MUSCULAR ELECTROSTIMULATION in SPORT and TECHNOLOGICAL ADVANCES

Introduction

Electrostimulation (ES) is no different to any other sports-related activity when it comes to the impact of recent technological advances and the more scientific approach now being taken to training. Both have radically changed our perception of this technique, and without the considerable scientific and technological advances we have seen, electrostimulation (ES) would not be available to the world of sport today.

The fundamentals governing the stimulation of nerve and muscle cells by electrical impulses have been known since the beginning of the last century. These laws were discovered and fully understood by eminent French physiologists like Lapicque and Weiss (1, 2). Through a series of remarkable experiments, they succeeded in calculating a mathematical correlation between the quantity of current and duration of application required to stimulate motor nerves. More recently, the work of Hill (3) has enabled an even better understanding of the processes involved. But the resources available at that time and the enormous size of electrical laboratory required meant that even obtaining a weak muscular response caused severe pain and burns. Today, with equipment no bigger than a large calculator, we can concentrate all the power of a bodybuilding gymnasium to express ourselves as we wish. As we will see later in this document, today's ES offers some very special additional benefits over and above those delivered by traditional muscle building training exercises.

However, no one is suggesting that active training no longer has a place, but neither is it an alternative to muscular stimulation. On the contrary ES is a complementary muscle working technique! Used as part of a sports preparation program, it can enhance the quality and performance of the overall training program. This is not based on choosing one technique in preference to another, but rather on methodology-based sequencing of the different training techniques to exploit their distinct and individual benefits. In this context, the benefits delivered by muscular stimulation can be substantial.

The results of advances in electronics

The first attempts at using ES in training were made at the Moscow Academy of Sports Science in the 1960s, directed by Professor Kotz. The results proved very encouraging, although they do look rather optimistic today. Rather than the 35% gain in strength then claimed to result from just three weeks of training, the real benefit (unless the circumstances are exceptional) was much more likely in the range of 5% to 15%, although this is still a remarkable achievement. The problem in Kotz's day was that the stimulation applied was quite uncomfortable and athletes found themselves subjected to something approaching torture sessions. If things had remained that uncomfortable, it seems unlikely that ES would ever have developed into an accepted sporting practice. As late as 1979, the physiologist, McDonnell (4), who had conducted a lot of research into the mechanisms that limit muscular performance, still thought of ES in these terms: "it cannot be used because of the very high voltages required and the impossibility of creating tetanic contractions".

The progress made in electronics, especially with the arrival of microprocessors, changed this situation radically. It became possible to be protected against the risk of burning and eliminate electrical pain, provided that the ES was applied using high quality equipment rather than some of the outlandish devices that seem better suited for creating aesthetic illusions than training muscle.

How exactly do electronics provide the type of stimulation that can be effective in increasing sporting performance? To understand this fundamental aspect of how stimulation works, we must first address the basic principles involved. In contrast to what many people thought for a long time (and which some of those involved in electrotherapy still teach) there is no magic current! Electricity has no particular innate ability to improve the condition of living tissue, especially muscle! All electricity can do is trigger the natural process of nerve stimulation to which the muscle fibers respond mechanically by doing a unit of work. ES is therefore just a means of imposing work on muscle fibers, which will, in turn, develop as a result of that work. But the fact is (and this is where the problem lies) that if it only makes a small percentage of muscle fibers do that work, we cannot expect to see that muscle progress significantly. Only working fibers will grow! The point is therefore to use ES to work the maximum number of fibers, i.e. as deeply into the muscle as possible. If only the surface fibers are worked, then the results obtained will also be fairly superficial. The basic problem of electrostimulation is therefore trying to work the maximum number of muscle fibers! In practical terms, thorough fiber stimulation means using powerful equipment whose current can be increased to maximize the number of fibers reached. But increased electrical current also means the risk of pain and burning. So the challenge was to exploit electronics to develop current pulses that were not only powerful and comfortable, but also risk-free. All of which is a long way away from the many gadgets seen on home shopping TV channels. Using technology very similar to that used by the best mobile phone systems and today's high quality electronic components, we can now generate the "optimum" electrical pulse. This pulse delivers maximum effectiveness (fulfilling Lapicque and Weiss's fundamental laws on excitation) with maximum safety and comfort for the patient (by minimizing the number of electrical parameters contained in the pulse). This optimum pulse is now available to work the maximum number of muscle fibers, so the limitation on ES is no longer electrical pain, but the sensation produced by the power of contraction.

With a genuine ES system, the user is aware of a growing feeling of tension in the muscle even before sensing the electricity. This contraction force rises with the current until the maximum number of muscle fibers is activated. Although few training or bodybuilding specialists seem to be aware of the fact, it is possible, under certain stimulation conditions, to achieve a degree of contraction approaching or (in some instances exceeding) maximum isometric voluntary strength! The stimulation conditions are therefore fundamental to the effect. Strong training programs must be followed; programs that allow a sufficiently long period of tetanic contraction. High quality electrodes must also be used at precisely defined motor points and the sportsperson concerned must be trained in the technique to a point where he or she can tolerate the sharp rise in current. Since the mid-1980s, it has been possible to identify central neurological fatigue by measuring the difference between the subject's maximum voluntary contractions and the high levels achievable by ES (5). This aspect of activating the maximum number of fibers using ES can also be used as a test to identify overtraining. Frischknecht (5a) of the London Institute of Physiology has demonstrated that using ES on the muscles of overtrained athletes can activate more fibers and produce greater strength than it was possible for those athletes to achieve by voluntary contraction, thus demonstrating the central neurological component as an essential factor in performance reduction as a result of overtraining.

It is therefore the progress made in electronics that has enabled ES to go beyond being a superficial treatment to provide a means of working muscle fibers much more thoroughly. Without this essential progress, ES could be of no practical use in sports preparation, but that progress alone would not have been sufficient for ES to become such an essential training technique. Other scientific advances were needed to control this technique and to understand how it could be applied to enhance performance.

The results of advances in muscular physiology

Although the ability to use advances in electronics to impose work by stimulating the maximum number of muscle fibers is a vital part of the equation, it teaches us nothing about the nature of the work itself. Walking a dog involves a certain element of muscular work, as does an interval training session, but it is clear that the nature of the work done in these two activities is very different. In the first example, the muscular work involved is not the kind that will improve the performance of an athlete, but the second example, if repeated often enough, can result in improved performance. So, working the maximum number of muscle fibers by means of stimulation is clearly of interest only if we can control the nature and quantity of that work in such a way that it enhances a particular type of muscular performance.

Much recent research work, such as that done by Lieber (6), shows, predictably perhaps, that where identical quantities of the same work are done, the outcome for the muscle is the same regardless of whether that work is done voluntarily or by using ES. As muscle fibers are unconscious, they have no awareness of the source imposing the work, so whether the action potential is sent directly from the brain or applied by the stimulation equipment, the fibers progress in exactly the same way as long as work done is identical in quantity and quality. Given these conditions, it became vital to gather sufficient knowledge about the physiology of muscle contraction and the work done by different types of muscle fiber so that electrical pulses could be programmed to apply a quantity and rate of work appropriate to performance of the muscle to be improved.

This brings us to the problem of programming of the stimulation parameters that will enable the equipment to impose a range of work rates. This programming must be based on the most up-to-date physiological data. Bear in mind that there are two main types of muscle fiber: slow fibers and fast fibers. These two fiber types are differentiated by a series of morphological and functional differences. Slow fibers contract slowly using little force, but are highly resistant to effort, i.e. they do not tire quickly and are therefore capable of working for longer periods. Unlike slow fibers, fast fibers contract quickly and with great force, but tire quickly. Slow fibers are those that deliver endurance, while fast fibers are what we use for strength and speed. We know the precise tetanization frequencies for slow and fast fibers. Slow fibers tetanize at approximately 35 excitations per second (35 Hz), while the figure for fast fibers is approximately 70 Hz. This data can therefore be used to help determine the frequencies at which we must program our electrical pulses to tetanize fast fibers to their maximum, thus creating force stimulation (for example).

The discovery of many other fiber variants in addition to these two main types (slow and fast) has meant that we have been able to improve our stimulation programs considerably and develop different levels of strength, explosive strength, endurance and resistance programs. We can now identify no fewer than eight types of fiber: I, IIA, IIB, IIAB, IIC, IID, IIM and IIα. All of these fiber types have different characteristics and perform in different ways. For example, one type of IIM fiber is found in particularly strong, fast muscles, like the jaws of primates (7). The tetanization frequencies of these fibers are even higher than those of other fast fibers, allowing them to work at very high speeds, rather like the ocular muscles that move our eyes so quickly. These fibers, with their very high strength and speed, are responsible for what we commonly refer to as explosive strength. They are likely to be found in the quadriceps of the "supermen" capable of running a hundred meters in under ten seconds. It is also possible to measure the muscle fiber action potential conduction speeds in these athletes; speeds which correspond to the tetanization frequencies for these very fast fibers, which is why the stimulation programs now being used so successfully by most of today's top skiers and Italian soccer players are based on these frequencies. The benefits ES can deliver for this type of athlete are being seen much more clearly now that these new so-called "explosive strength" programs are in use.

So, the progress made in muscular contraction physiology has helped us understand how to program stimulation parameters in such a way that they can impose different work rates to match the type of performance required: resistance, endurance, strength, explosive strength, etc.

The results of recent medical and biological research

The progress made in electronics and muscular physiology means we are now able to use stimulation to impose a pre-defined work rate on a maximum number of fibers, thus solving the problems surrounding the quantity and quality of work imposed by stimulation. Nevertheless, we have yet to progress beyond the precise similarity between voluntary contractions and electronically-induced contractions and the fact that when the nature and quantity of work done is the same, the effect on the muscle is identical. Would it be possible that there were other stimulation-specific benefits that could deliver special advantages to those using this training technique?

In fact, such special advantages do exist and can be very considerable. The fact that work done under ES imposes no cardiovascular strain or mental fatigue means that we can use this technique to increase the muscle training load without imposing general and/or mental fatigue. This in turn means that we can do more training of higher quality, which is where some other recent discoveries come into play.

It is pretty well true to say that in endurance training, the aim is to increase oxidative capacity or maximize oxygen consumption. This depends both on the quantity of oxygen delivered to the muscles (as a result of cardiac flow and blood oxygen concentration) and on the ability of the muscle to use that oxygen. Voluntary endurance training develops both of these, increasing cardiac flow and the oxidative enzymes found in muscle tissue. We have observed that cardiology patients suffering from cardiac decompensation (a lack of heart function resulting in reduced blood flow) are severely limited in terms of strength as a result of the poor capability of their muscles to absorb the oxygen carried by the blood. It therefore seems reasonable to assume that the oxygen consumption limit in endurance athletes is connected more closely to the oxidative abilities of muscle fibers than to cardiac flow. Furthermore, the oxidative abilities of muscle fibers experimentally transformed into slow fibers by stimulation are double that of the best endurance athletes (7a), thus demonstrating that stimulation holds out the prospect of considerable improvements in endurance. This ability to use stimulation to transform fibers into slow fibers with very high oxidative properties is used medically to transform small pieces of thigh muscle for use as sphincters (i.e. muscles required to work continually) in incontinent patients. The same process can be used to transform latissimus dorsi or pectoralis major muscle into fibers every bit as resistant as those found in the heart and therefore capable of contracting and providing permanent support for patients with heart problems.

ES also offers the benefit of enabling activation or preferential use of fast fibers (8). Athletes looking to increase their strength and speed have to work with very heavy weights and use contractions involving over 80% of their maximum strength. In fact, fast fibers are the last to be called upon in voluntary contractions, which begin with slow fibers, the fast fibers only coming into play as the contraction approaches its maximum. Thus athletes looking to increase their strength have to train using extremely heavy weights, a process that imposes significant stresses on the joint and cardiovascular system. It also exhausts the user physically and mentally and exposes him or her to the risk of muscular or osteo-articular damage. Just think how many people have wrecked their lumbar vertebrae by doing squats with enormous weights! With ES, fibers are activated from the surface right through to the depths of the muscle rather than according to the nature of the fibers involved. So even when ES is used to stimulate a contraction at only 50% of maximum strength, some fast fibers are already busy working, which would not be the case if the contraction were voluntary. ES therefore avoids the risks linked to using very heavy weights, as well as working more fast fibers than would be activated in a voluntary contraction of the same intensity.

Another special property of ES is that it enables the muscle fibers to be trained at an operating rate normally attained only in competition. Muscle fatigue during effort, which is defined as a decrease in the maximum power of contraction (power in terms of quantity of work done per unit of time), is linked partly to a central or neurological component (central fatigue) and partly to a peripheral component (muscle fatigue). The central component accounts for 40% of fatigue, and the peripheral component, 60%. Mental stress linked to competition and the athlete’s motivation to win significantly influences the central component, but has no effect on the peripheral component. So, during the competition, the central component of fatigue is reduced so that the motor neurons discharge their excitations to the muscle fibers in a more sustained way than is the case during training. The fibers are then incapable of complying with such requests from the nervous system because they are never called upon to function at such levels during training. ES enables muscle fibers to work at a higher rate (and therefore at higher motor neuron discharge frequencies) than an athlete could normally manage when training. So, when training with the use of appropriate ES, stress will reduce the central fatigue experienced during competition, because performance will have been improved by preparing muscle fibers through training them at the same work rate as that demanded during the competition. The result will be that they win more competitive events because their central fatigue and peripheral fatigue levels have been improved.

We have known for some time now that explosive strength is one aspect of sports performance that can be specifically improved by ES. During an explosive movement like jumping or throwing, the motor neurons begin by discharging to the muscle fibers at high frequencies of 80 to 100 Hertz. This level of activation is maintained for a very short time (less than one second) and the discharge rate of these motor neurons decrease very quickly even if the competitor maintains maximum muscle contraction. So, whatever form of voluntary training is used, the duration for which muscle fibers can be trained at high activation levels is short. When using ES, the programmed frequency continues to impose high activity levels on the fibers for as long as the contractions last and are repeated. ES can therefore deliver rapid improvements in explosive strength, because muscle fibers are trained at higher activity levels for extremely longer periods than could be achieved with voluntary training.

The results of new training and recovery concepts

Strengthening muscles without harmful hypertrophic effects to the cardiac wall.

In recent years, cyclists have been paying increasing attention to quadriceps strength. Improving performance is partly linked to the awareness that it is not only miles and VO_2max that count, but that quadriceps power and resistance are also fundamental issues. We only need to look at the powerful starts and accelerations seen in today's races, both in the mountains and on the flat. Gone are the days of maintaining constant speed: it's the more "beefy" quadriceps that finish first, because they start more strongly. It is conditions like these that have made muscle building exercise fundamental to boosting quadriceps strength throughout the year, not just in the winter months. However, traditional weight training exercises can, in addition to back pain, cause two serious problems for cyclists. The first is the tendency of these exercises to add to general fatigue and the second is to produce cardiac wall hypertrophies (also seen in weightlifters), which reduce the cardiac output and therefore blood flow, both of which are very important for cyclists. This second point explains why some cyclists notice a decrease in their cycling performance as a result of too much weight training in the gym. This is why the very top cyclists are replacing traditional exercises with ES. In today's professional cycle sport, training means using the bike to train the heart and improve technique, while working the muscles using high quality ES and appropriate programs.

Fewer injuries, less fatigue and improved technique

Now top-class Nordic skiers train with ES and the technique has transformed the training schedule. Those competing in this sport need to maximize their strength and explosive strength and did so by using enormous weights to do traditional weight training, with all the potential for serious injury, physical fatigue and mental fatigue that is involved. Fatigue placed a limit on the total time they could train, as well as limiting the time they could spend actually skiing. Today's Nordic ski training replaces traditional weight training exercises with ES, thus reducing fatigue and freeing up more time to improve ski technique. ES allows skiers to do more muscle development on their quadriceps (in terms of both quantity and quality), as well as giving them more time to concentrate on their technique.

Other sports are now moving in this direction. Italian volleyball players used to undergo punishing plyometric and weight training sessions involving heavy weights, but this has now been reduced by ES training. The result has been fewer injuries, and, thanks to the special advantages delivered by ES and described above, these Italian teams are now fielding smaller players able to jump 43 inches vertically.

The trend is also spreading to soccer, where ES offers considerable advantages for sportsplayers whose articular cartilages are already under siege.

Increasing medical and sports research is demonstrating the improvements in performance offered by ES (provided it is used seriously and using professional equipment). Sports that normally place less emphasis on weight training – swimming, for example – are also starting to investigate this technique now that research has shown how valuable it can be in improving swimmers' performance (11).

Recovery

Finally – and you've certainly earned it! – we will look at the issue of recovery. The use of a special ES recovery process is becoming increasingly widespread, because its effects are so remarkable and because the problem of recovery after competition or intense training has become such a vital issue for competitors. More often than not, it is experiencing this special application of ES that introduces sportspeople to the wider benefits of the technique. Once convinced of the benefits in recovery, they tend to move on to using it as a training technique in its own right.

Using Compex Sport active recovery consists of a single 20-minute ES session. The session begins by stimulating the muscles at a low frequency of between 9 and 10 Hz and decreases progressively and automatically every two minutes until it reaches the very low frequency of 1 Hz. This applies a very specific level of activity to the muscle fibers, which helps them recover more efficiently and reduces cramps to a minimum. As the frequency falls, the pulses automatically increase in amplitude to penetrate the muscle fibers more deeply and more thoroughly.

In direct contrast to jogging back to rest the day of competition or hard training (interval training, CAL work, etc.), this technique does not impose an increase in general and cardiovascular fatigue. Neither does it demand mental effort or impose great osteo-tendinous stresses.

Muscle fatigue is caused by the accumulation of lactic acid (12 and 13). Processes that speed up the elimination of lactic acid therefore improve muscle recovery (14). We know that lactic acid elimination is significantly accelerated by intense aerobic physical activity at around 30% to 60% of VO_2max (15 and 16) (but below the anaerobic threshold in any event!). The ideal way of eliminating lactic acid seems to be a level of activity that begins at 60% of VO_2max and reduces slowly to 30%. Within 30 minutes of ending approximately 10 minutes of VMA activity, blood lactic acid concentration of 11mlMole/l) falls to 3.5 after complete rest, to 2 after constant activity at 35% of VO_2max and to 1.2 (the normal resting rate) after activity while decreasing the work rate from 60% to 30% of VO_2max (17).

Active ES recovery using Compex Sport offers the added advantage of reducing the intensity of activity. The first few minutes of stimulation (at 9 Hz) impose muscle fiber activity at a relatively high percentage of VO_2max, a level that reduces progressively with the frequency (18). So, in terms of lactate reduction rate, this technique follows the ideal active aerobic recovery protocol, but with none of the potential problems of increased mental, general cardiovascular and osteo-tendinous fatigue.

The increased blood flow in specific tissues and muscles means faster recovery of cell function and balance, especially in terms of the interstitial fluid. As blood flow increases, the toxin elimination (intracellular H+) rate accelerates and the ionic balance (extracellular K+) and glycogen reserves are regained faster. The water, mineral salts and carbohydrates delivered by food will further aid recovery.

It has been successfully demonstrated that high quality ES definitely increases arterial blood flow in muscle masses subjected to stimulation (19). This increase in arterial flow is considerable with the rate being four times that of the body at rest, but with the great advantage that this is obtained with no increase in heart rate or arterial pressure, i.e. with no added general fatigue. The frequency delivering the maximum increase is 8 Hz (10). Furthermore, the venous return blood flow rate is also increased by the same factor as the arterial flow, thus delivering the genuine venous drainage that is so effective against the sensation of heavy legs. It is also believed that the mechanical effect of the successive muscular spasms applying pressure to the vascular structures (the pump effect) improves lymphatic drainage.

Our central nervous system naturally produces varying quantities of peptides, which have the ability to use the same receptor sites as morphine. These peptides can therefore deliver pain relief (the analgesic effect), as well as general muscle relaxation and reduced anxiety. These natural substances are called endorphins and encephalins and it has been known for several years that production of both substances can be increased by a variety of stimuli, but especially by electrical pulses (20, 21 and 22). The analgesic effect is most pronounced at a pulse frequency of 5 Hz (23).

The increased production of endorphins creates an analgesic effect and general muscle relaxation. In addition to this general relaxation, stimulation at the lowest frequencies (from 3 to 1 Hz) produces a local relaxation effect in the muscle masses directly subjected to stimulation. ES has been used medically for some years to modify muscle tone (24). This local relaxing or “tonolytic” effect is maintained for several hours after stimulation and enables better control of the movements made using these muscles (25). Results obtained empirically show that the maximum relaxation effect on healthy muscles after intense work is delivered at very low frequencies of 1 to 3 Hz (26 and 27).

So, after eliminating lactic acid (at 9-10 Hz) and increasing blood flow (at 8 Hz), the progressive decrease in frequency will cause the active recovery session to produce the “endorphin” effect (at 5 Hz), thus eliminating all pain. The local relaxation effect is then obtained during the last few minutes of the session by use of the lowest frequencies. The muscle is then perfectly relaxed and ready to work again.

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