BMC NEWS

Official Journal of the British Milers' Club

SUMMER 1986

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EDITORIAL

For this edition of the B.M.C. News we have departed from the usual format of news, views, training hints and correspondence and replaced them with a single feature around M.D. running. This is because we feel that this article fills a very specific need for both coaches and athletes, a need often under realised or over worked.

To be successful the athlete must have complete confidence that what he is doing in training is correct, this gives a great boost to performance and morals. To this end having a basic understanding of what he is doing and why, is essential. He must be able to communicate with his coach and be something more than a ventriloquist's dummy, they must have a common currency for communication and understanding and Dr. Sharp's lecture is pitched just right for this need.

The coach has two main functions

1. To manage an athlete's athletic career to whatever level the athlete can achieve.

2. To coach the athlete to go further, faster or higher. It is not to work for Ph.D in physiology.

It is true that if all the other requirements are met a physiologist would come to coaching with some significant advantage but unhappily this is not a common combination.

The managerial role in coaching demands that the coach must seek out and co-ordinate specialised help in meeting the requirements of training and coaching. It is regretable that we in the U.K. do not make the distinction between these two functions, a distinction readily preceived in Europe and the U.S.A. Different specialist skills are required for these two roles. Training, with its emphasis on conditioning, strength and the prevention and treatment of injuries requires at least a knowledge of what physiotherapy and osteopathy can do and when the physician or orthopaedic specialist must be called in. Not the common ability of many coaches nor should they get themselves lost in the maze of several specialities.

This brings us to the role of the physiologist. Any coach who is without an appreciation of basic work physiology will not be able to construct training schedules which specifically enhance a particular requirement of the athlete, and the athlete will not know why and what he is doing. To be effective, intensity, duration and frequency must be based on something better than the hunches or lore that has been handed down. Nor is it sufficient to indulge in the usual 'incantation' words such as "cardio-respiratory, Vo2 uptake, aerobic and anaerobic" whatever without any real knowledge just to impress whoever is listening. This is not a chiding of our members but a reminder to them that coaching knowledge is to be imparted from those who know to those who need to know or need to be corrected. The editor is well aware of his own groping in the past when not living near any

(editorial)

facilities, but he made a very determined effort to find them.

When considering the purely physical aspect of coaching athletics it is how the muscles work that is at the heart of the matter. It is for the foregoing reasons that we submit Dr. Craig Sharp's excellent lecture and the accompanying notes taken at the time, as supplying a neat description of how the 'machine' works and an insight into compiling running schedules. He does this by not merely listing the energy systems that we recruit in running but by indicating the duration, intensity and recoveries required.

Of course some athletes can withstand higher loads and shorter recoveries that others but the assessment of such factors for each individual is what the coach is there for. It is not the job of the scientist to provide the universal training schedule but if athletes can get to the physiologist's laboratory he will tell them within close limits just where the athletes' threholds are.

Today's standards of performance leave no room for the old casual approach. No small stone should be left unturned, to say nothing of the major rock of contribution made by the work physiologist.

Peter Coe.
Editor.

B.M.C NEWS
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The BMC is indebted to Dr N C Craig Sharp of the Human Motor Performance Laboratory of the University Of Birmingham and to the British Olympic Committee for permission to reprint the Essay and for the lecture given at The London Hospital on the 7th June 1986 on which the Notes are based.

THE BRITISH OLYMPIC ASSOCIATION

MUSCLE, An Essay for Coaches and Athletes

Dr N C Craig Sharp, The Human Motor Performance Laboratory, University of Birmingham.

With very few exceptions, most movement in and of the body are the result of the contractions of muscle cells. Laughing, talking, sneezing, crying, blinking, urinating, shivering, being sick, swallowing, goose-pimples, the heartbeat, constricting the pupil - and, of course, running, dancing, playing music, singing and jumping - are all carried out by the action of muscle. Virtually the only obvious body movement that is not directly due to muscle contraction is that of erectile tissue, as in penis or nipple, which change shape by 'turgor movement, as plants do. However, even the fluid-caused turgor movements ultimately start in the contraction of muscle cells in blood vessels, which cause pressure to rise. Blushing is due to a similar mechanism. If you think about it, you will see that virtually all human communication comes about through muscle action - from the muscles of the larynx for speech, to facial muscles for expression, to the muscles used in gesture.

Muscle can be thought of as a machine. Machines generally convert energy from one state into another. A car engine converts the original sunlight energy in the petrol into a heat explosion, which drives the piston into the cylinder to turn the crankshaft, thus converting the explosive energy into the mechanical energy which moves the car along. Muscle is far more elegant than this - it converts the chemical energy of the food directly into mechanical energy to move an arm or a leg.

The only active movement a muscle cell can make is to shorten. That means that a muscle can only pull. No matter how hard you push a garden roller, all your muscles are contracting and so shortening and pulling - the pull is converted into a push by the fact that the bones act as levers. So all the push of two international rugby scrums is really all pull.

Muscle may twitch involuntarily when it is fatigued, or it may lock into the painful contraction of cramp, and both of these are examples of muscle out of control. Normally, muscle is controlled. Ordinary body muscle is under voluntary control through what is known as motor nerves. Other muscle, such as that in the walls of blood vessels, or that which attaches to hairs to cause goose-pimples, or that of the iris which forms the pupil of the eye, is controlled by 'autonomic' nerves as part of the 'autonomic pilot' system that controls most inner body functions, and keeps us alive when we sleep. Still other muscle, such as that of the womb or uterus, is controlled by the chemical messengers known as hormones. Some muscle can only contract when stimulated to do so by a nerve impulse; other muscle, such as heart or intestine, has its own internal rhythm.

The above differences in function and control of muscle are associated with differences in the structure of the cells making upon the muscle. This gives three different types of muscle; first is 'skeletal' or 'voluntary' muscle, what most people think of as 'muscle'. It forms our body musculature and is (reasonably well!) under the control of our will, although it can act reflexly if, for example, you put your hand into a basin of too hot water. Second is heart muscle, which has some special features which will be described later, and third is 'smooth muscle', which is the type found in blood vessels, the stomach and intestines,the uterus and the urinary bladder. This muscle has very great resistance to fatigue, which is just as well as it would be awkward if the muscle of the stomach were to go into an oxygen debt in the middle of a meal! Smooth muscle also has the useful feature of ' accommodation', whereby on being stretched for a time, it can reset itself to accommodate to a new length and this is important, for example, in bladder function as it is part of the reason why the feeling of needing to urinate can "wear off".

Muscle Structure

What is thought of as a muscle - the biceps in the upper arm for example - is a collection of thousands of individual muscle cells. These cells are very long and thin, and bear the same relation to the whole muscle as the threads do to a thick rope. Each cellular thread has an exceedingly complicated internal structure. An appreciation of some of these inner features of the individual cell will help a lot in understanding strength and stamina, so they are shown in the diagram in Fig. 1. The main features to note are the 'mitochondria', the myoglobin, the glycogen and the 'sarcomere' with its two main proteins actin and myosin.

The mitochondria are where all the energy is generated for what is termed 'aerobic' exercise. This is the kind of exercise which you can keep doing for a long time, up to several hours. Aerobic means 'with air' (as aeroplane), more accurately it should be 'with oxygen'. Oxygen from the air you breathe is carried by the red cells of the blood right to the doorstep of every muscle cell. It is then transported inside the cell by the myoglobin molecules right to the mitochondria, and there it is used to release the chemical energy from perhaps some of yesterday's meals which have been stored as the substance glycogen. So, the mitochondria provide most (not all) of the energy for movement and exercise.

Most of the energy is used by the muscle cell to cause it to generate its pulling force, and this is done by the sarcomeres. As you see in the diagram, the sarcomere consists of two sets of interlocking rods, thicker ones called myosin and thin actin molecules. A sort of rachet mechanism operates between them to actively slide them past each other, and this shortens the whole sarcomere - and shortens every sarcomere throughout the entire length of the muscle cell. In this way, the individual cell shortens, and the whole muscle develops a force. The size of the force developed depends on the proportion of its own cells that the muscle recruited. If you lift a heavy weight, most of the cells in each active muscle will be in action; if you lift a cup of tea, then only a very small number of cells will have been recruited. Muscle cells are brought into action in small groups called 'motor units' and each such unit is supplied with a nerve which signals it to contract. Thus if you lift a succession of weights, from light to heavy ones, then without being aware of it you are simply bringing into action more and more motor units in the appropriate muscles.

As far as the muscle as a whole is concerned, there are only three things it can do. It can exert a strong force, and this is known as its <u>Strength</u>; and it can contract quickly, and this is its <u>Speed</u>; and it can go contracting and relaxing for a long time, and this is known as its local <u>Endurance</u>. Each of these attributes is important, in different proportions, in different sports; each can be measured in the laboratory, each can be trained and improved, and the three will now be described in turn.

Muscle Strength

The number of cells in a muscle does not increase to any significant extent no matter what the training. This number is predetermined - it lies in your genes. Just as there is genetic variation in height, or eye colour, so there is in muscle cell number, and hence strength. However, any muscle can become stronger with training, and when it does two main effects will have occurred. First, with strength training, the nervous system supplying nerves to the motor units of the particular muscle 'learns' to recruit gradually increasing numbers of the units in a maximal contraction. Each muscle has a particular upper limit in terms of the percentage of units activated in a maximal contraction - say 70%. The object of this is to provide a forced rest for the remaining 30%, which will be brought in as substitutes as the active ones tire. With strength training, the maximum percentage recruitment may increase to 75%, or 80% or even higher, and this will increase the maximum force the muscle can produce.

The second effect of strength training is to stimulate the muscle to synthesise more of the protein actin and myosin for its sarcomeres, thus enabling each individual cell to provide a greater pulling force. In the first two or three months of a strength training programme each cell does not enlarge very muscle, it simply becomes a bit more dense as it fills up with the sacromere proteins. So the muscle is not much larger, but it feels very much more firm to the touch, even when it is relaxed. This firmness is called 'tone'. If the training is prolonged beyond a few months, then the cells begin to enlarge, to 'hypertrophy'. Then, of course, the whole muscle gradually becomes obviously larger.

These two effects of strength training are interesting for two reasons. First, many women feel they need a bit more strength for their sport, for skiing, tennis, karate or whatever, but are worried lest they develop overlarge muscle. Exercise physiologists would certainly not regard such muscle in women as in any way unsightly - it is a most attractive feature. However, one can reassure such women by indicating that they can probably double their strength, with very little increase in muscle size, through the 'learning' process of the nervous system and the capacity the muscle cell has to absorb a lot of 'packing' of its contractile proteins to produce tone, but little hypertrophy.

Second, a considerable number of young men <u>want</u> to have muscles which are larger, and they may be disappointed that, after weeks of training they have not put on much bulk, although becoming much stronger and having much better tone. The message for them is perseverance. Once the nervous system has learned its part, and once the muscle cell has filled up, as it were, then the muscles will indeed become larger. If someone is interested only in muscle size, and not strength at all, then the training techniques would be rather different.

Basically, in training for strength, one has to lift weights which are close to the maximum, that one can lift. It is the strength and the tension so produced that seems to induce the muscle cells to switch on the production of the appropriate proteins. So, in a nutshell, strength training consists of low repetitions of heavy weights. These can be done with ordinary free weights, or in the safer and more convenient 'multi-gyms' which very many sports halls now have. Before attempting a strength training programme, it is important to get some instruction in the use of weights or multigym, to prevent injury.

Muscle Speed

Just as one is born with a set number of muscle cells, so one is also genetically programmed to have a given proportion of 'fast twitch' to 'slow twitch' cells in one's muscle. The fast cells can contract at about twice the speed of the slow ones. However, the slow cells get much more of their energy by aerobic means, whereas most of the fast cells are fairly anaerobic in their metabolism with a consequent high production of the crippling lactic acid. Most of the fast cells have this disadvantage, but not all - there is a type of fast cell which works on oxygen and is much more resistant to fatigue than its other anaerobic counterpart. Many animals have whole muscles which are fast or slow respectively, and you will have unwittingly noticed this for yourself on eating chicken. Here the breast - the flight muscle - is fast, while the leg - the muscle of posture - is slow. The much darker colour of the slow muscle reflects both the greater number of capillary blood vessels and the presence of greater amounts of the oxygen transport substance myoglobin, and both of these in turn reflect the far greater reliance of slow muscle on aerobically derived energy. Human muscle is a mixture of slow and fast, but some people have a very high proportion of fast muscle cells, and thy can become sprinters and jumpers. Those with high proportions of slow cells gravitate towards the endurance sports. This percentage distribution indicates a predisposition for one type of sport as opposed to another - however a very great deal can be accomplished by training. For example, Alan Wells was only the 6th ranked Scottish junior sprinter, yet he went on to win the Olympic 100 metres.

There is much debate as to whether one can in fact increase the population of fast cells, by recruiting some from the slow cells for example, although this does not seem likely. It is possible that the slow cells of Alan Wells may be faster than most people's fast cells! However, one can certainly work on what one has, one can considerably hypertrophy the population of fast cells. This has been demonstrated by taking biopsy samples from athletes before and after intensive training regimes. The way to train fast muscle cells is to do fast things! But, these fast movements have to be under some degree of load. It is no use waving one's arms frantically about in the air, or doing upside-down bicycling, because the fast motor units in many muscle only come into action when that muscle is producing more than about half the force of which it is capable. Fast skipping is good; as fast as one can for 30 seconds, with a similar rest, in sets of 10; or standing astride a low (10") bench and jumping up and down on it; or 'depth-jumping', which is jumping down from a platform about 2'6" high onto a mat and immediately jumping up again about 12", this being done in sets of 20; or sets of short sprints of 30 or 40 metres with a running start preferably down a slight incline to make you run slightly faster than you can run on the flat. Speed training for the arms usually involves fast movements with fairly light weights to provide the load, or the use of an isokinetic 'minigym' if there is one in the local sports centre.

In sport, it is often power which is required; to throw objects, to hit objects, to jump or to accelerate. In terms of simple physics, power is the rate at which a force is applied; in terms of muscle, rate equals speed and force equals strength. So, to gain power an athlete has to work on speed and strength.

A simple test of leg power is the vertical jump test. The subject stands sideways on to a wall, heels on the ground, and reaches up as high as possible to make a mark with a wet finger; then the subject crouches down into a set position which is held for a couple of seconds to eliminate 'bounce' effect, then jumps up to make a mark as high as possible on the wall. The distance between the two marks gives the height jumped. For men between 8" and 15" is average, 16" to 20" is good, and 20" to 30" excellent, with women's categories about 2" lower. With speed and strength training, particularly speed training, the height jumped will improve. Note that it is much better to compare oneself now with oneself before than to compare with different people.

Local Muscle Endurance

This is part of what is loosely called 'stamina', which consists of two main areas. First is the heart-lungs-red-blood-cell combination, which collectively delivers large quantities of oxygen to the working muscles. However, the muscles must have the ability to utilise the oxygen given to them, so the second component of stamina resides in the muscle, as 'local muscle endurance', which will now be discussed.

There are two distinct areas of local muscle endurance, reflecting the two ways in which muscle can generate energy, namely with oxygen (aerobically) or without oxygen (anaerobically). Basically, at low rates of working, a muscle can provide the energy aerobically, but as the work rate increases - as a runner goes faster for example or comes to a hill - then there comes a sort of metabolic threshold of energy supply, above which the muscle has to bring in its reserve anaerobic mechanism. So, there are two phases of energy supply for the working muscle. It is worth mentioning at this point that the sprinter goes straight into producing anaerobic energy as it is a much more powerful system than the aerobic one. The two mechanisms will now be described briefly.

Anaerobic local muscle endurance. The muscle must be able to handle the good blood supply coming from a well-trained heart. Once inside the muscle, the blood is diverted along the smallest blood channels, the capillaries (just wider than the red blood cells going through them). Each muscle cell is surrounded by about 10 capillaries if it is a slow cell, and less than half of this if it is fast. The number of capillaries can increase up to 50% with training. The myoglobin inside the cells, especially the slow ones, can also increase considerably with training, thus greater quantities of oxygen can be transported inside the cell into the mitochondria, which too greatly increase in size and number with training. Thus the whole capacity for the muscle cell to generate energy aerobically can very considerably increase.

Anaerobic local muscle endurance. As mentioned, if the muscle has to work progressively harder it may have to exceed its aerobic capacity; or if it has to work flat-out from the start then, metabolically, it has to leap straight into the higher energy production gained by anaerobic means. Energy is produced anaerobically in two ways in the muscle cell - without lactic acid and with it.

Without lactic acid ("Alactic energy"). Here, the energy comes from the energy store-substance 'creatine phosphate'. This can supply energy for just a few seconds of hard activity, with no penalising disadvantage. The amount of creatine phosphate can be increased with training.

With lactic acid ('Lactacid energy'). This, the more prominent anaerobic energy source, can supply energy for about 40 seconds of maximum effort. Or it can supply energy for surges of effort, for example a fast lap in a 10,000 metres race, or a sudden flurry of volleyed strokes and faster movements in a squash rally, or raising the stroke rate in rowing or canoeing.

Lactacid energy is produced in an enzyme cycle outside the mitochondria, and it uses only glucose as it's fuel, from which does not extract all the energy; it only takes the glucose molecule down as far as lactic acid. As the activity in the muscle cells gradually increases, the energy production, by whatever means, is forced to slow down, and the general feeling is of strong discomfort! With training, the amount of energy produced in this way can be increased, and also the buffering mechanisms for neutralising the acid, and the uptake mechanism in the liver and kidney for disposing of the lactic acid, can both be markedly increased. Also, the athlete becomes more tolerant of the discomfort.

In terms of training local muscle endurance: local aerobic endurance is gained along with whatever specific training is being done for the heart and lungs - running, cycling, canoeing, rowing, swimming, squash etc. The anaerobic endurance without lactic acid is gained automatically with speed training. Anaerobic lactic acid endurance has to be specifically trained for. The basic principle is that one has to work in periods which are long and hard enough to generate appreciable quantities of lactic acid, then there have to be rest periods which are long enough for it to disperse out of the muscle and to be taken up by the liver and kidney, which, of course, are also being trained. In practice, this means working hard for, say, 20 seconds, and resting for 40, with two or three sets of five repetitions of this. Gradually over weeks this is increased to perhaps 40 seconds of work and 80 seconds of rest, up to two or three sets of perhaps 10 or more times each. Each sport is specific, and each individual is different, but that is the basic pattern. The most sophisticated elite athletes and sportspersons have their 'anaerobic threshold' measured in the laboratory, and then aim to train very close to it, but the training principle is the same.

THE BRITISH OLYMPIC ASSOCIATION

MUSCLE PHYSIOLOGY, Notes by Brian Wilson on a lecture at The London Hospital on the 7th June 1986 by Dr N C Craig Sharp

STRENGTH

The maximum tension exerted by a muscle cell occurs between, not at, the limits of contraction. The greatest increases in strength are gained by exercising within the limits, not at the extremes e.g. cheat press ups rather then full press ups. HOWEVER, the limits must also be exercised to avoid injury from unusual ranges of movement during training and competition.

All evidence indicates that the number of cells do not change. Contrary to belief, injury rarely destroys muscle cells as they can be repaired by satellite cells GIVEN ADEQUATE REST.

Each muscle cell terminates in a tendonous process which is formed by collagen diffusing INTO the cell from OUTSIDE. Damage, which can be permanent, can occur at this termination especially in children and during strength training. Taking steroids considerably increases the risk.

The degree of contraction of a muscle depends upon the number of nerve cells which are recruited (used) by the central nervous system. A normal pattern exists which leaves many nerves unused, probably for emergency. Training can significantly increase the percentage recruited by laying down new patterns in the central nervous system. However, the patterns are VERY SPECIFIC. It has been found that possibly as much as 50% of strength training should be as near the competitive movements as possible. Some training should be on other muscle movements to avoid imbalances and injury in unusual situations. It is normal for the central nervous system to exercise a degree of inhibition so that not all nerves can be recruited and that there is some degree of tone in the opposite, antagonistic, muscle. This is a safety mechanism partially to avoid injury and partially in case the movement needs quick termination or reversal. The degree of inhibition can be changed by training giving an increase in the recruitment and hence strength of contraction. Examples are firing a gun close to the point of maximum contraction. The disinhibition allows a stronger contraction to occur with a change in the recruitment pattern. It is this phenomena that may account for some extraordinary feats of strength in crisis situations e.g. lifting cars off injured people.

Muscle strength increases by the synthesis of more protein. The synthesis is stimulated by using the muscle. There is growing evidence that 40% to 60% more protein is synthesised when muscles are loaded in a stretched condition rather than a contracted condition. This may account for the fact that children build up muscle more rapidly soon after growth of bones. It indicates that controlled eccentric work is best. For example, lifting a weight with both arms and lowering under control with one arm. It has been found that loads must be 92% to 96% of the maximum single lift and should be done in small pyramids and in 2 or 3 sets. General feeling is that 3 or 4 sessions per weeks are required. However, the Bulgarians have found that 3 or 4 smaller sessions PER DAY 3 or 4 times per week are more effective. What is important is that several hours of rest of the exercised muscles are set aside for protein synthesis to occur in response to the training stimulus.

It has also been found that about one third of the training should be done at the OUTER range of muscle stretch to avoid injuries. It is not needed at the inner range. Similarly the antagonistics must be strengthened at the same rate to give balance. This is partially to avoid injury (the majority of injuries are to the antagonistics e.g. the ham in runners not being strong enough to balance the strengthened quadriceps). It may also be connected with the need for elastic strength (see later) which is produced solely by the anatgonistics.

It has been found that strength can be retained in the competitive season by undertaking about one third of the training load of the conditioning phases, e.g. if 3 weight sessions were done in the winter, then 1 per week is required in the summer.

SPEED

Theoretically 7 metres per second is the maximum speed that muscles will allow an athlete to run. In practice speeds of up to 11 metres per second are achieved. It is thought that the difference is accounted for by a visco-elastic component supplied entirely by the antagonistics. As the muscle is contracted, the antagonistic stores energy as it is stretched. This energy can be released to supplement that from the main muscle.

Pliometric training, i.e. depth jumping and bounding, is probably increasing the visco-elastic component. In jumping down the elastic component of the antagonistics are recruited as a result of the stretch. It has been found that rebound vertical jumps lead to a 10% increase in height achieved over a standing vertical jump. There are no measures of the elastic component and there is no real theory on suitable training.

Muscle cells are recruited differentially according to the power required. At low loads, the slow twitch cells are recruited predominantly. The fast twitch, or anaerobic cells, are only recruited in large numbers when peak power is required. This is a natural reaction to conserve the fast cells which fatigue more easily than the slow cells. But the result of this is that speed training must be done at moderate loads to ensure that the fast anaerobic cells are recruited and exercised. High and low loads should not be used as the maximum torque of a muscle is reached somewhere between these. As fast cells fatigue very rapidly, speed training must be done with few sets of low repetitions with good recoveries.

Speed can also be improved by reconditioning the "gamma trail". Cells exist in the muscle spindles sensing the degree of stretch. They are set to a degree of sensitivity. When this threshold is reached, the cells trigger off the anatgonistics and damp down the neural signals to the main muscles. The degree of sensitivity can be altered. One way is to tense large muscle groups just prior to the need for fast movement. This tensing resets the sensitivity of the cells.

Fast muscle cells occupy larger areas than slow muscle cells. Whilst the present theories are that slow muscle cells can not be changed to fast cells, selective training can significantly alter the relative bulk of the two muscle types. For example, a group of canoeists were found to have slow to fast muscle cell areas in the ratio of 2:3 prior to training and 2:5 after training. NOTE THE NUMBER of cells did not change, only their relative volumes. There is some evidence that cell types can be changed as the difference between them lies in their enzyme producing components and the number of neurones (see later).

<u>ENDURANCE</u>

AEROBIC ENDURANCE requires a flow of oxygen in the blood. The density of the capillaries surrounding muscle cells can be markedly increased by slow endurance work. Increases from 500 per square meter to 850 per square meter have been found. Within the muscle cell, myoglobin transports the oxygen. This too can be increased, typically by 200% to 300%. The mitochondria within the cell use the oxygen. These can also be increased by 200% to 300% by volume.

ANAEROBIC ENDURANCE is dependent upon a chemical, ATP, in the cell for very short times (1 to 2 seconds) and there is no evidence that training can alter this. It is also dependent upon a chemical reaction, the CP cycle, within the cell. This can be very markedly changed in training, by as much as a factor of 5 by volume. Also the glycolysis cycle involving lactic acid can be improved. Enzyme production can be improved as well as the lactic uptake mechanism. The former requires long or intense work sessions with short rest periods. The latter requires short work sessions with long rest periods.

By definition, anaerobic training consists of up to 30 seconds of maximal work. Below maximal work and above 30 seconds, mainly aerobic cells are used. The actual time varies between athletes and can only be found by monitoring.

The blood flow slows down within 20 to 45 seconds after load. It is important that during that time the lactic acid diffusion must be stimulated. This only occur if 50% to 60% (the upper figure for athletes) of the load is maintained during the recovery.

Consider the anaerobic training needs of a 400 metre runner. Suppose he is a 45 second man. Then his 30 seconds repetitions should cover about 245 metres with a 45 second recovery covering 220 metres. If he was a 50 second man, then the repetitions are 220 metres in 30 seconds with a 200 metre recovery in 45 seconds. A 55 second woman would do 200 metres in 30 seconds with a 180 metre recovery in 45 seconds. A 60 second woman would do 185 metres in the 30 seconds with 165 metres recovery in the 45 seconds. These are only indicative. As training increases, lactic take-up improves and loads, recoveries and number of sets must be changed. Sets may be few with many repetitions e.g. 2 x 10, or many with fewer repetitions e.g. 7 x 3 with recoveries between sets of 5 to 15 minutes.

There is new thought arising in the trainability of different muscle fibres. It is believed that the difference between types of muscle fibre mainly lies in the nerves. Slow fibres have nerves working at 10 MHz whilst fast fibres have nerves working at 40 MHz. It is possible to enervate nerves electrically by applying the appropriate frequency and this can improve muscle endurance. This is technique used by physiotherapists and others in treatment. In the USA, Edwards thinks that marathon runners actually increase the percentage of slow twitch cells, not just their area. It may be that during training, fast twitch fibres become de-enervated and, in recovery, re-enervate at the slower frequency to produce slow twitch characteristics. The reverse might be possible.

Some study on endurance training with children has taken place in Scandinavia using identical twins. It shows that with boys gains in endurance can be obtained by training during pre-pubertal ages. BUT these improvements DO NOT carry over post-pubertally. With girls there appears to be a carry over. This difference may be related to growth and sex hormones.

Studies with children show that they are basically aerobic pre-pubertal and that the anaerobic capability develops with puberty. However, it is possible to improve the pre-pubertal anaerobic capabilities, but less so than in post-puberty.

It is worth noting here that recent studies, not reported by Dr Sharp, indicate that early return to training after injury predisposes the individual to early onset of arthritis. This confirms earlier studies in gymnastics which showed very alarming incidence of severe arthritis in females in the 30 to 40 year age range who had competed at high levels in gymnastics as pre-pubertal girls and had had injuries during this period.

In summary, research into muscle physiology shows that:

1. Strength training requires significant near maximal loads;

2. Speed training requires significant loads;

3. Anaerobic training has to be specific and requires short, but intense, loads with relatively short and active recoveries;

4. Pliometric training and strength training of the antagonistics are to be recommended;

5. At least 50% of training must be close to competitive movement;

6. Recovery times and activities are crucial and must be controlled;

7. One third of strength training loads are required to maintain strength;

8. Endurance training is of longer term benefit to girls than to boys;

9. Anaerobic training of pre-pubertal children is of very limited benefit.