DOCTOR OF PHILOSOPHY

# A study of the behavioural profiles of elite slalom canoeists

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# A STUDY OF THE BEHAVIOURAL PROFILES OF ELITE SLALOM CANOEISTS

by

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# ABSTRACT

# A STUDY OF THE BEHAVIOURAL PROFILES OF ELITE SLALOM CANOEISTS

S. J. BAKER

Using a multidisciplinary approach some physiological characteristics of a group of elite slalom canoeists were examined in an attempt to quantify the demands of slalom competition. Simulated conditions were incorporated for data collection whenever it was impracticable to collect data from paddlers in a slalom event.

A description of materials, methods and the validation of simulated procedures precedes the discussion of a survey of training routines adopted by a group of slalom canoeists.

Data pertaining to the paddle stroke characteristics of elite paddlers revealed that all subjects performed a similar type and number of strokes on an international course.

The aerobic demands of paddling the same route and manifested by the extent to which the cardiorespiratory system was mobilized, was found to be submaximal.

Anaerobic stress, measured during a World class competitive event as serum lactate content in a group of 19 subjects, was extremely high.

It is suggested that anaerobic training should feature prominently as an integral component of slalom preparation.

An experiment was designed and conducted to investigate the effects of a specific anaerobic training programme, over nine weeks, on the muscle development of a group of nine subjects.

A comparison of biopsy samples from the latissimus dorsi muscle prior to and immediately following the programme revealed that there was no significant change in the size of type I fibres (aerobic) that there was no apparent modification in the distribution of fibre types, but that there was a significant increase (82%) in the cross sectional area of the type II fibres (anaerobic).

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# CHAPTER 1

In the summer of 1980 the British canoe slalom team consolidated and emphasized their canoeing supremacy at Bala in North Wales by successfully defending the World Championship trophy. One of the three man team later in the meeting took the individual K1 slalom gold medal with a demonstration of determined and aggressive competitive skill. His performance was repeated once more at the 1983 World Championships ,this time abroad.

With this kind of success and the obvious depth of experience that British slalomists now enjoy, one might assume that the demands which slalom canoeing places on the individual competitor are well understood and adequately prepared for. However, from the author's experience and from interviews which have been conducted casually with many competitors in the higher slalom divisions, it appears that the majority develop their own interpretation of the demands of the sport.

There are few scientific studies concerned with slalom which might help guide competitors who are designing training programmes. Perhaps the dearth of studies reflects the difficulty of in vivo investigations since the events take place on rapid rivers amidst a maze of suspended poles and wires. Likewise it is impracticable to reproduce the

precise conditions of the event in the laboratory where data might be collected more conveniently.

Of course slalom is just one of a number of distinct and separate canoeing disciplines. The common factors between slalom, white-water racing, long distance racing, canoe sailing, canoe surfing, sprint racing and canoe polo to mention but a few competitive disciplines are that they all take place on water in fragile craft. There the similarity ends. For each event specific kayaks, canoes and paddles have evolved and the inherent skills are altogether dissimilar.

Research has been focussed on various aspects of canoeing and the results are applicable to many of the aforementioned disciplines. The pawlata roll was described in cinematographical and electromyographical (e.m.g.) terms by Baker and Aldwinkle (1967). Yoshio (1974) using a similar e.m.g technique studied kayak paddling performance on a simulator. Vrijen et al (1974) concentrated on the effects of training on maximum working capacity of canoeists. The results of a survey of the effects of cold immersion on performance experienced by canoeists were reported by Baker and Atha (1976). In Sweden in the same year Tesch (1976) attempted to relate the distribution of muscle fibres to oxygen uptake capacity in sprint canoeists. Attention was focussed on the disorienting effects on visual acuity in a

study by Baker (1977). More recently Court (1979) conducted a biomechanical analysis of the sprint canadian canoe stroke.

It would appear therefore from the brief description of the small number of studies that have appeared in the literature that there is considerable scope for further research in all disciplines. If Britain is to remain at the fore-front of slalom competition then our own competitors and coaches would be wise to base their training methods on proven fact rather than intuition and guess-work.

## The Problem

British slalom canoeing has enjoyed considerable success in recent years and much of this must be attributed to the development of the sport through its governing body, the British Canoe Union. The coaching structure is well established and frequent team training sessions are staged on the purpose-built international slalom course at Bala.

With the advent of new materials such as Kevlar, there has been almost a revolution in the design of new equipment which is now extremely light and strong.

In performance terms the elite competitors are highly skilled and of world rank order which implies that current coaching methods are sound. To some this might seem a remarkable achievement since coaches do not yet enjoy the

benefits of well conducted studies into coaching methods that many of their colleagues in other sporting disciplines take for granted. The approach adopted by current team coaches is largely skill orientated interval type training.

Perhaps if there were data available to our coaches then further improvement in the performance of our teams might be forthcoming.

## This then is the problem

Can the demands of slalom competition be identified, if so what are they and how can training methods meet them?

## Purpose

Using a multidisciplinary approach the purpose of this study is to investigate the physiological, the energetic and the biomechanical demands of competing in a slalom competition. In the course of achieving these objectives it is intended to find the answers to the following associated problems.

Associated Problems

1. To what extent can the demands of elite slalom competition be assessed?

2. In slalom competition to what extent is success influenced by:-

a. Aerobic work capacity?

b. Anaerobic work capacity?

c. A combination of a and b ?

3. To what extent does muscle fibre composition influence slalom performance?

4. Can muscle fibre size be influenced through training? If so how, why and what time-scale is involved.

## Research Hypothesis

Current elite slalom canoeists appear to exhibit no particular physiological characteristics crucial for success in competition.

## Definition of Terms

The following terms which appear in this script are defined as follows :-

AEROBIC a chemical reaction where organic fuels constitute electron donors and oxygen is the final electron acceptor. This reaction occurs in the mitochondria.

ALACTIC oxygen debt, The fraction of oxygen debt due to creatine phosphate cleavage.

ANAEROBIC an energy yield in which glucose and glycogen are broken down into two or more fragments and one of these fragments then becomes oxidized by another.

GLYCOGENESIS synthesis of glycogen from glucose.

GLYCOGENOLYSIS conversion of glycogen to glucose.

GLYCOLYSIS formation of lactic acid from glycogen.

ISOKINETIC contractions that involve the control of speed throughout the range of motion.

# CHAPTER 2

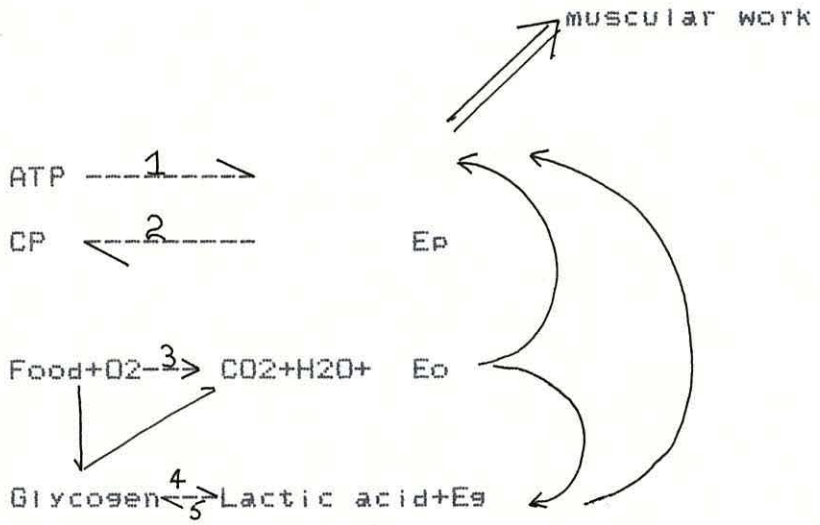
This review commences with a brief description of the energy sources involved during muscular activity followed by a brief anatomical description of skeletal muscle before progressing onto the significant muscle physiology reports.

## Muscular Energetics

During muscular actvity there are various sources of energy that are directly or indirectly utilized. However the only source that can be directly exploited in order to produce mechanical work , is derived from adenosine triphosphate (ATP) which splits into adenosine diphosphate (ADP) and phosphoric acid (PA). The quantity of ATP present in the muscle is small and therefore if a process of resynthesis was not involved, after only a few muscle contractions the energy supply would be exhausted.

Resynthesis also requires an energy source and this is derived from the cleavage of creatine phosphate (CP) into creatine and phosphoric acid (PA). The amount of CP present in the muscle is about three times the quantitiy of ATP and so the reaction can prolong activity. However if muscular work needs to continue, a further and more substantial energy source is required. Two supplies are available, one involves food combustion and the other is by glycolysis.

The total source of energy supply is summarized in fig 1.




Total energy =1-2+3+4-5
Steady state 1=2
E=3+4-5
Submax 4=5=0
E=1-2+3

Arrows indicate direction of energy. Numbers=energy quantities. Subscripts of E denote energy source: p is phosphogen; o is oxygen; g is glycogen.

Fig 1. Scheme to illustrate the main energy pathways during muscular exercise (modified after Margaria 1976)

These two energy pathways supply energy in quantities which are dependent upon the nature of the

muscular work load. The glycogen reaction referred to henceforth as the anaerobic energy pathway contributes to the energy supply at the onset of work. Energy from anaerobic sources is instantly and readily available. Although within this system alone a fraction of the energy can be attributed both to an alactic source which is a quick acting mechanism and to the 'lactacid' source which requires a longer time span to operate. The energy source derived from the combustion of food, termed henceforth the aerobic mechanism, is a much slower energy liberating system than that derived from glycolysis. The aerobic energy liberating system is extensive and is responsible for long term muscular activity where a steady state can be achieved. The system is dependent on a continuous oxygen supply thus the contribution of the cardiorespiratory system plays an important role.

Aerobic metabolism occurs in the mitochondria located within the muscle and the catalysts which facilitate the reaction are enzymes or coenzymes.

## Anaerobic Metabolism

The chemical changes that are involved during anaerobic metabolism have been described previously, but if these are considered when interacting with aerobic metabolism as might occur when particular demands are placed on the working muscle then the picture is not altogether clear. Margaria (1976) has suggested a hydraulic model which attempts to clarify the interaction of energy sources in muscular activity, fig 2.

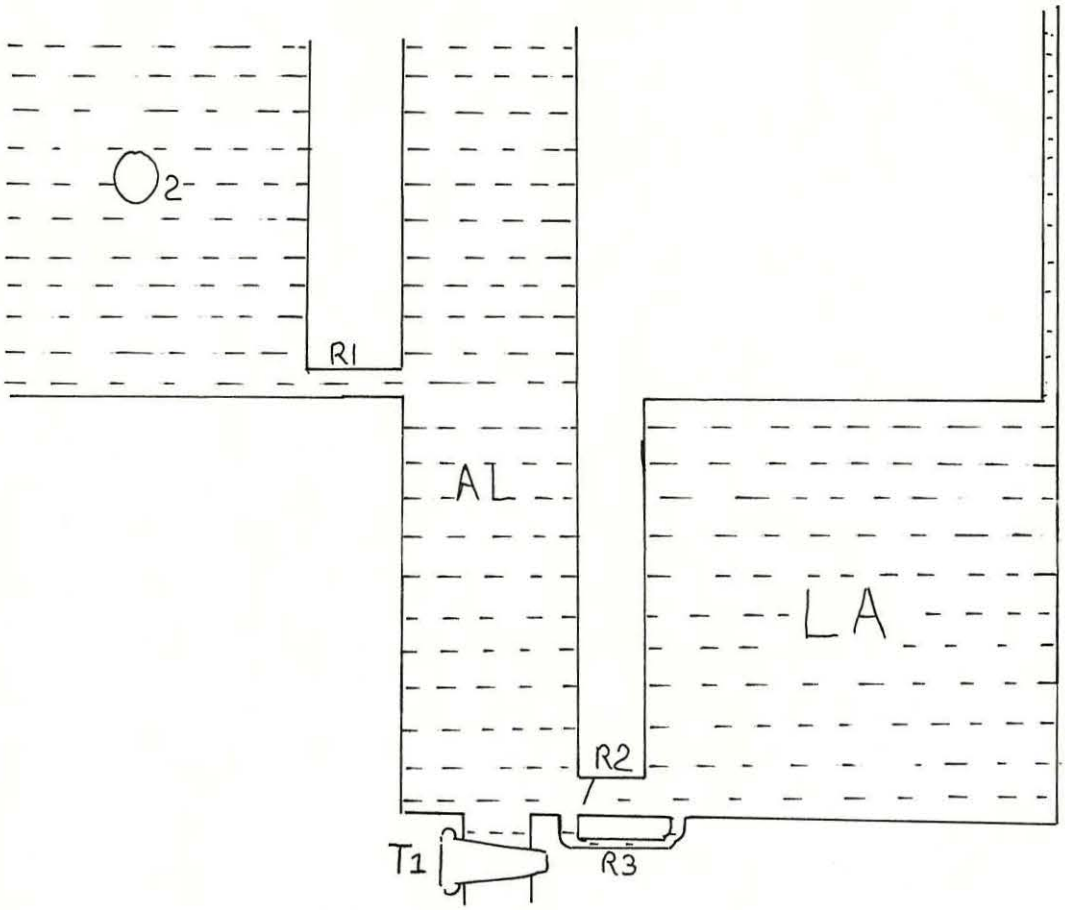



Figure 2. A hydraulic model to demonstrate the interaction of energy sources.

The centre container(AL) represents energy derived from phosphogen cleavage (anaerobic) -- the alactic energy source. The upper left container is of infinite capacity and represents the aerobic system where oxygen is delivered by the cardiorespiratory system. The right container (LA) represents the energy source supplied anaerobically which results in lactic acid formation. Connecting routes R1, R2, and R3 represents the flow of energy from each of the three energy systems, viz aerobic, anaerobic 1-alactic, anaerobic 2-lactacid.

At the bottom of the diagram in fig 2, the tap represents the requirement of muscular energy. When the demand is high such as during intense maximal activity the tap is opened fully. The alactic system supplies the immediate energy supply through phosphogen cleavage. However the aerobic supply which is responsible for replenishing all three systems cannot satisfy the demands through the R1 route, but continues to supply energy through this route. The amount of alactic energy represented relatively by the volume of the centre container rapidly becomes exhausted. As soon as the level in the centre container drops below R1 then the LA system begins to supply energy with the formation of lactic acid. Since this system is 'closed' then only a limited amount of energy is available thus the total energy output is severely restricted once the two anaerobic energy supply systems are depleted.

In submaximal exercise therefore the anaerobic energy liberating mechanism is involved in the form of phosphogen cleavage, but the aerobic system becomes involved progressively until a steady state is reached. With reference to the hydraulic model this state would occur when the level in the centre container is between its maximum and R1, and when the output through tap T1 is no greater than that supplied from O2 through R1. Therefore in submaximal work it would appear that lactic acid levels remain low. Perhaps this explanation satisfies those authors (Astrand et al 1964;

Hermannsen and Saltin 1967) who suggest that glycolytic processes are involved to a significant extent at submaximal levels of work.

The effect of training on anaerobic metabolism was studed by Williams et al (1967) and it was suggested that at similar levels of oxygen intake excess lactate production is greater in untrained individuals than in the trained state.However the method of lactate collection was by capillary puncture at the finger tip where considerable variation in the lactate reading can occur through a 'milking' effect if a poor puncture is made. Although Fahey et al (1975) have shown that capillary blood sampling is a reliable method for measuring blood haematocrit, a better although more technically difficult method is by veno puncture where blood is drawn from a major vein, normally in the forearm.

One of the most frequently employed indicators of anaerobic power/capacity is the rate of formation and total accumulation of lactic acid in the body (Asnevik et al 1969;Volkov 1970)In the context of field data collection blood sampling remains popular.However in the laboratory Volkov et al (1975) have suggested that assessment of anaerobic capacity should involve measurement of CO2 and max VO2 concurrently.

Rahe et al (1981) investigated the levels of

serum lactic acid found in subjects who were exposed to anxiety producing situations.

Serum lactic acid concentration is the reflection of a balance established between the body's lactic acid production and the metabolic breakdown of this substance in the liver.

One of the findings arising from this study was a positive correlation between a dimension of physical fitness and pre-activity serum lactate levels. Fitness was assessed in mile run times. Individuals who were fit showed higher initial serum lactate levels prior to a bout of strenuous activity. The physiologic mechanism thought to be responsible for this observed elevation in pre-activity serum accumulation was their presumably higher epinephrine output in response to the psychological stresses of the activity which in this case was drownproofing. Epinephrine release causes a modification in pyruvate concentrations.

The production site of lactic acid is in the working muscle and Diamant (1968) has shown that the lactate concentration in human skeletal muscle was much higher than in the blood immediately after maximal exercise. However shortly after the cessation of work when peak blood lactate level was reached this was aproximately the same as the muscle lactate level. These results seem to indicate that there is a fairly rapid distribution of lactate throughout

the body following intense exercise.

The optimum time to sample venous blood for maximum lactate concentration values appears to be approximately five minutes after severe work (Astrand and Rodahl 1977).

Serum lactate concentration remains a major indicator of the level of involvement of anaerobic metabolism and was used extensively in the course of this study when data on anaerobic metabolism was required.

The method of blood sampling was by venepuncture of an antecubital vein in the forearm.

## Aerobic Metabolism

The area of human performance which has been reported most frequently in the literature is aerobic metabolism. Perhaps this is best explained by the fact that quantification of oxygen uptake capacity has long been available and the techniques are relatively straight-forward to administer.

An extensive review of studies concerning aerobic capacity is inappropriate for this study but an outline of some salient points will be given.

### Oxygen Uptake

The consumption of oxygen as measured by the respiratory gas exchange reflects quantitatively the combustion of biochemical fuel in the form of carbohydrate, lipid and protein. For each litre of oxygen consumed about 20KJ of energy is liberated (Astrand and Rodahl 1977), hence the higher the oxygen uptake the higher the energy output (1000Joules = 5 Kcals).

Oxygen consumption during exercise has been studied extensively using the Douglas bag method where expired air is collected and the oxygen content measured. This method continues to provide valid results for oxygen consumption (Corry et al 1982) but is being replaced progressively by electronic gas analysers linked to micro-processors.

Oxygen uptake frequently has been expressed in litres per minute but this value fails to account for differences attributed to body build. Other workers have prefered to express oxygen uptake as VO2/Kg of fat free weight. Buskirk and Taylor (1957) were amongst the earliest workers to express oxygen uptake as VO2 per kilogram of body weight and in addition they concluded that VO2 max is affected by physical conditioning; fat free weight was calculated according to the method of Keys et al (1950) which incorporated body density.Margaria et al (1966) suggested that maximum oxygen consumption level is set by the capacity of O2 transportaton from the lungs.

The nature of maximal oxygen uptake measurement has always provided the athlete with performance problems due to the equipment and apparatus attached to him.Therefore some researchers pursued lines of investigation concerned with predicting max VO2 from submaximal tasks. Several nomograms have been produced to achieve this objective , one of the earliest being that produced by Astrand and Rhyming (1954). De-Vries and Klafs(1965) attempted to modify the methods of Astrand but failed to provide a significant improvement. Wyndam (1967) and Shepherd (1967) both reviewed the max VO2 procedure using submaximal tests and concluded that with a few limitations it was generally sound.

Reports on the effects of several types of training

vary enormously with an improvement in VO2 from 0% to 93% (Astrand and Rodahl 1977).

The most convenient form of exercise for the measurement of VO2 max is leg work usually on a treadmill or bicycle ergometer (McArdle+Magel1970; Sidney+Shepherd 1975). Several attempts have been made to relate the findings from laboratory apparatus to sporting performanes. Magal and Faulkner (1966) after measuring VO2 on a group of swimmers on the treadmill, during teathered swims and during free swims concluded that there was no significant difference between the three activities but suggested that there were advantages in the physiological assessment of swimmers swimming rather than running. Ferguson (1969) pursued a similar line of investigation by measuring VO2 during ice hockey exercise.

The reports mentioned hitherto have been concerned entirely with VO2 measurement during leg work. Although this relationship is appropriate for many sports it would appear to be inaccurate during activities involving arm exercise.Reybrouck et al (1975),Vokac et al (1975) and Astrand +Rodahl (1977) suggest that a figure in the range 70-85% of max VO2 is reached during arm work. For athletes trained and accustomed to arm exercise during their events, viz rowing and canoeing, a figure towards the upper limit of the range just given would be expected (Tesch et al,1976).

Wakeling and Saddler examined a group of 5 competitive canoeists for oxygen uptake on both a bicycle ergometer and while canoeing and their results were in broad agreement with the findings of Tesch et al, that arm work averaged 85% VO2 max of leg work.

In a study by Corry et al (1982) on maximum aerobic power of swimmers, swimmers were categorized as athletes who used their arms predominantly and measurement of VO2 max during arm work only was taken for these individuals. It was found that elite swimmers achieved a VO2 max reading of 79% of their running VO2 max. These authors suggest that a more realistic measurement of VO2 max is achieved when athletes are using muscle groups normally associted with their event rather than whole body VO2 max values. It follows therefore that VO2 max when measured on a treadmill is an appropriate indicator of running potential and likewise when VO2 is measured on a bicycle ergometer it is an appropriate indictor of cycling potential.

There are certain events where the conditions are inhospitable and impracticable for measurement of performance and in these cases it is more desirable to simulate event conditons. Most water-based sports fall into this category. If apparatus is designed for event data collection then it requires careful validation from both a biomechanicaland a muscular energetic view point. In a

recent report by Corry (1982) this objective was not achieved. The author describes a form of land ergometry where the subjects simulate the movements of a swimming stroke ,his conclusion regarding a biomechanical analysis of the stroke are based on the stated assumption that the pulling exercise is"sure to involve swimmers muscles" .

Having discussed briefly the principal energy liberating pathways involving anaerobic and aerobic metabolism it is appropriate to focus attention on the characteristics of skeletal muscle if a clearer understanding of muscular activity is to be forthcoming.

Muscle Anatomy

For a detailed anatomical description of skeletal muscle the reader is refered to a basic anatomy text (Greys Anatomy ), essentially a muscle consists of bundles of fibres covered by an outer membrane-the epimysium. Each bundle is wrapped separately in a layer of perimysium and consists of thousands of muscle fibres each embedded in a layer of connective tissue-endomysium, fig 3.

A skeletal muscle fibre is made up of myofibrils which lie close to the cell nuclei and mitochondria. The latter are visible only with the aid of an electron microscope. A single myofibril is composed of dark and light bands of protein as seen though a light microscope.

Huxley (1965) proposed a theory in which the protein filaments of actin and myosin moved over each other thus allowing a shortening or lengthening of the muscle. It was suggested that actin and myosin were connected temporally by a series of 'bridges' and when movement occured the bridges were in contact for a short distance of the action and then it was necessary for them to release and relocate at a point further along the opposing protein filament. Wilkie (1968) has described the action as being similar to a man pulling in a rope hand over hand.

One of the predictions from the sliding filament

theory was that when the muscle was stretched, the overlap between the actin and myosin would be reduced in length and therefore the tension as developed by the number of cross bridges would diminish. Conversely when the muscle contracts and the number of cross bridges increases then the tension developed by the muscle is greater.

The practical implications of this work to the athlete are gathering momentum and are manifested by the growing interest being shown in isokinetic training methods. Such is this interest that the first "European conference on the Isokinetic Revolution" was held at Magglingen in Switzerland in May 1984. The fundamental principle of isokinetic training is that tension in the muscle varies with its length of contraction as suggested by Huxley (1965). Isokinetic training devices apply appropriate loads to the muscle throughout its range of movement.

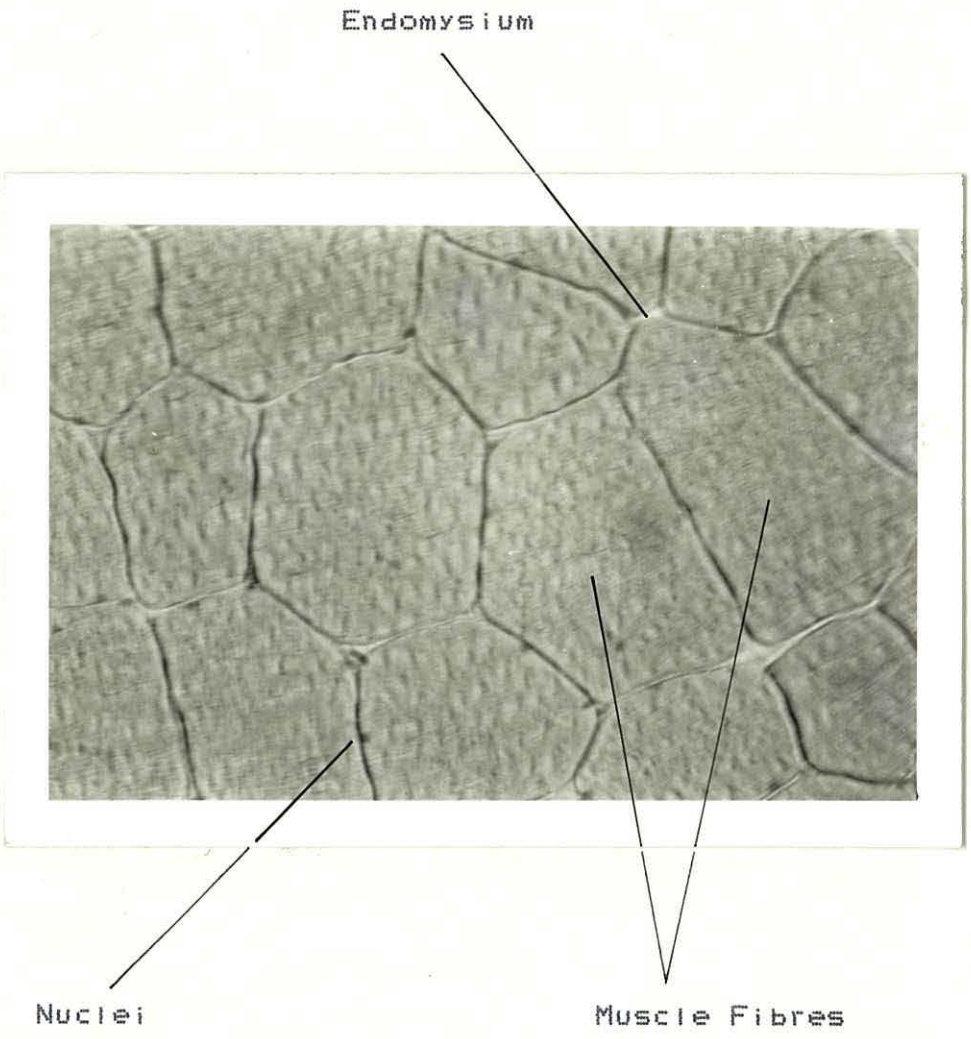



Figure 3. A micrograph annotated with some principal structures of human skeletal muscle.

Muscle Fibre types and Enzyme activity.

Stefano Lorenzini,an Italian physiologist classified muscle fibres into red and white categories as long ago as 1678.The explanation of the colour difference emerged later from work on rabbit muscle when Ranvier (1873) suggested that red fibres exhibited slow contraction speeds and white fibres exhibited fast contraction speeds.

A notable development in the history of histochemistry was the introduction of techniques which identified enzyme activity thus giving an insight into muscle energetics . It then became obvious that the two main muscle types, type I and type 2 ,were each involved predominantly in one of the two main energy liberating pathways. Type I was shown to be aerobic and type 2 was predominantly anaerobic.A schematic representation of the principal chemical reactions which occur during muscular work is shown in fig 4.

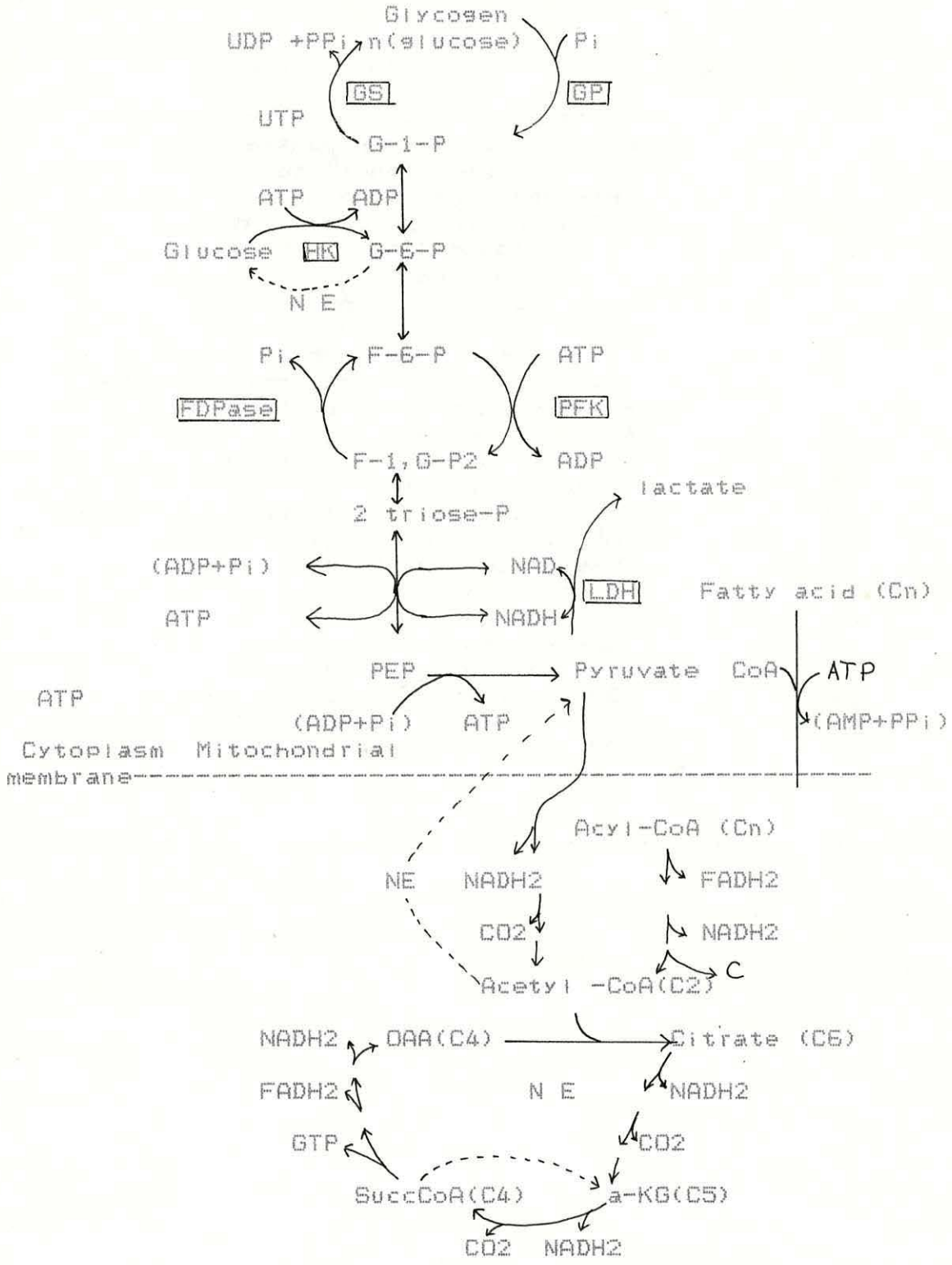



Figure 4. The principal chemical reactions which occur during muscular work. Those which are aerobic take place below the mitochondrial membrane involving the Krebs cycle. Anaerobic reactions occur outside the mitochondria.
(After Astrand and Rodahl 1977)
See over for abbreviations.

It can be seen from figure 4 that some enzymes are involved in the aerobic reaction which takes place inside the mitochondria while others, eleven in number, are involved in the anaerobic reaction.

The identification of specific enzymes at cellular level has recently opened a way for a direct correlaton to be made of the functional activity of individual muscle fibres.

The enzymes which were of particular interest in earlier studies were those associated with glycogen synthesis and breakdown (such as phosphorylase), oxydoreductases (such as dehydrogenases) and hydrolases (such as ATPase).

Attention was initially focussed on succinic dehydrogenase (Semenoff 1935; Seligman and Rutenburg 1951; Padykula 1952) when animal muscle was used and there was found to be a variation in the presence of the enzyme between individual fibres. Some muscles exhibited a strong succinic dehydrogenase activity such as the soleus (in the rat) which is composed of type I fibres while others such as biceps femoris and tibialis anteror which are composed of mixed fibre types exhibited a marked variation in enzyme actvity.

Exercise and intramuscular Histology

Animals have long supplied tissues for experimental study and much is now known about the changes that occur in animal muscle as a result of exercise. Some confusion arose from the different nomenclature which various authors adopted when describing muscle fibres.

Stein and Padykula (1962) who determined the intensity of succinic dehydrogenase activity in rat fibres reported a three fibre classification. Type A was white, type B and type C were red. Romanul (1965) found in the same muscle eight dfferent types of fibres based on enzyme activity. Kugeberg and Lars Edstrom (1968) who adopted Steins' three fibre classificaton reported that type A fibres fatigued after some 2000 contractions and recovery was slow. It was concluded that some physiological mechanism must protect these fibres from frequent or continuous use.

Following endurance exercise of adult guinea pigs, biopsy studies have revealed a significant increase in the percentage of red fibres in trained muscles (Barnard et al, 1970). The same authors in a subsequent study suggested that although there was an increase in the percentage of red fibres of guinea pigs following 18 weeks of training there was no change in the contractile propertes of the muscle fibres.

Attention was then focussed on specific muscles from

the guinea pig using another three fibre classification ( Barnard et al, 1971) based on the histochemical activity of NADH and ATPase. Fibres were named red, white and intermediate and correspond in function to fast twitch such as medial gastrocnemius, fast twitch such as flexor digitorum longus and slow twitch such as soleus. These results invalidate previous claims that red muscle fibres were slow acting. It was suggested therefore that fibres be referred to as fast-twitch red, fast-twitch white and slow-twitch intermediate.

While histochemical studies involving animals continued other workers were examining the biochemical changes that were taking place as a result of exercise. The findings from many animal studies (Oscia and Holloszy, 1971) were in general agreement that as a result of prolonged exercise enzymes which are involved in the mitochondrial matrix are adaptive and modify their complement. Anaerobic enzymes did not appear to respond to exercise in the same way. However only a few studies have concentrated on the effects of short term high intensity training (Gale and Nagle, 1971;Bagby et al, 1972). This may be due partly to the difficulties of the training itself, ie, to make the animals perform briefly at high work loads. However the principal findings were :-

a) that this type of training (in rats) caused a

modification in the contractile properties of the fast twitch fibres that were examined.

b) that high intensity exercise is based on carbohydrate catabolism including glycogenolysis and glycolysis (Staudte et al, 1972; Baldwin and Tipton, 1972).

In a study of selected muscles in the rat after sprint training Saubert et al (1973) suggested that most skeletal muscles possess sufficient anaerobic capacity to meet the demands of heavy short term intermittent work without adaptation to a higher level.

While there may be some implications to man in the findings of animal studies these results must be interpreted cautiously.

It was not until 1955 that these new histochemical methods of enzyme analysis were applied to man (Wachstein and Meisel 1955). As with previous animal studies succinic dehydrogenase activity varied between human muscle fibres and the more reactive fibres tended to be smaller in diameter.

Dubowitz and Pearse (1960) demonstrated that various oxidative enzymes were associated with a specific type of muscle fibre and they called this a type 1 fibre. They also labelled the fibre which exhibited a high glycolytic enzyme (phoshorylase content) as type 2. A two fibre classification was also favoured by Engel (1962) but his classification was

based on the myofibrillar ATPase activity of oxydative glycolytic enzymes. Engel's technique has been modified to reveal a much more sensitive method for fibre differentiation by Brooke and Kaiser (1970).

Other workers have concentrated their efforts on more complex systems of identification. Stein and Padykula (1962) investigated mitochondrial distribution using succinic dehydrogenase reaction. There are many technical problems associated with the study of enzymes and mitochondria. Enzymes are very labile. The mitochondria in which many of the oxidative enzymes are located are rapidly damaged when the blood supply is cut.

Many of these technical problems have now been overcome and research into mitochondrial energetics continues (Gohil et al ,1981). With added cytochrome C and progressive oxidation mitochondrial enzyme activity has been measured in human muscle from needle biopsy samples (Gohil et al 1981a) (Gohil et al 1981). The absence or reduction of enzyme action during human muscular activity may result in symptoms such as lethargy, muscle aching and reduced repetitive action.

The aerobic energy liberating pathway is undoubtedly the system most freuently used in normal sustained human performance. Consequently this system and the accompanying enzyme activity have received a great deal of attention. Recently however, some research has been directed

towards the enzyme changes and deficiencies that occur during glycolytic or anaerobic work. In 1970 Bonilla and Schotland described a method to demonstrate the deficiency of muscle phosphofructokinase (PFK). Essentially the technique involves an observation of the reaction between normal muscle and PFK deficient muscle to two substrates F-6-P and F-1,6-PP. If there is a deficiency of PFK then the results will show a varying intensity of staining.

Muscle Biopsy

Perhaps it is appropriate at this stage in the review to highlight the significant step made by the introduction of modern needle biopsy techniques to the study of muscle energetics. Prior to its introduction muscle biopsy was limited to animal studies or at best to human muscle samples taken from open biopsy. These samples were normally taken from patients with diseased muscle or during autopsies.

Although needle biopsy of human skeletal muscle was introduced over a century ago by Ducheene (1868) it did not become established as a diagnostic tool until the early 1970's.

Edwards (1971) described a modified needle biopsy technique which gave consistent results for measurements of a range of electrolytes. This method is currently (1984)

used in the metabolic unit at University College Hospital in London and was adopted for the biopsies taken in this study.

It is clear therefore from the recent introduction of modern needle biopsy techniques that the study of human energetics during, following and as a result of exercise is in its infancy.

## Human Performance

### Definition of fibre types:

During the remainder of this study the following nomenclature will be adopted to describe muscle fibre types. TYPE 1 refers to muscle fibres which have previously been called oxidative or slow-twitch fibres. TYPE 2 refers to fibres which are glycolytic or fast-twitch. There are three further subdivisions of TYPE 2 fibres, viz,type 2a , type 2b, and type 2c.

Type 2a although deriving its energy source from the anaerobic pathway, demonstrates some aerobic behavioural characteristics such as intermediate myosin ATPase staining (Brooke and Kaiser, 1970) . Type 2b fibres are truly anaerobic and are recruited for high intensity short term work. Type 2c fibres remain obscure in function and may be in a transitional stage as type 2a fibres modify to adopt the role of type 1 fibres (Brooke and Kaiser ,1970).

The development of human exercise studies and in particular those concerned with muscle energetics, followed closely the approaches adopted in the aforementioned animal experiments. It was established in the early 1960's (Frick,1963; Ekblom, 1968) that resting heart rate decreased with increased physical fitness as a result of

training. In 1968 it was demonstrated that aerobic training on a bicycle ergometer produced changes in the circulation of skeletal muscle (Varnauskas et al) and that succinic dehydrogenase increased by 61% in male subjects.

These findings were in broad agreement with those from a later study (Gollnick et al,1973) where it was shown that during prolonged submaximal work there appears to be a preferential utilization of type 1 fibres. Glycogen was seen to become depleted initially in type 1 and later type 2 fibres were recruited.

Much of the taining reported in the literature is aerobic in nature, the period of training tending to be long and the interval of each training session is also quite lengthy, up to an hour. The training intensity also tended to be submaximal. In a study by Gollnick et al (1973) the conditions just mentioned were adopted and the findings based on the histochemical analysis of biopsy samples again focussed on oxidative changes. Succinic dehydrogenase increased by a mean value of 95%, oxygen uptake increased by 13% and there was an increase in the area of type 1 fibres after training. These authors did note however, that there was a reduction in cross sectional area of type 2 fibres albeit small (7%). Although this is minor it was significant from the view point that not only did fibre type recruitment take place during activity but also that fibre atrophy could occur simultaneously over a short period of

time. Thus if the demand placed on a muscle was of a stressful aerobic nature and if there was an absence of anaerobic demand then there could be atrophy of type 2 fibres. If this is the case then for the athlete it is essential that the aerobic and anaerobic demands of his event are quantified and that his training routine reflects this loading.

Attention continued to be directed at the ultrastructure of skeletal muscle in an attempt to clarify the role of the mitochondrial mechanism. Although no quantitative changes could be observed in mitochondrial fine structure as a result of endurance training (Hoppeler et al, 1973), it was thought that an indvidual's maximum oxygen intake is limited not only by the capacity of the oxygen transport system but also by the oxidative capacity of the mitochondria in skeletal muscle. Little is yet known about how exercise enhances oxidative enzyme activity but it has been suggested by Saltin and Nazar (1976) that the observed changes are regarded as important for tissue utilization of oxygen. This suggestion was made after it was observed that the femoral vein in the trained leg had a higher oxygen content than in the untrained leg of the same subject.

Saltin (1976) also suggested that as a result of sprint training type 2 fibre area would increase and that following endurance training type 1 fibres will increase in cross sectional area. However in a study investigating the

effects of strength training on enzyme activity and fibre characteristics of human muscle (Thorstensson et al,1976) it was found that there was no change in fibre area after training. The main finding was a significant increase in the activity of the myokinase enzyme associated with type 2 fibres.

In a study by Costill and Daniels (1976) in which the gastrocnemius muscle of a group of elite athletes was biopsied and examined for fibre composition, it was suggested that while sprint and endurance athletes are characterized by distinct fibre composition, participants in strength events have relatively low muscle enzyme activity and a variety of fibre compositions.

Costill and Coyle (1979) however, reported that after isokinetic training there was a significant change in cross sectional area of both type 1 and type 2 fibres.

In isokinetic exercise more energy may be used during muscular exertion because acceleration is controlled mechnically by the training device. The muscle therefore is able to maintain a state of maximum contraction through its full range of motion and thereby a maximum demand is required on the work capacity of the muscle (Chu and Smith, 1971).

In contrast to elite athletes, eleven middle aged and untrained men subjected to a six month training programme, largely aerobic in nature, recorded significant

correlations between metabolic, physiological and morphological variables before and after training (Byland et al, 1977). The results indicated an increased oxidative capacity and this was found to be located primarily in type 2 fibres. No attempt was made in that study to distinguish between type 2 fibre sub-groups. There is a likelihood that type 2a fibres had increased their oxidative capacity (Jansson and Kaijser, 1977).

Muscle development and hypotrophy assocated with training are important benefits to the athlete. However most athletes at some time during their career suffer injury. In particular the consequences of bone fractures should be of interest to 'sportsmen'. In a study by Sargeant and Davies (1977) which investigated the functional and structural changes in muscle after disuse in plaster cast for six weeks, reported :-

1 Injured leg volume decreased by 12%.

2 There was a reduction by 12% of oxygen uptake in the injured leg.

3 There was a reduction of 42% in the cross sectional area of both type 1 and type 2 muscle fibres.

The general recommendations of this and similar studies on muscular atrophy is that non-injured limbs must be exercised daily if only by isometric exercises to avoid atrophy.

If a muscle is denervated, all fibres show progressive diminution in metabolic enzyme activity.

Glycolytic fibres lose glycolytic enzymes faster and oxidative fibres lose oxidative enzymes quicker and the difference between the fibre types tends to disappear. This leads to the question of whether the preferential energy metabolism of fibres is determined in some way other than by enzyme profiles.

The results from experiments with animals (Romanul and Van Der Meulen, 1966) in which the nerve supply to type 2 fibres had been interchanged with the nerve supplying type 1 fibres, suggested that fibres began to reverse their roles. It is now thought that muscle fibre energy metabolism is determined by the nerve supply. The means by which motor nerves determine the physiological properties and energy metabolism of the muscle fibre is unknown. One theory is that motor nerves supply hypothetical 'specific trophic substances' which are different for fast and slow muscles (Eccles, 1965). An alternative proposal by Drachman and Romanul (1970) is that the neural influence on both types of muscle fibres is mediated only through the neuromuscular transmitter, acetylecholine.

The significance of muscle fibre composition would appear to be of interest to the athlete. Sprinters, by genetic endowment possess a high percentage of type 2 fibres while endurance athletes tend towards a higher number of type 1 fibres. Figure 5 illustrates some relative proportions of type 1 fibre, measured in small numbers of

athletes for different events.

# FIBRE COMPOSITION

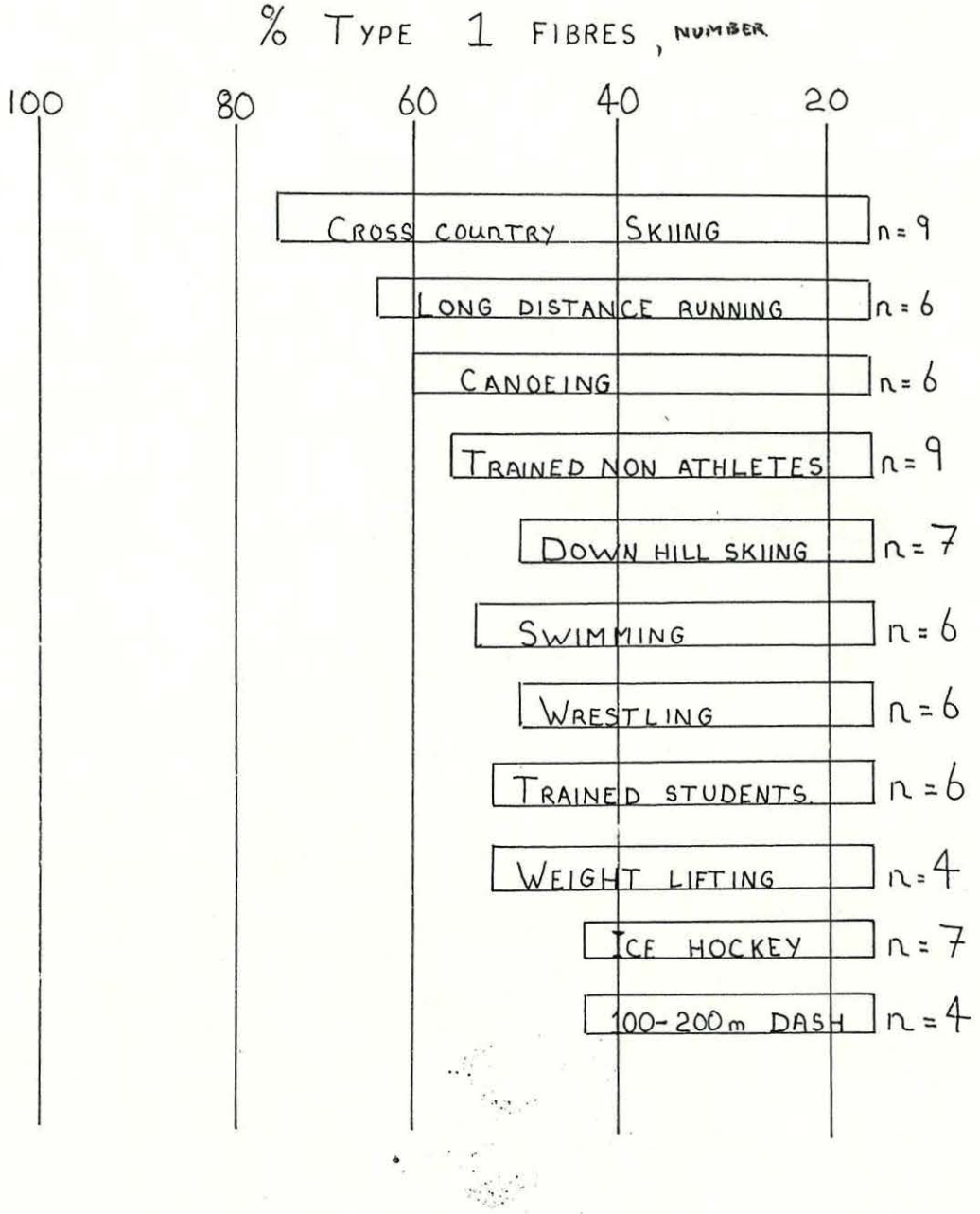



Fig 5. Muscle fibre composition expressed as a percentage of Type 1 fibres in different groups of top athletes. Mean values and total ranges are included (after Karlsson 1978).

It is clear from an observation of the number of athletes studied in figure 5 that a comprehensive picture of fibre types amongst different sportsmen is far from complete.

Fibre composition and fibre size were studied by Green and Thompson (1979) in elite ice-hockey players and it was reported that while fibre composition was within the limits of the normal population there was a significant increase in the cross-sectional area of type 2 fibres over a season's activity.

Muscle fibre hypertrohy has been observed on several occasions in studies mentioned previously; however, no mention has been made about increases in muscle fibre number in man as a result of exercise. Gonyea (1980) reported such an increase in the number of fibres observed in the fore-limb of the cat following exercise. He suggested that the increase might be due to fibre splitting. It might be argued that the apparent increase in number could be attributed to the uneven distribution of fibres within the muscle.

It is now possible for enzyme activity to be determined by non-invasive scanning although the facilities required for this process are limited to one London hospital (1983) and the cost of the machine was several million pounds. However muscle fibre typing which is still developing as a technique , depends on needle biopsy. If

there were other indicators of fibre function more readily accessible such as components of blood composition then biopsies for sporting purposes would be unnecessary. In a study to find such a link Ivy and Withers (1980) investigated the relationship between fibre types and lactate thresholds. The results suggested that the muscles's respiratory capacity (% type 1 fibres ) is of primary importance in determining the work rate at which blood lactate accumulation begins.

Lactate thresholds and aerobic-anaerobic thresholds have resulted in confusion due to the different values assigned to these variables by different authors. Kindermann (1979) suggested a definition which attempted to clarify the confusion and it was as follows :-

1. Aerobic threshold (formerly anaerobic threshold) to be approximately 2mmol of lactate per litre of blood.

2. Anaerobic threshold (formerly aerobic-anaerobic threshold ) to be approximately 4mmol lactate per litre.

These criteria if adopted will make it possible to determine individually the workload intensities for different forms of endurance training.

Blood lactate measurements have recently become a rapid, accurate and pain free technique involving a simple pin prick administered automatically by a machine which then displays a lactate content. It would appear that if more

results were forthcoming which related fibre type quantification with lactate accumulation and work loads, then athletes might have a further measure of progress readily available.

In a study of lactate concentrations in different fibre types resulting from varying intensities of isometric contractions, Tesch and Karlsson (1977) and Karlsson (1978) suggested that lactate concentration increase was faster in type 1 fibres in the muscle rich in type 1 fibres and faster in type 2 fibres in muscles rich in type 2 fibres. From these results it would appear that fibre typing based on lactate assays is impossible. These results contradict the previous findings of Gollnick (1973) which stated that at low isometric tensions a major reliance is placed upon type 1 fibres and at high tensions the reliance is on type 2 fibres.

We are not yet in the happy position of knowing all about fibre type development, muscle fibre type distribution in different muscles or of fibre type characteristics in athletes from various disciplines. The position is becoming clear at either end of the power-endurance continuum where sprinters, jumpers and power athletes in general have high proportions of type 2 fibres while the reverse is true for endurance athletes who tend to display higher proportions of type 1 fibres (Boreham 1980).

Canoeing Studies

A search by Medline revealed only a small number of studies relating to canoeing.Several cited works are concerned with paddling technique ( Granek,1959; Skilling,1976). Cooper (1974) reported on paddling kinematics while Wakeling and Saddler (1977) investigated the aerobic capacities of some British slalom canoeists and Vrijens et al(1974) conducted similar work on Swedish canoeists. Cermak et al( 1975) suggested some predispositions for top performance in speed canoeing. Tesch et al (1976) conducted a physiological investigation of Swedish canoe competitors,while Dal Monte et al (1976) evaluated paddlers from both a physiological and biomechanical aspect.

Paddle forces while canoeing have been studied with the use of strain gauges (Ishiko,1971; Voss et al,1974; Cooper ,1974). Most of these studies incorporated radio telemetry to relay information from the kayak to recording apparatus ashore.

There has been some disagreement between authors about the type of lever system which the paddle adopts during a stroke (Williams,1967; Court 1979).

Muscular analyses of canoeing strokes have been reported by Scott(1963) , Aldwinkle and Baker (1970),and Yoshio et al 1974.

Electromyographical recordings

A number of e m g records have been made of sporting performances, viz. tennis (Slater and Hammel, 1949), golf (Karr, 1955) shot putting (Herman, 1962), swimming (Ikai, 1964), gymnastics (Hebbelink and Borms, 1967), rowing (Ishiko, 1971) and canoe rolling (Aldwinkle and Baker, 1970). In many cases these studies have been carried out using a multicore cable telemetry system in order to record several muscle groups simultaneously.

In an electromyographical study (Yoshi et al, 1974) of the paddling stroke the most significant muscle activity during the pulling motion was posterior deltoid, latissimus dorsi, teres major and the triceps long head. The anterior deltoid and pectoralis major were most active in the opposite pushing arm.

Secher (1975) found that handgrip strength was the only strength factor which correlated with isometric rowing strength in a group of 40 oarsmen of international calibre. In another study of international oarsmen (Celentano et al , 1974), it was found that this calibre of athlete maintained a fairly constant pull duration over a wide range of rowing frequencies.

It was reported in an unpublished study by Humphreys (1982) that the fibre composition in the deltoid muscle of five elite slalom canoeists revealed an equal dependence

upon aerobic and anaerobic energy pathways. This result was in agreement with the conclusion suggested by Tesch (1976) that a prerequisite to high performance arm exercise was a high aerobic capacity. Tesch (1976) observed that in canoeists competing in shorter canoeing distances, more type 2 fibres were present in the deltoid. One champion did not fit this model; only six subjects were studied.

Wakeling and Saddler (1977) using a bicycle ergometer for predicting maximum oxygen uptake in slalom canoeists reported that successful slalom competitors are characterized by supranormal aerobic capacities and a considerable part is used in paddling. Some subjects demonstrated a high VO2 while cycling which was not reflected while canoeing.

In a study instigated by the Olympic Committee of North America (1982) and designed to investigate the aerobic and anaerobic potential of international level 'white water slalom ' canoeists, it was reported that elite paddlers utilized approximately 60% of their VO2 max during simulated competitive water runs. The same group of athletes demonstrated values of 80% of their maximum anaerobic capacity during simulated competitive slalom runs.

# CHAPTER 3

## Overview.

The purpose of this study is to investigate the physiological demands of competing in a slalom competition.

In order to achieve this objective as much data as was practically possible relating to the criteria of aerobic and anaerobic energy demands was collected during competition events.However it was found impracticable to measure accurately and realistically those parameters concerned with aerobic metabolism in competing canoeists.

Perhaps the overriding difficulty that was experienced in this context was the unwillingness of elite competitors to don equipment designed to measure oxygen uptake during competitive runs.

It was decided therefore that to overcome this problem oxygen uptake measurements would be taken in simulated conditions on an arm ergometer where the energy demands would correspond as near as possible to those exerienced during a competitive slalom run.The first part of this chapter describes the development and validation of this apparatus.

Prior to the collection of physiological data both in the field and in the laboratory it was decided that an investigation into the current training habits of top class slalomist was appropriate. The second half of this chapter

describes the questionnaire and the results.

The sections are described in the following order:-

Arm Ergometer

Rationale

Development

Bicycle Ergometer

Mechanical analysis of a forward paddling stroke

Cinematographical Analysis

Questionnaire

A survey of Training routines and Attitudes among elite slalom canoeists.

Results of the Training questionnaire

## ARM ERGOMETER

### Rationale

Attempts have been made with varying degrees of success to collect physiological data from canoeists while they are canoeing. Aldwinkle and Baker (1967) pioneered the E.M.G. muscle analysis in water during a canoe roll. Tesch et al (1976) used the douglas bag method to determine oxygen

uptake in sprint canoeists. Court (1979) used telemetry to monitor canoeing muscle action.

However the logistical and technical problems associated with 'on water' studies often cast doubt on the validity of data collection methods, particularly those associated with ventilation parameters.

Several researchers have attempted to overcome this problem by developing a dry land paddling simulator. Pyke (1973) modified a Monark bicycle ergometer by removing the pedals and extending the pedal cranks, the ends of which were linked to the loom of a paddle. Cooper (1974) reproduced this design to study sprint canoeing parameters in the laboratory. This apparatus was used for some data collection of an elite canoeist which is presented in this study.

Tesch (1976) used a mechanically braked bicycle ergometer for arm exercise to monitor oxygen uptake in the laboratory.

It was decided that while some data collection for this study was field orientated, there was a need for data collection in the more hospitable environment of a laboratory. With this in mind a paddle ergometer was developed.

## DEVELOPMENT

Previously most simulators had involved the modification of a bicycle ergometer where the work load could be monitored accurately. Initially this idea was deliberately avoided in favour of a more realistic device using a canoe, a paddle and a paddle tank. A te thered canoe in a swimming pool resembles closely the conditions experienced by a competitor prior to the start of a competition when the initial strokes effectively propel the craft from a stationary position. However for the study of continuous paddling action it would be necessary for the kayak to be moving relative to the water surface or alternatively for the water to be moving backwards in relation to the canoe. The last suggestion although realistic as a device for the ongoing study of canoeing action is perhaps too expensive for a single self-financed investigation.

The simulator mentioned penultimately was devised in a simplistic form sufficient for its effectiveness to be evaluated. It was found that although the paddling action required to move the device was similar to that required when canoeing, the advantages of the device failed to exceed those of a te thered canoe in a swimming pool. At this stage the line of investigation was halted.

BICYCLE ERGOMETER

Attention was focussed on a 'LODE' electronically braked bicycle ergometer with the view to modifying the machine to simulate the paddling action of canoeing.

The machine was inverted and a platform supporting an adjustable canoe seat and foot rest was constructed (fig 6 ).

Figure 6. The arm ergometer comprising of seat, platform and adjustable footrest.

Unlike previous simulators where pedal cranks have been extended and linked to a paddle shaft thus creating a variably angled loom, this effect was achieved here by replacing the pedals with short sections of neoprene tubing.The tubing was slightly flexible to accomodate a variation in hand geometry but sufficiently rigid to transmit power to the machine.

Variable resistance (in Watts) was applied to the device through a remotely controlled console.When this device was linked to a micro-processor through a digital to analogue interface a simulated paddle resistance similar to that found on a river could be programmed.

At this stage it is perhaps appropriate to consider the analysis of a paddling stroke before progressing onto the validation of the paddle ergometer

## MECHANICAL ANALYSIS OF A FORWARD PADDLING STROKE

Power from the canoeist's muscles is transmitted through the paddle to the water.The resistance offered by the water to the paddle blade is isokinetic in nature in that the paddle moves progressively backwards through the water as more power is applied.The mean pressure on a paddle blade is 45gr/cm*2 measured by a friction tube attached to the centre of the blade.

In mechanical terms the leverages employed during a

paddle stroke on one side of the canoe vary depending upon the style of the individual. Fig (7) illustrates a first order lever system where the left paddle experiences resistance offered by the water and the left hand acts as a fulcrum.The effort is applied through the right hand. Fig (7) also illustrates a technique where the fulcrum is at the right hand and the effort is applied through the left hand, this is a third order lever system. Finally Fig (7) illustrates a combination technique where the two previously mentioned lever systems are combined and act simultaneously.The latter technique appears to be the one favoured by slalom canoeists when paddling forwards.

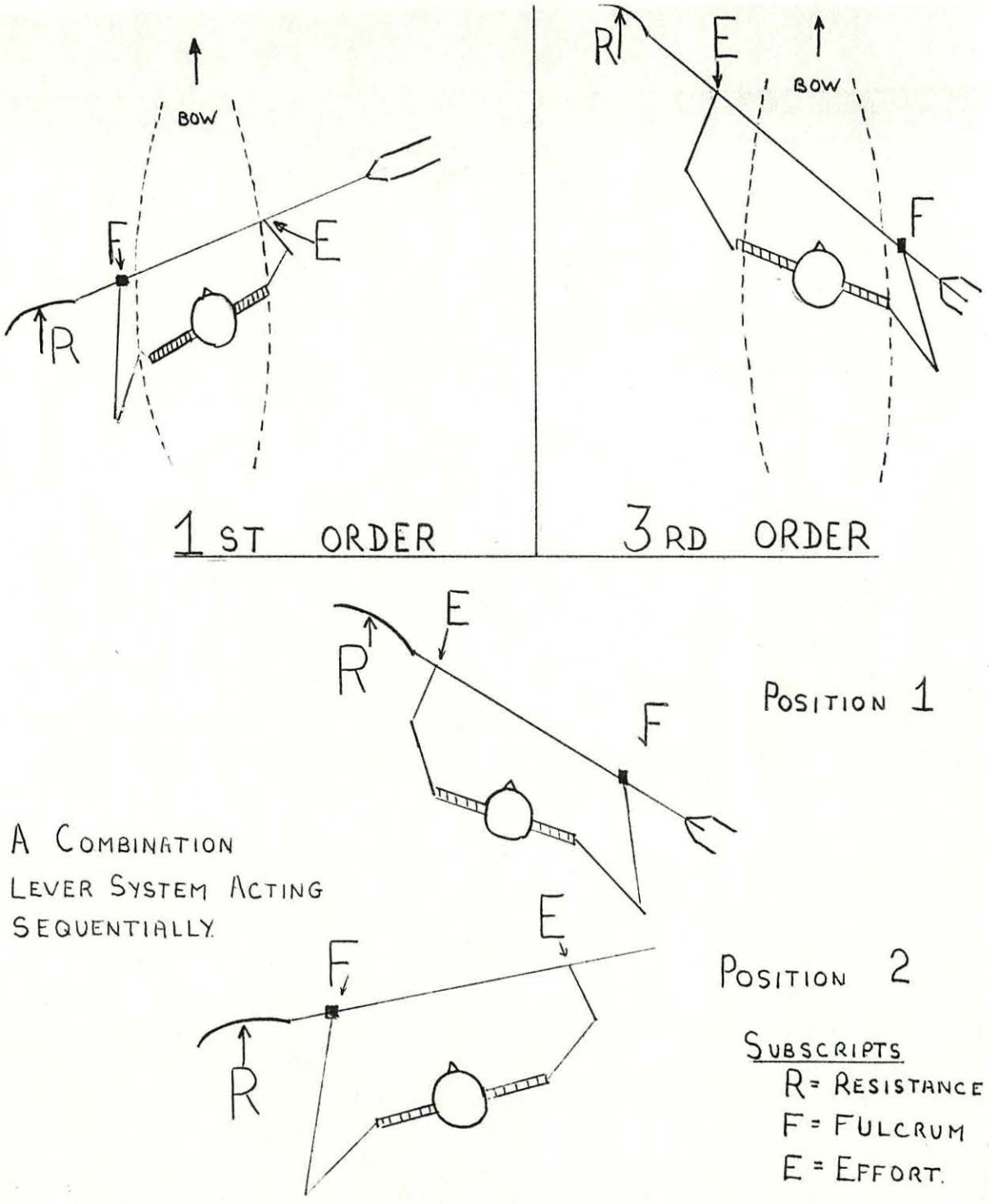



Fig 7. The lever systems adopted in a paddling stroke.
The upper left figure illustrates a first order lever system were the left arm is actively pushing.
The upper right figure shows a third order lever system where the left arm is actively pulling.
The centre diagram illustrates a combination lever system where the canoeist adopts a third order lever in the initial phase of the stroke then followed by a first order lever.

## MUSCLE ANALYSIS

The lower body musculature plays a large isometric and synergic role during propulsive canoe strokes. During the power phase the back and thigh muscles are involved in slight extension of the hips but maximally in a synergic role to allow the upper body musculature to effect a protagonist action. Cermak (1975) reported that in canoeists the muscles of the back were particularly strong.

The humeroscapulo joint complex is involved in extensive movement during canoeing activity and this is described systematically in table (1).

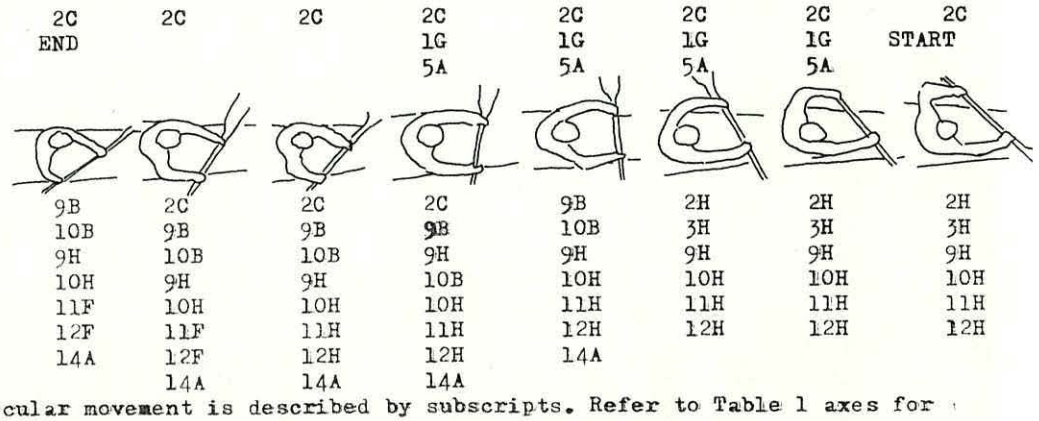
It can be seen from this table that during the pulling phase when the humerus is drawn backwards (extended) the latissimus dorsi muscle is a major protagonist . Simultaneously the other humerus is pushing forwards (horizontal flexion) caused primarily by the pectoralis major. Although many other muscles are involved actively at some stage during a propulsive phase of the forward paddling stroke, both the latissimus dorsi and the pectoralis major are particularly interesting. These muscles are superficial in location which makes them suitable sites for electromyographical analysis.

The latissimus dorsi was a muscle which Court (1979) reported as being noticably active during the propulsive stage of the canadian canoe stroke.

Table 1
Shoulder joint muscles and their actions

| | A flex | B ext | C abd | D add | E inw rot | F outw rot | G hor flex | H hor ext | |
|---|---|---|---|---|---|---|---|---|---|
| 1. Ant Deltoid | PM | | Asst | | Asst | | PM | | 1 |
| 2. Mid Deltoid | | | PM | | | | | PM | 2 |
| 3. Post Deltoid | | Asst | | Asst | | Asst | | PM | 3 |
| 4. Supraspinatus | | | PM | | | | | | 4 |
| 5.Pect Maj Clav | PM | | Asst | | Asst | | PM | | 5 |
| 6.Pec Maj sternal | | PM | | PM | Asst | | PM | | 6 |
| 7.Coracobrachialis | Asst | | | Asst | Asst | Asst | PM | | 7 |
| 8.Subscapularis | | | | Asst | PM | | Asst | | 8 |
| 9.Latt dorsi | | PM | | PM | Asst | | | Asst | 9 |
| 10 Teres Maj | | PM | | PM | PM | | | Asst | 10 |
| 11 Infraspinatus | | | | | | PM | | PM | 11 |
| 12 Teres minor | | | | | | PM | | PM | 12 |
| 13 Biceps L head | | | Asst | | | | | | 13 |
| 14 Biceps S head | Asst | | | Asst | Asst | | Asst | | 14 |
| 15 Triceps | | Asst | | Asst | | | | | 15 |

PM = PRIME MOVER.




The muscular movement is described by subscripts. Refer to Table 1 axes for each subscript.
Subscripts above the doll refer to left arm; those below to the right arm.

Validation of Paddle Ergometer

The latissimus dorsi and the pectoralis muscles together with anterior and posterior deltoid were selected as criteria for comparing the pattern of movement during a canoe stroke on water with that produced when performing on the arm ergometer.

EMG recordings were taken from a subject seated in a canoe on a swimming pool ( fig 8).The same subject,who was a recent member of the British slalom team, was connected in the same way to the emg machine to record shoulder girdle muscle actions while performing a paddle stroke on the simulator (fig 9).

Figure 8. A subject seated in a kayak connected to an electromyograph. Subject and apparatus moved simultaneously.

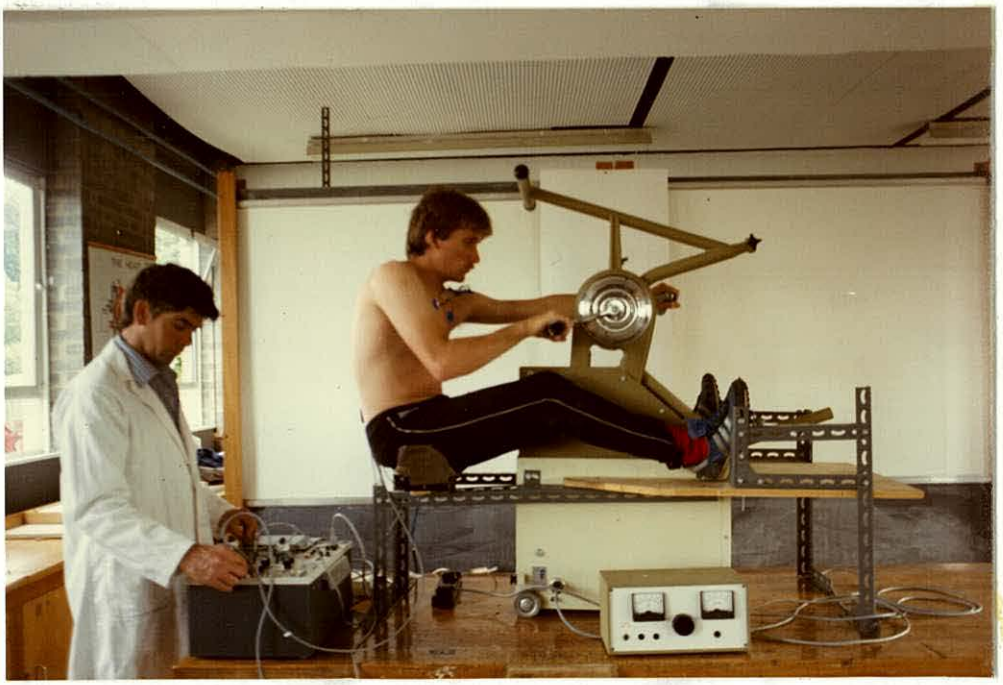


Figure 9.A subject on the arm ergometer.

Figure (10) illustrates the emg results both on water and on the ergometer for a complete paddle cycle.

A complete paddle cycle commences when the left hand is furthest from the vertical body axis in the sagittal plane, it is pulled downwards towards the axis and then is pushed upwards and out to regain the start position.

The paddle action commences with vigorous activity in the left anterior deltoid ( fig 10a) which although not acting in a propulsive extension of the humerus, is responsible along with the medial deltoid in supporting the humerus in a forward flexed position. The intensity of anterior deltoid action is 11 points ( a point corresponds to each time the pen trace crosses the mid line of the pen sweep).

Simultaneously left posterior deltoid and left latissimus dorsi act in a propulsive extension of humerus as the hand and paddle is pulled backwards through the water, posterior deltoid 7 points, latissimus dorsi 10 points.

The description above is summarized in Table (2)

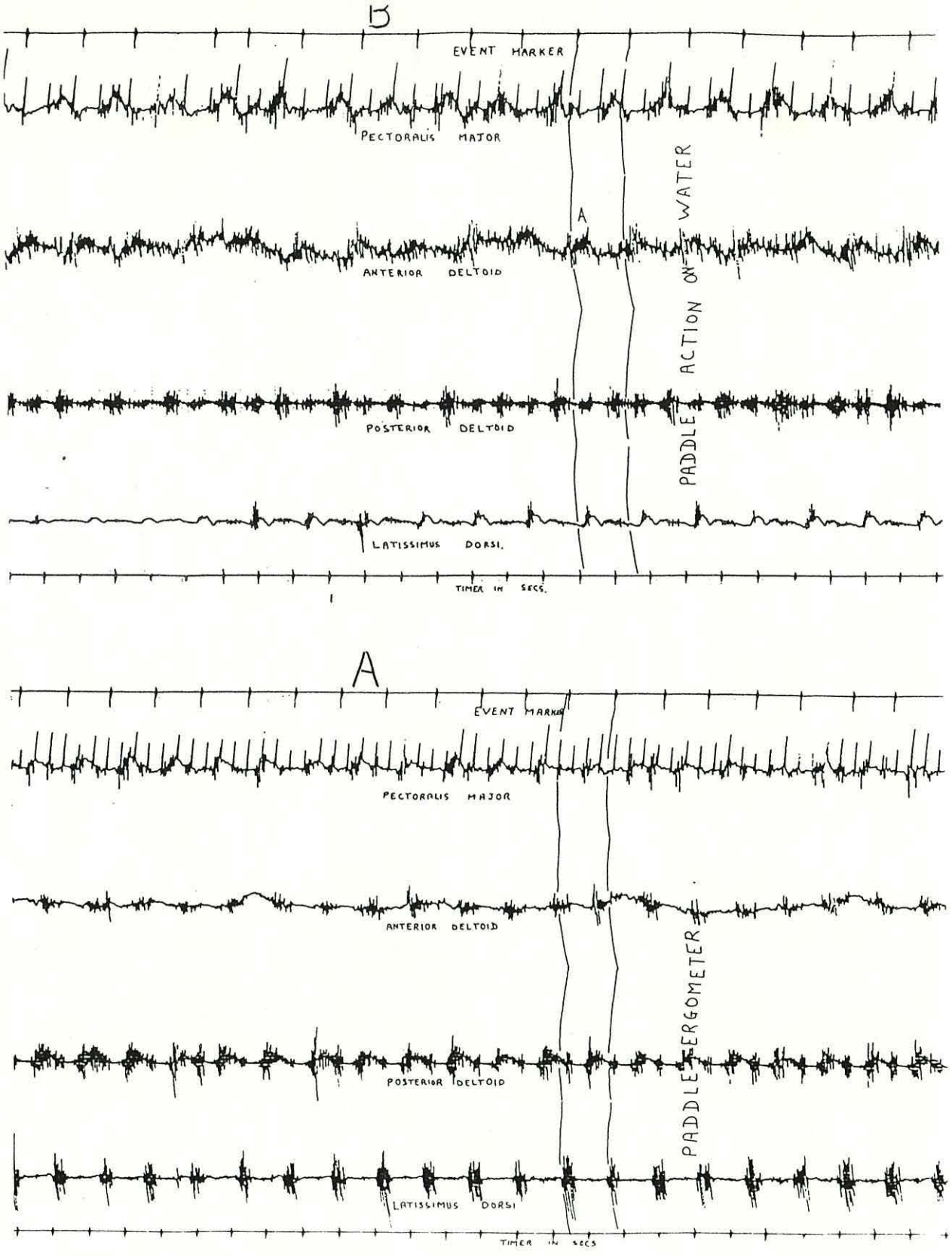



Figure 10. Two e m g traces of four muscles acting simultaneously on each trace. The event marker intervals indicate a complete paddle cycle of the left hand (A) on the paddle ergometer and (B) while paddling a kayak on water.

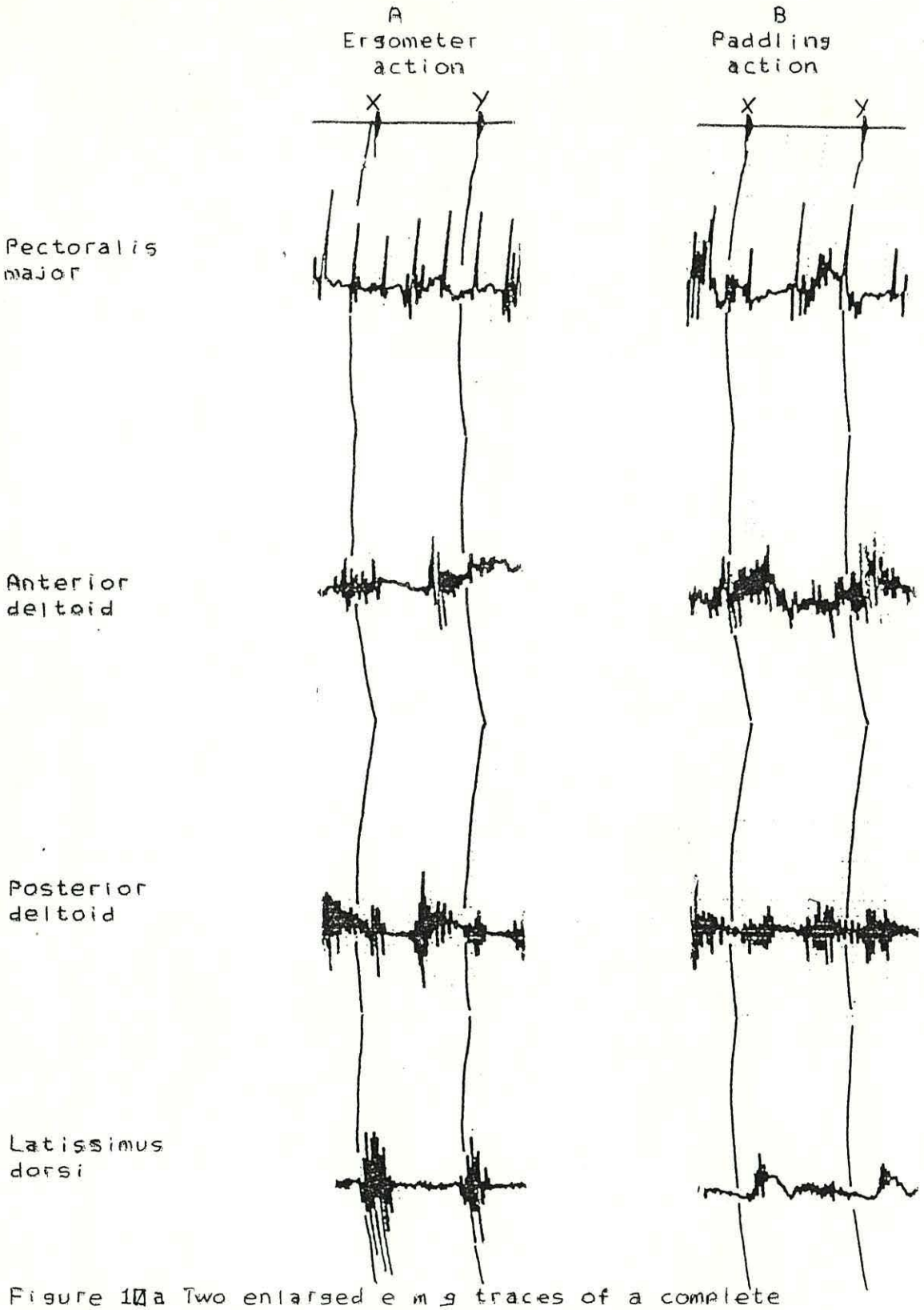



Figure 10a Two enlarged e m g traces of a complete paddle action (A) on the ergometer and (B) in the Kayak. Line X denotes the beginning of the paddle cycle, Line Y indicates the end.

Table 2

A summary of contraction phases of four muscles during a complete paddle action on the ergometer and in the kayak

| Contraction time ms | Pectoralis major | | Anterior deltoid | | Posterior deltoid | | Latiss dorsi | |
|---|---|---|---|---|---|---|---|---|
| | Er | Ky | Er | Ky | Er | Ky | Er | Ky |
| 0-500ms | 3 | 3 | 2 | 4 | 3 | 3 | 4 | 3 |
| 500-1000ms | 3 | 2 | 1 | 2 | 3 | 2 | 1 | 1 |
| 1000-1500ms | 3 | 3 | 3 | 3 | 4 | 4 | 2 | 2 |

Subscripts

Er contractions during ergometer action
Ky contractions during kayak action

| | |
|---|---|
| 1 = little or no contraction | 0-3 points |
| 2 = weak contractions | 4-8 points |
| 3 = moderate contractions | 9-12 points |
| 4 = intense contractions | 13+ |

A similar protocol is adopted for the description of the full cyclic paddle action on the paddle ergometer commencing when the left hand is furthest from the vertical body axis in the sagittal plane and returns to that position after having moved backwards, downwards, upwards and forwards.

A muscular description of the movement observed from the emg traces starts with latissimus dorsi action during the first third of the pull phase of the left arm with a simultaneous yet somewhat less vigorous assisting action of the posterior deltoid. The anterior deltoid is also slightly active in the first phase (5 points), possibly in a synergic role.

The second phase of the action is dominated by the posterior deltoid which is involved in the change of direction when the olecranon reaches its furthest backward point and then proceeds to track forwards as the pushing action commences.

The pectoralis major commences its action at the apparent change over point between the pull and push although the intensity of its action is not as great as one might expect during the push phase, this phase might be a misnomer.

During the last phase of the push action anterior deltoid is active together with posterior deltoid.

This description is also shown in Table (2).

Summary of muscle actions

The observed pattern of activity in four selected muscles during a full paddling stroke while canoeing on water was similar to that observed during a full cycle on the arm ergometer.

Of particular importance was the duration and intensity of the latissimus dorsi muscle during the action. The intensity of this muscle when on the ergometer was similar to that when canoeing but the duration of this action was slightly longer on the ergometer. The latissimus dorsi muscle was that selected to be trained and then biopsied so the effect of the ergometer in this context was most satisfactory.

## CINEMATOGRAPHICAL ANALYSIS

The forward paddling stroke while canoeing and the arm action during work on the paddle ergometer were both filmed using 8mm cinematography in the frontal, sagittal and transverse planes although not in a synchronized manner. The entry point and exit point of the paddle blade were used for synchronization cues during subsequent frame analysis. The camera speed found to be most suitable was 18 frames per second.

The body segments studied were the humerus and the vertebrae and from the analysis of each frame the loci of these segments were plotted.

The results of the cinematographical analysis are illustrated in figures 11, 12, and 13 where a comparison between the canoe paddling action and simulator action during a single right hand pull can be made.

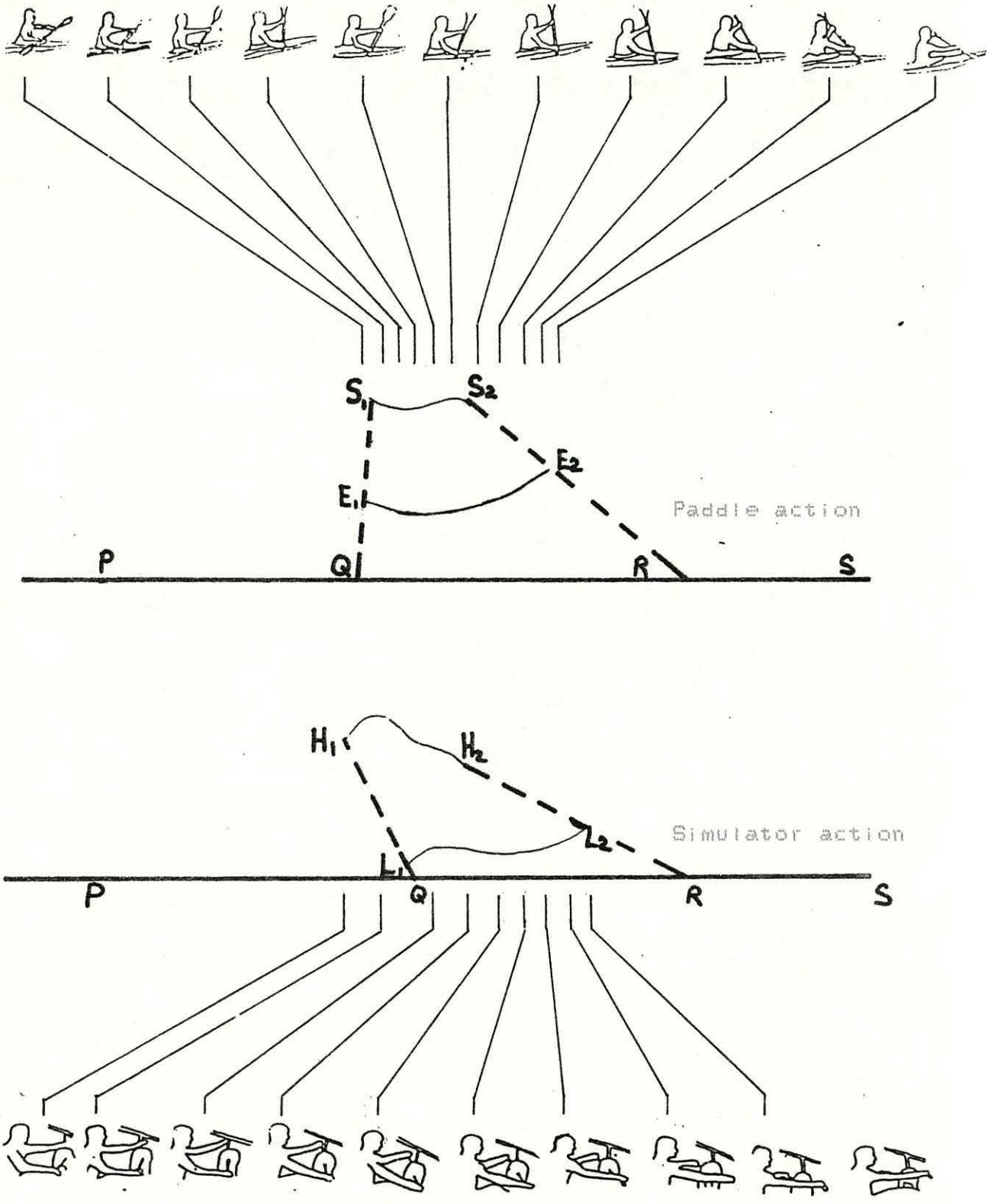
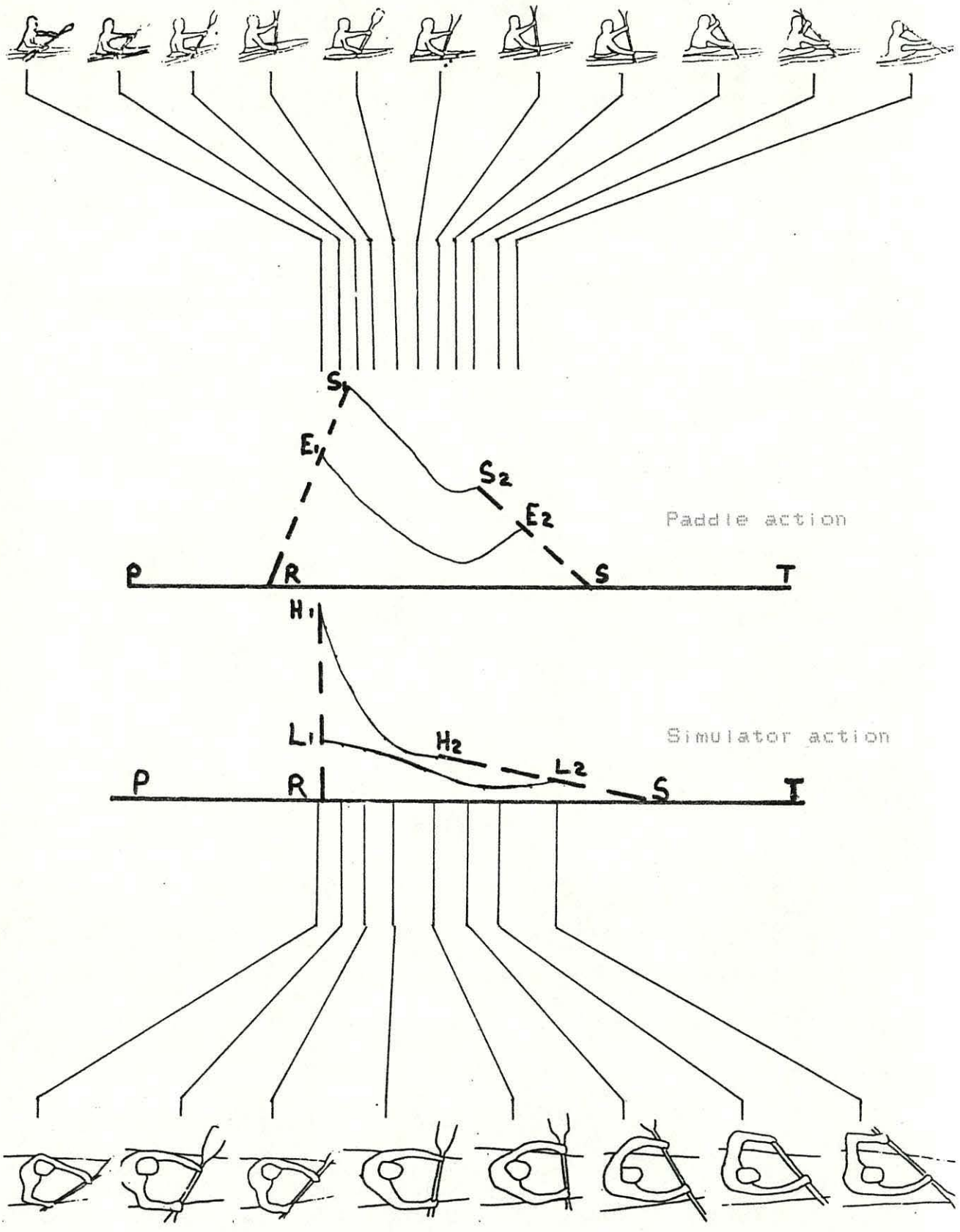



Figure 11. The locus of the head of humerus during a single right hand paddle action is shown by S2----S1; during a simulator right hand cycle by H2----H1. E2 though E1 and L2 through L1 are the loci of the olecranon during the paddle action and simulator action respectively.




Figue 12. The locus of the head of humerus during a right hand paddle action is shown by S2----S1; during a right hand simulator action by H2----H1. E2 through E1 and L2 through L1 are the loci of the olecranon during the paddle action and simulator action respectively.

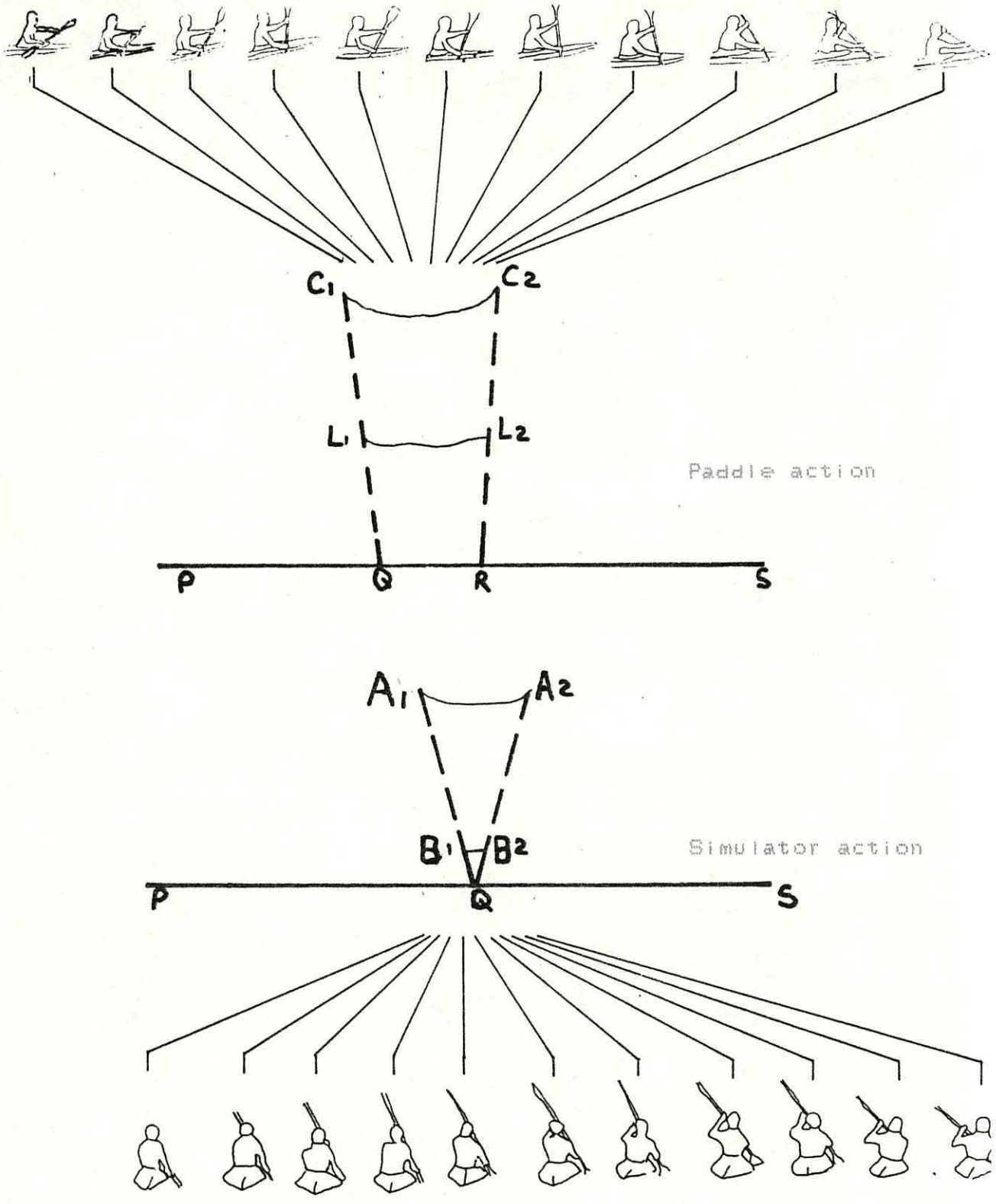



Figure 13. The locus of the 5th cervical vertebrae during a right hand paddle stroke is shown by C2----C1; during a right hand simulator action by A2-----A1. L2 through L1 and B2 through B1 are the loci of the 5th lumbar vertebrae during a paddle action and simulator action respectively.

Figure 11 shows the action observed from the sagittal plane.The 'dolls' shown at the top and bottom of the figure were taken from the film, and serve as a guide to the sequential position of the humerus during each arm action.Both the actions while paddling and on the simulator were of a similar duration ie within 2 frames.

The initial and final angle of the humerus during the canoe stroke is illustrated in figure 11,by S2 $\hat{R}$ S and S1 $\hat{Q}$ S respectively.Likewise the initial and final angle of the humerus during the simulator action is shown by H2 $\hat{R}$ S and H1 $\hat{Q}$ S respectively. It would be erronous to compare the angles directly between paddling and simulator from this film due to the imprecise nature of filming while on the water. However a visual inspection of the loci reveals that the range of movement on the simulator was marginally less than that observed during the paddling stroke.

Figure 12 illustrates the locus of the humerus from the transverse plane.The dissimilarity between the initial angle S2 $\hat{S}$ T and H2 $\hat{S}$ T of the humerus while paddling and on the simulator respectvely is clear. During the paddling stroke the subject can determine the point of entry of his paddle and this becomes habitual. On the simulator the furthest point during the revolution of the paddle arm is a

function of the length of the peddle crank, which is fixed.

Once again comparative angular measurements were not intended to be taken from this film but a visual inspection of the loci S2 through S1 and H2 through H1 do not differ widely; this trace shows the head of humerus during both actions.

When the paddling action was observed from the frontal plane (posteriorly) the locus of the cervical spine is illustrated by C2 - C1 in figure 13. This is not unlike the cervical trace on the simulator shown by A2 - A1 , also in figure 13. A striking difference is seen in the movement of the lumbar vertebrae L2 - L1 (canoe) and B2 - B1 (simulator). While canoeing the subjects were observed to move their craft sideways during the pulling phase thus explaining the trace L2 through L1. On the simulator however there was a fixed seat which prevented this action thus explaining the trace B2 through B1.

This cinematographical exercise has highlighted some dissimilarities between the action of paddling a right hand stroke while canoeing and pulling the right hand lever on the paddling simulator. On the whole the pattern of movements were sufficiently alike to give confidence in the design of the simulator.

Conclusions of two independent methods of validating the paddle ergometer.

The broad aim of producing a paddle ergometer was to be able to reproduce a paddling action in the controlled environment of the laboratory, which closely resembled that experienced while paddling a kayak on water.

The results of the electromyographical analysis of four propulsive canoeing muscles revealed that a subject working on the arm ergometer produced a pattern of muscular activity which resembled closely that while canoeing on water.

The cinematographical analysis of the same actions revealed that the range of upper body and arm movements is slightly less on the ergometer than that observed while canoeing on water, but nevertheless the overall pattern was similar.

Based on these results the ergometer was adopted without further modification for subsequent use in the study.

A Survey of Training routines and Attitudes among Elite Slalom Canoeists.

Rationale:

The problem which this study attempts to solve is as follows:- "Can the demands of slalom competition be identified, if so what are they and how can training methods meet them ?"

It was thought appropriate to initiate this investigation by conducting a questionnaire which enquired into the training habits and beliefs of elite slalom competitors. It was hoped that the results of this exercise would not only reveal the current training methods that were being employed but also the logic and reasoning underlying the choice of such methods.

Method

A questionnaire which enquired into the methods, frequency and modes of training was administered personally (by the author) to a group of 30 elite slalomists.

The aims of the exercise were to investigate the degree of awareness of training methods shown by competitors, to reveal the availability and utilization of training facilities and to indicate the depth of applied coaching.

The size of the sample questioned although small (n=30) , represents the upper echelons of the sport. It was

felt that competitors of this calibre were those most likely to be exposed to modern coaching and training techniques and therefore their responses would reflect a comprehensive picture of current practices.

Results of the Questionnaire

The types of training most frequently employed and reported by slalomists in the sample are illustrated in fig 14.A large number of slalomists (29) used kayak sprinting as part of their routines and when questioned further on this point the majority considered that extended sprinting (1000 metres) was a useful exercise. Tesch et al (1976) reported that the highest oxygen uptake of all the racing distances was obtained after 1000 metre races.

If aerobic capacity is firmly established as an important factor in slalom performance then the competitors in the sample are adopting a sound training principle by sprinting 1000 metres in kayaks.

If however this belief is a fallacy and anaerobic training is of prime importance then shorter sprint distances might prove more beneficial.

It was noticable from the returns that few competitors employed isokinetic training methods (Pipes and Wilmore 1975; Astrand Rodalh 1977) particularly in view of the increase in number of isokinetic 'mini gyms' round the

country. Perhaps the problem is that there is a lack of advice and guidance for using this type of equipment.

The small number (4) of subjects who incorporated isokinetic training methods in their regimes included one ex world champion and the current world champion (1983).

The duration and frequency of training habits are illustrated in fig 15.It can be seen from this figure that half the sample (15) trained up to five hours per week.The second largest group (8) trained between 14 and 18 hours per week.Both world champions fell into this group.The majority of the sample (18) trained between 5 and 7 days per week.

Although guidelines on training frequency are specific to each event there is a dearth of information to support such advice in canoeing. The figure of 7 days per week for training frequency,reported in the questionnaire, seems high unless distinct and contrasting training methods are employed.The greatest danger of such regular training is a loss of motivation.

The majority of the sample (23: Table 3) received guidance in their training programmes and all the sample (100%) expressed a willingness to modify their routines on authoritative advice.A large number (76%) included mobility exercises and all employed a pre-training/competition warm up period ranging from 5-30 minutes.Once again both world champions tended to extensive warm up bouts.

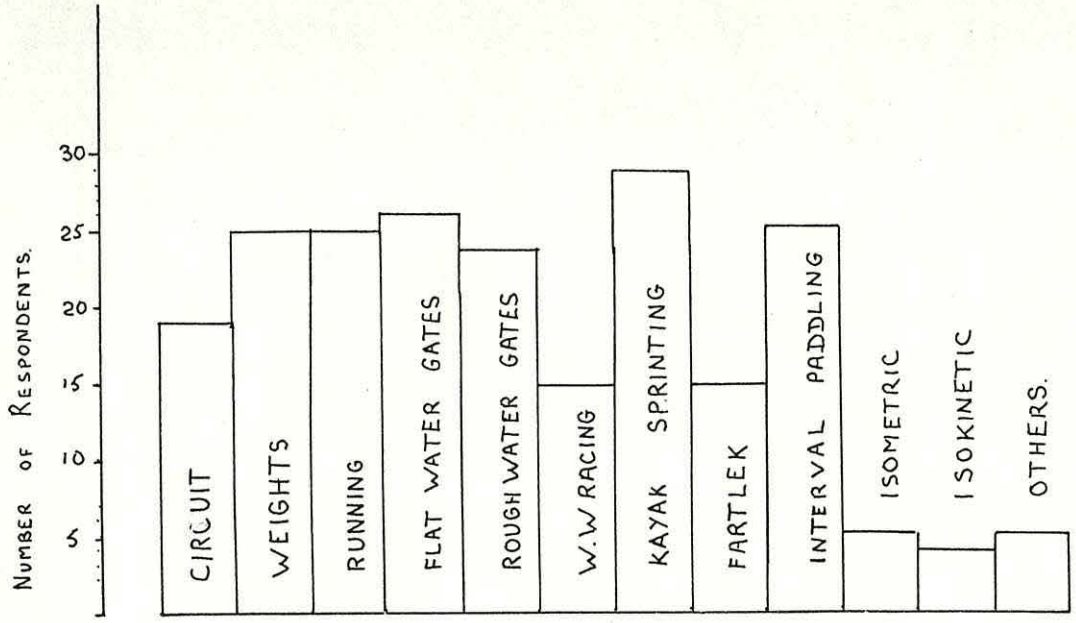



Fig 14. illustrating the types of training adopted by 30 slalomists

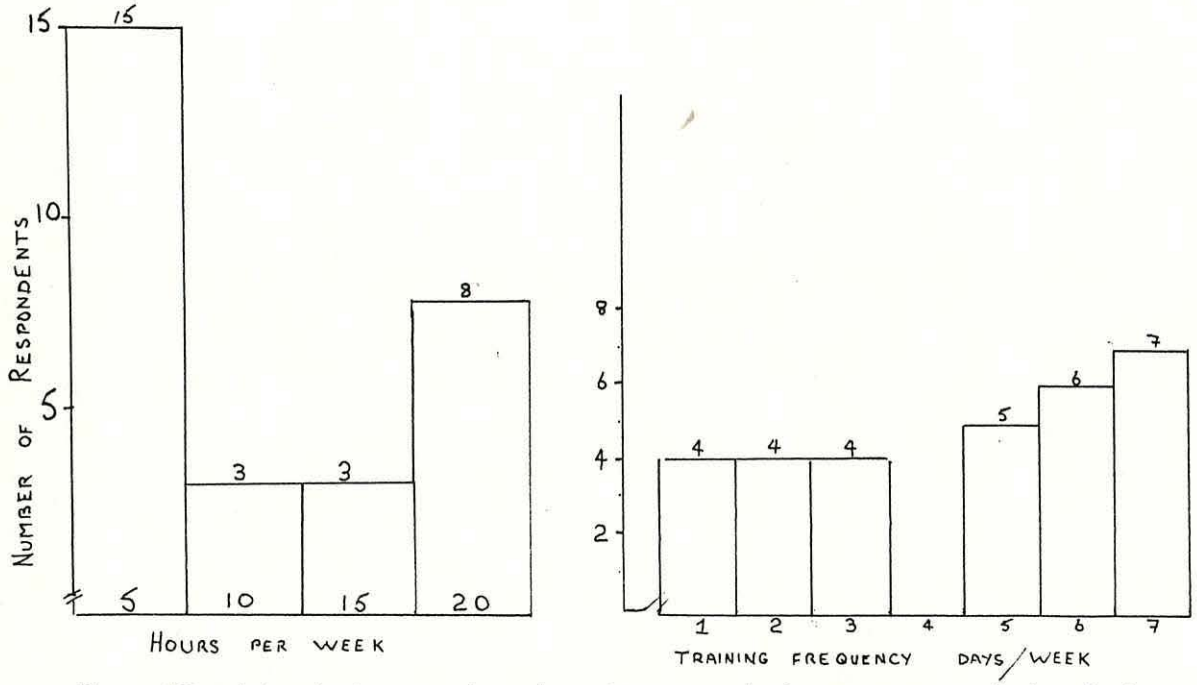



Fig 15. illustrating the duration and frequency of training recorded by 30 slalomists.

Table 3

The responses from 30 subjects to specific questions.

| Question | % YES | % NO |
|---|---|---|
| Is your training guided | 77 | 23 |
| Will you modify training if advised | 100 | - |
| Do you include mobility exercises | 77 | 23 |
| Do you warm up | 100 | - |
| Length of warm up | 5 to 30 minutes | |
| Do you use special diets | - | 100 |
| Have you vomitted during training | 50 | 50 |
| Do you know your resting pulse rate | 77 | 23 |
| Do you use pulse as a guide during training | 50 | 50 |

Special dietary requirements were considered unnecessary by all respondents but the type and timing of meals were reported as important factors on competition days.High energy liquid intake several hours prior to competition was a common occurrence.

Half the sample experienced illness in the form of vomitting during training periods although none reported this as a measure of training intensity often used in that way by track athletes.

Approximately 75% of the sample were aware of their resting pulse rate value but only half (15) used pulse rate as a training guide.

Conclusions.

The overall picture which emerges from the data on training habits seems to be one of generality.There does not appear to be a particular routine or specific principles which are common to the majority of the canoeists sampled.

There does appear to be a hint of emphasis,knowingly or otherwise, placed on aerobic development.It is suggested that perhaps this results from an awareness on the part of coaches and competitors of the importance of repetitious skill training.There was also evidence from casual

conversations with the subjects that there existed a conservative historical influence which one respondent expressed "if the method was good enough for that champion then it is good enough for me"

A feeling that resulted from this survey and from the casual conversations which took place between the author and many canoeists was that there appears to be lacking, convincing data on the demands of slalom performance on which competitors might base their training programmes.

# CHAPTER 4

## Overview

In order to assess the physiological demands of competing in a slalom event, where-ever possible data were collected during competition. If this proved unrealistic then an attempt was made to collect data during a simulated run on an international slalom course. As a last resort when the two aforementioned methods were inappropriate data were then collected in the laboratory.

This chapter is devoted to a description of four independent methods of data collection.

Each method together with the results will be described separately in the following order:-

4.1 Stroke Count

4.2 Heart Rate

4.3 Oxygen Uptake

4.4 Lactate Levels.

==========

4.1

## Stroke Count

Slalom events require the competitior to manoeuvre his craft as fast as possible from the start through a series of gates (up to 30) to the finish. The route inevitably requires the competitor to perform a combination of different paddling strokes of which some are forward propulsive strokes, some are reverse strokes and some are combination 'moving draw' strokes. Needless to say each stroke involves a particular pattern of muscle activity.

It would be useful for competitors to be aware of the proportion of different strokes that might be necessary when paddling particular slalom courses. An implied assumption of that statement is that all competitors perform a similar type and number of strokes for a particular course.

There was no evidence to suggest that this assumption was correct.

It was decided therefore to count the number and classify the types of strokes which a competitor performed on a slalom course.

### Method

Strokes were classified into three categories:-

a. Forward propulsive stroke;

The paddle blade moved from an entry point forward of the cockpit passed the cockpit to exit near the rear deck.There was to be no apparent steerage attempt during the action.

b. Reverse paddling stroke;

This is a pushing stroke where the blade enters the water close to the rear deck and moves forwards to exit near the front deck.It is intended to brake the forward moving kayak or propel it in a reverse direction.

c. Combination stroke;

This describes any other stroke which is neither a forward nor a reverse stroke.

Initially it was hoped that accurate stroke counts might be taken from a video recording of competitors' runs.This method was evaluated and abandoned for operational reasons in favour of manual stroke counting.

The method which proved most effective involved four trained observers each equipped with a portable cassette recorder and strategically positioned along the slalom course.

Each observer was responsible for counting and classifying the strokes performed by the competitor on his section of the course.Each competitors' number (displayed on a bib) was called out verbally by the observer prior to

entering his section of the course.In the same manner the types of stokes were spoken and recorded automatically on tape.

It was a simple task to collate these data from the cassette tape at a later date.

This method was used to quantify the variety of strokes performed by 20 elite slaLomists competing in a national event.

The venue chosen for the stroke count was the international canoe slalom course at Bala in North Wales which is between 700 and 800 metres in length. A number (in the range 26-30) of slalom gates were suspended from wires spanning the river at intervals down the course. A competitor must negotiate each gate in a prescribed manner this being either forward down stream, forward upstream or reverse down stream .Thus the canoeist is constantly turning the kayak in order to assume a correct presentation.

A new course is designed for each slalom competition but the length of the course and the number of gates are determined by international rules.The details of the course used for data collection in this study were typical and are shown in table 4

Table 4

The characteristics of the slalom course

Number of gates 28

Forward downstream 16

Forward upstream 7

Reverse downstream 5

Course length 700 metres

---

Results

The results of the stroke count exercise are shown in Table 5

Table 5

The results of a stroke count for 20 competitors at a national slalom event at Bala

| Stroke | Range | Mean | SD |
|---|---|---|---|
| FP | 132-144 | 136.9 | 5.13 |
| RP | 34-40 | 36.6 | 2.7 |
| CS | 40-49 | 45.7 | 3.39 |
| Total | 211-236 | 222.05 | |

N=20
FP=forward paddling
RP=reverse paddling
CS=combination strokes

What is particularly striking about these data is the small range in the number of each stroke category. For 20 competitiors the mean number of forward paddling strokes was 137 with a variation of +-5, the mean number of reverse strokes was 37 +-3 and the mean number of combination strokes was 45+- 5. These data suggest that the total slalom skill may be at least partially 'closed' in nature that is to say that each competitor follows a similar course on the river and performs a similar number and type of manoeuvering strokes on any section of the course.

Each particular course design would produce a sequence of stroke patterns. Forward paddling strokes are interspersed with combination and reverse strokes. The energetic implications of this pattern of activity is that muscle groups which are predominatly involved in forward propulsion experience a rest phase, albeit short lived, when reverse and combination strokes are performed.

It would appear from these data that for a competitor to reach the finish line of a slalom course no single muscle group is active continuously, but that several distinctive muscle groups act sequentially.

## Conclusions of the stroke count.

It is suggested that stroke counting is a exercise which can produce useful data on which coaches can design skill training programmes .

The term 'horses for courses' is somewhat appropriate to slalom canoeing in that different slalom venues require almost specific patterns of paddle strokes.Thus in final training sessions for a particular event the duration of the course and the type and number of strokes should feature prominently during training intervals.

It is suggested that the alactic and lactacid energy supplies might extend for the duration of an event (2.5-3 mins) for each muscle group and that the demands which are placed on the aerobic energy liberating system are minimal.

In any sporting event where the demands required of the aerobic energy liberating mechanism are severe, high oxygen uptake values are accompanied by near maximal heart rates (Margaria, 1976).Heart rate is a reliable indicator of VO2 function and is readily accessible.

It was decided that if heart rate was monitored during slalom performance then the aerobic contribution might be quantified.

4.2

## Heart Rate

Resting heart rate (65-70 beats per minute), normally under the influence of the cardiac vagal nerves ,is also affected by several other extereoceptor and interoreceptors.

One of the several effects which stress produces in the athlete is an increase in sympathetic nerve activity which through the vasomotor centre in the cerebral cortex causes an increase in heart rate (HR) , cardiac output and blood pressure.

In many types of work the increase in HR is approximately linear with the increase in work load. In a trained individual, provided the exercise is not maximal a similar linear relationship holds true for HR and oxygen uptake,VO2 (Astrand and Rodahl 1977).

An attempt was made in this study to monitor HR during a simulated run on an international slalom course in order to investigate the role played by aerobic metabolism as manifested by HR changes.

There are several elaborate methods of measuring HR, some are direct while others are indirect. Direct methods of linking subjects by screened leads to HR monitors are convenient in the laboratory but much less feasible in field

studies. Telemetry techniques overcome many problems associated with cables and leads when subjects are mobile such as on a treadmill and this method is often employed for some outdoor studies but a power supply is necessary and the range of pulse transmission is often limited.

An alternative method to collect HR data incorporates a device called an Exercentry (trade name) which is secured to the subject's chest in a harness (fig 16). HR is continually recorded and displayed on a L E D screen on top of the device. Additionally there is an audible signal that sounds when HR either exceeds or falls below values preset on two large dials.This device is particularly useful to the athlete during training sessions when HR values are used as guides to training intensity.

If the exercentry is used in conjunction with a portable cassette recorder in a kayak then heart rates in excess of predetermined values can be recorded.

Both the telemetry system and the exercentry device were evaluated for use in this study. Telemetry posed many operational problems ,principal amongst these was the limited range of reliable signal reception.

The exercentry device was found to be reliable and particularly suitable because only upper absolute HR values were of interest and not a continuous record.

The device and tape recorder were self contained and battery operated and the supporting chest harness and

electrodes were comfortable to the subject causing no interference to his upper body action.

Figure 16. The 'exercentry' heart rate monitor secured to a subject with a harness.

A total of 20 experienced canoeists including British team members provided HR data during complete runs on the international slalom course. The results are now presented.

Results

The mean heart rates recorded by the exercentry device are shown in Table 6

Table 6

The mean heart rates of n=20 canoeists while paddling, stepping and resting.

| | paddling | stepping | rest |
|---|---|---|---|
| Mean | (175 | )185 | 61.9 |
| Range | | 22 | 15 |
| SD | | | 4.83 |

Comparative data for these subjects consisted of resting pulse (taken at carotid artery following 10 minutes rest, sitting) and heart rate during a standard 18" step test. All subjects recorded HR in excess of 185 beats per

minute during a three minute step test at a rate of one step cycle per 2 second, precise values in excess of 185 were not sought but some subjects reached this value earlier than others.

The interesting finding from these data was that not one subject exceeded the upper limit of 175 beats per minute while paddling the slalom course. There was little doubt however that the effort that these competitors were exerting during their simulated runs was near maximal since many recorded "good times" on the course, by their own assessment.

It would appear from these data that the role played by the aerobic energy supplies, while important is not dominant.

Perhaps continuous heart rate data by telemetry from competitors in a slalom competition might reveal details of periods of particular cardiovascular stress, but the author feels that this information would not contribute more significantly to the aerobic/anaerobic slalom debate than the data presented here.

4.3

## Oxygen Uptake

In any vigorous activity lasting for more than two minutes the oxygen carrying capacity of the cardiovascular system is progressively mobilized. The effectiveness of muscular effort during prolonged work is determined largely by the capacity to deliver oxygen in quantity to the mitochrondria. Thus oxygen uptake capacity expressed either in litres per minute or in millilitres per kilogramme of body weight (sometimes lean body mass is the index used) per minute is commonly employed as a criterion of aerobic efficiency.

Tesch et al (1976) used oxygen uptake as a criterion measure in elite Swedish sprint canoeists and found that those involved in distances over 1000 metres exhibited large oxygen uptake values ( ) 5.4 L/min) while those competitors in events of less than 500 metres exhibited much lower oxygen uptake values ($\bar{x}$=3.4 L/min).

Cermak et al (1975) also used oxygen uptake amongst other parameters as a measure of aerobic capacity in 'distance canoeists' and his findings were in close agreement with those of Tesch, namely that the significance of high VO2 values increase with longer distances.

Rationale

For the purpose of this study oxygen uptake capacity was employed as a contributory factor to establish a more complete profile of the physiological characteristics of slalom canoeists.

The results of the training survey reported earlier suggest that many slalomists in their training, concentrate on aerobic development knowingly or otherwise.

In the previous section the results of heart rate while in simulated competition suggest that maximal values are not demanded and a reasonable assumption might be that likewise maximal oxygen uptake in the event is also not demanded. However these athletes are using their arms and shoulder girdle muscle complex predominantly and it might be argued that a large proportion of oxygen uptake might be involved in the energetics of this musculature.

Vokac, Bell, Bautz-holter and Rodahl (1975) have observed that the oxygen uptake at maximal effort is usually 15-25% lower in arm work than in leg work. They also report that the opposite is true in submaximal work.

During a slalom run not only is the competitor eager to reach the finish line in the fastest possible time but he is also careful not to contact any slalom poles en route. It is suggested that the skill component just mentioned might cause some competitors to work at less than maximum rate in

order to achieve 'clear runs'.This view is shared by some world class canoeists and has been discussed with the author.They feel that there is a point in time at which they can concentrate their efforts on speed and almost disregard the slalom gates because they 'know 'that these will be negotiated without much attention being directed to them.

There is still little evidence reported in the literature to guide these athletes, particularly the aspiring competitors, when constructing a meaningful training programme.

It hoped that data on the aerobic demands of slalom canoeing collected in this study can go some way to elucidating the problem.

Method

A simulated work load of forward ,reverse and combination paddling strokes was devised for the canoeing simulator.This protocol was based on the results of the stroke count exercise which has been described previously.

The subject worked while wearing a face mask and inspired volume and expired oxygen content were measured using a 4 channel Oscillograph (Washington MD4) connected to an OX 140 oxygen transducer and an FC 140 MK 11 coupler.

This apparatus has proved valid and reliable in extensive trials conducted previously ( Docherty 1983:

unpublished thesis UCNW Bangor).

Five canoeists participated in this exercise, three were of moderate standard, the forth was well experienced while the fifth was the current world slalom K1 mens champion (1984).

In addition to the task using the simulator a separate investigation was conducted using 5 additional elite slalomists. These individuals were assessed for maximum oxygen uptake using legs on a bicycle ergometer , working at a submaximal rate. Final oxygen uptake values were predicted using the adjusted nomogram for the calculation of maximum uptake from submaximal pulse rates by Astrand (1977).

Results

The results of the simulated stroke pattern for three minutes on the canoeing simulator for five subjects of varying ability are shown in table 7.

Table 7

Oxygen uptake of five canoeists using a simulated stroke pattern on a canoeing simulator.

| SS | Kg | VO2 L/min arms | ML/Kg arms | VO2 L/min legs predicted | ML/kg legs |
|---|---|---|---|---|---|
| 1 | 72 | 3.4 | 47.2 | 4.1 | 56.9 |
| 2 | 68 | 2.8 | 41.2 | 3.7 | 54.4 |
| 3 | 68 | 2.6 | 38.2 | 3.6 | 52.9 |
| 4 | 70 | 2.0 | 28.6 | 3.8 | 54.3 |
| 5 | 70 | 2.4 | 34.3 | 3.9 | 55.7 |

Subjects 4 and 5 were experienced slalomists the latter being the 1984 world champion.

For each subject maximum VO2 values were predicted using submaximal HR during leg work as criteria and these values are shown in the last column of data.

If the VO2 values for the arm work are expressed as a percentage of the predicted VO2 max then a relationship between the demands which these subjects made upon their aerobic system during arm work is more apparent. Table 8 shows this relationship.

Table 8

The relationship between VO2 arm work and VO2 leg work for five subjects.

| SS | VO2 arms | VO2 max legs | % VO2 max during arm work |
|---|---|---|---|
| 1 | 3.4 | 4.1 | 83 |
| 2 | 2.8 | 3.7 | 76 |
| 3 | 2.6 | 3.6 | 72 |
| 4 | 2.0 | 3.4 | 57 |
| 5 | 2.4 | 4.2 | 57 |

The striking observation from table 8 is the large percentage of maximum oxygen uptake which the first three subjects demonstrated.These subjects were not experienced in slalom competition compared with the last two ie SS 4 and 5.

If the results for all elite slalomists during arm work were of the magnitude of oxygen uptake shown by the first three subjects in this trial then there would be some grounds to suppose that the metabolic demand during slalom work was aerobic in nature. However the results of VO2 arm work from the two elite slalomists ,although small in number, suggest that within three minutes just over 50% of VO2 max is mobilized.

The results of a further test conducted on subject 5 in the Department of Physical Education at the Univerity of Birmingham in which he was given repeated bouts of arm work

each of three minutes duration with one minute of rest between bouts on a paddle ergometer are shown in table 9( personal communication from R Fox to the author).

The gas measuring equipment ,a 'Oxycon' oxygen and CO2 analyser ,was much more sensitive to gas changes than the Washington oscillograph used previously.

Table 9

The results of VO2 for arm work at minute intervals in three minute work bouts interspersed with one minute of rest. The work was continued to exhaustion. The subject was the 1984 slalom world champion R Fox.

| min | %O2 | VO2 L/min | VO2 ML/KG | ELAPSED TIME mins |
|---|---|---|---|---|
| 1.0 | 5.0 | 1.81 | 25.8 | |
| 2.0 | 6.0 | 2.36 | 33.7 | |
| 3.0 | 5.7 | 2.45 | 36.3 | 3 |
| 1.0 | 4.8 | 2.08 | 29.8 | |
| 2.0 | 5.0 | 2.78 | 39.8 | |
| 3.0 | 5.2 | 2.68 | 38.2 | 6 |
| 1.0 | 4.7 | 2.36 | 33.7 | |
| 2.0 | 4.9 | 3.21 | 45.9 | |
| 3.0 | 4.6 | 3.24 | 46.3 | 9 |
| 1.0 | 4.6 | 2.78 | 39.8 | |
| 2.0 | 4.7 | 3.55 | 50.7 | |
| 3.0 | 4.5 | 3.43 | 49.0 | 12 |
| 1.0 | 4.9 | 3.57 | 50.9 | |
| 2.0 | 4.3 | 3.77 | 53.8 | |
| 3.0 | 4.2 | 3.85 | 55.0 | 15 |
| 1.0 | 3.9 | 3.90 | 55.7 | |
| 2.0 | 4.0 | 4.01 | 57.3 | |
| 3.0 | 3.7 | 4.14 | 59.7 | 18 |
| 1.0 | 3.1 | 2.17 | 31.0 | |
| 2.0 | 2.7 | 1.32 | 18.8 | |
| 3.0 | 2.7 | 1.18 | 16.8 | 21 |
| 1.0 | 2.5 | 0.94 | 13.4 | |
| 2.0 | 2.8 | 1.89 | 12.8 | |
| 3.0 | 2.7 | 0.69 | 9.8 | 24 |
| 1.0 | 3.2 | 0.67 | 9.5 | |
| 2.0 | 3.2 | 0.60 | 8.5 | |
| 3.0 | 3.5 | 0.53 | 7.6 | 27 |
| 1.0 | 3.5 | 0.54 | 7.7 | |
| 2.0 | 3.8 | 0.07 | 1.0 | |
| 3.0 | 3.8 | 0.00 | 0.0 | 30 |

The highest oxygen uptake reached by the subject (RF) in table 9 was in the 6th work bout that being 18 minutes after commencing exercise.The value reached was 4.14 litres per minute.

His oxygen uptake after 3 minutes which is approximately the time taken to complete a slalom course,was 2.45 litres/minute.if this time is extended to two bouts of three minute work periods then his oxygen uptake is 2.68 litres/min which is 65% of the highest value reached in this test after 18 minutes.

After 18 minutes of activity had elapsed this subject demonstrated a sudden decline in performance and a correspondingly marked reduction in oxygen uptake.

The results pertaining to oxygen uptake presented so far, when interpreted cautiously, suggest that elite slalomists utilize between 50 and 60% of their oxygen uptake capacity during a simulated slalom run.

There are some sporting events in which a high oxygen uptake is a prerequisite for international success.Perhaps the most demanding aerobic sport is Nordic Biathlon where the athlete must ski over long distances across country and during this period shoot accurately at targets.It is not uncommon for this type of athlete to

record VO2 max values in excess of 6 litres/min.

If a high VO2 max was a pre-requisite for success in slalom canoeing then a survey of elite slalomists would reveal a pattern of high innate VO2 max values.

Such a survey was conducted with a group of five world class slalomists and the results are shown in table 10.

Table 10

Heart rates from five elite slalomists while pedalling a bicycle ergometer at a work load of 175 watts for three minutes. Predicted VO2 max are shown.

| SS | HR | Predicted value |
|---|---|---|
| 1 | 160 | 3.0 L/min |
| 2 | 156 | 3.2 |
| 3 | 148 | 3.6 |
| 4 | 148 | 3.6 |
| 5 | 154 | 3.3 |

It can be seen from Table 10 that the highest predicted maximum oxygen uptake was 3.6 L/min recorded by two subjects,3 and 4.

The accuracy of predicted maximum uptake values from submaximal heart rates is questionable but generally the variation is reported to be approximately 10%. If the highest value recorded in Table 10 is increased by this error value (10%) the results of 3.96 L/min is still modest for a world class athlete (sprint canoeists 5L/min; 800-1500

metre runners 5.1 L/min ,Astrand and Rodahl 1977) unless of course the requirements of his event are largely anaerobic in nature.

Subject 4 was the 1984 world K1 champion and the highest VO2 value that this athlete has recorded previously is that shown in table 9 , 4.14 L/min. The difference between his predicted value based on HR and that measured empirically is a 13% increase.

The suggestion proposed from the stroke count data that different muscle groups contribute sequentially to a slalom run and that energy for these muscles is supplied largely from the synthesis of creatine phosphate (alactic energy supply) and through the formation of lactic acid thus not involving a maximum aerobic contribution is further supported from the VO2 data.

Based on these data it is suggested that slalom competition places a somewhat greater demand on the anaerobic energy liberating system than was previously thought.

4.4

## Lactate Levels

In a recent study by Davis and Vodak (1976) it was proposed that the alteration in selected respiratory gas exchange parameters was a sensitive noninvasive technique to assess the onset of metabolic acidosis (anaerobic threshold). Although a much prefered method to blood sampling for laboratory studies, this method is entirely unsuitable for field trials. Metabolic acidosis particularly during field experiments is more commonly determined from blood lactate assays.

Capillary puncture at the ear lobe or finger tip is a common technique used to measure lactate levels. However many biochemists have more confidence in lactate results obtained from venous blood samples.

Venopuncture was the method chosen for use in this study and the author, who received medical training for this procedure ,performed all the sampling described.

### Rationale

Due to the conflicting views and lack of evidence concerning the energetics of slalom competition, an attempt was made to determine the part played by the anaerobic energy liberating mechanism.

If the anaerobic system contributed significantly to

the energy supply then this would be apparent by an accumulation of lactate in the circulating blood.There is a delay of some minutes before lactate, which is produced at the muscle site, is washed into the general circulation.

From the view point of convenience a delay of some five minutes (optimum time for sampling lactate-Astrand Rodahl,1977) following a competitive slalom run is an ideal time for athletes to regain composure,disembark and move to a location where they can give a blood sample.

The competitive event chosen for this study was the Pre-World International canoe slalom championships. Considerable stress was placed on the British competitors since the results of this event would influence team selection for the World Championships.

Method

Nineteen national and international slalom competitors agreed to give a venous blood sample following their final run at an international slalom event.

Post competition blood samples were drawn from individuals in four events. The events were:-

1. Mens kayak singles

2. Mens Canadian singles

3. Mens Canadian doubles

4. Womens kayak singles.

Each competitor, after finishing his/her final competitive run left the water and was seated in a mobile laboratory at the side of the river.

An area of skin over a prominent antecubital vein was dried and cleaned with sterile swabs.

5cc of venous blood was drawn using a disposable needle and syringe within five minutes +- 30 secs of each competitor's finish time.

To each blood sample was added a drop of E D T A which stabilized the lactate reaction. Each sample was centrifuged within two hours and the plasma drawn off. The plasma samples were assayed for lactate content in the local hospital pathology laboratory.

Comments on procedure

Associated with any invasive technique there is always a risk of subsequent infection despite thorough

cleansing procedures.

There is some doubt relating to the finer legal points concerning who is qualified to perform venopuncture. The overiding consideration is one of negligence and even a medical doctor is liable if negligence is proved. A written consent form signed by the patient is of little value in a court of law.

The procedure adopted here was that the author was trained in venopuncture technique by a doctor and the local Ethical Committee gave consent and support for the project. Each subject who gave blood was asked to sign a consent form which although not exonerating the author from the consequences of subsequent infection, did ensure that blood was given freely and not under threat or duress.

Care was taken to reasure subjects and those who were squeamish about needles and injections were encouraged to look away. Only one minor problem was encounted that being the location of suitable vein in one subject. After several attempts a sample was obtained.

No subsequent complaint of injury or discomfort was reported by any subject when seen later in the season.

RESULTS

The results of Lactate sampling are shown in Table 11.

Table 11

The lactate content of blood (serum) taken from members of the British canoe slalom teams in four events during an International competition.

| A | B | C | D | E |
|---|---|---|---|---|
| K1MEN * | RF | 1.8 | 15.3 | 4 |
| K1 | JS | 1.31 | 14.5 | 5 |
| K1 | RM | 1.3 | 17.1 | 5 |
| K1 | AS | 2.0 | 17.2 | 4 |
| K1 | PG | 1.8 | 16.8 | 5 |
| | | | | |
| C1MEN | LW | 1.6 | 15.3 | 5 |
| C1 | PK | 2.1 | 14.3 | 4 |
| C1 | SC | 1.9 | 11.9 | 5 |
| C1 | WB | 1.2 | 10.8 | 5 |
| | | | | |
| C2MEN | RW | 2.0 | 9.6 | 5 |
| C2 | PH | 1.8 | 9.6 | 4 |
| C2 | RJ | 1.7 | 8.8 | 5 |
| C2 | DS | 1.9 | 13.3 | 5 |
| C2 | RN | 2.1 | 12.6 | 4 |
| C2 | EJ | 1.3 | 11.1 | 4 |
| | | | | |
| K1GIRLS | JH | 2.0 | 9.6 | 4 |
| K1 | SC | 1.3 | 12.8 | 5 |
| K1 | JR | 1.5 | 12.8 | 5 |
| K1 | SG | 1.9 | 13.6 | 4 |

Subscript A=event:
B=initials:
C=resting lactate mmol/l
D=post competition lactate mmol/l
E= post event time to sampling in mins
Base line lactate levels approx 1.5mmol/L.

Table 12

Means and standard deviations of lactate levels from 19 international competitiors in four slalom events

| Event | Mean lactate mmol/l | Range mmol/l | SD | Sample size |
|---|---|---|---|---|
| K1men | 16.18 | 2.7 | 1.2 | 5 |
| C1men | 13.10 | 4.5 | 1.75 | 4 |
| C2men | 10.83 | 4.5 | 1.68 | 6 |
| K1girls | 12.20 | 4.0 | 1.77 | 4 |

Table 13

Summary table for results of ANOVA on lactate levels for 4 slalom events

| Variation | SS | DF | MS | F |
|---|---|---|---|---|
| Between events | 81.31 | 3 | 27.10 | 9.09* |
| Within " | 44.77 | 15 | 2.98 | |
| Total | 126.08 | 18 | | |

* (F3,15, .01=5.42)

The highest mean lactate concentration recorded in this investigation (16.18 mmol/l) is close to that reported by Burke (1981. 16.94mmol/l) taken from track cyclists.Both sets of results calculated from data collected during competition exceed maximum lactate values reported by others in experments using the treadmill

(Gass,1981-14.2mmol/l:Astrand,1960-14.75mmol/l) and the bicycle ergometer (Daves,1979-12.34mmol/l:).

It is interesting to compare the mean lactate score from each event and these are as follows:-

Mens K1= 16.2 mmol/l

Mens C1= 13.1 "

Mens C2= 10.8 "

Girls K1= 12.2 "

It would appear from this comparison that the mens events can be ranked, from lactate scores, according to the input effort by the competitors.

When this suggestion was put to them there was aggreement that because the K1 event uses a double bladed paddle then both the left arm stroke and the right arm stroke are involved in heavy propulsive work. In the Canadian event however, only a single bladed paddle is used and there is a period during which no propulsion takes place as the blade is moved back to the beginning of the stroke phase.This might even be classed as a short recovery period.

The result of lactate formation in all the events sampled but particularly in the mens K1 event demonstrate the major contribution made by the anaerobic energy

liberating mechanism.

There is no doubt that because of the fact that this competition was a selection event for the World Championships the following year each competitor was under some psychological stress which might account for a fraction of the measured lactate content.

# Chapter 5

## An anaerobic training programme

This part of the study is devoted exclusively to a description of an experiment which was designed to assess the effectiveness of an anaerobic training programme on muscular development.

### Rationale.

Over many years of active competition and later of canoe coaching the author has developed the firm belief that slalom canoeing involves to a major extent the anaerobic energy liberating mechanism. However until a view, no matter how strongly expressed, is supported by indisputable evidence one can aspire only to the level of pursuasive debate.

The problem of establishing the role of anaerobic metabolism during slalom competition is described elsewhere in this study. The stage beyond that is to investigate the changes that might result from the implementation of an anaerobic training regime. Of course a training programme for whatever activity must concentrate on various aspects of development which will be determined by the demands of that activity if these are known. Within the context of this study reference to training will imply training for a competitive event.

Many studies have described the general effects of

training and perhaps the reference quoted most frequently is that by Astand and Rodahl (1977; Table 12-1). Although it is of interest to the athlete to know that there will be an increase in blood volume and total haemoglobin content or that there will be a thickening of the articular cartilage to mention but three effects, his ultimate concern will be the effects that his training is having on his competitive performance. The elite athlete needs to know not only about the beneficial effects of training but also about the specificity of training. Not all types of training will be beneficial to him. Indeed some might even be disadvantageous to his development.

If a training programme was to be devised for slalom canoeing and during that programme the anaerobic system was to be stressed it would be desirable to know the answers to the following questions:-

1. How can the anaerobic system be stressed?

2. What are the effects of such a stress programme?

3. What time scale is involved to achieve these objectives.

The experiment

Based on these questions an experiment was designed to investigate the effects of an anaerobic training programme.

This experiment depended on the help and cooperation

of the local health service and in particular a consultant surgeon at the Caernarfon and Anglesey hospital, Mr R H P Oliver.

During a canoe slalom competition approximately 85% of a competitors paddling strokes are of a forward propulsive type (see stroke count p81). There are several muscles in the shoulder girdle complex that are involved either entirely or partially in such a pulling action. A powerful protagonist for extension of the humerous on the humero-scapula joint and one which is close to the skin surface is the latissimus dorsi muscle. There was no evidence in the literature which indicated that this muscle had been biopsied and studied histochemically so it became an attractive choice for this experiment.

The latissimus dorsi has its origin on the thoracic and lumbar spine, it spreads across the back to twist and insert into the bicipital groove of the humerus. As the muscle narrows towards its head so it can be palpated towards the posterior surface of the armpit in the region of the posterior auxillary fold.

In outline the experiment consisted of exposing the latissimus dorsi and other related muscles through an arm exercise programme to nine weeks of anaerobic training in nine male subjects. Muscle samples were taken from each subject using the needle biopsy technique prior to training

and then immediately following the nine week programme. Histochemical analysis of muscle samples revealed fibre composition, fibre size and enzyme activity.

Each phase of the experiment is described in detail in the hope that similar research in the future might benefit if only in a reduction of the time taken for the extensive preparations which are neceassary.

Selection of subjects

A group of 9 men aged between 19 and 24 years volunteered for the project.Their physical characteristics are shown in Table 14.

Table 14

The mean physical characteristics of nine subjects prior to the training programme.

| | |
|---|---|
| Age | 21.5 years +- 2.5 |
| Weight | 70.98 kg +- 5.28 |
| Height | 177.8cm +-5.0 |

Each man was a fit and active sportsman following a teacher training course in Outdoor Education.None had any previous experience of competitive canoeing but all were competent canoeists and all were experienced rock climbers.There was

evidence of above average upper body strength in all subjects.

Prior to the study an electrocardiogram and blood pressure measurement revealed no abnormalities in any subject. Each subject signed a consent form agreeing to participate in the project.

A comprehensive explanation was given to the group about the aims of the study but for motivational reasons the biopsy surgery was described casually and without emphasis.

Training routine

Prior to training, muscle biopsies were taken and this technique is described in the next section.

Each subject trained on the arm ergometer described previously, three times each week for nine weeks. The machine was situated in a light and temperature controlled laboratory. Training times with only a few exceptions commenced at 7pm each evening. Each subject was asked to record training times , work loads and intervals in a note-book provided.

Anaerobic training is difficult for any athlete to endure but in this study it was even more difficult for the subjects to remain motivated due to the repetitious nature of the exercise. The author, who supervised all 48 training sessions ( not all subjects trained on the same evening),

spent a considerable time in motivating subjects to maintain a constant effort on the training machine.

Interest and variety elements which are essential components of a realistic event training routine, were deliberately neglected in the programme design since it was to be supervised.

Week one was devoted to anthropometric and physiological data collection during which time subjects became accustomed to the training apparatus. Each subject established a maximum arm work load (in watts) which could be maintained for three minutes. A percentage of this value was used for each training session according to Table 15.

At the beginning of week six new maxima were re-established for each subject.

Table 15

The training programme which nine subjects followed for nine weeks.

| Week | Work interval | Work intensity % max | Revs/min | Rest min | Reps |
|---|---|---|---|---|---|
| 1 | Familiarity with equipment | | | | |
| 2 | 3mins | 40 | 40 | 1 | 10 |
| 3 | 3 ' | 50 | 40 | 1 | 10 |
| 4 | 3 ' | 55 | 40 | 2 | 10 |
| 5 | 3 ' | 60 | 40 | 2 | 10 |
| | reappraisal of max work load | | | | |
| 6 | 2mins | 60 | 40 | 2 | 10 |
| 7 | 1.5 | 80 | 40 | 3 | 10 |
| 8 | 1 | 90 | 40 | 4 | 10 |
| 9 | 1 | 100 | 40 | 4 | 10 |

Muscle Biopsy

Muscle biopsy specimens were taken from the latissimus dorsi muscle of each subject immediately prior to commencing week one of the training programme. Biopsy specimens were also taken within 24 hours of the last training bout in week nine.

A recent technique employed for histochemical studies of human muscle is needle biopsy. The logistical, the ethical and the technical problems associated with invasive surgery outside the confines of a hospital are formidable.

Invasive surgery requires:-

1. Ethical committee approval.
2. The services of a surgeon or experienced doctor.
3. Special equipment

The resulting muscle samples must then be treated histochemically and this involves:-

4. Deep freezing in liquid nitrogen.
5. Section cutting in a cryostat.
6. Chemical staining and mounting.
7. Microscopic measurement.

These problems are described separately as they arise during the progress of the experiment.

Pilot study

A pilot biopsy in the latissimus dorsi muscle was performed on the author by the surgeon who despite his extensive experience had never performed a needle biopsy operation.The subsequent muscle sample provided the author with the opportunity of practising the histochemical procedures already mentioned.The pilot experiment was a most useful exercise for both the surgeon and the author to modify their respective procedures before embarking on the main study group.

Unlike animal studies it is impractical for additional muscle samples to be taken from human subjects if the first is damaged or lost during subsequent treatment.

Histochemistry

Human muscle biopsy and subsequent histochemical treatment are normally undertaken in institutions which specialise in muscular abnormality and disease .Two leading institutions in this field are the Metabolic unit at University College hospital (UCH) and the Jerry Lewis Muscle research centre at Hammersmith Hospital both in London.

Both these centres were contacted and a proposal of the training study was submitted.The author was invited to both institutions to discuss the proposal and to observe

some biopsy operations and histochemical techniques.Since the techniques which, in particular, UCH adopt are modifications of those reported in the literature it was recommended that these be adopted in the training study.

Ethical Committee approval

An outline of the project under the guidance of a surgeon was submitted to the local Ethical committee. Approval and enthusiastic support composed the reply.

Surgery

Mr R H P Oliver, the chief surgeon at the local hospital agreed to support the project by performing the biopsy operations himself or providing the services of one of his medical team if he was indisposed. In addition Mr Oliver recommended the project to the Local Research Committee for grant aid. A successful outcome to this application provided funds for purchasing some of the equipment listed in table 16 (appendix A ) and the chemicals required for histochemistry.

Table 16

The items of equipment necessary for needle biopsy procedure.

5 UCH Biopsy needles medium size.
Dewar flask for liquid nitogen.
Swabs, cotton wool, elasterplast, sterets.
Pre-packed dissecting blades.
Phials of lignocaine anaethetic.
Disposable syringes and needles.
2 sets of fine dissecting forceps.
Autoclave ( a domestic pressure cooker is ideal).
Silver foil (to encase needles during autoclaving)
Deep freeze.
Dissecting microscope.
Laboratory stand and clamps.
Circular secions of cork (wine bottle size).
Marker pen.
Micro-touch latex medical gloves.
Plastic container for immersion in liquid nitrogen
Tissue tek mounting medium.
Isopentane.

Preparation for biopsy operations

The biopsy needle (fig 17) consisting of three parts, operates efficiently only if the cylindrical cutting edge of the inner section is extremely sharp. Prior to each biopsy the edge was honed professionally.

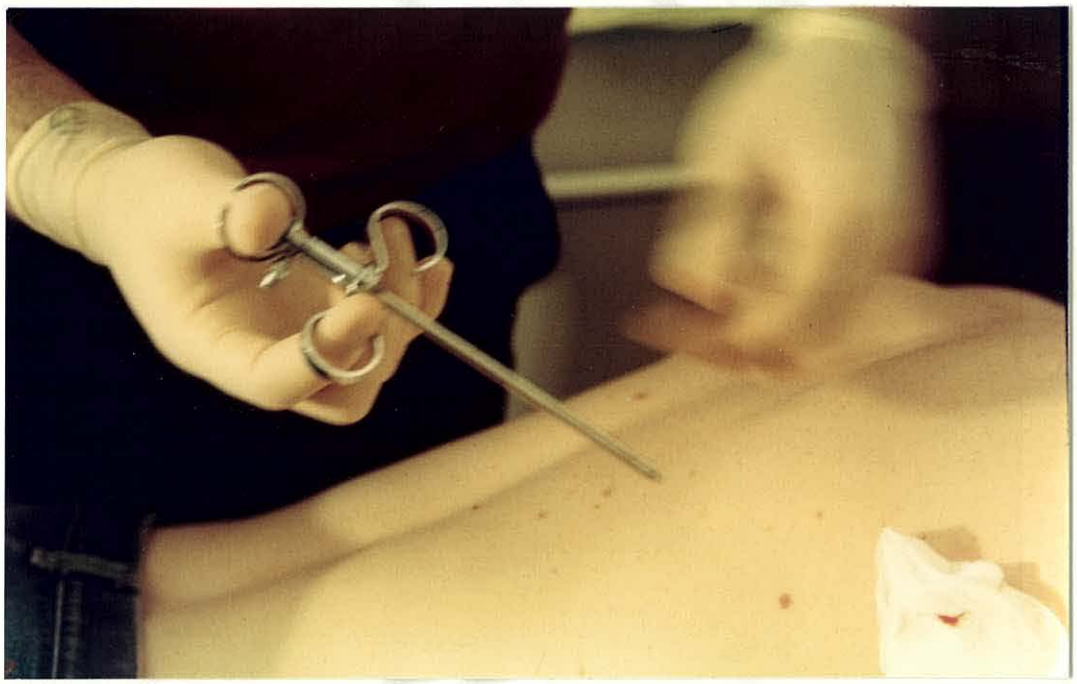


Figure 17. A muscle biopsy needle about to be inserted into a subject.

A domestic pressure cooker served as an autoclave, was portable and could perform its function close to the operating bed so that needles were available freshly sterilized.

The biopsy needles were wrapped in aluminium foil then autoclaved and could be handled in the foil without the risk of contamination.

A major logistical problem was the collection, transportation and storage of liquid nitrogen as late as possible prior to the biopsies being performed. It is essential that muscle samples are deep frozen as soon as possible (within 20 minutes) after being removed from the patient.

Liquid nitrogen evaporates quickly when in contact with air but this rate is reduced considerably if the liquid is stored in a 'Dilvac'Dewar flask with a self venting lid and even more so if the flask is then placed in a deep freeze.

Muscle samples are best mounted in tissue tek mounting medium on a small section of cork which can be labelled with indelible ink.

Once mounted the sample must be frozen quickly but if immersed directly in liquid nitrogen there is rapid surface cooling which then forms an insulating barrier to the deep tissue.This is particularly serious if enzymes are being studied because continued enzyme modification can

occur deep inside the tissue section while on the surface it has been suspended.

A less rapid freezing process is achieved if the muscle section is immersed in isopentane which has been cooled to the temperature of liquid nitrogen. By immersing a suitable plastic vessel containing isopentane into the liquid nitrogen the cooling effect causes the isopentane to thicken in texture progressively upwards from the base of the vessel and this change in viscosity can be monitored simply with a piece of stiff wire.Once the muscle sample has been totally immersed in the isopentane it can be transfered cork uppermost directly into the liquid nitrogen.

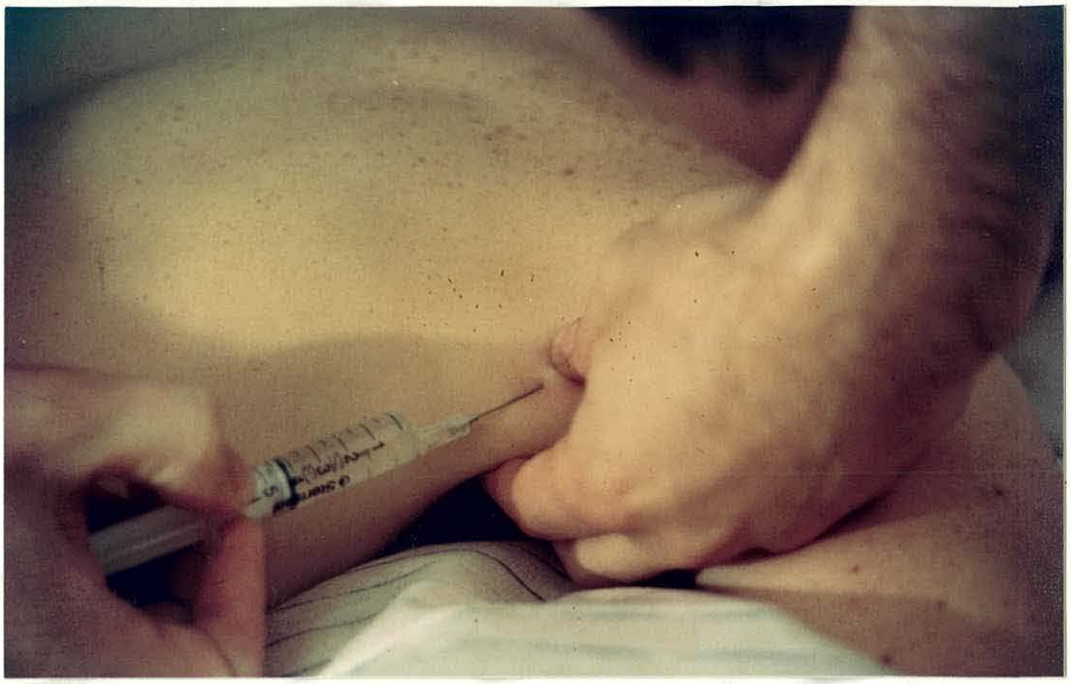


Fig 18a An injection of lignocane

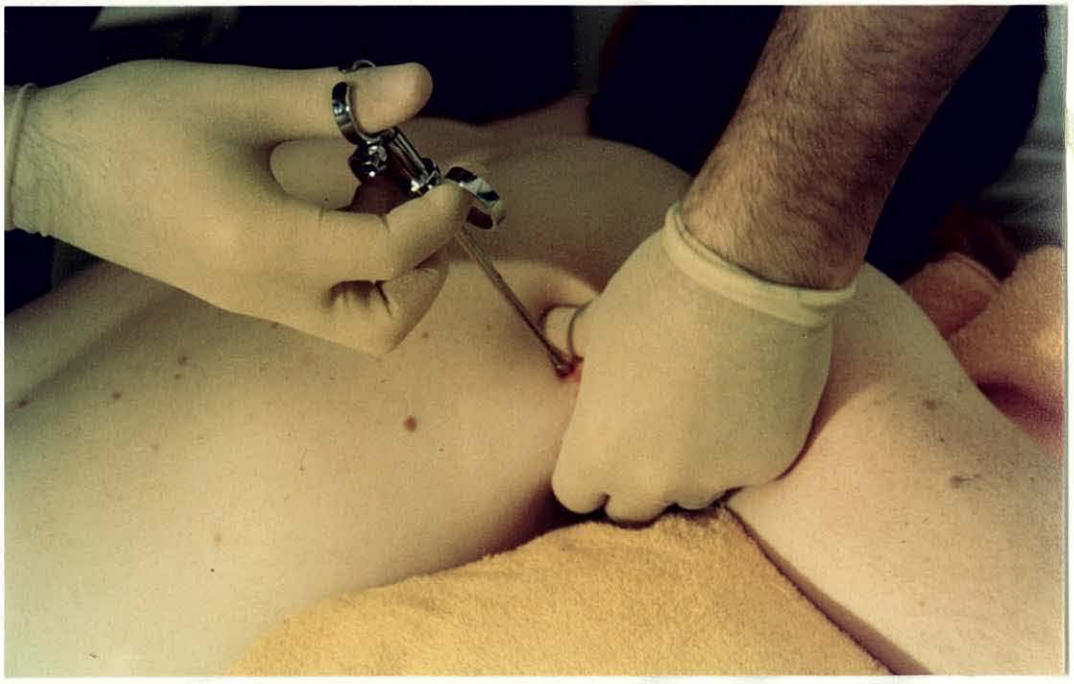


Figure 18b. Muscle biopsy procedure.

Biopsy procedure

The subject assumed a prone position with the dominant arm abducted and supported by a pillow. At a point approximately 3cm below the posterior auxillary fold an area of skin was cleaned with a steret injection swab.

5cc of 1% lignocane hydrocloride was injected through a disposable needle and syringe (fig 18a).

Once anaethetized an incision approximately 2cm long was made through the skin, any bleeding was continually swabbed away.

With his left hand the doctor held a pinch of skin firmly extending from the surface of the posterior auxiallary fold round underneath the arm-pit (fig 18b).

The biopsy needle, in the closed position and held with the right hand, was inserted through the incision until it reached the outer surface of the muscle bundles.This point was obvious because its progress into the muscle was halted.To invade the muscle fibres considerable force was necessary and this was best achieved by the doctor bringing his body weight to bear over his right hand.The sensation of invading a muscle was likened to pushing the needle through the skin of an orange.

Once inside the muscle bundles the centre cutting section of the needle was withdrawn, suction was applied by a large syringe at the nipple on the needle handle and then

the cutting edge was driven down vigorously.

The needle was withdrawn in the closed position and the eye of the needle carefully searched for the muscle section.This was transfered to a saline gauze with fine forceps and examined under a dissecting microscope. If the quality of the sample was poor then the biopsy procedure was repeated through the same incision.

After a successful biopsy the wound was cleaned and covered with a small elastoplast.If there was some bleeding then pressure was applied for a few minutes and then the wound covered.

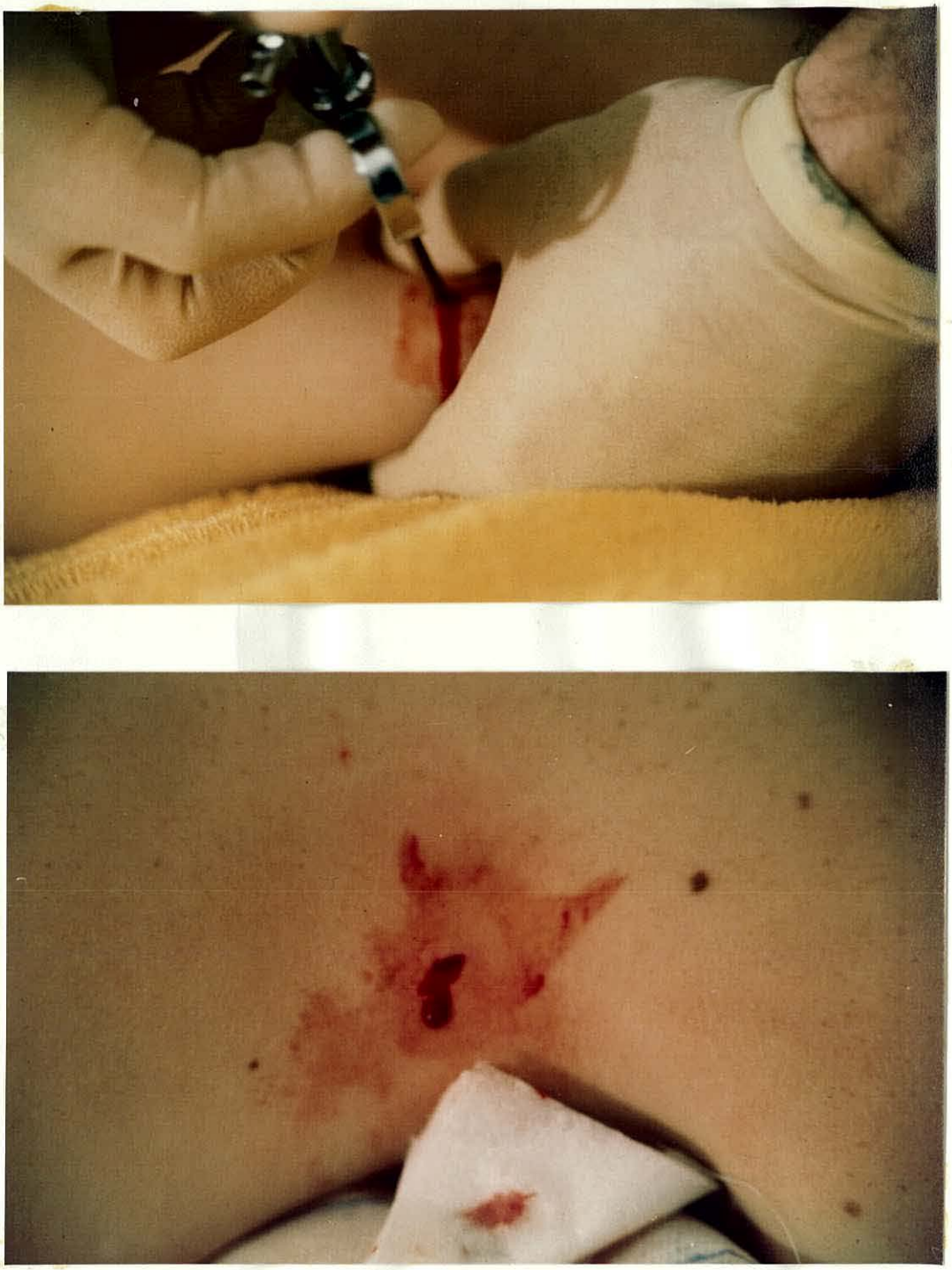


Figure 18b. Muscle biopsy procedure.

Mounting procedure

The muscle sample was transfered from the gauze to a cover glass (fig 19) where it was examined under a dissecting microscope. The sample was orientated with fine forceps until the fibre striations were parallel and horizontal. The sample was then turned with the fibres orientated vertically and transfered to the cork .

The sample was surrounded by a layer of tissue tek mounting medium and the cork was lowered into prepared isopentane. When the sample had frozen giving a white appearance it was transfered directly to the liquid nitrogen.

After completing five biopsies the flask and samples were transfered to a deep freeze overnight. The following day all samples were transfered to a cryostat cabinet at a temperature of -20C. The remaining four biopsies were performed also on the following day.

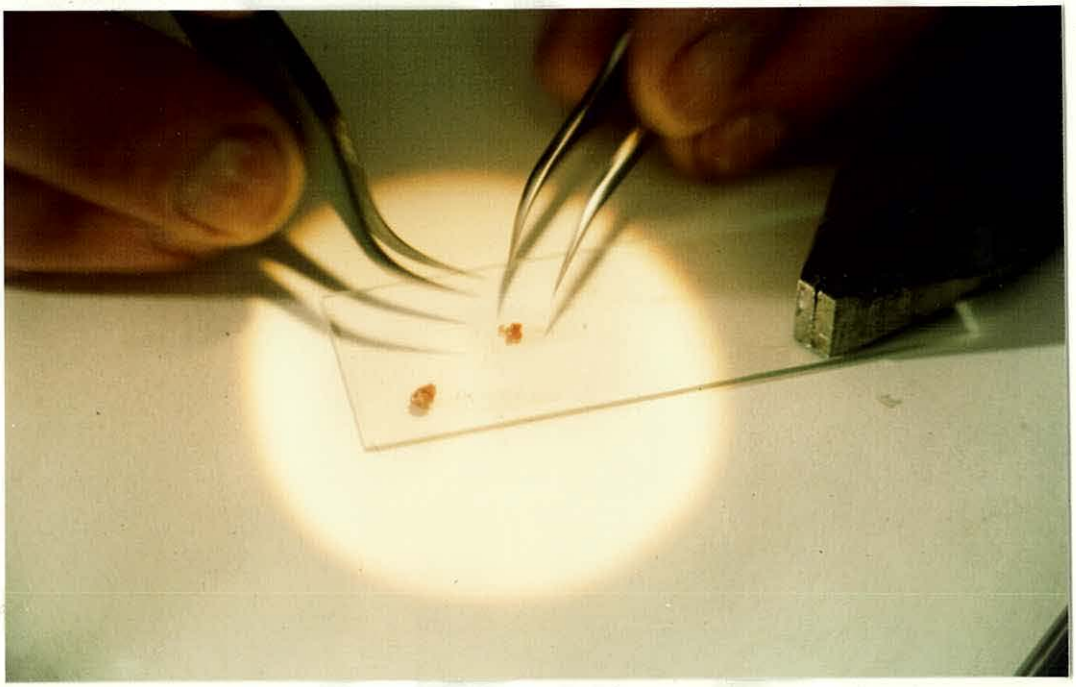


Figure 19.A muscle sample orientated with fibres lying vertically on a cover glass.

## Histochemistry

Deep frozen muscles samples in liquid nitrogen were transfered to a cryostat at -20 C. A microtome blade was honed and placed inside the cabinet to cool along side several metal racks for holding cover slips.

### Cutting procedure

Each numbered section of cork supporting the muscle sample was frozen on the face of a chuck with a layer of water.

The chuck was centralized in the microtome and manually the block was advanced towards the blade in units of 10mu. Several trial sections were discarded until satisfactory sections appeared under the antiroll bar. These sections were transfered to a cover glass and placed in the metal racks which were numbered.

This procedure was repeated until approximately 50 sections each 10mu in thickness were taken from each muscle sample.

### Staining

The following equipment required for histochemical staining can be found in most well equipped laboratories:-a balance (+- .0001 gm accuracy, a pH meter, a heated water bath, an electic timer, a refrigerator, columbia jars and

rinsing troughs.

All chemicals used in this study were newly purchased and particular attention was given to the shelf life of the enzyme salts and solutions. In some cases the shelf life was shorter than the period between biopsies and therefore new chemicals were ordered. A list of the chemicals used are shown in appendix B.

The author, although not a biochemist, prepared with the help of a competent lab assistant all the chemicals and stains, and performed the section cutting, staining, mounting and finally the analysis. Not only did this allow for a greater understanding of the procedures and underlying theory but it illustrated that one was dependent on only a small number of personnel for assistance and guidance and that as a prerequisite for a project of this nature one need have only a basic knowledge of chemistry rather than an extensive biochemical background.

Each muscle sample was treated with several stains (as used at UCH and the Jerry Lewis metabolic units in London) and these, with the procedure, are described.

1. Adenosine Triphosphatase (ATPase) at 9.5 pH.

ATPase at pH 9.5 dissolves the intermyofibrillar network thus highlighting muscle fibres. Furthermore the

ATPase present in specific muscle fibres is dependent upon the pH value and this effect can be used to differentiate fibre types.

ATPase procedure

1. 5mg ATP dissolved in a few drops of distilled H20. Add 10 ml of .1 M glycine/Nacl buffer wih .75 ml Cacl2. Check to pH 9.5

2. Add one drop of dithiothreitol solution.
   (do not re pH as this damages the electrode)

3. Incubate at 37°C for 30 minutes.

4. Rinse well in distilled H20.

5. Immerse in 2% Cocl2 for 3 rinses, 1 minute each.

6. Rinse well in distilled H20.

7. Immerse in dilute (1:10) ammonium sulphide solution for 30 seconds (use fume cupboard).

8. Rinse well in running tap water.

9. Dehydrate in ascending alcohols.

10. Clear in xlyene , 3 minutes.

11. Mount in resin.

ATPase 4.6 and 4.3 pH's

1. Preincubate at 37°C in sodium acetate buffer for 10 minutes.

2. Wash in distilled H2O.

3. Proceed as for 9.5 method.

**********

NADH-Tr -Coenzyme linked Dehydrogenase
(NADH-tetrazolium reductase)

These enzymes act as carriers of electrons in the enzyme chain and when interrupted in their path by the introduction of a tetrazolium salt, a deeply coloured formazin product is deposited which serves as an indictor of the possible source of energy in muscle metabolism.

In particular type 1 and type 2 fibres are clearly demonstrated.

NADH -TR procedure

1. Place 1-2 drops incubating solution onto the section ensuring complete coverage.

2. Incubatefor 30 minutes at 37°C.

3. Ascend in 30% 60% 90% acetone and descend again to remove fat.

4. Wash in distilled H2O.

5. Fix in 15-20% formalin solution for 10 minutes.

6. Mount in glycerine jelly.

**********

Perodic Acid Schuff (PAS) stain

This stain demonstrates glycogen in the muscle, however several other compounds present in the muscle such as other polysaccharides and glycolipids take up the stain and at times confusing results can occur.

Procedure for PAS stain

1. Fix section in acetic ethanol fixative for 10 minutes.

2. Wash in distilled water ( for control section digest in 5% diatase for 1 hour ).

3. Place in .5% periodic acid for 2-5 minutes.

4. Wash in distilled H2O.

5. Place in schiffs reagent for 10-15 minutes in the dark.

6. Wash in running tap water for 10 minutes.

7. Dehydrate, clear and mount.

**********

Phosphofructokinase ( PFK)

The enzyme PFK catalyses the conversion of fructo-6-phosphate (F-6-P) to fructose-1,6-diphosphate (F-1,6-PP) in the absence of this enzyme glycogen cannot be broken down to lactic acid. A lack of staining when F-6-P is used as substrate indicates a muscle lacking in PFK.

In this study no such deficiency was expected but the stain was used as a health monitor.

Procedure for PFK stain

1. Place section on a damp filter paper and place on a few drops of the incubating medium , leave for 1 hour at 37° C.

2. Wash with distilled water.

3. Mount in glycerine jelly.

Repeat with f-1,6-pp as substrate .

**********

Haematoxylin and Eosin

Harris haematoxylin is a general purpose stain giving particularly clear nuclear staining (fig 21).

Haematoxylin procedure

1. Place sections in Harris Hx for 3 minutes.

2. Blue in Scotts tap water substitute for 2 mins.

3. Differentiate in .2% acid alcohol until pink.

4. Re-blue as appropriate (step 2).

5. Place in 1% eosin for 15-20 seconds.

6. Wash quickly in distilled H20.

8. Clear in xylene and mount in resin.

**********

Analysis of staining results

Many stains are used as diagnostic tools for muscular disease and are suitable only for qualitative measurement.Haematoxylin, PAS and Phosphofructokinase fall into this category. Observations of the results of these stains are discused in the results section.

ATPase and NADH are the stains that allow quantitative measurement of fibre types and size.

A Wild M5 microscope with a fibre optic light was used for fibre graphing. Orientation and fibre counting was achieved under a Leitz Dialux microscope. Micrographs were taken with a Leitz Wetzler Orthoplan microscope.The last two microscopes are expensive and highly specialized items of equipment that would not be found in an average laboratory.

Muscle fibre size

Dubowitz (1973) states that it is notoriously difficult to judge the size of fibres in a muscle biopsy by simple inspection. Of the variety of methods which have been employed by different laboratories Dubowitz recommends (personal communication 1982) a method which combines simplicity and speed but is reasonably accurate.

Muscle fibres stained with NADH are magnified 100 times and the lesser diameter is measured to the nearest 10 mu.200 fibres are measured although in statistical terms

this number is quite high. In a study on measuring error by Mathieu et al (1981) the authors conclude that it is more efficient to use the time available to measure less precisely more pictures from a large number of sections than to achieve a very high precision on a few subsampled fields.

Fibre typing was achieved by dividing a micrograph into a grid and counting the dark-type 1 fibres and the light-type 2 fibres which had suffered ATPase staining. Only slides which displayed clearly over 50 fibres were used to calculate the ratio of type 1/type 2 fibres.

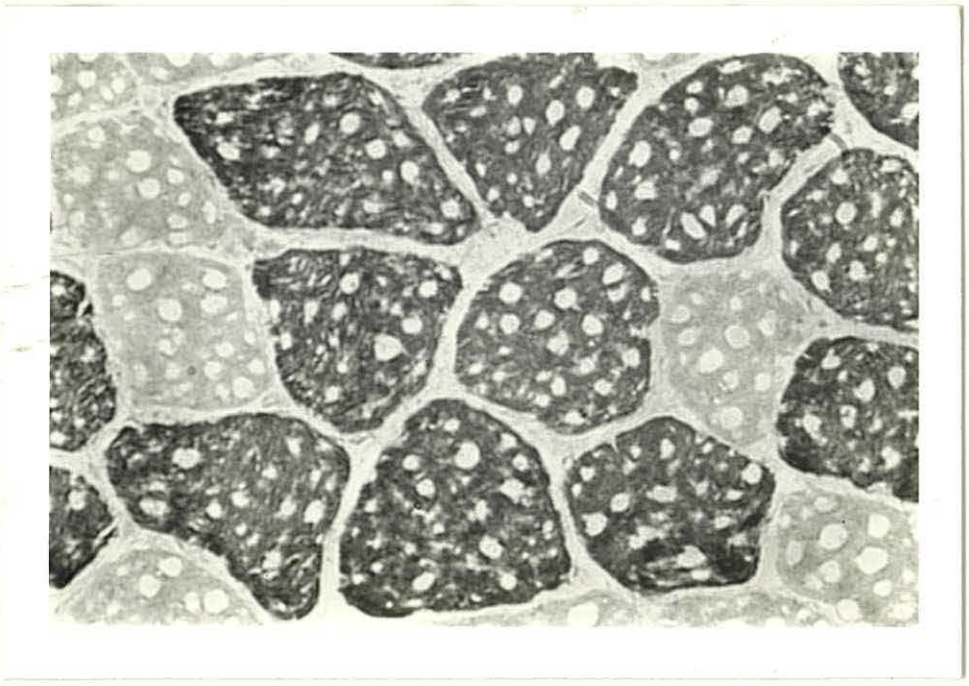


Figure 20. A micrograph showing an ATPase stain. The light stained fibres are type 2 and the dark fibres are type 1.

An attempt was made to differentiate the subdivisions of type 2 fibres into type 2a, 2b and 2c catogories based on staining with ATPase at different pH values. The results of this technique were disappointing. The tissue samples frequently dislodged from the cover glass during the preincubation period. Colloidin, a transparent non-interactive chemical was added in an attempt to secure the sections but without success.

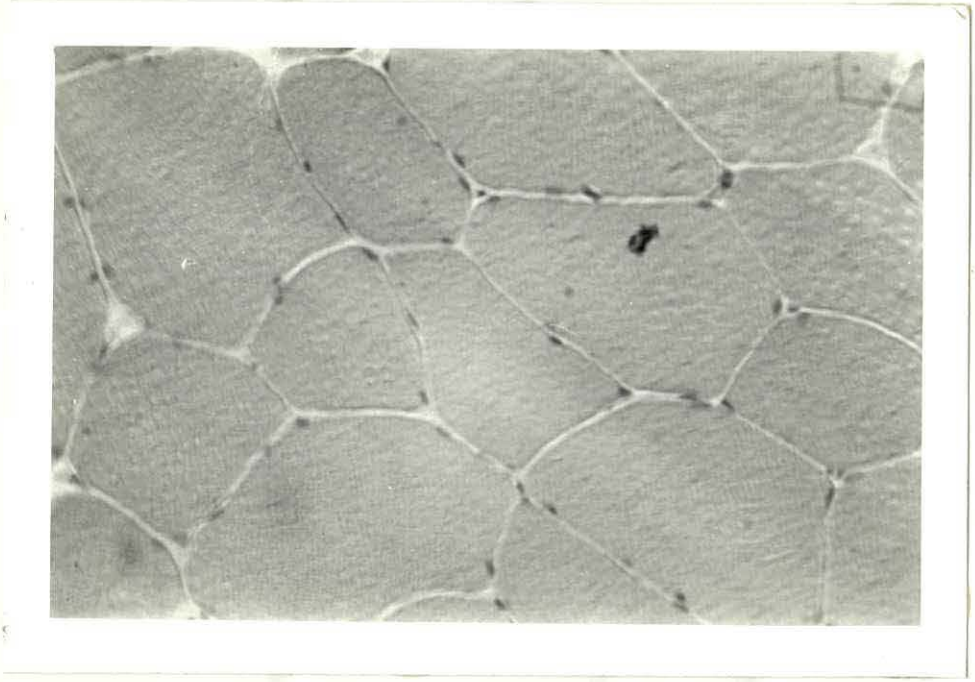


Figure 21. A micrograph showing nuclear structures after treatment with haematoxylin.

## Results of the Anaerobic Training Programme

Prior to and immediately following an intensive nine week training programme of arm exercise on a LODE arm ergometer each subject

1. recorded VO2 for arm work

2. underwent a needle biopsy operation in the latissimus dorsi muscle of the dominant arm.

The results of pre and post training VO2 for nine subjects are shown in Table 17.

Table 17

The results of oxygen uptake of nine subjects before and after an anaerobic training programme. A work load of 100 watts was applied for 3 minutes and subjects performed at 40 RPM

| | Pre training | | Post training | |
|---|---|---|---|---|
| ss | Wt. Kg | ml/Kg/min | Wt. Kg | ml/Kg/min |
| 1 | 67.1 | 40.7 | 67.4 | 39.3 |
| 2 | 83.0 | 41.2 | 82.5 | 36.4 |
| 3 | 68.9 | 29.6 | 70.1 | 32.7 |
| 4 | 69.8 | 29.3 | 69.4 | 29.4 |
| 5 | 65.7 | 37.9 | 66.3 | 36.5 |
| 6 | 65.7 | 32.3 | 65.7 | 30.4 |
| 7 | 70.3 | 32.4 | 70.6 | 37.7 |
| 8 | 69.8 | 35.8 | 70.4 | 31.5 |
| 9 | 72.1 | 41.2 | 72.4 | 39.5 |
| $\bar{X}$= | 70.26 | 35.56 | 70.53 | 34.8 |

From Table 17 it can be seen there was a slight increase in the mean body weight between pre and post measurements of .27 Kg. There was a decrease in mean VO2 of .76 ml/Kg/min following the training programme. Data of oxygen uptake from pre and post training was treated with a Student t test with a no significant result (t=.37) between pre and post test VO2 values.

The training programme was designed to avoid aerobic development and therefore it was expected that there would be little or no increase in oxygen uptake values following this training. It can be seen from the results of the t test that a no significant difference result confirmed expectations.

Muscle fibre analysis from biopsy samples.

Muscle sections taken from each subject before and after the training programme were treated histochemically and muscle fibre composition was assessed on ATPase and PFK activity. The results of this procedure are shown in Table 18

Table 18

The percentage of fibre type 1 (aerobic) and type 2 (anaerobic ) obtained on two occasions , pre training and post training from nine subjects. Subjects are displayed in rows.

| | Pre training | | Post training | | |
|---|---|---|---|---|---|
| Ss | A | B | A | B | Sum |
| 1 | 57 | 43 | 54 | 46 | 96 |
| 2 | 48 | 52 | 52 | 48 | 150 |
| 3 | 58 | 42 | 53 | 47 | 243 |
| 4 | 39 | 61 | 39 | 61 | 150 |
| 5 | 49 | 51 | 47 | 53 | 112 |
| 6 | 61 | 39 | 48 | 52 | 129 |
| 7 | 39 | 61 | 37 | 63 | 402 |
| 8 | 58 | 42 | 45 | 55 | 108 |
| 9 | 49 | 51 | 52 | 48 | 163 |
| X | 50.7 | 49 | 47.3 | 52.4 | 172 |
| R | 22 | 22 | 17 | 17 | 306 |
| SD | 8.4 | 8.4 | 6.6 | 6.7 | 91.1 |

Subscripts:-

A = % type 1 fibre
B = % type 2 fibre
Sum = total fibres counted

The large variation that can be observed in the fibre count totals (column 6 Table 18) is attributed to the variability of the staining quality. Some samples provided good stains while in others only part of the sample could be used for fibre counting. However all totals were in excess of 96 which is considered entirely adequate for fibre counting assessment.

The largest proportional difference between type 2 and type 1 is seen in subject 7 who exhibits 61% type 2 and 39% type 1 fibres on the pre-training biopsy and 63% type 2 and 37 type 1 on the post-training biopsy.

The smallest proportional difference is demonstrated by subject 5 where 51% type 2 contrast with 49% type 1 on the pre-training biopsy and 53% type 2 contrast with 47% type 1 on the post-taining biopsy.

The range between the percentage fibre type differences for each biopsy lies between 0% and 26%. When examined more closely seven subjects recorded a percentage difference of 10 or less while two subjects, 6 and 8, both recorded a 26% change in type 1 to type 2 proportions between biopsies . This figure is high and is at the limit of variation in fibre typing that may be attributed to random fibre type distribution within the muscle.

There is no previously reported evidence that may be used as a comparison of muscle fibre type distribution within the latissimus dorsi muscle. It has been suggested

casually by researchers currently involved in biopsy work at University College Hospital-London (personal communication) that a variation of up to 25% in fibre types might result from subsequent biopsies due to intra-muscular fibre distribution patterns.

It would appear from the results of the two biopsies reported here that the majority ,7 out of 9 subjects demonstrated no modification in the percentage of fibre types from the latissimus dorsi muscle as a result of training.

The data were treated with a Student t test and the result demonstrated that there was no significant difference between the number of type 1 fibres observed on both occasions (t=.02 :critical value of t =2.26, $\alpha$ =.05). Similarly the number of type 2 fibres showed no significant difference when counted on two occasions (t= -1.0:critical value of t=-2.26 , $\alpha$ =.05 ).

Two subjects however, did demonstrate a 26% modification in fibre types between biopsies. Both subjects recorded a similar trend towards a higher type 2 fibre count after training.

It is suggested cautiously that the magnitude of the recorded difference in fibre types recorded by these two subjects is attributed to intra-muscular fibre distribution rather than a change in fibre types due to a training

effect.

The remainder of the results are in aggreement with the general feeling that muscle fibre distribution is not affected significantly by a training effect.

In addition to fibre typing ,cross sectional area was also observed in both types of fibres before training and following training based on the NADH stain. The minor diameter of fibres was measured and used for cross-sectional calculations. The results of this procedure are shown in Table 19.

Table 19

Type 1 and type 2 fibre cross sectional area taken from pre-training and post-training biopsy samples in nine subjects.

| | Pre-training | | Post-training | | |
|---|---|---|---|---|---|
| Ss | Fibre area $\mu$*2 Type 1 | Type 2 | Fibre area $\mu$*2 Type 1 | Type 2 | Ss |
| 1 | 2003 | 2744 | 1919 | 5155 | |
| 2 | 1573 | 3678 | 2578 | 6066 | |
| 3 | 2669 | 4265 | 2408 | 3984 | |
| 4 | 1763 | 3837 | 1918 | 4449 | |
| 5 | 2003 | 2374 | 1817 | 4895 | |
| 6 | 2309 | 3965 | 2451 | 3228 | |
| 7 | 2066 | 2563 | 1452 | 7614 | |
| 8 | 1596 | 2001 | 2434 | 4313 | |
| 9 | 1872 | 2089 | 1758 | 5047 | |
| $\bar{X}$ | 1984 | 3057 | 2082 | 4972 | |
| Range | 1096 | 2264 | 1126 | 4386 | |
| SD | 327.8 | 826.3 | 371.5 | 1199.8 | |
| t test | -.5598 | | -3.719 | | |

A closer observation of the values of type 1 fibres in Table 19 reveals that five subjects increased their fibre cross-sectional area following training while the remaining four showed a decrease in type 1 cross sectional area.

It can be seen also from Table 19 that only subject 3 showed a decrease in cross sectional area of type 2 fibres between the first biopsy (4265 $\mu$*2) and the second (3984 $\mu$*2).The remaining eight subjects showed large increases in type 2 fibre areas.If the change in cross-sectional area is expressed as a percentage between the first and the second biopsy the trends are shown in Table 20.

Table 20

The percentage difference in cross sectional area of fibres for the pre-training and the post-training biopsies.

| Ss | Type 1 fibres % increase between biopsies | Type 2 fibres % increase between biopsies |
|---|---|---|
| 1 | -4 | 87 |
| 2 | 64 | 65 |
| 3 | -10 | -7 |
| 4 | 9 | 16 |
| 5 | -9 | 106 |
| 6 | 6 | 19 |
| 7 | -29 | 197 |
| 8 | 52 | 116 |
| 9 | -6 | 142 |

The largest increase in type 2 fibre cross sectional area ,197% ,is seen in subject 7 who also reduced his type 1 fibre area by the largest amount ,29%. Only one subject, number 3 demonstrated a reduction in type 2 fibre area and this was small, 7%.He also demonstrated a similar (10%) reduction in his type 1 fibre area.

The differences between the pre and post training areas of both types of fibres were subjected to a t test and these results are shown in Table 21. There was no significant difference in the size of type 1 fibres between biopsies.However as might be expected from casual observations of Table 19 , there was a significant difference in type 2 size between biopsies.

Table 21
The results of a t test between two biopsies of type 1 and type 2 fibres in nine subjects

| | Type 1 fibres Pre/post data | Type 2 fibres Pre/post data |
|---|---|---|
| t value | -.544 | -25.7 # |

Critical value of t = 2.896

# significant

These data demonstrate in no uncertain way that the training programme had a dramatic and selective effect on muscle fibre development. Marked changes are seen in the size of type 2 which are anaerobic fibres as a result of

brief interval high intensity training over a nine week period.

Muscle sections were also stained with heamatoxylin and PFK which revealed qualitative rather than quantitative data. As expected all specimens revealed a healthy appearance with no apparent abnormalities, Fig 22.

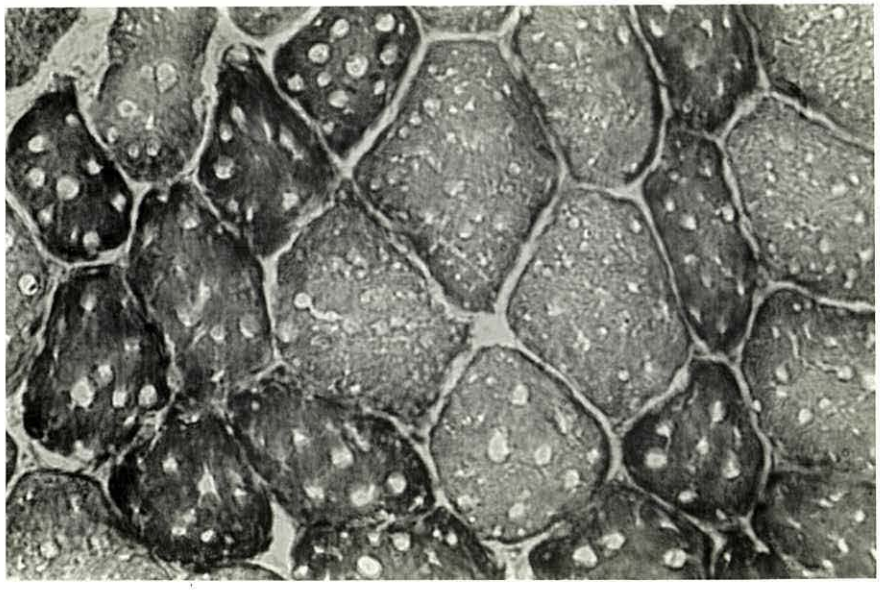


Figure 22. A micrograph showing an even distribution of fibre types with no abnormal atrophy due to disease.

If muscle biopsies are being taken to assess sporting performance then it is perhaps worthwhile to check also on the normality of other key enzymes at the same time.

An attempt was made to differentiate between type 2a and type 2b fibres using the ATPase stain at a lower pH value.Unfortunately these results were very disappointing with no specimens suitable for measurement.The reasons for this failure are not clear,all the chemicals were new and pH values and incubating temperatures were carefully checked. The author was warned casually of a possible difficulty with this technique while visiting UCH in London although at that time a remedy was not offered.It would have been particularly interesting to observe any changes in type 2a and type 2b distribution.

Other workers (Barnard et al 1971; Goldnick et al 1973 ) have suggested that following prolonged training (5 months) of aerobic work both type 1 and type 2 fibres showed an increase in oxidative potential.

In a study by Costill et al (1979) on the adaptation of skeletal muscle following strength training it was found that fibre composition had suffered a modification.These authors suggest with caution that there may have been an increase in the number of type 2a fibres due to a shift of type 1 to type 2a and 2b to 2a.This is the first time that such a change in man has been reported in the literature. It

is interesting to note that Gonyea et al (1977) reported muscle fibre splitting in the forelimb of the cat after strength training.

Conclusion

What is particularly striking about these results is the magnitude of the change in type 2 fibre cross-sectional area.This was brought about by a training programme based on the principles of anaerobic develoment.These were intensive work periods of short duration (1 min) interspaced by long and total rest periods (4 mins) repeated ten times on three occasions each week for a total of nine weeks.

The nature of the exercise was isotonic anaerobic work. To some extent there was a momentum effect as the paddle ergometer was pushed. This means that the tensions exerted by the actin and myosin filaments at the cross bridges site within the propulsive muscle were not constant.

A further development would be an investigation into the muscle tension curves developed at the cross bridges site within the ultra structure of the myofibrils as a result of isokinetic training .

The results have demonstrated that specificity of training (Astrand 1984) is matched by specific physiological development.

# Chapter 6

## Overview

An attempt has been made in this study to examine some of the behavioural profiles of elite slalom canoeists. During the planning of this investigation there was a deliberate neglect of the major role played by psychological factors such as motivation and personality traits during slalom competiton. Of course a profile of slalom competitors cannot be complete without the inclusion of these and other salient factors but it was felt that there were a number of crucial and fundamental physiological variables that hitherto had not been quantified which needed to be established prior to a more complete profile investigation.

A problem common to any investigation using human subjects is the availability and continued cooperaton of subjects with the study team. In experiments where individuals experience considerable discomfort and perhaps a certain amount of pain the success of the study often hinges on the willingnes of the subjects to continue with the programme.

In this investigation a substantial amount of data were collected from competing slalomists. However there were occasions when even the most cooperative competitors declined to participate in further trials because of the

fear that their immediate success might be adversly affected due to incumbent apparatus. During non competitive trials excellent cooperation was forthcoming from several British team members.

In experiments where human tissue samples are required, it is essential that the study team is highly skilled and experienced in handling this kind of material. In order to secure a quantity of human tissue the procedure is complex with an inherent risk of infection.It is therefore often impracticable (except in cases of medical illness) for the provision of additional tissue samples to replace the original where there have been treatment errors etc.

During the course of this study it became increasingly apparent to the author that more experience with the treatment of animal tissue samples would have been beneficial prior to treating human tissues. Perhaps this point might be considered by the reader who anticipates persuing a similar line of investigation.

# DISCUSSION

Astrand and Rodahl (1977) stated what is now believed by many sports scientists to be the first step to an investigation into any sporting activity when they wrote

> "An analysis of the energetic demands of different sport events and the athletes capability to fulfill these demands may help him or her in both training and the selection of suitable events".

It would be quite reasonable for the layman who is aware that British slalom canoeists currently (1984) hold several world titles, to assume that the sport has been thoroughly researched and is well understood. Unfortunately, this is not the case, but it is hoped that the results of this study will allow coaches and competitors to focuss some attention on the demands of the event that have proved to be significant.

However, results of any investigation are meaningful only when the reader is satisfied that they relate to a specific problem and that the techniques employed for data collection are valid and reliable. In this study the problem related to the energy demands of competing in a slalom competition and the methods employed to collect data pertained to aerobic and anaerobic energy liberating processes.

Initially it was observed that on the same slalom course competitors perform a similar number and type of propulsive stroke. It was possible therefore to quantify the work load required from a particular muscle group during paddling action for a specific course.

Forward paddling strokes involve a group of muscles which might be termed protagonist and it is within this group that chemical energy is converted into mechanical work.The corresponding group of muscles located on the opposite side of the joint involved in the same action are termed antagonist muscles. Although there is movement within the antagonist group , a negligible amount of energy is involved. Reverse paddling strokes cause the roles of the muscle groups just described to be reversed.

In energetic terms this means that muscle groups experience rest phases during a 'slalom run', as forward paddling strokes are interspersed with reverse paddling strokes. If the energy pathway within these muscle groups is predominantly aerobic then a certain amount of oxygen replenishment might occur across the mitochrondrial membrane. If the energy pathway is anaerobic involving alactic and lactacid sources then these brief respites might delay the onset of peak lactate accumulation within each muscle group.

Aerobic or Anaerobic.

Lactate produced during anaerobic glycolysis diffuses from the muscle and accumulates in the blood where, if measured, it can serve as an indicator of the extent to which anaerobic processes are activated during a work bout (McGrail et al 1977). At equivalent absolute levels of oxygen uptake, blood lactate concentrations are greater during arm work when compared to leg work (Bevegard et al 1966).This may be explained by the notion that for a given work load as the muscle mass decreases the anaerobic contribution to the total work output must increase.

In this study, lactate values recorded from a group of slalomists after competing in an international event were amongst the highest recorded lactate values from any sportmen reported in the literature.

In the light of these results it is suggested that the protagonist muscles responsible for slalom action derive the majority of their energy supply from anaerobic sources. Furthermore, it is suggested that the timescale for the yield of anaerobic energy might extend for several minutes viz the duration of competition, due to the sporadic action of the muscles involved.

Piehl and Karlsson (1977) investigated the depletion patterns of glycogen synthetase and phosphorylase in man and concluded that there was an even distribution of the enzyme

glycogen synthetase in the two type of muscle fibres (type 1 and type 2). They reported that after intensive work, depletion was greater in muscles rich in type 2 fibres.

In the light of this information it is reasonable to suggest that competitors with protagonist muscles rich in type 2 fibres might be equipped with a physiological advantage to perform anaerobic work for a longer period of time. Of course one must not overlook the psychological adaptation to training which may enhance the athletes' capacity for maximal exertion.

In a previous study in the same laboratory when muscle biopsies were taken from five slalomist of national and international calibre, it was concluded that the distribution of fibre types in the medial deltoid muscle suggested that these individuals possessed muscles most suitable for aerobic work (Humphrey 1982). These results were in broad agreement with those from a study by Tesch et al (1976) who also selected the deltoid as a study muscle in canoeists. Of course the implication from this conclusion was that slalom canoeists tended to exhibit a high poprortion of type 1 fibres and thus the demands of slalom competition must be largely aerobic in nature.

Perhaps the findings from these studies (Humphrey, 1982; Tesch ,1976) might be explained in several ways.

The action of the medial deltoid during extension and horizontal extension of the humerus is to abduct the humerus to a position most advantageous mechanically for horizontal extension. In this role it is most likely that the action of medial deltoid is not maximal, it is also sustained and thus it is acting aerobically.

In addition to this suggestion slalomists expend a considerable amount of time and energy during their training routines repeating 'gate practices'; 26 out of 30 slalomists who were questioned about their training habits reported that flat water gate practice was a major item of training.

This sort of repetitious training will have a profound influence on type 1 fibre (aerobic) development. Jansson and Kaijser (1977) in a study on muscle adaptation to extreme endurance training suggested that type 2a fibres have the ability metabolically to adapt to high oxidative demands and that the level of enzyme activity is more dependent on the nature of physical activity than on fibre composition. Other research revealed similar findings (Holloszy et al, 1970 ;Saltin et al, 1976)

Vanuska and Bjorntorp (1968) found that 6 weeks of training produced in man, a mean decrease in exercise muscle blood flow and an increase of succinic dehydrogenase activity with an estimated increase in maximal aerobic power of 30% .

It is suggested that the fibre development observed in studies of fibre types amongst canoeists, resulted from the influence of the two aforementiond factors, viz training and the role of the deltoid.

The influence of aerobic metabolism during a slalom run might best be assessed if there was a reliable method of monitoring ventilation parameters without the need for athletes to don restrictive and complex apparatus.

Wakeling and Saddler (1977) who investigated the aerobic capacities of some British slalomists using methods of VO2 determination which incorporated a bicycle ergometer and sprint distances on the water, concluded that slalom canoeists demonstrated high aerobic capacities. However they also reported that apparently these high values did not seem to be utilized by the subjects while on the water.

A similar finding was reported by Cooper (1982) where the max VO2 of a group of elite canoeists, on a cycle ergometer was found to be unrelated to max VO2 while canoeing. However the same author reported that the relationship of max VO2 on the ergometer canoeing and paddling performance is highly significant.

In this study the results of maximum heart rates during simulated competitive runs on an international river course were used as an indicator of the involvement of the cardiorespiratory system. The highest recorded heart rates

on the river were not maximal with a mean value of 14 beats per minute less than that recorded by the same subjects while performing a three minute standard step test. It was evident from these data that the cardiorespiratory system was taxed far from maximally during a simulated slalom course on a river.

Additional data of oxygen uptake values were collected from subjects performing a simulated paddling course on a canoe ergometer.The results from experienced canoeists demonstrated that a little over 50% of their maximum oxygen uptake was mobilized during the simulation. In contrast inexperienced canoeists demonstrated that a higher proportion of their VO2 max (mean 77% VO2) was mobilized. It is reasonable to conclude that the more experienced canoeists were also more highly skilled and as a result more economical in their energy expenditure.

A further trial, with the current world champion paddling in simulated conditions, revealed that after working for the period normally taken to complete a slalom course his VO2 was 61% of his maximum. Furthermore his maximum VO2 was reached after six intervals of three minute intensive work bouts (18 minutes of work) interspersed with one minute of rest between bouts.

These data when considered together with those concerned with lactate accumulation after competition support the premise that the involvement of anaerobic

metabolism in the protagonist muscles of slalom action is maximal and that aerobic metabolism becomes involved progressively. It is not unreasonable to suggest that the role played by major synergic muscles of the trunk and thighs would contribute in no small way to the onset of aerobic metabolism.

The implication for competitors is that training routines between muscle groups might become more specific. Protagonstic muscle groups such as latissimus dorsi,teres major and teres minor, pectoralis major,anterior and posterior deltoid should be exposed progressively to anaerobic stress. The remaining major muscle groups of the trunk and lower body should then continue with exercises which involve,to a major extent,the cardiorespiratory system thus promoting aerobic development.

The Effects of Training

In a study by Vrijens et al (1975) which investigated the effects of training on maximal working capacity it was reported that subjects who were not trained to arm work obtained better results of VO2 on the bicycle ergometer that canoeists. In an arm test, on the contrary, the group of paddlers had signficantly higher scores for maximal oxygen consumption and sustained workload. Israel and Brenke (1967) reported similar findings in a comparative study of arm and leg work.

The number of reports concerning the effects of short term high intensity training is small so it was considered appropriate to investigate the effects of such a programme that might be adopted by slalom canoeists.

One of the associated problems that this investigation attempted to solve concerned the influence that specific training methods might have on muscle fibre size and the time-scale of any development.

A programme with brief intervals of work interspersed with long periods of rest was repeated 10 times on each of three session, each week for nine weeks. The results of post training muscle biopsies ( 9 subjects) revealed that type 2 fibres had significantly increased in cross sectional area by a mean value of 82% (range -7% to 197%).

Since there are no studies reported in the literature with results comparable with fibre developments that have been observed in this study these results must be interpreted alone. It would seem that a programme of training can be designed to affect particular fractions of muscle development.

The time-scale involved in a modification of fibre development previously described was approximately nine weeks. However throughout this period it was found that a considerable amount of motivation was required on the part

of individuals to maintain maximal effort during the training routine.

Staudte and Exner (1972) concluded that with a development of type 2 fibres there was a corresponding increase in muscle tension, an increase in the enzymes hexokinase and citrate synthetase. Saubert and Armstrong et al (1973) reported that the effects of sprint training in rats caused a modification in the anaerobic enzymes. In muscles rich in type 2 fibres lactate increases more rapidly in type 2 fibres (Tesch and Karlsson 1977).

In contrast to these suggestions Polgar (1973) concluded that the physiological roles of muscles was a function of enzyme adaptation to work demands and that fibre size is relatively unimportant.

There is little doubt that the evidence currently available for a balanced debate relating to anaerobic development is incomplete.

In a recent document distributed to members of the French slalom team (1981) there was considerable emphasis placed on anaerobic development throughout a ten month training programme (Fig 23 ) concurrently with aerobic development (Koechlin et al 1981).However a cautious note at the end of this report recorded that one must realize that there are many factors involved in total slalom performance and all of these are interdependent.

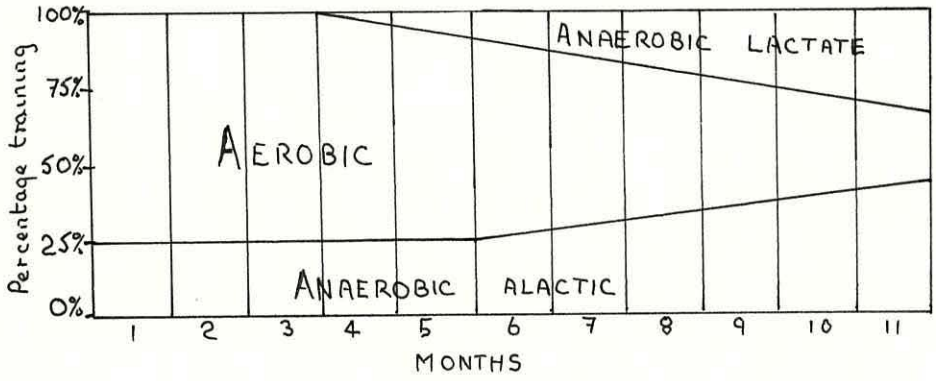



Figure 23. A suggested pattern of relative energy contributions to be adopted for slalom training (as suggested to the French slalom team).

In 1982 the United States Olympic Committee initiated a project to :-

1. Evaluate maximal aerobic and anaerobic potential of international level whitewater slalom canoeists using arm-cranking.

2. To compare aerobic and anaerobic use during padding on water with maximal capacities (on land).

The findings of this 'US' study appeared to be somewhat inconclusive . Perhaps part of the penultimate paragraph from this report summarizes the ongoing debate,

> "Because the events are about 4 minutes in duration, probably about 50% of the total energy utilized comes from aerobic metabolism and 50% from anaerobic metabolism.

The results of research into isokinetic exercise are impressive. The superiority of such exercise in building strength and speed is staggering (McCardle and Magel, 1970: Councilman, 1979: Chu and Smith, 1971). Pipes and Wilmore (1979) reported that isokinetic training at high limb speeds affects significantly greater changes in muscular strength at all limb speeds particularly those more associated with athletic events. Muscular soreness which often accompanies other types of training is notably absent in athletes who use isokinetic methods.

According to Huxley (1974) a muscle develops its maximum tension at approximately 60% of its contraction length. During isotonic contractions it would appear that the load which a muscle moves at the extremity of its contraction is suitable only for that part of the muscle, viz those cross bridges which are active during extremity contractions. As the muscle contacts and shortens then the load becomes progessively easier for the muscle to manage and so the training stress is reduced.

This problem of appropriate muscular stress throughout the range of movement of a contracting muscle is overcome in isokinetic training. Thoughout the range of movement a maximal resistance is applied progressively as more cross bridges are activated. Thus at the extremity of the range of movement, where muscular injury and soreness is most likely to occur during isotonic training, injury is less likely during isokinetic exercise because appropriate muscular resistance is applied.

It is interesting to note that in the survey into training methods conducted and reported in this study , only four slalomists employed isokinetic training methods but of those four, one was the current world slalom champion and one was a recent ex-world slalom champion.

## Summary and Conclusions

It would appear from the results of this and other investigations into predispositions for top performance in slalom canoeing that no particular physiological characteristics seem to be essential.

Due to the nature of slalom competition the aerobic demands of the event are technically difficult to determine, and even then the results are inconclusive. However, whilst there is little doubt that there is a significant contribution made by aerobic metabolism to the energy demands of the event, it is suggested that the magnitude of this contribution is less than was previously thought.

The anaerobic demands of slalom competition have proved to be substantial and significant. It is suggested that these demands are greater than the values of 50% recently reported (US Olympic study 1981). In view of the findings of this study it is recommended that slalomists incorporate anaerobic training stress into their year round training routines. Further it is suggested that "gate practice" skill development incorporates brief intervals (up to one minute) of intensive effort interspersed with rest periods of several minutes (up to three minutes).

It would appear from the results of biopsy studies

on slalom canoeists that currently there is insufficient evidence to determine whether slalomist are characterised by particular muscle fibre patterns.

It is suggested that in view of the apparent anaerobic demands of slalom competition, elite competitiors who possess, knowingly or otherwise, a high proportion of type 2 fibres in the dominant propulsive canoeing muscles might have an advantage in performance, with appropriate training.

Specific training routines with intensive work bouts of less than one minute duration interrupted by total rest periods of several minutes produce substantial increases in the cross sectional area of the active type 2 muscle fibres over an eight week period. It is suggested that hypertrophy of the propulsive muscles and the increased muscle bulk resulting from this type of training would not adversly affect competitive performance in slalomists.

Slalom canoeists while training on the water are incorporating isokinetic training methods due to the ←constantly changing pressure that is experienced at the paddle blade. It has been stated many times that there is no better method of training than performing the sport for which one is training (Burke, 1980).

It is recommended that these athletes when exercising off the water, adopt isokinetic training methods

which incorporate the principles of anaerobic stress. That is isokinetic contractions, where the resistance is high and the speed of movement is controlled throughout the range of motion, should be practised for short periods interspersed with periods of complete rest.

A Cybex II machine (from NOMEQ Nottingham) is just one device that when adapted, is ideal for isokinetic training.

This study has focussed attention on some important physiological variables associated with slalom competition but the findings and recommendations must be interpreted in the context of the total demands of the event. Further research is necessary particularly into psychological parameters pertaining to performance.

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# APPENDIX A

Equipment for muscle biopsies

5 UCH muscle biopsy needles
OCT mounting compound
2 staining racks
2 slide boxes
2 boxes of slides
4 boxes of cover glasses
Kuehne's forceps
Fine dissecting forceps
12 columbia jars
4 staining troughs
Sandrest test tube rack
30 phials 5% Lignocane
30 scalpal blades
20 pairs latex gloves
1 box slide labels
Dilvac flask
Pressure cooker
Marker pens
First Aid facilities, cotton wool etc.
Disposable syringes
Disposable needles
Silver foil
Circular corks
Liquid nitrogen

Use of :-deep freeze, microtone, microscopes, balances and general laboratory equipment.

## APPENDIX B

### Chemicals for biological staining

| | |
|---|---|
| Iso-pentane spectrosol | 500ml |
| Ethanol absolute | 500ml |
| Nitro blue tetrazoium | 0.25gr |
| Haematoxylin Harris | 25gr |
| Diatase | 100 gr |
| Adenosine-5-triphosporic acid | 2gr |
| Nicotinamide-adenine dinucleotide | 0.1gr |
| Dithiothreitol | 0.5gr |
| Sodium acetate buffer | 500ml |
| Eosin | 25gr |
| Glucose-6-phosphate | 0.25gr |
| Cobalt chloride | 0.25gr |
| Periodic acid | 10gr |
| Xlyene | 2 litres |
| Glycerine jelly | 1 litre |
| Glacial acetic acid | 2 litres |
| Potassium Bicarbonate | 50ml |
| Magnesium sulphate | 50ml |
| Sodium chloride | 5gr |
| Calcium chloride | 50ml |
| Ammonium sulphate | 50ml |
| Sodium arsenate | 1 carton |
| Fructose-6-phosphate | 0.1gm |
| Fructose 1,6 diphosphoric acid | 1 pkt |
| Sodium acetate buffer | 500ml |