Muscles and their red and white fibres

The effects of exercise and training

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In these health-anxious times, exercise offers some reassuringly simple prescriptions. A daily dose of organised activity, whether it be jogging, Pilates, pumping weights in the gym, or brisk walking is generally seen as the cornerstone of a healthy lifestyle. Doctors, dietary consultants, personal trainers, journalists and, of course, the fitness industry form a chorus of support for the benefits of regular exercise.

Much of this is perfectly justified. A reasonable amount of daily exercise is essential to the preservation of a healthy human body. Muscles which are not exercised waste away; those which are vigorously and regularly exercised gain in strength and bulk. Yet few people have any detailed idea about the effects of exercise on muscles or general body health.

One of the key points is that the red and white fibres in muscles are quite differently affected by exercise. Excessive development of white fibres can lead to a physique which is ideal for the weight-machine but leads to an inability to sit at a computer for more than a half-hour without backache. A proper balance between red and white muscles fibres is necessary for general health and well-being.

The aim of this paper is to set out the basic facts about muscles, how they do their job and how they are affected by exercise and training. It is short on detailed prescriptions because people are different and want different things from their exercise programmes. Instead, it provides the information for people to make their own judgements on what they want to achieve and how to go about it. Healthy living is not about chasing exercise and other fads but about understanding how one's body works and taking responsibility for how one uses it.

The skeletal muscles

There are around six hundred skeletal muscles in the body and their role is to generate force or movement. They are called skeletal because they are connected at one or both ends to a bone in the skeleton. It is these muscles which are affected by exercise and training.

The skeletal muscles are often referred to as striated because, under a microscope, they show alternating light and dark transverse bands, giving them a striped or striated appearance. They are also referred to as the voluntary muscles because they are, to a greater or less extent, subject to conscious or voluntary control.

Each skeletal muscle contains hundreds to thousands of elongated cells called muscle fibres. The number of fibres varies according to the size of the muscles. The smallest muscle in the body, the tensor tympani in the inner ear, contains only a few hundred fibres. The first lumbrical muscle, in the back of the hand, contains about 10,000 fibres and the medial gastrocnemius, one of the big calf muscles contains over a million.[1]

These fibres are capable of contraction and relaxation and vary in length from 2 mm

[1] McComas (1996) p4

to about 300 mm.[2] They vary in diameter from 10 to 100µm (micro metres or millionths of a metre) in diameter,[3] with an average of around 50µm.[4] This is about the diameter of a human hair.

The muscle fibres are bound together into bundles of 10 to 100 fibres; these bundles are called fasciculi or fascicles. Groups of fascicles in their turn are bound together and surrounded by sheets of connective tissue called fasciae to form the muscle. This connective tissue attaches to the muscle tendon which is itself composed of connective tissue. The tendon then attaches to bone; where the tendon is in the form of a flat sheet it is termed an aponeurosis.[5] The central part of the muscle is usually termed the belly and it is here that the main contraction occurs.

Structure of muscle fibres

Each muscle fibre is itself a complex structure. It has a surrounding of connective tissue called its sarcolemma. Within the sarcolemma is a substance called sarcoplasm. Running through the sarcoplasm are numerous longitudinal threads called myofibrils. They are about 2 µm in diameter and run the whole length of the muscle and it is these which have the banded or striated appearance. They are the contractile elements in the muscle; they do the actual shortening and lengthening. Within the myofibrils are tiny structures called sarcomeres which slide back and forth on each other causing the fibril to shorten and lengthen.

Adenosine triphosphate (ATP)

All bodily activity requires energy, or fuel. The immediate energy source used by muscles is a substance called adenosinetriphosphate (ATP). This is synthesised inside the muscle fibres themselves by tiny mechanisms called mitochondria. Each mitochondrion is an egg-shaped body, called an organelle, about one millionth of a metre long. Because of their function in generating ATP, they are sometimes referred to as the "powerhouses" of the cell.[6]

Blood supply to the muscles

All the muscles are served by the body's blood supply, otherwise known as the vascular system. In this, arteries carry blood away from the heart, dividing as their distance from the heart increases; the smallest arteries are referred to as arterioles. As the arterioles enter a tissue they divide into a huge number of microscopic blood vessels called capillaries (hairlike). These ferry in the oxygen and nutrients needed by the tissue and remove the waste products.[7] As they leave the tissue, the capillaries unite to form small veins called venules. These merge to form veins which bring the blood back to the heart. [8]

The heart itself is divided into four chambers. The two upper ones are called atria (entry halls) and the lower ones are called ventricles (little bellies). The right atrium

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[2] Rowett (1990)p38

[3] Tortora (2000) p273

[4] McComas (1996) p4

[5] Tortora (2000) p271

[6] Ibid. p84

[7] Ibid. p272

[8] Ibid. p670

receives deoxygenated blood from the principal veins and passes it to the right ventricle which pumps it into the pulmonary artery. This takes it to the lungs where there is what is called a gas-exchange, in which up the blood absorbs the oxygen in the in-breath and gives up the carbon dioxide which is expelled in the outbreath. The reoxygenated blood is taken back to the left atrium of the heart by the pulmonary veins. It is then passed to the left ventricle which pumps it into the aorta on its way around the body once more.[9]

Generally, each skeletal muscle is served by an artery and one or two veins.[10] Inside the muscle, each muscle fibre is in close contact with one or more capillaries and exchanges between the blood and the fibre take place through the walls of the capillaries.

During exercise, muscle activity increases and various changes take place in the body. As McComas says,

> *…the pulse quickens, blood pressure rises, muscle blood flow increases and breathing becomes deeper and more rapid.*[11]

These changes increase the rate at which the necessary materials for the formation of ATP are brought to the active muscles and the waste products are carried away. The increase in blood pressure is a result of the contractions in muscles causing increased resistance to blood flow.

Red and white muscle fibres

Muscles do their work by contracting or shortening their fibres. These fibres are conventionally divided into two broad categories, red and white, sometimes referred to as Type I and Type II. In practice, the division is not clearcut and physiologists use a variety of sub-divisions within the broad red-white distinction.

Red fibres

In red (Type I) fibres, the colour comes from myoglobin which is a red-coloured oxygen-binding protein found only in muscle fibres.[12] The fibres with the darkest red colour contain the largest amount of myoglobin. These fibres obtain their energy supplies by the process known as aerobic cellular respiration which means that the muscles produce their ATP using oxygen and other products from the blood.[13] These products include glucose obtained from the breakdown of pyruvic acid, fatty acids from the breakdown of adipose tissue (fat) and amino acids from the breakdown of proteins.[14]

These red fibres are also described as slow oxidative fibres (SO) or simply as slow fibres. In older publications, they were often referred to as tonic fibres. Their production of ATP is relatively slow but is efficient in its use of the available raw materials. The waste products are water and carbon dioxide which are carried away by the blood and hence there is no build-up of waste products in these fibres. They

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[9] Rowett (1990)p112

[10] Tortora (2000) p271

[11] McComas (1996) p211

[12] Tortora (2000) p273

[13] Ibid. p285

[14] Ibid. p285

respond slowly and are sometimes described as slow twitch. Aerobic cellular respiration provides enough ATP for prolonged activity as long as the blood can continue to provide the necessary oxygen and nutrients and take away the waste products. The red fibres are adapted for maintaining posture and for gentle and endurance-type aerobic activities.

White fibres

The white (Type IIB) fibres, also known as fast glycolytic (FG) fibres, or simply as fast fibres, are the largest in diameter and the strongest.[15] Because they have a low myoglobin content they appear white in colour. They are also referred to as phasic fibres.

They obtain their energy by a process known as anaerobic cellular respiration which does not rely on oxygen and other substances supplied on a continuing basis by the blood. Instead they depend on stores of glycogen and other substances which accumulate in the fibres when the muscle is resting.

When the muscle is called into action, the glycogen in the white fibres is broken down via a set of reactions in a process known as glycolysis [16] in which ATP and lactic acid are produced. Muscle fibres relying on anaerobic respiration can keep going for 30-40 seconds of maximal activity.[17] After that, fatigue sets in as a result of the depletion of glycogen and the build-up of lactic acid. These muscle fibres are able to contract strongly and quickly, hence their designation as fast-twitch, and are used for short duration actions.

Intermediate and slow tonic fibres

Another type of fibre, intermediate in diameter between the red and the white, is referred to as fast oxidative-glycolytic fibre (FOG). These fibres are stronger than the red and are often designated Type IIA. They respond more quickly than the SO fibres, hence they are also termed “fast”. They generate their ATP by both cellular respiration and anaerobic glycolysis.

Yet another type of muscle fibre is termed slow tonic. Gray’s anatomy says

> *…this type of fibre is more common in birds and reptiles but is present in the extrinsic ocular muscles and stapedius muscle of the middle ear in man.*[18]

The extrinsic or extraocular muscles are extremely complex and their behaviour is outside the scope of this paper. It appears the slow tonic fibres play a part in enabling these muscles to sustain their tension in the face of fatigue when carrying out the highly specialised and delicate movement requirements of the eyes.[19]

Creatine phosphate and lactic acid

All muscles when they are at rest produce a small amount of a substance called creatine phosphate. Since this can be quickly converted into ATP it means that

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[15] Ibid. p289

[16] Ibid. pp874, 892

[17] Ibid. p283

[18] Williams (1995) p752

[19] Davson (1990) p671

muscles are always ready for action. The amount of creatine phosphate produced by the muscles in this way provides enough energy for about 15 seconds of maximum activity.

This has led to a belief that creatine dietary supplements will assist athletic performance and manufacturers have been quick to market a wide range of creatine-based products for which semi-miraculous beneficial effects are claimed. In practice, the total consumption of creatine phosphate by the adult body is 2 grams per day, all of which is synthesized by the muscles, with the raw materials being obtained from normal food.

Tortora reports that, although trials in which large doses of creatine taken by American footballers showed some gain in muscle bulk, other studies failed to find any performance enhancing effects. He also warns on the possible negative effects of taking creatine supplements, saying that

> *…ingesting extra creatine tends to shut down the body's own synthesis of creatine and it is not known whether natural synthesis recovers after long-term creatine supplementation.*[20]

Muscle aches are often attributed to a build-up of lactic acid and this has conventionally been seen negatively. Recent research has shown that the issue is more complex than usually supposed. Although an increased amount of lactic acid in the muscles during intense exercise can be responsible for a burning pain, the lactic acid produced by the muscles during their normal production of ATP serves many useful functions in the body. It can act as a fuel during exercise. It is carried to other parts of the body by the bloodstream and is the preferred energy source for the heart, liver, and kidneys. It is also used by the liver to produce glucose. All the lactic acid produced during exercise is used by the body within a couple of hours.[21]

Nerve-supply to the muscles

All the skeletal muscles are well supplied with nerves which control their actions. The nerve signals come from specialised cells known as somatic motor neurons in the brain or spinal cord; they are also known as motor neurons or motoneurons. As Tortora says

> *The neurons that stimulate skeletal muscle to contract are the somatic motor neurons. Each somatic motor neuron has a threadlike axon that extends from the brain or spinal cord to a group of skeletal muscle fibers.*[22]

The axon carries the impulse or signal from the motor neuron to the muscle fibres it controls. As McComas says

> *When a muscle is required to contract, it is sent the necessary instructions in the form of nerve impulses (action potentials) by large cells lying in the ventral gray matter of the spinal cord (or in a corresponding region of the brainstem). These cells are the*

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[20] Tortora (2000) p283

[21] Kamen (2001)p21

[22] Tortora (2000) p271

motoneurons of which there are usually a hundred or more for each muscle.[23]

A motor neuron together with all the skeletal muscle fibres it stimulates is called a motor unit. Typically, the fibres of a motor unit are distributed through the muscle rather than clustered together but all the fibres in a motor unit act together. All muscle movements controlled by the central nervous system are carried out by motor units rather than single muscle fibres and all the varied reflex and voluntary contractions of a muscle are achieved by different combinations of motor units.[24]

The average number of fibres in a motor unit is 150 but this varies greatly. The muscles which are used in delicate control tend to have large numbers of motor units with small numbers of fibres in each. [25] The external rectus muscle of the eye, for example, has 2970 motor units with an average of 9 fibres in each, while the platysma, the large flat muscle stretching from the upper chest up to the chin, and highly important in facial expression, has 1096 motor units with an average of 25 fibres in each. In contrast, the medial gastrocnemius, in the calf, has 579 motor units with an average 1934 fibres per unit.[26]

Twitch contraction

The term twitch contraction is used to refer to the response of all the fibres in a motor unit to a single signal or motor impulse from its motor neuron. A twitch contraction has three stages or phases. The first is called the latent period during which the fibre is responding chemically to the nerve impulse and lasts about 2 milliseconds. The next phase is the contraction which lasts from 10 to 100 milliseconds. After this contraction, the muscle fibre relaxes in about the same amount of time.[27] A rapid series of motor impulses brings about a sustained contraction of the fibre.

Proportions of red and white fibres in different muscles

Most muscles are a mixture of different types of fibres. In animals there is usually a preponderance of one type or other, typically characterised by the red meat of beef or the white meat of poultry. In human beings, the usual muscle has about 50 percent each of red and white fibres.[28]

There are, nevertheless, significant differences in the proportions of red and white fibres in different human muscles. Muscles which play a major role in posture tend to have a higher proportion of the red non-fatiguable fibres. These postural muscles which are constant gentle action during sitting or standing are sometimes described as antigravity muscles, a term used by Sherrington. Perhaps the earliest recognition that they contained a higher proportion of red fibres was by Sherrington's pupil and colleague Denny-Brown in 1929.[29] Tortora also points out that the

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[23] McComas (1996) p25

[24] Ibid. p183

[25] Tortora (2000) p286

[26] McComas (1996) p185

[27] Tortora (2000) p286, 287

[28] Garlick (1990)p35

[29] McComas (1996) p191

> *…continually active postural muscles of the neck back and legs have a high proportion of SO [red] fibers …*[30]

In data provided by McComas, the soleus, one of the lower calf muscles connecting into the Achilles tendon is shown as having 80 percent red fibres.[31]

The functioning of the postural muscles was of particular interest to David Garlick, an Australian medical doctor who specialised in sports medicine and established both masters and degree courses in the subject at the University of New Wales during the 1970s and 1980s. Around this time he became interested in the Alexander Technique and went on to train as a teacher of the Technique at a well-known Alexander training school in Sydney.[32] Based on his own experience, he felt the Technique was relevant to much of his scientific work on exercise and sports medicine; but he was also deeply interested in investigating how the findings of Alexander, who was himself Australian, were underpinned by developments in neuroscience and physiology.

Referring to proportion of red fibres in the postural muscles, he observed:

> *It is now realised that not only the soleus (deep in the calf) is a postural muscle with predominantly red fibres. The new discoveries by Brisbane–Sydney scientists have found that deep back muscles, such as multifidis, and also one of the anterior or front abdominal muscles, transversus abdominis, are postural and contain mainly red fibres.*[33]

Muscles of the shoulders and arms which, in contrast with the postural muscles, are not constantly active but are used for intermittent activities such as lifting and throwing, have a considerably higher proportion of white fibres. McComas lists the biceps brachii, for example, as having about 40 per cent red fibres.[34]

Order of recruitment of red and white fibres

The term "recruitment" is used to describe the bringing of motor units, that is groups of similar types of muscle fibres, into action by the nervous system. It is remarkably sophisticated in ensuring that the fibres most suited to the task in hand are brought into action when they are required.

This means, in practice, that if the red fibres, which are the weakest, will suffice, only they are recruited; but if greater force is required, the nervous system brings the intermediate fibres into action; and if these are not sufficient for the task, the white fibres come into play. Tortora describes it as follows:

> *…the different motor units in a muscle are recruited in a specific order, depending on need. For example, if weak contractions suffice to perform a task, only SO (red) motor units are activated. If more force is needed, the motor units of FOG (Type IIA) fibers are also recruited. Finally, if maximal force is required, motor units of FG*

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[30] Tortora (2000) p290

[31] McComas (1996) p195

[32] Acker's Alexander Technique Teacher Training School, Darlinghurst NSW

[33] Garlick (D2-8)p32

[34] McComas (1996) p195

> *(Type IIB) units are also recruited. Activation of various motor units is controlled by the brain and spinal cord.*[35]

McComas says:

> *There is good evidence that the type I motor units are mostly employed during weak or moderately strong contractions of a sustained or repetitive nature. As the contractions become stronger, Type IIA units are recruited and, finally Type IIB units also. In certain very rapid or sudden corrective movements, however, the Type II units may have lower thresholds than Type I units.*[36]

The last point about the lower thresholds of Type II fibres in the above quotation is important. It means that when a very fast muscular response is required, even though it only requires a weak or moderate contraction, the quick-reacting white fibres are mobilised. Brushing an insect away from the eye, for example, requires a mixture of speed and delicacy of touch which is best provided by mobilising the white fibres.

McComas also makes the point that the amount of effort required determines the initial recruitment pattern but further observes that as the action proceeds, the nervous system switches between fibre types depending on the effort needed at the time. In experiments in which volunteer subjects were subjected to tests in which they pedalled on laboratory exercise machines or simply sustained a force, the experimenters found that

> *… in both types of exercise, pedalling and sustained contraction, the slow-twitch fibres were used for weak contraction, the fast-twitch ones being used for greater effort.*[37]

The details of the order of recruitment of the different fibres used by the nervous system under different circumstances are thus quite complex. But the general picture is clear. When the body is being used properly, the basic work of maintaining sitting and standing postures as well as the requirements of gentle to moderate rhythmic activity are met by the non-fatiguable red fibres. When, however, there is a need for a more vigorous or a very quick response, the nervous system brings the white fibres into play.

Effects of disuse on muscles

If muscles are not used regularly, they shrink, or atrophy, and myofibrils are lost, which means the muscles become incapable of functioning properly. When a broken limb is enclosed in a cast, for example, the loss of muscle bulk can be quite dramatic. As McComas says

> *If a muscle is no longer used fully, either as the intended result of an experiment or, in human subjects, because of an injury to a limb, the muscles can undergo striking atrophy and become weaker.*[38]

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[35] Tortora (2000) p290

[36] McComas (1996) p210

[37] Ibid. p210

[38] Ibid. p274

There is considerable evidence from animal studies that the red fibres show the greatest wastage when they are not used.[39] McComas remarks that both types of muscle fibres atrophy when they are not used but

> *…the amount of atrophy will depend on the usage of the muscles prior to immobilization and will therefore always be greater in antigravity muscles than their antagonists…*[40]

The antigravity muscles are those which maintain the shape and balance of the body against the influence of gravity and hence are in use a great deal of the time.

He mentions that experiments in which rats were suspended in a sling so their hind legs were out of contact with the floor

> *…have been unanimous in identifying the Type I (slow-twitch) fibers as having the greatest atrophy and loss of tetanic force.* [41]

The reference to tetanic force here means the ability to maintain a particular level of force by means of a steady state of muscle contraction. There is also evidence that after disuse, the nervous system seems to "forget" how to recruit the full motor unit population fully.[42]

The effects of disuse extend beyond the affected muscles themselves and there is a deterioration in the nerves directly involved in controlling these muscles. This makes physiological sense, since feeding nervous impulses into non-functioning muscles is a waste of body resources. Thus, while the proper functioning of muscles depends on their receiving appropriate impulses from the nerves supplying them, the continued health of the nerves equally depends on feedback from the muscle.[43]

Referring to such experiments, in which disuse has led to a greater deterioration in red rather than white fibres, Garlick draws an important inference for the use of the postural muscles in humans, saying

> *The fascinating implication for human beings is that if muscles are not appropriately used in posture, the functional change in the red fibres of the extensor, anti-gravity muscles may be that these muscles become less able to act as anti-gravity muscles – a vicious circle so that a person becomes less able to stand and sit unsupported.*[44]

In summary, it is quite clear that a certain amount of exercise, in which both red and white fibres are brought into action, is essential for bodily well-being. The next question is how much and what type of exercise is required. Answering this requires a more detailed examination of the effects of exercise on muscles.

Effects of exercise and training on muscles

In the broadest sense of the word, exercise means using voluntary muscles for physical work, walking and general everyday actions. The other meaning of exercise,

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[39] Ibid. p292, 296

[40] Ibid. p288

[41] Ibid. p292

[42] Ibid. p289

[43] Ibid. p279

[44] Garlick (D1-4)p119

which is closer to the Latin root of the word (*exercere = to practise),* is to do specific things to develop the muscles in certain ways. This is often referred to as training and generally means going to the gym, running hard, rowing, and so on.

Many people believe that regular workouts in a gym or vigorous running will provide them not just with bigger and stronger muscles but with a general improvement in their physical well-being. This is based on the fact that vigorous exercise, for whatever purpose, causes major short-term changes in muscles and if this exercise is repeated regularly, the muscles adapt to the demands made upon them and exhibit long-term changes.

McComas says:

> *A number of important biochemical changes take place within the muscle fiber during contractile activity, but the normal milieu within the fiber is usually restored by a variety of enzymatic processes within minutes or hours. However, if the contractions are unusually strong or prolonged, and if they are repeated, then a combination of structural and biochemical adaptations take place that ensure that the muscle is better suited to the work demanded of it.*

He goes on to point out that the muscles adapt to the demands being placed on them:

> *Thus, if force or power is required, the muscles become stronger; if on the contrary, the muscle activity is of long duration, then the muscles become less readily fatigued. Although the changes are most obvious in the muscle fibers, the motoneurons are also affected in terms of their patterns of recruitment and impulse discharges.*[45]

The problem facing people trying to plan the optimum exercise programme for themselves is that increased strength and greater endurance are not necessarily compatible objectives. To understand this, it is necessary to examine the changes which occur in red and white fibres when they are subject to exercise.

Effects on red fibres

Regular rhythmic activity, such as walking or jogging, primarily employs red fibres and is the basis of the endurance training routines used by athletes running marathons and distance events. One of the surprising results of this kind of training is that the muscles can become more slender. McComas says that

> *…endurance training results in muscles that are not only more effective during sustained activity, but also in the case of long-distance runners, more slender. The explanation for the smaller girth is that the myofibrils, and the fibres themselves, are reduced in cross-sectional area. It is likely that this adaptation allows better diffusion of metabolites and nutrients between contractile filaments and the cytoplasm, and between the cytoplasm and the interstitial fluid.*[46]

In addition to reducing the girth of the red fibres, McComas reports that endurance training leads to an increase in the proportion of red fibres in the relevant muscles by changing the characteristics of some of the white fibres to those red fibres. He also

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[45] McComas (1996) p299

[46] Ibid. p304

remarks that endurance training is more reliable in producing its expected results than strength training. He goes on to explain that

> *…in contrast to the rather variable and generally unimpressive results of human strength training regimes, endurance training produces well-defined consistent changes. Like electrical stimulation in animals, the results of human endurance training are to make some of the Type II fibers acquire the physiological, biochemical and structural features of Type I fibers.*[47]

McComas also provides the results of analyses in which the red-white fibre balance in various endurance athletes, orienteers, long distance runners and cyclists, are compared with controls. All of these analyses show that, compared to the controls, the endurance athletes had a much higher percentages of Type I fibres.[48] Given the wide natural differences in muscular makeup between individuals, it might, of course, be argued that it was their endowment of a higher proportion of red fibres that attracted them to such activities in the first place. What is not in doubt is that that those who engage in endurance activities tend to have a higher than average number of red fibres in their muscles.

Effects on white fibres

The effects of exercise which mobilises the white fibres are dramatically different from those of endurance training. When subjected to forceful activity, sometimes described as strength training, the muscles involved are subject to hypertrophy: they increase in bulk. This is because the white fibres increase in diameter as a result of the production of more myofibrils and other components.[49] The capacity of the fibres to store glycogen is also increased. There may also be a certain amount of transformation of red to white fibres. It has been shown, for example, that sprint training, which develops the white fibres, can reduce the number of Type I fibres.[50]

The effects of intensive strength training can be quite spectacular. McComas says:

> *The huge gains in muscle mass following strength training in humans are remarkable, and have become the inspiration for body-building competitions and fitness magazines.* [51]

Perhaps the most defining characteristic of training which increases the bulk of the white fibres is known as *The specificity of exercise principle.* [52] It is also known as the SAID principle: Specific Adaptation to Imposed Demands. Basically, this means that people get better at the particular exercise they are carrying out but the effect on other activities is small.

In a study of people who did 12 weeks of work on their knee extensors, it was found that muscle bulk was greatly increased and the strength as measured by the weights lifted was increased by 200 percent. Tests of the subjects' strength when measured by

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[47] Ibid. p305, 310

[48] Ibid. p307

[49] Tortora (2000) p273

[50] McComas (1996) p301

[51] Ibid. p228

[52] Kamen (2001)p72

their ability to exert an isometric pressure, that is to maintain a given level of pressure without moving the legs, was only 15 percent greater.

Findings such as this have led exercise and sports scientists to the formulation of the rule that the greatest changes resulting from training exercises are in the ability to perform the training task. One of the reasons for this is that as a result of the training there is a neural adaptation so that the task is carried out more efficiently and only the muscles directly involved in the task are used. [53]

Kamen highlights the specificity of training in the following terms:

> *Endurance training on a bicycle will result in the greatest adaptations in cycling and lesser adaptations in running or rowing. Strength training can even be machine-specific. Gains in muscular strength by training on a machine made by one company may not be so great when measured by a strength test performed on a machine made by another company.*[54]

Unless the training regime is continued, the effects are quite short-lived. Once a person who has been following a particular training regime stops, the effects of the exercise wear off at about the same rate as they occurred during the training.[55] In other words, if a person following a particular muscle-building programme in a gym achieves the muscle bulk they intended and then stops, the muscle will reduce in bulk at about the same rate as the build-up occurred.

One of the strangest findings, within the conventional fitness and exercise paradigm, is that simply thinking about exercise can have a significant effect on muscle strength. Kamen reports on a four-week study in which three groups were involved. One group was asked to practice moving the little finger away from the others as a means of strengthening the abductor digiti minimi muscle. Those in the control were simply tested at the beginning and end of the 4 week period. The members of the third group were brought into the lab and asked to think about moving the finger and while they were doing so to imagine a voice shouting: harder, harder. The interesting result was that the exercising group showed a 30 percent increase in strength; the control group showed virtually no change; and the purely thinking group showed an increase of 22 percent.[56]

Health and exercise

Apart from training for specific sporting or athletic purposes, or body-building for the sake of appearance, much emphasis is placed on the health benefits of exercise. While regular exercise is essential to prevent muscle atrophy, much of the effort expended in vigorous exercise for the sake of health may be wasted if not counterproductive. Kamen states that the maximum health benefits are obtained from relatively gentle exercise.

> *…very easy exercise (low intensity and short duration) can make the biggest improvements in the health benefits of exercise…the benefits plateau at 50% intensity and 30 minutes duration. Exercise of greater*

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[53] McComas (1996) p304

[54] Kamen (2001)p46

[55] Ibid. p

[56] Ibid. p42

intensity or longer duration provides little additional benefits to general health.[57]

He also points out that there are considerable differences between exercising for health and training for a specific muscle-building purpose.

Low-intensity exercise, which most people would rate as "very easy" (about 40 to 60% of maximal capacity) is recommended for good health. Exercise below 60% of maximal intensity may improve health but does not produce the specific training benefits for physical performance.[58]

There is also a health price to be paid for intense training. It induces considerable amounts of damage in the muscles, including torn sarcolemmas, damaged myofibrils, and increased blood levels of substances which are normally confined within the muscles. For 12 to 48 hours after a period of strenuous exercise, skeletal muscles often become sore with accompanying tenderness, stiffness and swelling.[59]

Kamen is particularly clear about the widespread and serious effects of over-training:

Too much training combined with inadequate rest periods can result in decreased performance, reduced aerobic capacity, decreased ability to store glycogen for ATP regeneration, weight loss, muscle soreness, and higher resting and exercising heart rates. Overtrained athletes manifest low levels of important amino acids like glutamine. The immune system weakens so that individuals may be more susceptible to colds and infections…Overtraining also negatively affects the performer's psychological health…The stress of too much exercise adversely influences the body's ability to handle other stressors.[60]

Kamen also remarks in relation to the differing effects of endurance and strength training regimes that

…it's not easy to design an all-purpose exercise program that would provide optimum benefit to both aerobic and anaerobic performance systems.[61]

One of the problems involved in developing such an all-purpose exercise programme is that different training regimes can interfere with each other. Exercising aerobically, for example, can hinder anaerobic performance and vice versa. It has also been found that the number of mitochondria which provide ATP for aerobic activity decreases with strength training but increases with aerobic exercise training. Similarly, it has also been shown that strength training decreases the myoglobin content of muscles, which hinders aerobic activity.[62] In other words, increased strength tends to lead to reduced stamina.

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[57] Ibid. p73

[58] Ibid. p73

[59] Tortora (2000) p274

[60] Kamen (2001)p48

[61] Ibid. p46

[62] Ibid. p46

An Alexander Technique perspective

David Garlick's understanding of physiology and sports medicine, and more specifically the role of the red and white muscle fibres, enabled him to apply a scientific perspective to various aspects of the Alexander Technique. A particular concern of Alexander teachers, for example, is to wean their pupils from excessive muscular tension when standing or sitting. Garlick observes

> *Interestingly, the red, postural fibres are the ones most susceptible to not being used appropriately such that they become less 'red-like' and less non-fatigable. It then takes time to restore their characteristics and this is where the Alexander Technique plays such a significant role. It is a procedure of 'non-doing',' non-interfering', of 'letting-go', 'not gripping' – these are, in a sense, ways of allowing these red muscle fibres to exercise without interference from other muscle fibres. The Alexander Technique can be regarded as an 'internal' form of exercise.*[63]

He also comments

> *Note, though, that if a person characteristically tries to avoid using these postural fibres by sliding down in a seat, standing asymmetrically or supporting the trunk by leaning, then these postural fibres become under-used and begin to lose their non-fatigable, 'red-fibre' qualities…*[64]

At a more general level, the Alexander Technique provides a means of utilising the characteristics of the postural reflexes, as elucidated in the classic neuroscientific work of Sherrington and Magnus, to achieve the optimum mobilisation of the muscular system. The word "reflex" has been subject to so many different interpretations over time, and even in contemporary neuroscience, that it is essential to make clear from the beginning what is meant here by the term.[65] Luckily for the purposes of this paper, Sherrington's definition of reflex is admirably clear and unambiguous; he takes particular care to distinguish reflex behaviour from learned or habitual behaviour.

> *Habit arises always in conscious action; reflex behaviour never arises in conscious action. Habit is always acquired behaviour, reflex behaviour is always inherent and innately given. Habit is not to be confounded with reflex action.*[66]

The postural reflexes, as Magnus' work showed, operate subcortically; they are controlled from the brainstem and there is no involvement by the cortex. The whole complex business of posture is controlled reflexly by an integrating mechanism or control system in the brain stem. As Magnus says

> *The result of the present study is that in the brain stem, from the upper cervical cord to the midbrain, lies a complicated central nervous apparatus that governs the entire body posture in a coordinated*

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[63] Garlick (D1-8)p6

[64] Ibid. p6

[65] Prochazka (2000)

[66] Sherrington (1948)pxvi

manner. It unites the musculature of the whole body in a common performance…This is the apparatus on which the cerebral cortex plays, as complicated melodies are played on a piano…[67]

The relevance of this is that bringing the postural muscles, with their predominance of red muscle fibres, into play cannot be done by any act of will. The more a person tries to do so, the more likely it is that the resultant motor command will activate the white rather than the red fibres. The harassed office worker, determined to have a hard workout in the gym, is almost certainly going to mobilise the white fibres. It is small wonder that such health-conscious people, regularly working out, can discover that though they have impressively bulky chest and shoulder muscles, they are so weakened in their postural musculature that they must rely on a lumbar support if they have sit upright in a chair for more than a couple of minutes.

In the ideal muscle-fibre recruitment pattern, the red fibres are mobilised first, the intermediate next and the white fibres as needed for major effort. But the white fibres, with their fast-twitch characteristics, are also mobilised for fast responses to emergencies such as spotting a lion or, more likely, a "fatal error" message on a computer screen. After a hard and stressful day at the office, the most likely result of a visit to the gym is that the normal fibre recruitment process will be bypassed and the person will plunge straight into developing their fast-twitch fatiguable white muscle fibres.

The crucial question for anyone considering exercise is how to avoid the mobilisation of the white fibres by the motor cortex and allow the natural mobilisation pattern to occur. Walter Carrington, who began working with Alexander in the 1930s, wrote a paper analysing Magnus' work in the light of what Alexander had discovered. After another fifty years of experience of the workings of the Technique, Carrington agreed to the republication of this same paper in 1994, affirming his continuing belief in the correctness of his original analysis.

In this paper, he provides probably the most succinct summary of Alexander's work that has yet been produced. Carrington is here referring to the subcortical postural control systems in the brainstem, what he calls the integrating mechanisms, and says of Alexander's discovery:

The essence of his discovery is that by means of a certain manner of employment of the different parts of the organism which are susceptible to voluntary control, it is possible to eliminate interference with the functioning of the integrating mechanisms and thus restore normality. The whole basis of Mr Alexander's technique is the teaching of how to eliminate interference with the autonomic functioning of the organism.[68]

Avoiding interference with what nowadays might be described as the optimum recruitment pattern for the red and white muscle fibres, is not a simple matter but is the fundamental task which Alexander Technique teachers set out to achieve in themselves and their pupils. Habit and that most pernicious of slogans "*No gain without pain*", make it difficult for people to accept that stopping doing the wrong thing is an essential precursor to allowing the right thing, in this case, the proper order of recruitment of the muscle fibres, to take place. The unfortunate fact for many

[67] Magnus (1925)p653

[68] Carrington (1994)p52

people is that it is extremely difficult for someone who is not properly aware of the issues to avoid worsening rather ameliorating their muscular and postural problems by means of exercise.

In conclusion

This paper has attempted to produce a broad overview of the present medical and neuroscientific consensus on the effects of exercise and training on the muscles. It is a background briefing aimed at anyone interested in exploring these issues, especially in relation to health or fitness programmes they may be considering for themselves or others.

Certain facts are not in dispute. Muscles which are not used shrink and weaken. No one seriously doubts the fact that healthy living needs regular exercise. The practical question for ordinary people is what kind of exercise and how much of it should they be taking. There is no lack of advice on these questions from a multitude of sources, much of it involving substantial expenditures of time and money. The underlying facts set out here are intended to help people make an informed personal choice.

The first point is to be clear about what exactly one wants to achieve and to be aware of the price one has to pay for it. To be a top-class athlete, one needs to train at a level of intensity far beyond that which ordinary people find acceptable. Those who choose the speed and strength events which require intense development of the white muscle fibres are likely to find they are substantially less fit for ordinary life and may well suffer significant health problems.

For those who do not aim at athletic fame or fortune, moderate regular exercise will provide the maximum health benefits. But here, again, the type of exercise matters. The more specific and strength-oriented the activity, the more the specificity of exercise principle applies, and the less the general health benefits. Intense training in lifting heavy weights with one's legs makes one considerable better at doing precisely that but has few, if any, general health benefits and is quite likely to impair one's ability to sit an office chair without getting backache or a stiff neck.

In all cases, it important to ensure that muscle fibre recruitment takes place in the optimum manner. Apart from short-term emergencies this means bringing the red fibres into play first and only recruiting the intermediate and white fibres intermittently and as they are required. Stiffening, tightening, gritting the teeth, being determined, and the various mantras with which the goal-oriented, motivate and prepare themselves for exercise in the hope of gaining fitness and health are likely to be totally counterproductive.

In the gym, or before the exercise class, a few moments ensuring that one has released all unnecessary muscular tension before plunging into action provides some chance of getting the muscular system into action in a beneficial manner. The most important preparation for any kind of exercise is to stop and ensure that one's intelligence and critical faculties are properly engaged.

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Acknowledgements

This paper is based on talks given at the Constructive Teaching Centre in London. Grateful thanks are due to Kri Ackers and Tanya Shoop for their very helpful comments on a previous draft.

17 February 2008

E-mail: Alexander@gfoley.demon.co.uk