48.35).

Post-Hoc Data Analysis

Due to the large standard deviations experienced with some of the results of the main raw data, and since the groups were already very small in statistical terms, it was felt that it would be justifiable to discard possible 'weaknesses' to each group. Thus, a revised set of data was subjected to statistical analysis, (Table 28). Essentially, the cyclists were reduced to four subjects with the loss of subject E.W. (despite being a good cyclist, this subject also participated at a reasonable level in cross-country skiing and distance running), the runners were also reduced to four with the loss of subject B.G. (an athlete who had commenced

Table 21

Group Means (in seconds); Maximal MRT and t1/2 $\dot{V}O_2$on

		Cyclists		Runners		Swimmers		Skiers	
	Mode	X	SD+/-	X	SD+/-	X	SD+/-	X	SD+/-
MAX	TM	37.91	4.780	32.22	9.968	39.18	7.100	36.30	4.710
MRT	LG	57.66	13.310	58.01	10.366	59.48	8.910	58.79	3.234
	AR	78.97	17.67	76.31	20.90	67.19	10.38	78.28	22.74
MAX	TM	27.43	3.584	23.02	8.325	28.66	3.883	26.22	3.610
t1/2 $\dot{V}O_2$on	LG	40.98	8.591	39.90	5.822	40.79	4.114	40.06	2.880
	AR	53.98	12.07	48.83	13.79	48.35	7.24	51.73	15.68

TM = Treadmill LG = Cycle ergometer AR = Arm crank

Figure 14

Maximal MRT; Treadmill

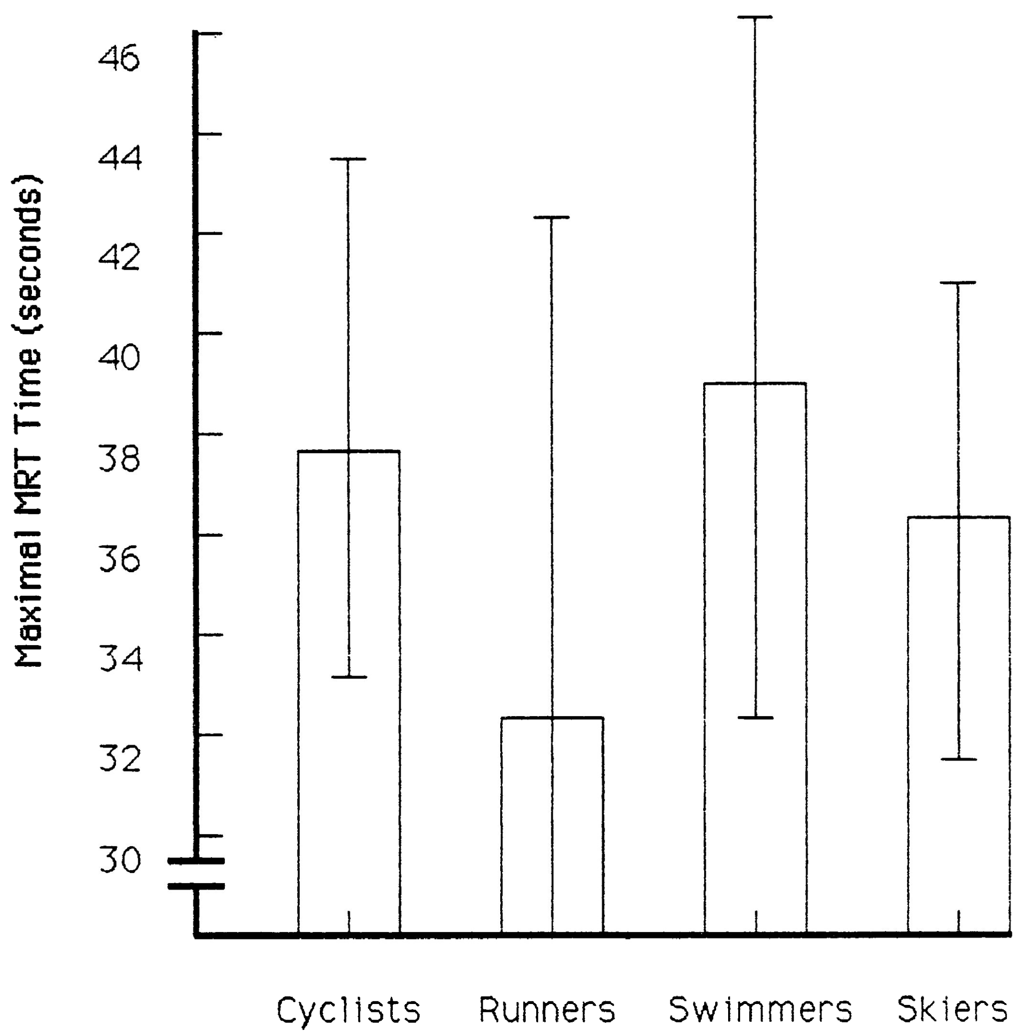


Figure 15

Maximal MRT: Cycle ergometer

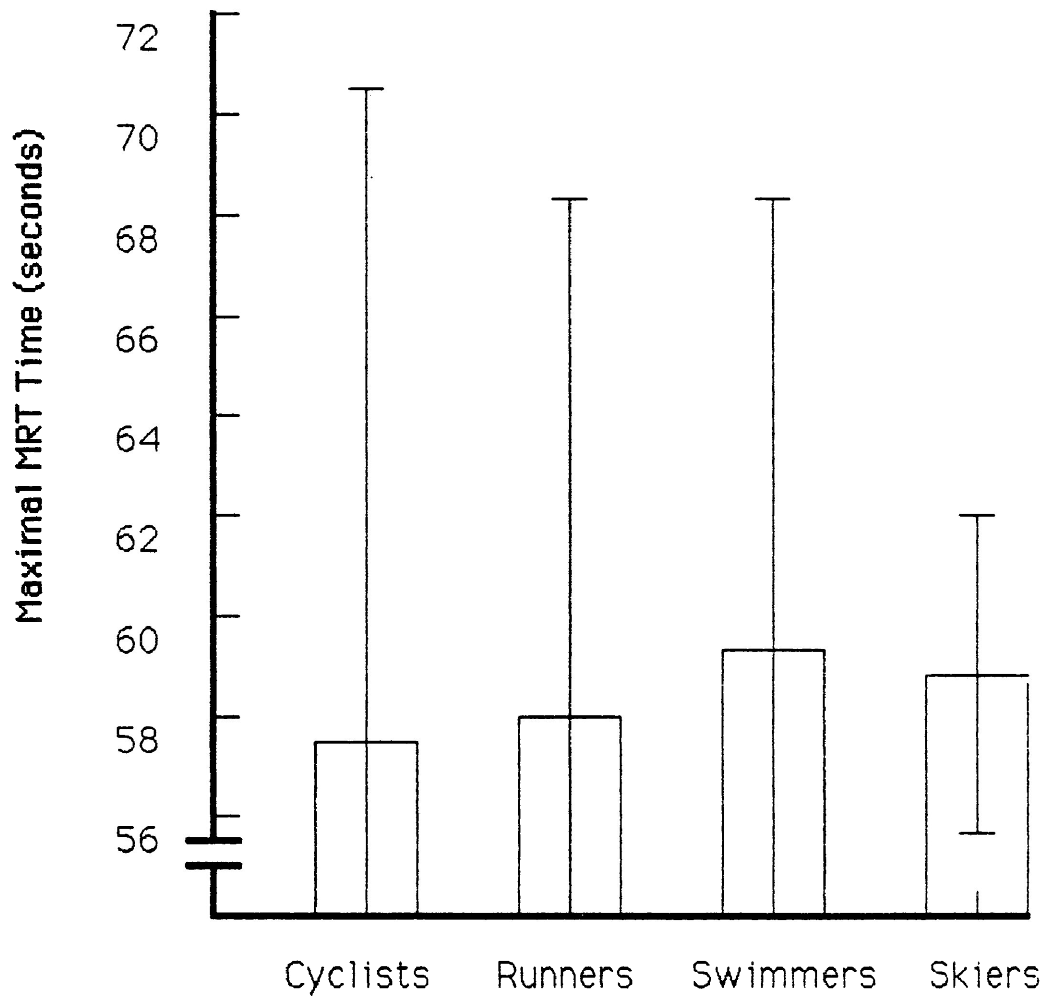


Figure 16

Maximal MRT; Arm ergometer

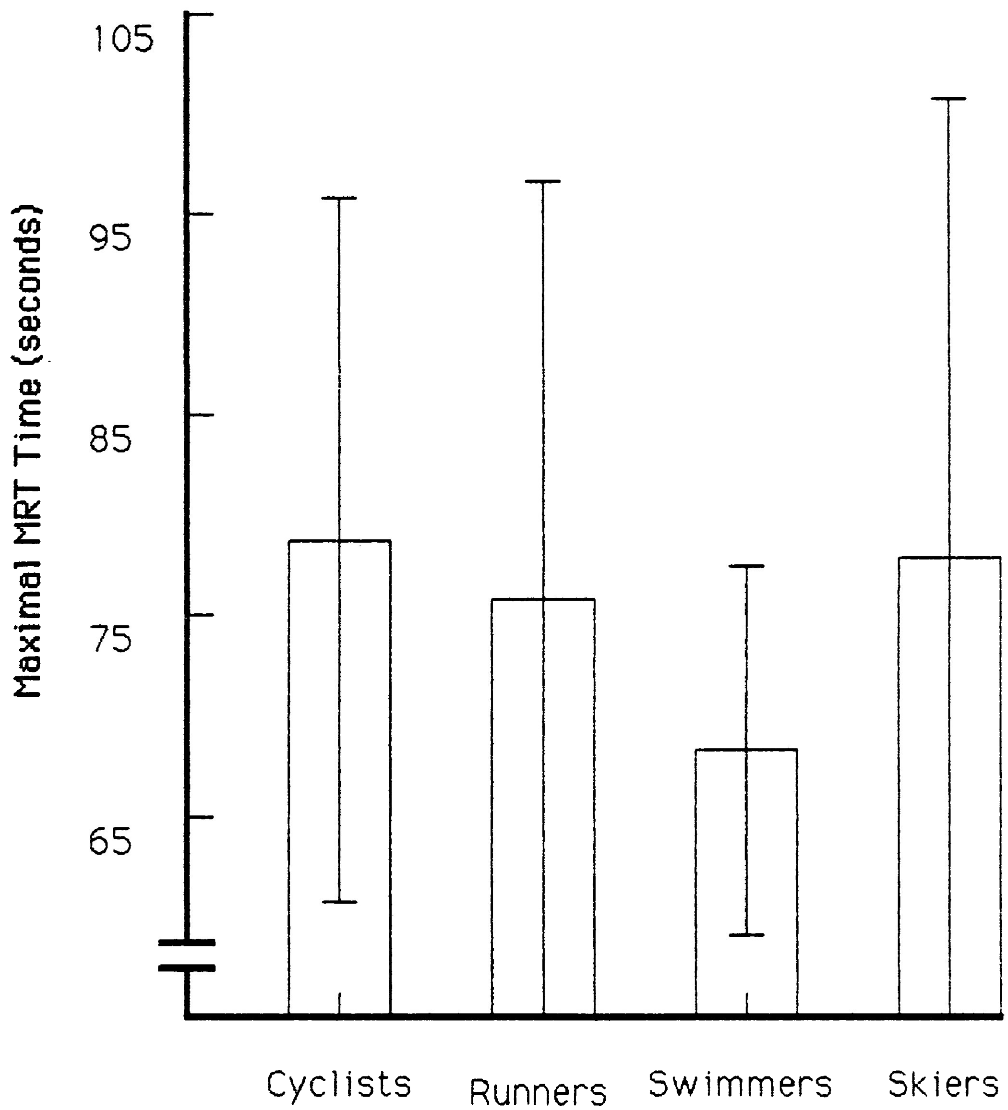


Table 22

Maximal MRT; Treadmill: Analysis of Variance

Group	X	SD+/-	F-Ratios			
Cyclists	37.91	4.780		Cyclists	Runners	Swimmers
Runners	32.22	9.968	Runners	NS		
Swimmers	39.18	7.100	Swimmers	NS	NS	
Skiers	36.30	4.710	Skiers	NS	NS	NS

NS = No significance (p>0.05) between groups

Table 23

Maximal MRT; Cycle ergometer: Analysis of Variance

Group	X	SD+/-	F-Ratios			
Cyclists	57.66	13.310		Cyclists	Runners	Swimmers
Runners	58.01	10.366	Runners	NS		
Swimmers	59.48	8.910	Swimmers	NS	NS	
Skiers	58.79	3.234	Skiers	NS	NS	NS

NS = No significance (p>0.05) between groups

Table 24

Maximal MRT; Arm crank: Analysis of Variance

Group	X	SD+/-	F-Ratios	Cyclists	Runners	Swimmers
Cyclists	78.97	17.67				
Runners	76.31	20.90	Runners	NS		
Swimmers	67.19	10.38	Swimmers	NS	NS	
Skiers	78.28	22.74	Skiers	NS	NS	NS

NS = No significance (p>0.05) between groups

Figure 17

Maximal t1/2V̇O2on; Treadmill

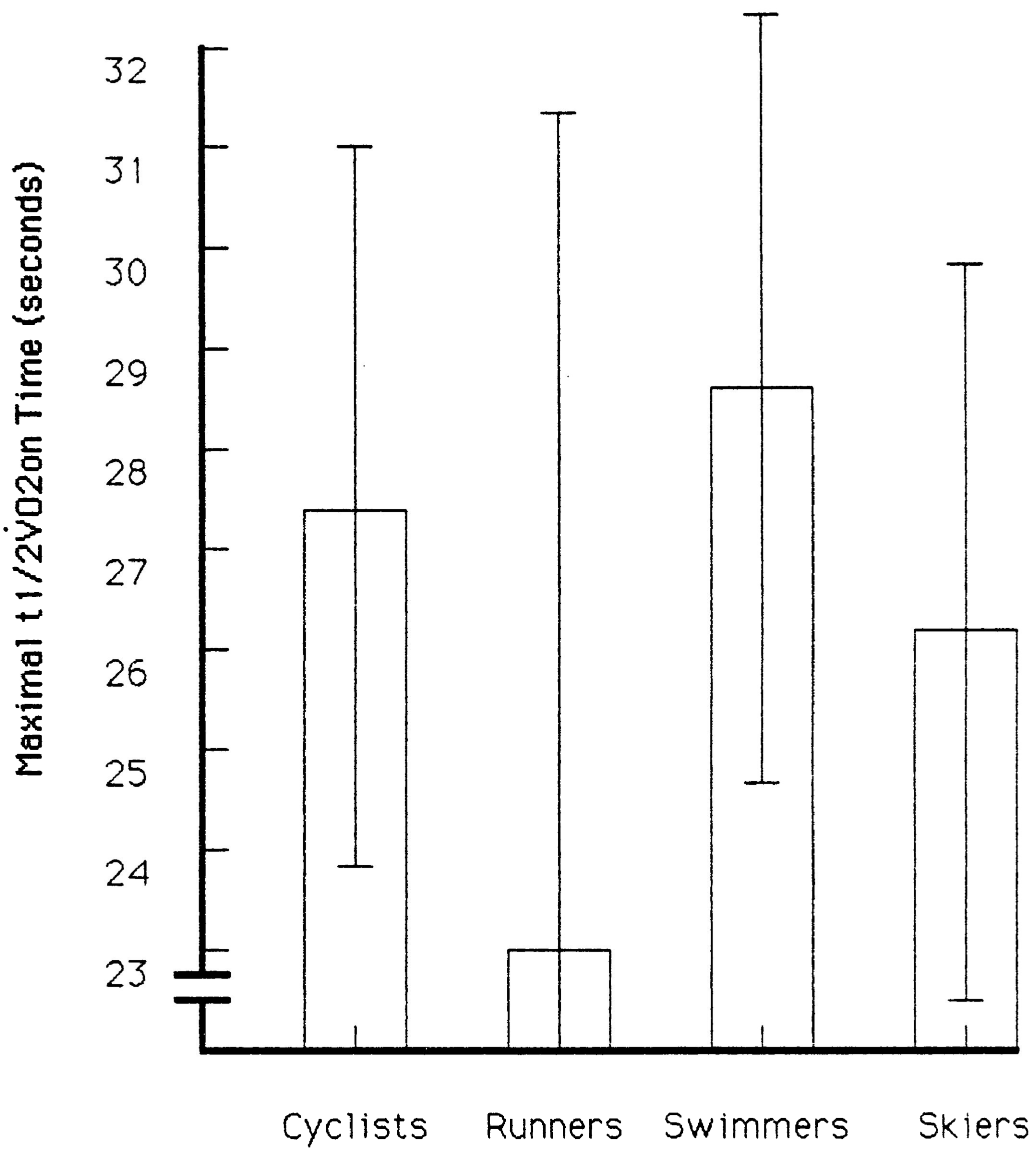


Figure 18

Maximal t1/2$\dot{V}$O2on; Cycle ergometer

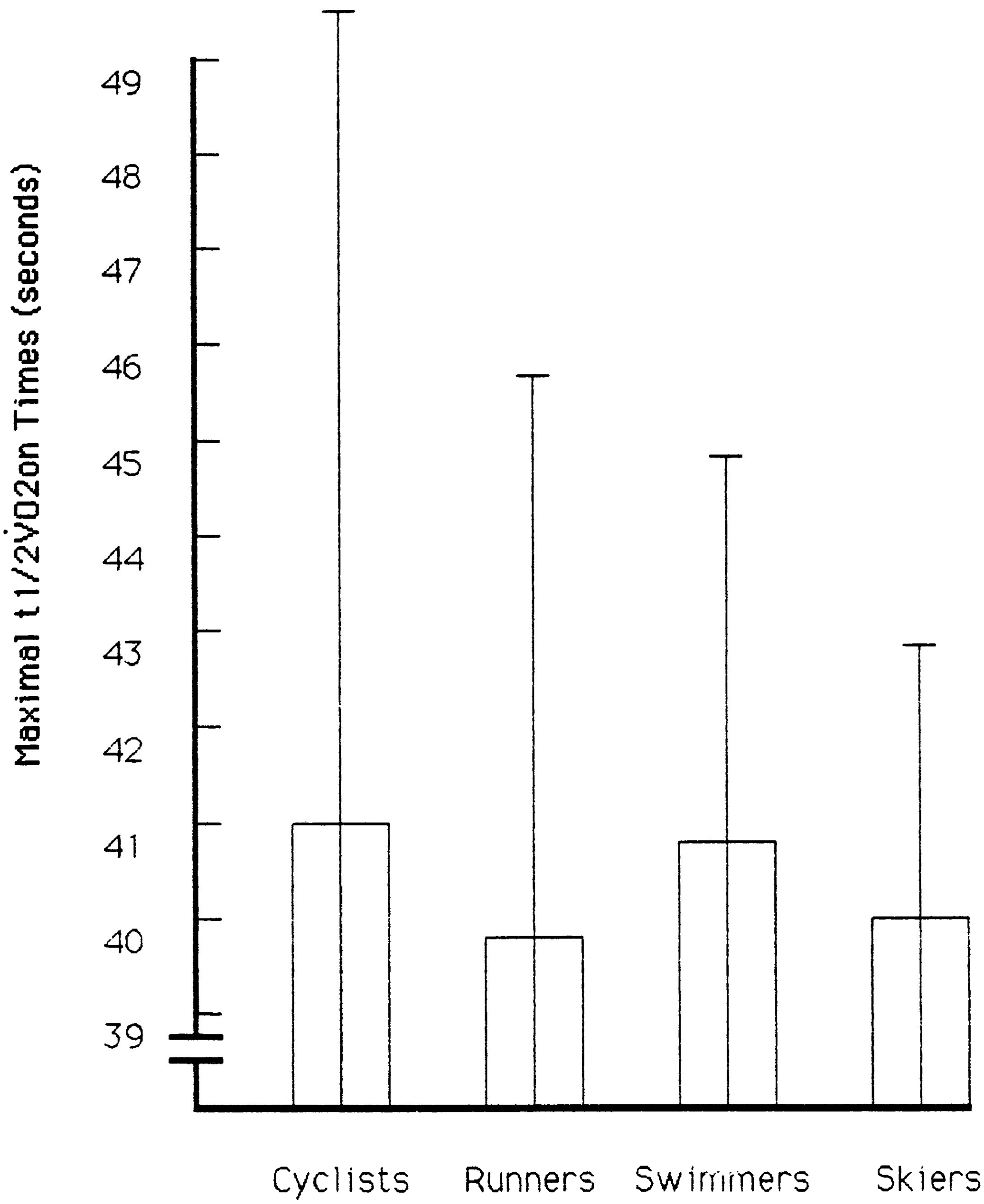


Figure 19

Maximal t1/2V̇O2on; Arm ergometer

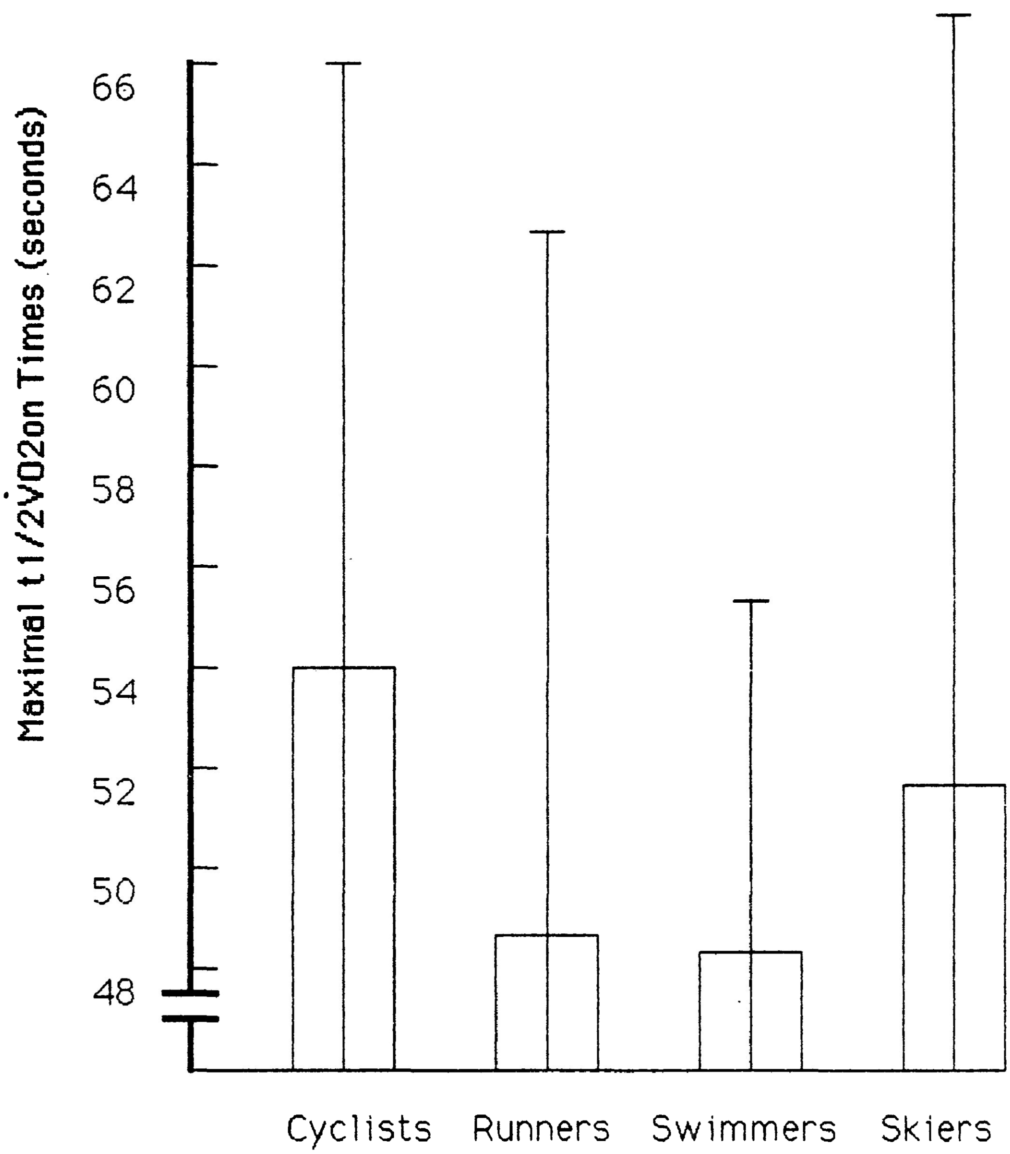


Table 25

Maximal t1/2$\dot{V}O_2$on; Treadmill: Analysis of Variance

Group	X	SD+/-	F-Ratios			
Cyclists	27.43	3.584		Cyclists	Runners	Swimmers
Runners	23.02	8.325	Runners	NS		
Swimmers	28.66	3.883	Swimmers	NS	NS	
Skiers	26.22	3.610	Skiers	NS	NS	NS

NS = No significance (p>0.05) between groups

Table 26

Maximal t1/2$\dot{V}O_2$on; Cycle ergometer: Analysis of Variance

Group	X	SD+/-	F-Ratios			
Cyclists	40.98	8.591	Cyclists	Runners	Swimmers	
Runners	39.90	5.822	Runners	NS		
Swimmers	40.79	4.114	Swimmers	NS	NS	
Skiers	40.66	2.880	Skiers	NS	NS	NS

NS = No significance (p>0.05) between groups

Table 27

Maximal t1/2$\dot{V}O_2$on; Arm crank: Analysis of Variance

Group	X	SD+/-	F-Ratios			
				Cyclists	Runners	Swimmers
Cyclists	53.98	12.07				
Runners	48.83	13.79	Runners	NS		
Swimmers	48.35	7.24	Swimmers	NS	NS	
Skiers	51.73	15.68	Skiers	NS	NS	NS

NS = No significance (p>0.05) between groups

serious triathlon training and was, therefore, cycling and swimming), and the swimmers were cut to two subjects (S.L. and J.D.) on the basis of age and experience. The cross-country skiers were considered to be a truly 'elite' group, as reflected by their overall impressive showing and the closeness of their test results, and, thus, were left as a complete group. A similar process of statistical analysis was followed as was seen with the original, and this information is presented via Tables 28 to 35. This 'post-hoc' data will be evaluated within Chapter V (Discussion).

Table 28

Revised subject data; Mean scores

Group	n	Age (yr) X	Age (yr) SD+/-	Height (cm) X	Height (cm) SD+/-	Weight (kg) X	Weight (kg) SD+/-
Cyclists	4	18.75	3.202	175.20	10.11	67.96	10.73
Runners	4	21.75	3.775	181.87	8.78	72.94	10.84
Swimmers	2	18.00	2.828	183.60	11.88	76.95	12.94
Skiers	5	21.40	1.342	175.80	9.47	69.21	8.96

($\dot{V}O_2$ l·min^{-1}) Group	Treadmill X	Treadmill SD+/-	Cycle X	Cycle SD+/-	Arm X	Arm SD+/-
Cyclists	4.5335	0.5318	4.2355	0.4887	2.4933	0.2979
Runners	4.9090	0.7696	4.6803	0.6393	3.2932	0.5394
Swimmers	4.9705	1.1688	4.4295	0.5339	3.8290	0.4398
Skiers	4.6738	0.7198	4.2372	0.4856	3.3820	0.5208

Table 28, continued

($\dot{V}O_2$ ml·kg^{-1}·min^{-1})	Treadmill		Cycle		Arm	
Group	X	SD+/-	X	SD+/-	X	SD+/-
Cyclists	67.150	7.108	62.650	5.902	36.902	2.481
Runners	66.975	2.513	64.125	2.595	45.025	1.401
Swimmers	64.100	4.384	57.150	3.465	49.900	2.687
Skiers	67.020	2.379	61.120	0.705	48.600	1.938

% Aerobic Power comparison to Treadmill score

	Cycle		Arms	
Group	%	SD+/-	%	SD+/-
Cyclists	93.43	1.24	55.05	3.663
Runners	95.63	4.14	67.175	4.066
Swimmers	90.35	10.54	78.15	9.546
Skiers	91.32	3.62	72.52	0.563

Table 29

Group Means (in seconds): Submaximal MRT and t1/2$\dot{V}O_2$on: Revised Data

		Cyclists		Runners		Swimmers		Skiers	
	Mode	X	SD+/-	X	SD+/-	X	SD+/-	X	SD+/-
Submax	TM	34.27	6.612	30.14	4.006	32.49	0.340	34.41	4.595
MRT	LG	37.80	3.569	40.90	6.385	39.68	0.675	38.12	4.935
	AR	56.80	9.055	50.02	2.482	48.56	11.216	42.19	4.501
Submax	TM	24.47	4.029	20.86	3.780	22.27	0.060	24.43	2.611
t1/2	LG	27.19	2.389	28.38	4.936	29.08	0.657	27.89	3.840
VO_2on	AR	36.52	3.830	33.13	2.295	34.95	8.859	29.04	3.543

TM = Treadmill LG = Cycle ergometry AR = Arm crank

Table 30

Group Means (in seconds); Maximal MRT and t1/2$\dot{V}O_2$on: Revised Data

	Mode	Cyclists X	Cyclists SD+/-	Runners X	Runners SD+/-	Swimmers X	Swimmers SD+/-	Skiers X	Skiers SD+/-
Max	TM	38.23	5.457	32.08	11.505	41.44	6.906	36.30	4.710
MRT	LG	53.13	9.960	59.29	11.509	61.72	4.083	58.79	3.234
	AR	75.30	18.050	67.90	10.530	59.19	10.960	78.28	22.74
Max	TM	27.62	4.110	22.67	9.569	29.90	4.409	26.22	3.610
t1/2	LG	38.17	6.757	40.85	6.258	43.47	2.659	40.06	2.880
VO_2on	AR	51.34	12.150	43.54	8.160	43.00	7.080	51.73	15.68

TM = Treadmill   LG = Cycle ergometry   AR = Arm crank

Table 31

Percentage variation from Treadmill scores and Analysis of Variance: Revised Data

(Treadmill $\dot{V}O_2max$ = 100%)

PVO_2legs

Group	X%	SD+/-	F-Ratios	Cyclists	Runners	Swimmers
Cyclists	93.43	1.24				
Runners	95.63	4.14	Runners	NS		
Swimmers	90.35	10.54	Swimmers	NS	NS	
Skiers	91.32	3.62	Skiers	NS	NS	NS

PVO_2arms

Group	X%	SD+/-	F-Ratios	Cyclists	Runners	Swimmers
Cyclists	55.050	3.663				
Runners	67.175	4.066	Runners	19.64**		
Swimmers	78.150	9.546	Swimmers	21.66**	4.57*	
Skiers	72.520	0.563	Skiers	14.35**	8.74**	NS

* = $p<0.05$ ** = $p<0.01$ NS = No significance ($p>0.05$)

Table 32

Aerobic Power; Absolute: Analysis of Variance: Revised Data

Treadmill data; $\dot{V}O_2max$ ($l \cdot min^{-1}$)

No significance ($p>0.05$) between groups

Cycle ergometry data; $P\dot{V}O_2legs$ ($l \cdot min^{-1}$)

No significance ($p>0.05$) between groups

Arm cranking data; $P\dot{V}O_2arms$ ($l \cdot min^{-1}$)

	Cyclists	Runners	Swimmers
Runners	6.74*		
Swimmers	20.70*	NS	
Skiers	9.09*	NS	NS

* = $p<0.01$

NS = No significance ($p>0.05$) between groups

Table 33

Aerobic Power; Relative: Analysis of Variance: Revised Data

Treadmill data; $\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)

No significance ($p>0.05$) between groups

Cycle ergometry; $P\dot{V}O_2legs$ ($ml \cdot kg^{-1} \cdot min^{-1}$)

	Cyclists	Runners	Swimmers
Runners	NS		
Swimmers	NS	8.05*	
Skiers	NS	NS	8.05*

Arm cranking; $P\dot{V}O_2arms$ ($ml \cdot kg^{-1} \cdot min^{-1}$)

	Cyclists	Runners	Swimmers
Runners	33.34*		
Swimmers	35.64*	9.67*	
Skiers	64.69*	9.51*	NS

* = $p<0.01$ NS = No significance ($p>0.05$) between groups

Table 34

Submaximal MRT; Analysis of Variance: Revised Data

Treadmill

No significance (p>0.05) between groups

Cycle ergometry

No significance (p>0.05) between groups

Arm crank

	Cyclists	Runners	Swimmers
Runners	NS		
Swimmers	NS	NS	
Skiers	10.16*	9.59*	NS

* = p<0.01   NS = No significance (p>0.05) between groups

Table 35

Submaximal t1/2$\dot{V}O_2$on: Analysis of Variance: Revised Data

Treadmill

No significance ($p>0.05$) between groups

Cycle ergometer

No significance ($p>0.05$) between groups

Arm crank

	Cyclists	Runners	Swimmers
Runners	NS		
Swimmers	NS	NS	
Skiers	9.23**	3.94*	NS

* = $p<0.05$ ** = $p<0.01$

NS = No significance ($p>0.05$) between groups

CHAPTER V

DISCUSSION

Aerobic Power

The initial incremental $\dot{V}O_2max$ and $P\dot{V}O_2$ tests performed on all three modes of ergometer (treadmill, cycle, arm crank) and previously illustrated (Figures 1 to 6; Tables 6 to 11), show that there are certain key characteristics emphasising differences between these athletes. The treadmill did not produce statistically significant results ($p>0.05$) between the groups at the absolute level ($\dot{V}O_2$ in $l{\cdot}min^{-1}$), however, in gross terms the runners mean $\dot{V}O_2max$ of 4.7888 $l{\cdot}min^{-1}$ shows a clear superiority over the swimmers' mean $\dot{V}O_2max$ of 4.461 $l{\cdot}min^{-1}$. It is interesting to note that, from a subjective point of view and despite some habituation to the equipment, the swimmers were not particularly 'comfortable' when working on the treadmill. The cyclists (mean $\dot{V}O_2max$ = 4.5814 $l{\cdot}min^{-1}$) and the cross-country skiers (mean $\dot{V}O_2max$ = 4.6738 $l{\cdot}min^{-1}$) also displayed better $\dot{V}O_2max$ values than the swimmers on the treadmill. These differences were further emphasised when the data was considered at the relative level ($\dot{V}O_2$ in $ml \cdot kg^{-1} \cdot min^{-1}$), with the cyclists, runners, and cross-country skiers all returning values of over 67 $ml \cdot kg^{-1} \cdot min^{-1}$, whilst the swimmers could only manage a score of 61.06 $ml \cdot kg^{-1} \cdot min^{-1}$. These values were significantly different ($p<0.01$) for the runners and skiers as compared to the swimmers. Obviously, the fact that the swimmers were the heaviest group (although not significantly so; $p>0.05$) had a major affect on these 'relative' treadmill scores. This aspect lends support to the Eriksson, Berg, and Taranger (1978) suggestion that a relative $\dot{V}O_2max$ expressed in $ml \cdot kg^{-1} \cdot min^{-1}$ may cause inaccurate evaluations of aerobic capacity for swimmers, and that absolute values ($l \cdot min^{-1}$) or O_2 consumption relative to height ($ml \cdot height^2 \cdot min^{-1}$) should be used since swimmers do not support their entire bodyweight when swimming.

The cycle ergometer $P\dot{V}O_2$ tests provided similar results to the treadmill in that there were no significant differences ($p>0.05$) at the absolute level, although the runners, somewhat surprisingly, produced a noticeably higher average $P\dot{V}O_2$ (4.6264 $l \cdot min^{-1}$) than the cyclists (4.2966

$l \cdot min^{-1}$), who had been expected to produce scores closer to their treadmill values than the other groups due to the nature of this test and it's specificity to the cyclists' sports involvement. Table 12 shows that the cyclists performed at 93.76% of their treadmill $\dot{V}O_2max$ when on the cycle ergometer, whereas the runners exhibited only a 3.02% reduction (96.98%) from their treadmill score. The swimmers produced a mean $P\dot{V}O_2$ for cycling of 4.1882 $l \cdot min^{-1}$ (95.34% of their treadmill score), whilst the cross-country skiers could only manage 91.32% of their treadmill value (4.2372 $l \cdot min^{-1}$). In relative terms, this information produced a significantly higher ($p<0.01$) mean $P\dot{V}O_2$ for the runners (65.12 $ml \cdot kg^{-1} \cdot min^{-1}$) than either the swimmers (57.52 $ml \cdot kg^{-1} \cdot min^{-1}$) or the cross-country skiers (61.12 $ml \cdot kg^{-1} \cdot min^{-1}$). The results of the cyclist DZ do not seem to have had a significant effect on the mean relative $P\dot{V}O_2$ for the cyclists group as an initial glance might expect, in that the mean score excluding this subject would have been 65.65 $ml \cdot kg^{-1} \cdot min^{-1}$ for the cycle ergometer, compared to 70.525 $ml \cdot kg^{-1} \cdot min^{-1}$ for the treadmill; this would still have yielded a percentage value (cycle vs. treadmill) of 93.09%.

The arm cranking $P\dot{V}O_2$ results revealed a clear advantage for the swimmers, with this group recording the highest O_2 consumption levels at both the absolute and relative levels (3.562 $l{\cdot}min^{-1}$ and 49.2 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ respectively). In contrast, the cyclists were significantly lower ($p<0.01$) than the other three groups at the absolute and relative levels. In terms of percentage variation from their respective treadmill $\dot{V}O_2max$ scores, the cyclists exhibited the greatest fall-off with an arm cranking $P\dot{V}O_2\%$ score of 56.96%. The runners recorded 70.92% and the cross-country skiers 72.52%. The swimmers, however, returned a mean value of 80.28%, and illustrates a distinct variation between this group and the cyclists, runners, and cross-country skiers. Additionally, the runners and cross-country skiers exhibit a greater than 10% increase over the cyclists for this measurement.

Thus, it has been shown that the four groups are not too widely distributed in their percentage variations for the cycle ergometer relative to the treadmill. Whilst the runners produced the closest value on the cycle ergometer to their treadmill score, all four groups were well above the 90% mark. This result may be related to a number of aspects, such as the large muscle masses involved in cycling, and the involvement of the legs in 'day-to-day' living. By contrast, the wide disparity between the arm cranking percentage results may be an indication of the degree to which the arms are involved in the four sports activities. Obviously, the arms and shoulders (together with the back muscles) are of paramount importance for swimmers and the ability to reach 80.28% of their $\dot{V}O_2max$ score by arm cranking shows this sport's specific adaptation. The relatively high percentage scores of the runners (70.92%) and the cross-country skiers (72.52%) for the arm crank versus the treadmill also shows a high degree of 'arm' involvement in their respective activities. Whilst the cross-country skiers' arm usage is obvious, the runners' are less so in that the arm action when running (particularly for distance running) is usually observed as a 'balancing' or 'reaction' motion. However, the arm action does contribute to overall efficiency of a runner's style and, where distance running is concerned, this action may take place at an intensity that encourages improved O_2 uptake by the arms. The low relative percentage of the cyclists arm $P\dot{V}O_2$ could be due to the lack of actual movement of the arms when cycling and that the muscle action of the arms is essentially of an isometric nature, and, thus, may not enhance improved O_2 consumption to as high a degree as with runners and cross-country skiers.

When discussing the differences between various 'populations' as regards certain parameters, it is normally assumed that the sample populations have an established minimum level of homogeneity. If this 'homogeneity' does not exist, then the degree to which the validity of any differences in the experimental parameters are regarded should be open to debate. In this investigation, the 'homogeneity' may be questioned due to the imbalance between the swimmers' group and the other three groups in terms of age variation and possibly performance standard. The swimmers were significantly younger ($p<0.05$) than the other three groups. However, in terms of specific sports ability, swimmers tend to be younger at peak than other athletes, although this may well be due to socio-economic reasons than to purely physiological considerations.

Obviously, the small size of the groups used in this investigation may also be subject to criticism, however, when moving into the area of 'elite' groups, the population of any such group is immediately reduced and this, together with problems such as geographical disparity of possible subjects and the fact that physiological experimentation requires considerable time commitment from all concerned, means that 'large' populations are hard to achieve in the 'real' world'.

The variations found between the groups for the aerobic power scores provided obvious justification for the investigation of the ventilatory kinetics involved, particularly when considering the idea that 'statistical significance' pertaining to dynamic concepts, such as those occurring frequently within human physiological function, may be an unnecessary prerequisite in positively identifying the existence of some process or the difference between 'samples'. This statement should not be seen to be a waiver of thorough preparation of experimental design and data analysis, but as a realisation that, whilst statistically a given sample variation may not be significant, in real terms as a 'working physiological process' the variation may be extremely 'significant'.

Ventilatory Kinetics

Evaluation of the transient oxygen uptake kinetics of these four sports via their submaximal and maximal responses to the three modes of ergometry reveals some interesting trends, although not all of these are deemed to have statistical significance, (Tables 14 and 21).

The results from the treadmill tests show a clear pattern with the runners producing the fastest transient oxygen uptake times, both at submaximal and maximal work levels. However, these times were only significant ($p<0.05$) for the submaximal responses when compared to the swimmers and the cross-country skiers. The maximal responses were statistically jeopardised by the large standard deviations of the groups, although the mean time differences between the groups should not be ignored, since, in physiological terms, a time difference of approximately three to four seconds for a process that only takes around 32 seconds from start to fininsh (i.e., runners' group: maximal MRT treadmill = 32.22 seconds) should arouse interest and generate future investigation. Indeed, similar 'non-significant' differences permeate throughout this investigation. As regards the treadmill, the other three goups were relatively closely grouped for their submaximal t1/2 $\dot{V}O_2$on and MRT times, although at the maximal level the cross-country skiers showed slightly faster responses than the cyclists and swimmers. Thus, the treadmill findings support the Powers et al. (1985) suggestion that those athletes, of similar trained states, with a higher $\dot{V}O_2$max will exhibit faster transient oxygen uptake responses at the onset of work than those who have lower $\dot{V}O_2$max values.

The response times for the cycle ergometer produced some unexpected results, since the cyclists returned the overall fastest times despite not having had the highest $P\dot{V}O_2$. This contradicts the trend demonstrated by the treadmill results and the findings of Powers et al. (1985), and lends support to Lake et al. (1986), who said that the level of $\dot{V}O_2$max does not seem to 'dictate' the adjustment rate of $\dot{V}O_2$ at the onset of exercise in athletes of a similar trained level. However, the range in the response times (Tables 14 and 21), both at submaximal and maximal levels, is relatively small and there were no significant differences ($p>0.05$) found between the groups. It should be noted that whilst the cross-country skiers produced the fastest submaximal $t1/2\dot{V}O_2$on and MRT response times, they could not repeat this at the maximal level. Additionally, the cyclists produced the slowest maximal $t1/2\dot{V}O_2$on response for the cycle ergometer, yet went on to record the fastest maximal MRT response time. The swimmers, at the submaximal level, produced a 'slow' time for the t1/2$\dot{V}O_2$on response (swimmers; 28.51 seconds/runners; 28.42 seconds), but went on to record a 'comfortably' faster time than the runners for the MRT (39.54 seconds vs. 40.41 seconds). Obviously, a number of factors may be responsible for these results, not least the small 'n' involved in this study. However, a more pressing concern should be voiced in that perhaps accurate evaluation of ventilatory kinetics should involve a slightly more advanced, or evolutionary, approach. This aspect will be addressed more fully at a later stage.

The results for the arm ergometer show that at the submaximal level, the cross-country skiers had the fastest response times (Table 14), but that at the maximal level the swimmers returned the fastest $\dot{V}O_2$ adjustment times (Table 21). Additionally, the runners produced a faster submaximal t1/2$\dot{V}O_2$on time (31.33 seconds) compared to the swimmers (33.04 seconds), but went on to produce a slower submaximal MRT time than the swimmers (47.03 seconds vs. 46.03 seconds). The cyclists produced the slowest response times at all levels and these were significant for the submaximal t1/2$\dot{V}O_2$on, when compared to the runners'

($p<0.05$) and the cross-country skiers ($p<0.01$), and the submaximal MRT, when compared to the runners, swimmers, and cross-country skiers ($p<0.01$). However, despite the slower response times for the maximal tests, the cyclists times were not significantly different ($p>0.05$) than those for the other three groups. The relatively 'slow' response times of the swimmers' group for the submaximal work are surprising considering that this group displayed such a superiority over the other groups for arm $P\dot{V}O_2$ and managed to produce the fastest times at maximal work. Figures 8 to 19 illustrate the variations for these response times between the subject groups at the given test levels.

Due to the conflicting nature of these results, albeit relatively small, it was decided to perform a revised data 'post-hoc' analysis by discarding certain subjects who were thought to have training effects which might compromise the reliability of their test results. It was, of course, realised that this would further reduce an already small 'n' for the study, however, it was thought to be justifiable under the limitations of the investigation. The 'process' has been described in Chapter III (Methodology) and the revised information is provided via Tables 29 to 35. Unfortunately, this approach did not produce any significant changes in the original results and essentially mirrored the initial findings.

Thus far, it is possible to remark that, despite not having the support of statistical significance at all levels, there are distinct differences in the time component aspect of the ventilatory kinetics of these four sports groups. These differences may be seen to involve two levels, namely an overall difference between the groups and a specific difference between limbs at the individual level. Although some conflicting results were found, a trend towards the idea established by Hagberg et al. (1978) and Powers et al. (1985) that those subjects with a high $\dot{V}O_2max$ have faster $t1/2\dot{V}O_2on$ responses was found (Figure 20 and Table 36). Indeed, an analysis of this $\dot{V}O_2max/t1/2\dot{V}O_2on$ relationship using the data from this investigation yielded a significant negative correlation ($p<0.01$) of $r = -0.887$ overall.

Pendergast et al. (1980) suggest that an increase in the rate of $\dot{V}O_2$ uptake, and, thus, a faster oxygen transient response in a trained athlete is due to changes in some form of control mechanism at the peripheral level. The increase in the number of mitochondria within endurance trained muscle is well-documented and Hickson et al. (1978) indicated that this

Figure 20

Relationship between $\dot{V}O2max$ and $t1/2\dot{V}O2on$

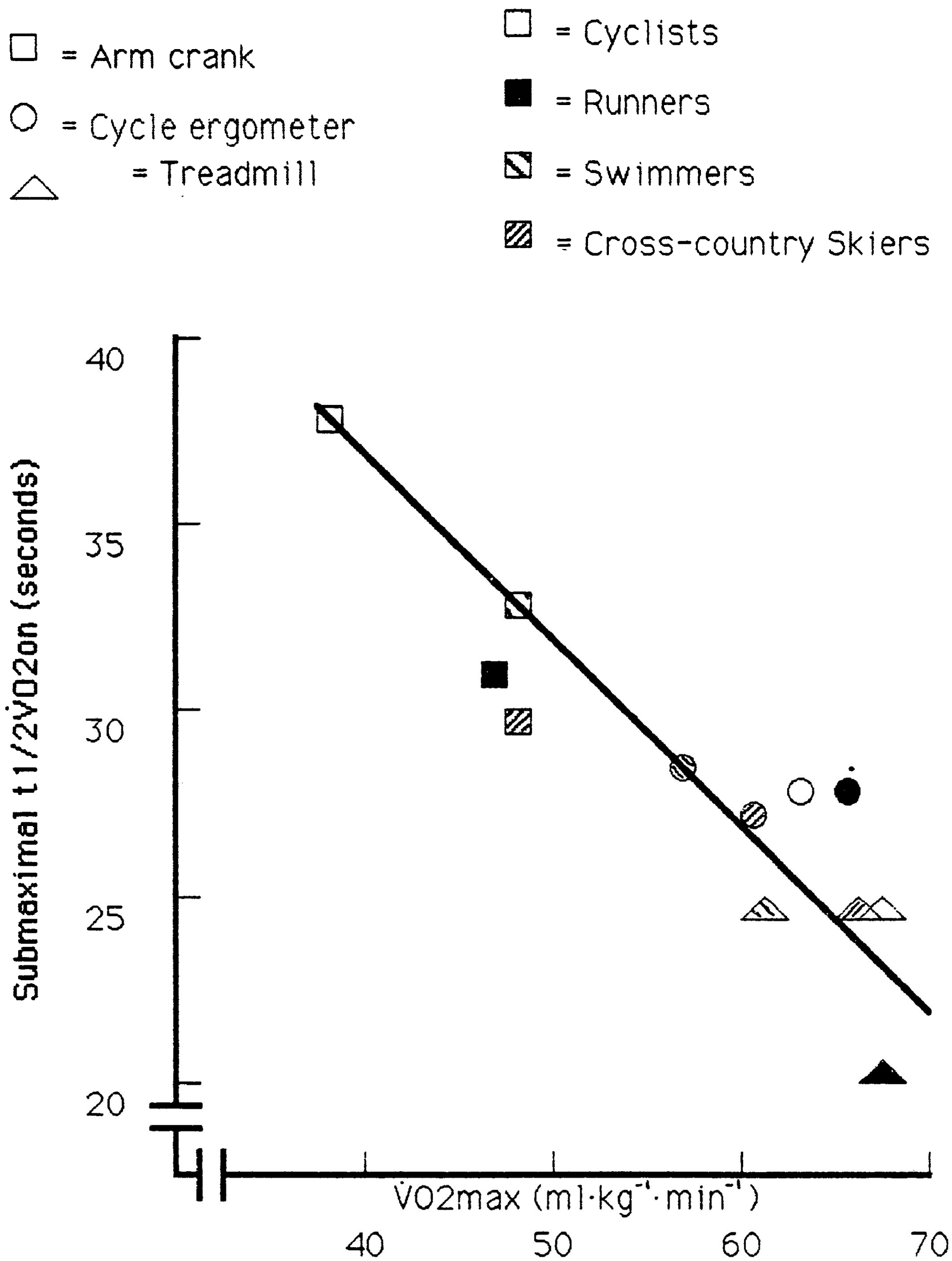


Table 36

Relationship between $\dot{V}O_2$max and submaximal t1/2$\dot{V}O_2$on response times

r = -0.887		Mode		
Group	Data	Treadmill	Cycle	Arm Crank
Cyclists	$\dot{V}O_2$	67.82	63.36	38.42
	t1/2	24.23	28.04	38.55
Runners	$\dot{V}O_2$	67.08	65.12	47.16
	t1/2	20.35	28.42	31.33
Swimmers	$\dot{V}O_2$	61.06	57.52	49.20
	t1/2	24.63	28.51	33.04
Skiers	$\dot{V}O_2$	67.02	61.12	48.60
	t1/2	24.42	27.90	29.04

increase in mitochondrial concentration may allow a faster response of respiratory mechanisms to stimulus demands. Since the number of mitochondria present increases within endurance trained muscle, the increase in $\dot{V}O_2max$ or $P\dot{V}O_2$ of the endurance trained individual compared to the pre-trained state is not surprising. Additionally, at the submaximal level, if the number of mitochondria within a muscle has been increased due to endurance training, a single mitochondrion does not have to reach the same level of oxygen uptake in order to establish a given $\dot{V}O_2$ as when there were fewer mitochondria. Scheuer and Tipton (1977) state that increased oxygen utilisation by the cell may be due mainly to increased oxygen extraction across the 'peripheral bed'. Also, the endurance training regimes followed by elite athletes increase the contribution of certain enzymes to maintaining a high level of aerobic metabolism in the mitochondria and even relatively small increases in the capacities of such enzymes (e.g., carnitine transferase and oxoglutarate dehydrogenase) are thought to be of paramount importance to elite performance. Indeed, Davies and Thompson (1979) have clearly shown that elite endurance athletes are able to perform at extremely high percentages of their

$\dot{V}O_2max$ for extended periods, which means that such athletes are able to metabolise glucose at high rates and that virtually all of the pyruvate produced through the aerobic pathways is converted to acetyl- CoA for complete oxidation by the Krebs cycle. Thus, highly trained endurance atletes are seemingly able to sustain a high glycolytic rate without the usual concurrent rise in lactate level, due to mechanisms acting to maintain cytosolic pyruvate and NADH (the two substrates for lactate dehydrogenase) at low concentrations.

It is in this region of discussion that a link between the concept of 'anaerobic threshold' and the transient oxygen uptake response may be hypothesised. Brooks (1985) states that the lactate anaerobic threshold is not due to a sudden increase in production of lactate (although increased production per se must not be totally discounted), but to a difference between the rate of removal and the rate of accumulation of lactate. Since endurance training has been demonstrated to increase oxidative capacity and reduce transient oxygen uptake response times (Pendergast et al., 1980; Cerretelli et al., 1979; Hickson et al., 1978.), higher anaerobic thresholds should also be seen in endurance athletes. Additionally, after a period of endurance training, Karlsson et al. (1972) showed that blood lactate concentrations increased at a lower rate for a given workload than they did prior to training.

As an ancillary issue, this investigation found the groups to have differing abilities when performing the constant load maximal tests as compared to the incremental load maximal tests. The cross-country skiers were able to match and improve upon all their incremental load $\dot{V}O_2$max and $P\dot{V}O_2$ scores via the constant load tests, whilst the cyclists were also close, failing only on the treadmill where they scored a group mean of 99.6% for the constant load versus the incremental load. On the other hand, the runners did not manage to repeat their incremental load maximal scores via the constant load protocols, particularly when arm cranking. The swimmers produced the lowest relative values for the constant load tests and, as with the runners, did not match their incremental load maximal scores.

To recap upon the main investigation, it can be seen that differences were found between the four groups in terms of 'peripheral' oxygen consumption and oxygen uptake kinetics. Additionally, peripheral adaptations within the groups were clearly shown to exist, particularly concerning the upper extremities. During the course of experimentation and analysis, the author became conscious of inadequacies concerning current methods of analysing ventilatory kinetics and it is this aspect that will now be addressed.

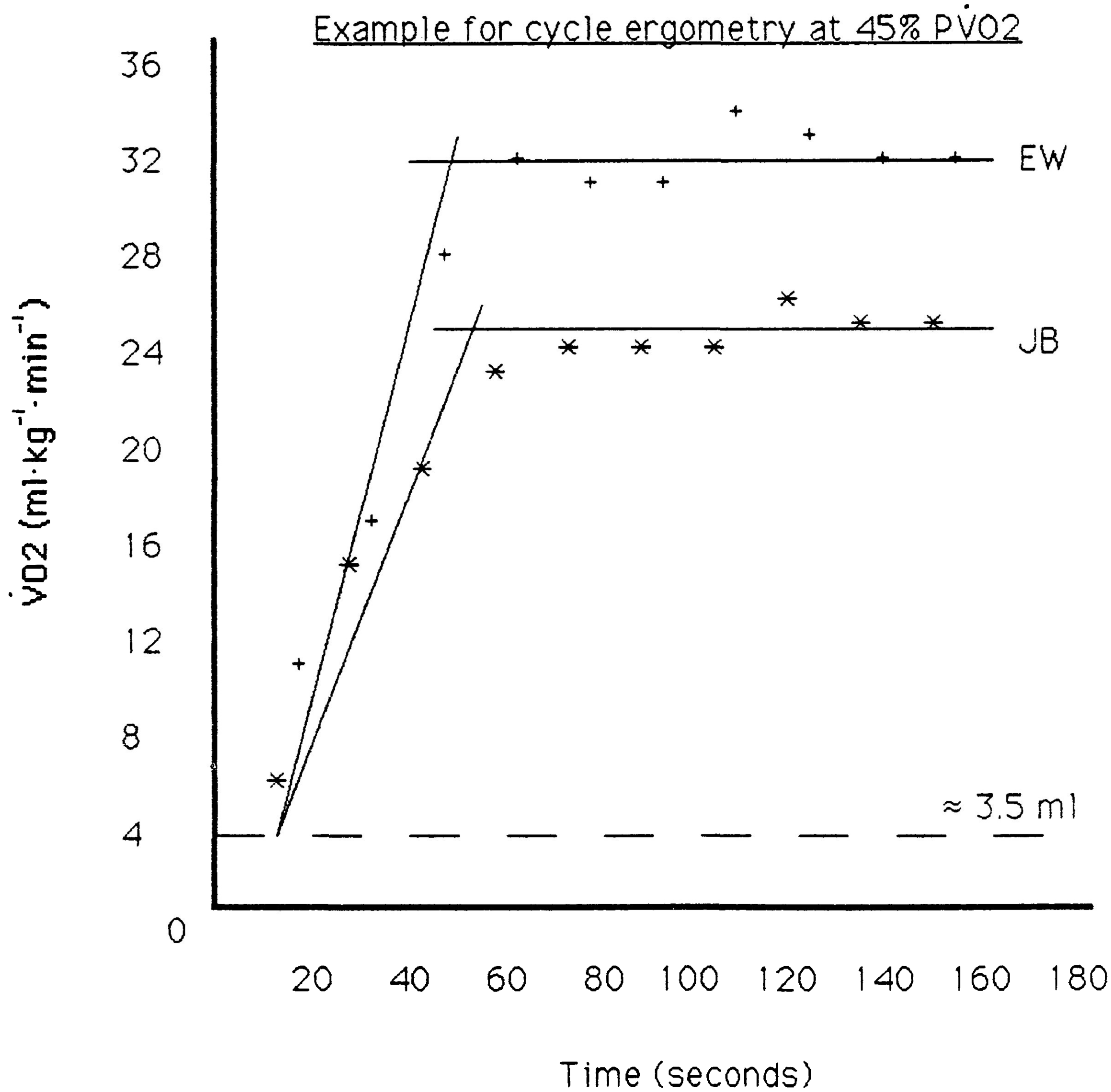
To date, analysis of ventilatory kinetics, particularly at submaximal levels, has concerned itself with 'relative' conditions such as 't1/2$\dot{V}O_2$on at 45%$\dot{V}O_2$max'. This approach is obviously logical since it establishes 'common ground' for analysis and discussion. However, this single dimensional approach can give rise to misleading information when dealing with complex physiological phenomena, particularly when initial analysis reveals similar MRT and t1/2$\dot{V}O_2$on times at a given %$\dot{V}O_2$max for different experimental groups. Indeed, dissimilar ventilatory kinetic times may even be misinterpreted due to this 'approach'. For example, using two hypothetical groups of athletes, both with similar endurance training programmes, but from different sports disciplines, an analysis of ventilatory kinetics might reveal extremely close MRT and t1/2$\dot{V}O_2$on times at a given %$\dot{V}O_2$max. Unfortunately, discussion of such relative results would lead to the conclusion that from a purely physiological point of view the two groups are of a comparable nature, whereas an investigation of the results utilising an 'absolute' aspect as well could very possibly lead to a different conclusion. That is, consideration should take into account the absolute changes in oxygen consumption such that the 'rate of change' ($ml \cdot sec^{-1}$) becomes an important development. In this investigation, occurrences of 'close' MRT and $t1/2\dot{V}O_2on$ times are relatively common, for example, subject EW (a cyclist) and subject JB (a swimmer) produced submaximal MRT responses (at approximately $45\%\dot{V}O_2max$) for cycling of 40.62 seconds and 40.18 seconds respectively Initial discussion would conclude that the ventilatory kinetics of these subjects were very similar, however, at the absolute level subject EW produced a change in $\dot{V}O_2$ of 21.1 ml from a resting level to the computer-calculated MRT, whereas subject JB responded with a $\dot{V}O_2$ change of 13.9 ml from rest to MRT. In terms of submaximal rate of change to the point of MRT (thus utilising the steep portion of the transient uptake curve), subject EW's value was approximately 0.52 $ml \cdot sec^{-1}$ compared to subject JB's value of approximately 0.35 $ml \cdot sec^{-1}$ (Figure 21).

Figure 21

The Magnitude of Change in $\dot{V}O2$ as a Factor for Consideration

Subject EW = cyclist — Submax MRT = 40.62; Rate of change ≈ 0.52 ml sec

Subject JB = swimmer — Submax MRT = 40.18; Rate of change ≈ 0.35 ml sec



Similar comparisons may be considered for the $t1/2\dot{V}O_2on$ values as well. Thus, the absolute aspect gives a clearer indication of the efficiency at the relative level, and this author strongly believes that this aspect should have an important role in the investigation of ventilatory kinetics.

Furthermore, the use of a single component exponential function, with or without a time delay, needs to be reviewed since the process currently advocated may not be sensitive enough to respond exactly as the ventilatory mechanisms within the body. Applied physiology should possibly look to biology (particularly as regards 'growth functions') to improve the quantitative analysis of ventilatory kinetics, especially at the onset of exercise. The discussions and suggestions considered by von Bertalanffy (1957) and Richards (1959) would seem to be steps in the right direction for applied/exercise physiologists interested in pursuing this area. Also, increased computer usage can only help the upgrading of exercise physiologists' research into the area of ventilatory kinetics.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study examined the aerobic power and transient oxygen uptake responses of four groups of athletes, with each group representing a different sports activity (cylists, runners, swimmers, and cross-country skiers), to determine the possible existence of peripheral adaptations in terms of oxygen utilisation. A cross-sectional design was followed to examine submaximal $t1/2\dot{V}O_2on$ and MRT, together with maximal $t1/2\dot{V}O_2on$ and MRT, as well as describing the absolute and relative aerobic power scores for the groups in relation to the three modes of ergometry (treadmill, cycling, and arm cranking). The groups were drawn from local 'national calibre' athletes with current histories of strenuous physical training, incorporating an endurance bias.

The subjects voluntarily performed a series of tests, presented in a randomised fashion and with a suitable period of rest (at least 24 hours) between each effort. Strong verbal encouragement was given where necessary, although well-documented criteria were followed so as to establish standardised test completion parameters. Gas analysis was carried out using a pre-calibrated computerized Beckman Metabolic Cart (MMC Horizon II System) programmed for 15 second interval probes.

The transient $\dot{V}O_2$on responses were quantified via a single exponential process given as $\Delta\dot{V}O_2(t) = \Delta\dot{V}O_2ss(1-e^{-(\frac{t-TD}{\tau})})$, where Δ reflects the increment above the previous (rest or exercise) steady state level, ss represents the steady state or asymptotic value, TD is the time delay parameter, and τ is the time constant. One-way analysis of variance statistical methodology was then undertaken to evaluate the raw data.

Conclusions

The following conclusions have been derived from the analysis and discussion of this investigation:

1. Differences in aerobic power for each group for given modes of ergometry were thought to be due to sports specific adaptation, as illustrated by:

a). higher relative $\dot{V}O_2$max scores for cyclists, runners, and cross-country skiers than swimmers on the treadmill (significantly so for the runners and cross-country skiers versus the swimmers; $p<0.01$).

b). higher relative $\dot{V}O_2max$ scores for the cyclists, runners, and cross-country skiers than the swimmers on the cycle ergometer (the runners were significantly higher than the swimmers and the cross-country skiers; $p<0.01$).

c). significantly higher relative $\dot{V}O_2max$ scores for the runners, swimmers, and cross-country skiers than the cyclists for arm cranking ($p<0.01$), with the swimmers producing the highest $\dot{V}O_2max$ scores.

2. Differences in ventilatory kinetics for each group were considered to be due to peripheral adaptations having occurred because of sports specific endurance training regimes, as illustrated by:

a). the runners having the fastest maximal MRT on the treadmill

b). the cyclists having the fastest maximal MRT on the cycle ergometer.

c). the swimmers having the fastest maximal MRT on the arm crank ergometer.

3. $\dot{V}O_2$max and t1/2$\dot{V}O_2$on response times seem to be clearly linked, although this 'link' is as yet not fully determined, as evidenced by a correlation coefficient of $r = -0.887$ ($p<0.01$).

4. A tentative connection between the transient oxygen uptake response and blood lactate accumulation seems to be suggested through current ventilatory kinetic analysis and physiological theory.

5. Evaluation of ventilatory kinetics needs more careful analysis and understanding if overgeneralisations and misinterpretations are to be avoided. Of particular concern, is the lack of acknowledgement of the importance of the actual magnitude of change in $\dot{V}O_2$ from a steady-state rest condition to a steady-state work level.

6. The transient oxygen uptake response does seem to have a role in describing the sports specific adaptation of elite athletes, although further investigation needs to be pursued to identify the exact nature and extent of this role/ability.

Recommendations

1). Two 'levels' of further study in this area should be pursued:

a). an improved version of the current investigation should be undertaken, possibly examining one sports group at a time, using a greater number of subjects, and involving other sports disciplines.

b): longitudinal studies should be entered into to monitor the ventilatory kinetics of athletes over time as they move through their training/competitive year.

2). The magnitude of change in $\dot{V}O_2$ in relation to the time aspect of ventilatory kinetics needs greater consideration in future investigation. Thus, a two-dimensional approach needs to be used when discussing ventilatory kinetics:

a). MRT and, or, $t1/2\dot{V}O_2on$ at a given $\%\dot{V}O_2max$.

b). rate of change of $\dot{V}O_2$ ($ml \cdot sec^{-1}$) at a given $\%\dot{V}O_2max$ (utilising the steep part of the oxygen uptake curve).

3). The possible interrelationship between transient oxygen uptake response times and lactate accumulation needs to be investigated.

4). The fundamental quantitative functions with which ventilatory kinetics are examined need to be improved upon so as to improve the accuracy of future evaluations.

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Appendix A

Cyclists: Mean Raw Data: Submaximal oxygen transient response times (seconds)

		Subject				
Test	Mode	DZ	AN	GM	PF	EW
Submax t1/2	TM	24.0654	26.7304	18.9814	28.1168	23.2614
	LG	29.8365	27.2844	24.0382	27.6070	31.4387
	AR	34.0190	33.4487	41.8343	36.7858	46.6642
Submax MRT	TM	34.1725	39.5433	24.9718	38.3781	33.1912
	LG	42.1526	38.7202	33.6557	36.6803	42.2679
	AR	53.1207	49.3457	69.9483	54.7943	69.7978

Appendix B

Cyclists: Mean Raw Data: Max test oxygen transient response times (seconds)

		Subject				
Test	Mode	DZ	AN	GM	PF	EW
MAX	TM	22.2824	31.4739	26.5929	30.1242	26.6697
t1/2	LG	29.2306	37.8016	45.4304	40.2173	52.2355
	AR	39.5929	68.3895	48.4169	48.9483	64.5572
MAX	TM	31.1501	43.6995	37.0313	41.0332	36.6321
MRT	LG	41.0445	52.5557	65.4229	53.4911	75.7938
	AR	58.3112	100.7292	69.1335	73.0252	93.6756

Appendix C

Runners; Mean Raw Data: Submaximal oxygen transient response times (seconds)

		Subject				
Test	Mode	BG	TH	MH	RM	ED
Submax	TM	18.3184	19.5699	22.9315	24.749	16.1931
t1/2	LG	28.5430	25.3109	23.0788	33.0248	32.1194
	AR	24.1322	33.2057	34.1090	29.9346	35.2794
Submax	TM	26.2638	30.1621	31.7995	33.9863	24.6091
MRT	LG	38.4397	38.7195	32.8382	46.0702	45.9834
	AR	35.0536	53.5481	49.2197	47.7419	49.5725

Appendix D

Runners; Mean Raw Data: Max test oxygen transient response times (seconds)

		Subject				
Test	Mode	BG	TH	MH	RM	ED
MAX t1/2	TM	24.4488	26.3993	25.6008	30.0571	8.6121
	LG	36.0985	38.1443	37.5549	37.4778	50.2278
	AR	70.0076	54.2513	41.3809	43.9509	34.5818
MAX MRT	TM	32.7874	36.0535	34.6671	42.0908	15.5156
	LG	52.9115	53.6653	55.7424	51.3937	76.3421
	AR	109.9501	82.1956	65.7448	66.8210	56.8410

Appendix E

Swimmers; Mean Raw Data: Submaximal oxygen transient response times (seconds)

Test	Mode	Subject MD	AF	KB	SL	JB
SUBMAX	TM	29.5814	24.9450	24.1105	22.2227	22.3080
t1/2	LG	28.4094	23.5304	32.4390	29.5479	28.6181
	AR	23.6665	34.3281	37.3166	41.2147	28.6865
SUBMAX	TM	42.0295	34.0720	32.9735	32.7257	32.2450
MRT	LG	43.3597	33.7605	41.2152	40.1538	39.1997
	AR	37.5526	45.2755	50.1939	56.4952	40.6333

Appendix F

Swimmers; Mean Raw Data: Max test oxygen transient response times (seconds)

		Subject				
Test	Mode	MD	AF	KB	SL	JB
MAX	TM	32.5183	24.2974	26.6942	26.7832	33.0185
MRT	LG	41.0354	41.9146	34.0893	41.5929	45.3537
	AR	47.1758	50.3633	58.1972	37.9894	48.0035
MAX	TM	46.4732	30.0594	36.4705	36.5592	46.3251
t1/2	LG	70.9775	55.4072	47.5625	58.8369	64.6118
	AR	66.9951	70.2005	80.3644	51.4454	66.9428

Appendix G

Cross-country skiers: Mean Raw Data

Submaximal oxygen transient response times (seconds)

		Subject				
Test	Mode	PM	MS	DB	KT	SP
SUBMAX	TM	23.7992	25.7906	21.9237	22.3727	28.2385
t1/2	LG	32.0602	23.4798	28.6083	30.9558	24.3930
	AR	28.7776	25.0328	26.6617	34.1344	30.6139
SUBMAX	TM	35.6127	35.6621	29.6522	30.2485	40.8515
MRT	LG	44.1140	33.1199	38.6125	41.5571	33.1790
	AR	42.8583	36.9272	38.7509	48.3116	44.0886

Appendix H

Cross-country skiers; Mean Raw Data

Max test oxygen transient response times (seconds)

		Subject				
Test	Mode	PM	MS	DB	KT	SP
MAX	TM	25.4627	30.6719	20.7519	27.4836	26.7075
t1/2	LG	40.8692	42.9917	37.3593	42.3665	36.6977
	AR	36.3854	73.8735	61.7529	46.1161	40.5231
MAX	TM	34.5408	42.4649	29.5945	37.4570	37.4591
MRT	LG	58.7062	62.2963	58.5795	60.7024	53.7071
	AR	52.1387	109.4816	92.9329	67.1076	69.7472