ElectroMyoStimulation
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Introduction to EMS by Susan Breister

Electrical muscle stimulation (EMS) is the application of electrical current to elicit a muscle contraction. Contraction of the muscle with EMS is different than the typical or voluntary contraction of the muscle that is initiated by the central nervous system, (i.e. weight lifting). The nature and quantity of this work depend on the parameters programmed in the electrical stimulator device. Put simply, the EMS device can do what the brain is incapable of doing. While the brain is capable of stimulating a majority of muscle fibers, an EMS device can stimulate up to 100% of the muscle fibers (thus producing greater synchronization among fibers). Furthermore, unlike the human brain, an EMS device can deliver consistent and high quality impulses to the working muscles without inducing cardiovascular and psychological fatigue. This yields better and safer muscle performance results compared to voluntary training alone.

The basic tool to make the muscles work is the electrical pulse. This stimulus is delivered from the EMS device to the muscle via the nerve fibers or the motor-neurons. The role of the pulse is to cause a response of the muscle by converting the nerve impulses into a muscular mechanical activity. This mechanical (basic muscular) response is called a “twitch”. Each time the electrical pulse is repeated, the excitation (or the initiation of the twitch) of the muscle occurs and the muscle twitch is repeated again. When muscles are stimulated with frequent impulses, the muscle fiber reaches the point of contraction when each twitch (basic response) has no time to end before the following excitation. Therefore, the muscle reacts with a constant contraction. This phenomenon is called tetanization and it is due to the summation of the basic responses. As the frequency (number of stimulations per second) of stimulation impulses increases, each individual twitch becomes less pronounced, up to the point of reaching contraction, and that is when the appearance of muscle contraction becomes smooth.

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1 It is different in regard to its source. Excitation of the motor neuron (action potential) that is initiated by the nervous system or by an electrical impulse is always exactly the same, i.e., the law of “all of nothing,” and each excitation induces the same basic mechanical response of the muscle. Therefore, for the muscle, its work is similar, whether initiated by the nervous system or by EMS (for a same level of activation, of course). In effect, muscle has no consciousness; it is unable to differentiate if the excitation has been initiated by the nervous system or by EMS. In this regard, voluntary, muscle work is induced by the nervous system: brain → spinal chord → motor nerve → muscle. EMS eliminates this process by exciting the motor nerve in order to impose work by the muscle.
The quality and quantity of the muscle work will depend on the programmed parameters and the intensity used. (Proper electrode placement also is a factor). These preprogrammed parameters are:

- The Electrical Pulse which triggers the excitation of the motor neuron.
- Pulse Frequency or Rate in Hertz (the number of pulses delivered in a second)
- Duration of Contraction (the measure of time that the muscle contraction is maintained)
- Duration of Rest (the rest time between the contractions)
- Number of Repetitions (the number of times the muscle contraction-rest cycle is repeated)

The intensity (measured in milliamps or mAmp) is not preprogrammed, but is increased manually while the EMS device is on. The number of muscle fibers recruited that do the programmed work depend on the intensity of the device. If the stimulation is applied with a significant/high intensity level, a larger percentage or number of muscle fibers will be recruited/trained. Only the fibers recruited by the EMS will be worked and make progress. Contrary, low current intensity would result in very few muscle fibers being recruited, thus resulting in less progress.

These impulses are transmitted from the EMS device to the skin via electrodes. Electrodes are pre-gelled pads to which the lead-wires to the device are attached. They are able to conduct the electrical current to the skin and motor nerve below. When electrodes are placed on the skin and the intensity on the unit is turned on, the stimulation is transmitted to the muscle and by way of the motor nerve. Electrical current flows through the tissue between the electrodes, with consideration given to proper electrode size, placement, and quality of the current. This will allow one to better reach the goal of increased intensity level for the best training effect on the muscle.

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An Overview of EMS

Electromyostimulation (EMS), also called electrostimulation (ES) or even eStim, terms that will be used interchangeably throughout this report, refers to the non-voluntary contraction of the muscle by way of (or induced by) electrical impulses. The potential value and effect of EMS is obvious when one considers that voluntary muscular activation is governed by the central nervous system (CNS), which sends signals via electrical impulses through the nerves to command the muscles to contract. Similarly, EMS causes the muscle to contract by stimulating directly the motor nerves, but while bypassing signals from the brain. In effect, EMS produces a conditioning effect on the muscles based on the electrical stimulation that induces muscular contraction.

An important consideration with EMS is that motivation and voluntary effort become irrelevant since EMS-based contractions are involuntary. This means that no matter an individual’s frame of mind, the magnitude and extent of contraction is self-regulated. However, an individual undergoing EMS still must be motivated to tolerate sufficient EMS to “overload” the muscles to produce change. For rehabilitation purposes or to slow the effects of atrophy, EMS does not have to be that demanding (although steadily increasing to overload the muscle). More serious fitness

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2 The discomfort factor may sound like a negative selling point, but it must be realized that this is no different than productive exercise as a whole, in that a person must endure some discomfort in order to realize significant change in physiological function. Nonetheless, do not be mislead to think that EMS is very uncomfortable – only different and strange in sensation until one is used to it. Unfortunately, older EMS systems are not of the same quality as the Compex Sport system used at the I.A.R.T. Fitness Logistics center, and EMS as a whole has received a bad rap as a result. Compex uses an alternating current with an electronic pulse described as Symmetrical BiPhasic (a square or rectangular wave). This means that the electrical signal is compensated equally so that the user does not experience the intense stinging pain associated with other types of electrical delivery EMS systems (particularly those used in older research). Some medical (prescriptive) EMS devices use this more “comfortable” wave form, but only Compex uses this technology within the exercise and sport industry.
enthusiasts and athletes have greater tolerance for EMS, and it usually will take only a few sessions to become used to the prickly sensation. Experienced trainees are more capable of tolerating EMS sensation since they are accustomed to the efforts of productive resistance training and the goal to do well. (Furthermore, the higher a person’s fat level, the higher the current needs to be since fat cells would act as an insulating barrier between the EMS current and the motor units (MUs) of the muscles.)

If one were to investigate the various studies that involved EMS it would be discovered that some studies show nearly no difference with EMS, whereas others show a marked difference of up to 40% improvement in isometric strength and peak force output3. The differences likely have much to do with the application of EMS, the specifics of frequency and stimulation, motivation to endure increasingly higher EMS currents, and whether individuals were elite athletes or sedentary case subjects.

Further, comparison of studies and formulating valid conclusions concerning EMS use is difficult at this time because of inadequate standardization of experimental procedures reported, such as an experimental group training with EMS in addition to other forms of exercise, a group receiving EMS superimposed on voluntary contractions, or a group receiving EMS as the only method of exercise.4 Also consider the modes of stimulation (frequency, intensity of EMS current, pulse duration), differences in training protocols (number and duration of the sessions), methods in testing procedures, and the muscle groups studied; all of which exist among dozens of studies.

As will be discussed later, we have had very positive results with EMS integration, although based on specific applications that seem to differ from many of the studies conducted in the field. In general, we have noticed changes in force output and physical appearance. We will not quantify the extent to which there were changes in muscle mass, since hydration and glycogen concentrations in the muscle can make such quantification or measurement difficult. Suffice it to say that there were visual differences (full and harder looking muscles) as a consequence of fewer exercise sets coupled with EMS. The ‘harder’ appearance of the muscles is an unexplainable effect, but one that is reported regularly among bodybuilders who spend several hours a week practicing posing (intense muscular contractions) prior to a competition. Other positive effects we have noted include a superior exercise experience induced by more intense muscular contractions, deeper fatigue, and superior pump.

**Strength & Muscle Gains with EMS**

**Strength Development**

Although EMS has a beneficial effect on muscle hypertrophy, it has a greater effect on strength production, and in some instances, EMS can improve motor control and muscle contractility without affecting hypertrophy5, although that would depend on the application of EMS. Greater strength influence may be the result of a more direct stimulation of Type IIb fibers, which are stimulated most since EMS is superficial (the current is applied extracellularly to the nerve endings) and Type II are located mostly toward the surface of the muscle. This means a very short distance between the EMS electrode and the Type IIb innervation. Conversely, Type I fibers lie deeper toward the bone and are not as susceptible to EMS stimulation. (On a related note, one study has suggested that Type IIb fibers recruit preferentially during eccentric movement.6 This may be the reason why negative-based exercise, if not abused, has a greater effect on strength development, as suggested by Arthur Jones and his experience in working with advanced bodybuilders.

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Analogously, the preferential effect on Type IIb fibers may be why EMS works so well to help develop strength and power output of the muscles.

There are other reasons why Type IIb fibers result in preferential recruitment during EMS. The diameter of motor axons has an influence, whereby large units have lower excitability but are more sensitive to demanding conditions. The sudden impulse of EMS current also contributes to this excitation, particularly if the current is sufficiently high. A third factor involves the reflexes of the muscles to their environment. Cutaneous EMS electrodes seem to inhibit small motor units while exiting the larger motor units, likely because of the sudden and intense impulse induced by EMS. This does not mean that Type I fibers will not contract, but are less preferred to contract. However, this would depend on the intensity of the EMS current since a setting of “low” mAmp current may not be sufficient to excite large motorneurons.

Further note that during voluntary work, muscle fiber recruitment occurs through varying the number of motor units activated (spatial recruitment) and/or the force generated by a given motor unit (rate coding), by altering the discharge frequency of the innervating α-motoneuron. In other words, during voluntary training the discharge frequency of motor units is modulated throughout the contraction. And depending on the leverage of the body parts to complete a task, and the changes in leverage throughout a full range of motion, different amounts of fibers will work at given times, and even different amounts of fibers in different areas of the muscle. This does not occur during EMS (at a constant frequency). With EMS this physiologic recruitment system is disrupted and, instead, all motoneurons in the area of EMS current flow are depolarized (i.e., there is a reduced difference in electrical potential), regardless of fiber diameter. This suggests that although there is a preference for Type IIb fibers to contract, Type I and IIa fibers certainly contract as well.

A mistake that may be made with this information is the view that sudden bursts of movement (with resistance) are ideal for maximizing muscular strength/force since there is a preference to activate Type IIb fibers. However, maximum force test results show that voluntary contraction is more effective at low speeds. Also, the amount of Type IIb activation determines the rate of force production. In this regard, rapid, explosive movement often does not allow for maximal muscle contraction, even when using resistance since the extreme forces experienced at the beginning of an exercise (to initiate movement) increases momentum significantly so that far less muscle tension is experienced throughout the remainder of the ROM.

There can be changes in muscle contractile characteristics from heavy explosive training, i.e., one becomes more proficient at explosive weight training. Yet there is greater risk of injury when training in this manner, and there is little evidence that the specificity of explosive weight training has any bearing (positive influence and carry-over) to non-specific motor patterns of athletic activities outside weight training.

What EMS can do is to assist in increasing muscular contraction speed to increase muscular demands and Type IIb recruitment. This can be done in two ways. Traditional EMS requires that a body part be fixed or restrained while EMS is applied in an isometric environment. However, EMS also can be applied during voluntary exercise, such as the leg press, and at moderate to slow speeds, but while being stimulated by an electrical current that will induce intense, peak muscular contractions within 0.5 seconds. In this manner, concentric movement begins once EMS kicks in, and as EMS sustains for three or more seconds, the trainee proceeds to full contraction (this method of EMS application will be discussed later).

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7 It then may be speculated that the more Type IIb fibers in a muscle, the greater the contraction (force produced) based on a certain mAmp setting. Relatively speaking, the fewer the Type IIb fibers in a muscle, the higher the EMS settings need to be to equal the same degree of contraction (and possibly gains) with all other factors remaining equal.


9 Torostowski, J. et al. *Influence of electrostimulation on human quadriceps femoris muscle and muscle mass.*
Explosivity (contraction speed) is the time required for the muscle to reach its maximal force output. Explosive movements (jumps, throws) are elicited with a very high discharge frequency from the brain. However, such bursts can be sustained only for very brief periods (few ms) and will induce a quick central fatigue and, therefore, only allows small quantities of training. EMS allows the muscles to sustain larger quantities of explosive training, with high frequency stimulation that can be sustained for longer duration (3s) when compared to voluntary work alone.

Further, when using EMS, it is understood that isometric force gains are greatest at angles as muscles approach full contraction\textsuperscript{10}, which makes sense considering the contractile effect of EMS and the greater number of activated fibers in that position. However, placing a muscle in the shortest position (toward full contraction) while under the influence of EMS can result in spasms. For this reason, muscles are placed either in a stretched or “midway” position when applied as an independent means of muscle conditioning. Further, considering that the greatest strength gains are toward full contraction, whether speaking of EMS or traditional strength training, it may be wise that voluntary exercise focus more on weak range training at the point of stretch, and whether using EMS as a supplement or included during exercise. Doing so would guarantee a more even strength curve and distribution of force output.

Also, one’s training position and gains in strength are related, similar to isometric training being angle-specific.\textsuperscript{11} For this reason, EMS during full-ROM exercise may be best as opposed to fixing the joint at any particular angle. But if EMS is implemented without exercise and to improve athletic function, i.e., improvement in strength at particular joint angles, fixing joint angles appropriately and where applicable, and applying EMS in a stand-alone environment may be best.

**Muscular Development**

Certainly EMS can and does have an effect on muscle development, whether as treatment of muscular atrophy (to allow for a faster recovery of muscular volume after immobilization or surgery), or for general strength and hypertrophy in healthy individuals. Do not under-estimate EMS’ potential since the stimulus does work muscle fibers sufficiently that Type IIa and IIb will deplete of glycogen\textsuperscript{12} and sufficient fatigue and tissue damage does occur. The extent in which this occurs, as alluded to, depends on the nature of EMS application. In general there is far more muscle fatigue, phosphocreatine uptake and intracellular pH acidity as EMS contractions increase in time and the shorter the rest periods between those EMS contractions. One study compared a series of 10-second EMS contractions followed by 10-second rests to another protocol of 10-second EMS contractions to 50-second rests; each protocol was performed for 12-repetitions total over a number of sessions\textsuperscript{13}. It was demonstrated that the first protocol resulted in about twice the muscle fatigue, four times the phosphocreatine update, and a continual increase in intracellular acidity (whereas the second protocol stabilized in intracellular pH acidity after the first six EMS contractions).

The study concluded that the first protocol would be more ideal for healthy muscle, particularly with an emphasis to develop both strength and muscle, whereas the latter protocol may be more relevant for atrophied or injured muscle (to allow for proper replenishment of energy resources and to reduce fatigue). The latter method also would be effective for strength athletes, such as sprinters, Olympic lifters, or others who focus more on brief and intense bursts of effort while limiting muscle fatigue (so long as there is sufficient rest between 10-second bouts).


\textsuperscript{11} Maffiuletti, N.A., et al. *Electrostimulation and basketball players’ performance*. UFR STAPS, Université de Bourgogne, Dijon Cedex, France. Aristotelian University of Thessaloniki, Hellas. Faculté de Medecine de St. Etienne.


The findings above should come as little surprise since the same holds true with resistance training. If a bodybuilding style of workout was compared to that of a powerlifting or Olympic lifting style of workout, whereas the former utilizes greater glycogen, produces greater fatigue, and involves a more significant muscle pump than the latter two methods, we can see how intensity of contractions, duration (tension time) of sets, and the measure of rest between sets can influence muscle hypertrophy over exercise skill (strength) acquisition.

Further, as stated before, if the focus is on strength and power development, it may be best that EMS be implemented in a stand-alone environment and not while exercising. Certainly strength gains will be produced if employed during exercise, but the I.A.R.T. has not determined if the gains are better if EMS is used on its own – and we have not discovered other scientific investigations to that effect. The point is that there must be sufficient rest between contractions to replenish phosphagen (ATP) and to avoid lactic acid production and other factors that increase fatigue (to keep force production high). If this is not done, then contractions cannot be maintained at maximum levels. It has been suggested that phosphagen replenishment is 50 percent complete in 22 seconds and fully complete after two minutes. The Compex Sport “Strength” mode provides 19-35 second rests between 4-second contractions, whereas the “Power” mode provides 28-34 second rests between 3-second contractions.

Conversely, it is possible still to incorporate EMS in a strength and power environment, such as lifting a weight during the time of contraction and then to rest otherwise. In this manner, a form of rest-pause training is implemented but with more intense and powerful contractions.

**General Application and Cautions**

EMS use must be prescribed as cautiously as any form of exercise. Too much stimulation too often can produce effects more closely linked to endurance and ST characteristics, i.e., overuse atrophy of Type Iib fibers resulting from an adaptation to resist fatigue. Such a change in enzymes, oxidative characteristics may be desired or warranted, just as some trainees incorporate high repetition and set protocols when there needs to be more focus on muscular endurance than on strength and size.

The potential for EMS to induce change in different manners also signifies its limitations in that there is nothing “magical” about EMS, but simply an effective tool to alter physical function. As with traditional strength training, muscles do return to their original state after EMS is terminated and avoided, known as the *detraining effect*. However, and like weight training, the rate at which muscles return to a less functional state appears to be much slower than the rate at which muscles are altered when subjected to stimulation.

The length of each EMS contraction is of consideration. Certainly Type I fibers could sustain a constant contraction for several minutes but this type of protocol may be too uncomfortable for most users. Furthermore, as stated, EMS (if the current is set high enough) tends to prefer Type Iib fibers and lengthy contractions would not be appropriate for reasons of potential overuse atrophy or loss of force production. One study demonstrated that force output began to drop after 8.2 seconds of a constant EMS current, although the extent to which this happens depends on the frequency. The Compex Sport system used at our facility does not exceed 8-second contractions.

However, it is more than the length of the contractions that must be considered in proper EMS prescription, including the intensity of the current (mAmp) and the frequency (Hz), the latter of which refers to the number of (oscillating) fiber contractions per second as the muscle contracts as a whole. It has been suggested that greater amplitudes as training progresses does not necessarily result in greater contractile force and this has been discovered in our own experiments whereby if the intensity or frequency is too great force production actually decreases. This may be the result of both voluntary and involuntary reactions. A very intense EMS current can cause a trainee to resist because of the unusual and non-adapted discomfort (please see 17 : discomfort → sensation) of the EMS and associated force of contraction, and further resistance possibly may be manifested by the CNS as it activates the antagonist muscle, thus resulting in a co-contraction with the agonist. However, it also has been noted that greater amplitudes (within reason) may need to be increased as fatigue sets in order to sustain the contractile forces produced at the beginning of the workout or “set.” In other words, a fitness practitioner could increase EMS current slowly during a set of voluntary exercise and as repetitions progress toward muscular failure or if used in a stand-alone environment. In this former instance, EMS counteracts central fatigue induced by voluntary work.

**Specific Applications**

The uses of EMS far exceed rehabilitation or as a stand-alone method of muscle conditioning, although those two aspects will be discussed here. Some applications we have discovered include the following:

- The most obvious purposes of EMS is to increase force production, whether in healthy or atrophied muscles, and whether used as a stand-alone method or integrated within exercise sessions.
- EMS can be used in instances of overuse injuries, such as tendinitis or sore joints, caused by repetitive strain whereby regular movement results in inflammation and discomfort. I have had this condition in my forearms for several years, although it has improved greatly so long as I avoid certain exercises and apply exercise responsibly. With EMS I have been able to remove wrist curls and reverse wrist curls from my exercise regimen while maintaining forearm strength (dynamometer tested) and muscle mass/girth. It should be evident that those afflicted with certain conditions, including arthritis, would benefit from implementing EMS as a stand-alone method at times of peak inflammation or as an adjunct to regular training to reduce set volume.
- Delay of atrophy for reasons of injury, extensive travel without access to a gym (advanced trainees who want to sustain size), or otherwise are key reasons for using EMS. In rehab settings, EMS is ideal to maximize force production and to stimulate hypertrophy while minimizing fatigue, particularly when nervous function has been compromised as a result of injury. The nerves are activated, and not the muscle fibers directly, which is why there exists far less fatigue than with voluntary contractions – i.e., muscle fibers are far less excitable

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25 Use EMS for rehab and medical purposes at your own risk. In many instances government departments (e.g., FDA) have not approved EMS for rehabilitative or medical use. The examples provided in this section are for information purposes only.
than nerve branches. And since motivation to exercise and move body parts is not a concern, the rehabilitation process will accelerate.

- EMS is useful in the treatment of paralyzed patients and/or the restoration of muscle function before patients are capable of voluntary exercise. In this respect, as well as standard rehabilitation cases, EMS can serve to accelerate muscle re-education.

- Other medical-based purposes for EMS use include the temporary reduction of spasticity, reduction of contractures, and reduction of edema.

- EMS is becoming more popular in sports training to increase strength and muscle, particularly during in-season when too much strength training can affect athletes adversely from excess mental and physical fatigue. As a related aspect, EMS can train muscles explosively without athletes undergoing explosive weight training; and this means a decrease in the risk of injury. In fact, EMS is more effective in this regard since the use of weights slows muscles from exploding as quickly as possible. Athletes then could focus on slow, intense quality of movement during weight training coupled with EMS as a stand-alone system to produce quick, powerful contractions. Several EMS studies (including many quoted in this report) have demonstrated faster muscular contraction rates from EMS alone and with no risk of injury. EMS works well in this capacity since it conditions muscles to contract rapidly and even to sustain the quality of contraction for longer, i.e., consistent and high levels of force production that are not possible when exploding a barbell.

- EMS will increase muscular inroading and local fatigue for a greater muscle building effect and briefer workouts, i.e., the need for fewer sets. This effect means greater muscular stimulation with a reduced loss of energy resources and time spent at the gym. Superior contractions, workouts and muscle inroading is ideal at times when a “blitz” is undertaken, or during a period in which a trainee desires to increase workout demands to accelerate gains, to stimulate a lagging body part, or to break through a plateau. EMS also can be cycled into a training program when a trainee desires to take a layoff from traditional exercise.

- EMS can be used prior to a traditional workout as a means of pre-fatigue, thus enabling the use of lighter weights with similar conditioning results. It also can be used after a traditional workout to produce further muscular work but without having to perform more joint- and tissue-wearing weight-training sets. Furthermore, EMS can be used to train those muscles a person prefers not to exercise, a typical situation with calves, abdominals and forearms, for example.

- EMS is ideal for beginners to learn how to feel muscles, and those muscles that are supposed to be working in an exercise, and to accelerate strength and muscle development as a whole. Fitness practitioners who need to make the best progress possible with their clients (in order to retain those clients) should heed this marketing advice.

35 Maffiuletti, N.A., et al. Electrostimulation and basketball players’ performance. UFR STAPS, Université de Bourgogne, Dijon Cedex, France. Aristotelian University of Thessaloniki, Hellas. Faculté de Medecine de St. Etienne.
• EMS can be applied in different combinations and in different settings. During exercise, for example, eStim can be applied during concentric movement, whereas eccentric movement can occur during eStim rests. EMS would be highly useful during Powerfactor or static hold training, to increase the quality and duration of peak force contractions and progress. EMS also would be very useful in pure-negative training, whereby a weight is lifted and then lowered during eStim. Doing so would allow for the use of greater weights since the contraction produced by eStim would assist negative strength potential. (In this regard, when eStim is of a sufficient level of intensity, trainees would discover that they lift more weight during concentric movement. We have noticed an average of 10-15% increase in lifting ability, although more experienced EMS practitioners have reported upward of 30-35% increases in concentric ability.)

The thighs completely relaxed (top) and under the influence of eStim contractions (bottom) while restrained in a leg extension machine and at a fixed knee joint angle. Notice the depth of muscle separation in this bent-leg position, which is typical of a straight-leg position when the quadriceps are contracted fully. This indicates the degree of muscle fiber recruitment involved in eStim. The “sample” photographs were the result of only Level I and intensity 20 of a possible Level V and intensity 100.
Experimenting at Fitness Logistics Testing and Performance Center

In early January 2004, an advanced trainee performed various isometric pre-tests at various angles in the standing biceps curl, shown as a solid line on the graph below, with the highest force measured at 53.5 pounds (75°) and the lowest force measured at 44.3 pounds (135°). Forces were measured using the Dillon Quantrol AFTI force gauge system (www.cscforce.com). This was followed by a dynamic test using a 37.5-pound dumbbell for exercise, a load determined by taking 80-percent of the weakest position force output. Seconds after the set of biceps curls to muscular failure (that terminated at 65 seconds), the isometric test positions were repeated, shown as a dashed line on the graph. The shaded area between these two tests is the amount of fatigue produced by the exercise, thus exhibiting a loss of strength by about 20 percent at the most noticeable point.

Details behind this testing and the strength curve’s characteristics can be read by downloading the Force Gauge report at http://www.FitnessLogistics.com/articles/products/productreviews.html. Fast forward to March 30, 2004, 9 AM. The same arm was tested at 135-degrees, the same angle that produced the lowest force output at 44.3 pounds when fresh. The objective was to determine the effects of EMS being able to increase muscular force output beyond normal levels.

It must be stated, however, that each successive test followed a previous test, which means some degree of fatigue was encountered, and increasing eStim intensity on each test further resulted in some fatigue. To explain the latter instance, EMS begins at zero on the Compex Sport system. The “Power” setting was selected, being a 3-second burst at the selected setting of stimulation (Level I, 104 Hz contraction frequency) followed by 30-seconds rest. After building up to 50 mAmp (and this will produce a certain level of fatigue in the stimulated muscle), each subsequent test thereafter was proceeded by a 3 second “build-up” burst from 50 mAmp to 60 mAmp. And the same when the current increased from 60 to 70 mAmp for the fourth test. Each 3-second EMS burst was too brief to increase (“rev up”) the mAmp to the appropriate level and, therefore, between each test there was a 3-second increase of EMS that produced a certain measure of fatigue; a measure that is unknown but likely cumulative between tests. The procedure was as follows:

Diagram 5

[Graph showing pre-test and post-test force output with shaded area indicating fatigue between tests.]
1. Set EMS at 30 mAmp to prepare the left biceps for EMS environment.
2. 30-second rest.
3. Perform an isometric test at 135-degrees without EMS (use of an arm-blaster and other body restraining increased isolation and accuracy of force test results).
4. 30-second rest.
5. Increase stimulation to 50 mAmp in preparation for next isometric test at same joint angle (3-second stimulation and fatigue encountered).
6. 30-second rest.
7. Perform an isometric test with EMS at 50 mAmp.
8. 30-second rest.
9. Increase stimulation to 60 mAmp in preparation for next isometric test (3-second stimulation and fatigue encountered).
10. 30-second rest.
11. Perform an isometric test with EMS at 60 mAmp.
12. 30-second rest.
13. Increase stimulation to 70 mAmp in preparation for next isometric test (3-second stimulation and fatigue encountered).
14. 30-second rest.
15. Perform an isometric test with EMS at 70 mAmp.

If we look at each test individually (starting next page), a pattern can be seen. In the first test, with no EMS, a maximum force of 46.6 pounds was produced, a force that developed somewhat slowly to avoid jerking and registering a high amount of force. A maximum amount of force could be sustained for about one second before declining (also, the subject terminated the effort once it was felt that the force began to reduce). The force improved from the 44.3 pounds in the January 2004 test, but only marginally. The slight improvement likely was due to the fact that the subject was not fully restrained (and there is some margin for error in form) and that some rehabilitative measures occurred to help correct the strength deficit at the 135° position as shown in the chart on page 54.

In the second and third tests, the most notable characteristics are the immediate peak in force and the ability to sustain a hard contraction for the duration of the prescribed EMS stimulation (3 seconds in these instances). This can have a definite effect in force development with a different system setting, such as the “resistance” mode on the Compex Sport unit at 7 or 8-second stimulation followed by 7-seconds rest. Using this mode, a person can rest during the rest phase, but also can perform a 7-second negative followed by a 7-second positive/contraction. This method of application will be discussed later.

Test 2, at a 3-second contraction under the influence of 50 mAmp and a frequency of 104 Hz produced a peak of 47.4 pounds. Test 3, at a 3-second contraction under the influence of 60 mAmp and a frequency of 104 Hz produced a peak of 49.9 pounds. Increases in force production were possible despite any fatigue that occurred from one test to the next.

The powerful, yet compact design of the Compex eStim system
Test 1 (no EMS)

Test 2 EMS (50 mAmp)

Test 3 EMS (60 mAmp)
If we look at all three tests superimposed, we can see how Tests 2 and 3 produce a more intense contraction for longer. Also note that Test 3 is a bit more erratic and not as smooth as Test 2 since the eStim was at the “fine line” of being a bit too extreme relative to the subject’s adaptation of eStim during exercise, a factor that will be discussed later.

Another test with the same arm and at the same joint angle was conducted on April 13, 2004, 4 PM. This test occurred a day before biceps training, to ensure fully recovered biceps and minimal pre-fatigue caused by previous test trials. The goal of these tests was to determine the measure of involuntary force produced by eStim. The test below was on the Compex Sport “strength” setting (4-second contraction) at 100 Hz contraction frequency (Level 5). The reader will notice that the level of contractile force rose, dipped slightly and then spiked again. This reaction likely was caused as a protective measure against an intense contraction as the antagonist (triceps) attempted to contract to prevent the agonist (biceps) from exerting too hard. But once the central nervous system (and possibly the subject’s subconscious) determined that the stimulus did not pose a danger, the triceps relaxed to allow the biceps to contract fully.
It could be argued that the Compex setting was too intense, since force output should be a relatively flat line, straight across, rather than a series of peaks and valleys. This is highly evident if we look at the graph below, which contraction duration was at 7-seconds (“resistance” mode) with a frequency of 70 Hz (Level 5). After a 7-second delay, the EMS kicked in at around data point 43 and at 90 mAmp; and was then increased to 100 mAmp within a few seconds, as depicted by the graph’s highest peak at data point 80.

Three things are of interest in this graph. One, the higher the eStim current, the more erratic and less continuous is the muscular contraction quality, although the rate of muscular contraction (frequency) was 30 Hz less than in the graph above. Two, the higher the eStim, the more difficult it is to maintain full muscular contraction. Three, a higher eStim does not mean always that greater muscular force can be produced, as exemplified by the above graph that produced nearly 14-pounds of involuntary force at 70 mAmp, whereas the graph below shows only 8-pounds of force at 100 mAmp.

The reason “more is not better” is important to understand with EMS application is that one must allow for proper adaptation to transpire before increasing eStim. Sometimes a dramatic increase in exercise demands can produce favorable results, but with eStim results can be short-circuited literally. Compex recommends that a trainee spend at least 3-4 weeks on each “level” before progressing to the next level. With our subject, Level 1 and an appropriate (tolerable) eStim was used for about one month, and progressing to Level 5 proved far too extreme for his nervous system.

The influence of using too high a setting can be seen further in a force test that was produced about ten minutes before the involuntary test above. The chart below depicts the force output of a 4-second contraction at 70 mAmp and with a frequency at 100 Hz (Level 5 of the “Strength” setting on the Compex system). The highest peak in force is only 41.9 pounds, less than it was in the previous tests on March 30 (and without eStim, as per Test 1).

36 Discovering a fine balance between the current (mAmp) and the frequency (Hz) produces an ideal eStim environment.
A fourth testing date was conducted on April 26, 2004, 9 AM. The test below depicts a voluntary contraction (approximately 3.5 seconds) without eStim, about one month from the first eStim test date. Between these tests, four biceps workouts were conducting using eStim during exercise with 7-seconds eStim on the positive and 0-seconds eStim on the negative. The result below shows a force of 52.7 pounds (while ignoring the spike at the end) and a greater ability to sustain a hard contraction for longer. Also note that the final biceps workout prior to this test was only at 35 mAmp at a frequency of 55 Hz (Level 2 of the “resistance” mode on the Compex system), a level of eStim that was lower than employed during previous test settings. However, the added stimulation was sufficient to produce a training effect to enhance the quality of muscular contractions and inroading during exercise. The result was an increase of approximately six pounds of static force in a four-week period.
A fifth testing date at the 135-degree position was conducted on June 6, 2004, 10:15 AM. The test below depicts a voluntary contraction (approximately 4 seconds) without eStim, 67 days from the first eStim test date and 41 days from the last test. Since the last test, three biceps workouts were conducted for two “work” sets each session. The final workout included EMS at Level II and 55 mAmp and all biceps sets involved 7-seconds eStim on the positive, 0-seconds eStim on the negative. The result of this test was a peak output of 57.8-pounds (more than the highest force output at the strongest position in the initial test!). There was an improvement/difference of 5.1 pounds force from the last test and 13.5 pounds force total from the initial test at the 135-degree position. It also should be noted that the Compex Sport system used has 5 “levels” and upward of 100 mAmp of stimulation available, and this could mean further improvement and changes in force output.

On June 4, 2004 we conducted a different type of test to determine the implications of EMS on negative-only training. We wanted to ascertain the strength result differences when EMS is applied to the eccentric portion of an exercise (dumbbell concentration curl), although the muscle would still be influenced to contract or shorten under eStim. Based on the involuntary EMS contraction that produced nearly 14-pounds of force, on page 57, we speculated that EMS force would compliment the amount of weight a person could lower. After all, if EMS can improve the amount of weight a person can lift, the same should be true during eccentric movement (as well as isometric work often performed by strength athletes to work “sticking points”). This could have an important bearing on advanced training methods since it has been suggested that greater strength gains (and muscle inroading) occur from negative-based exercise. And if even more weight could be used, to produce greater muscle inroading, then it may be possible to produce greater net gains in strength or, at least, the same measure of gains with fewer sets/less activity.

To make the experiment even more unbiased, the right-handed subject trained the right arm as usual, with no EMS. A load of 50 pounds was used, or about 35% more weight than this subject typically would employ.37 The left arm also used a 50-pound load but with EMS. To maintain consistency between arms, each negative repetition for left and right biceps lasted eight seconds, followed by a four-second delay (to coincide with the rest-pauses between eight-second EMS stimulations; Level 5 of the Compex “resistance” modality at 60 mAmp and 70 Hz frequency). Both arms exercise until it no longer was possible for the biceps to lower the weight in eight seconds and cadence decreased to seven seconds or less. Furthermore, lowering the weight meant a consistent eight seconds without allocating excess time in the zone where leverage is greatest (top half of the curl) and less time in the zone where leverage is lowest (bottom half of the curl). If consistency in movement of a repetition did not uphold, the set was terminated.

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37 Eccentric ability is about 30-40% greater than concentric ability.
The results: The subject reported that his left arm typically is one repetition short of the right arm’s ability. The left arm with eStim completed seven quality repetitions, whereas the eighth rep decreased in movement quality and took less than eight seconds to complete. The stronger right arm completed only six repetitions before breaking form and increasing in velocity by the seventh repetition. The subject indicated less intensity of effort was required to lower the weight with eStim, particularly at the top half as the weight begins to lower, which is logical since eStim produces the best effect at a point of full muscle contraction. What this could mean for long-term negative-only training is unclear, but it is evident that eStim does produce a favorable effect by increasing muscle strength and ability.

Method of Application

There are so many ways in which EMS can be applied to an exercise environment, or as a stand-alone system. Our experiments implemented EMS within a rather unique methodology, i.e., during exercise. Two examples of using EMS in an exercise environment were explained, and include a 7-second positive with eStim followed by 7-second negative without eStim, as well as incorporating eStim on negative-only exercise to increase negative force production. Another example of using EMS during exercise (with the 7-second contraction and 7-second rest setting) could be to perform a 4-second concentric without eStim, followed by a 3-second static hold with eStim, and then a 4-second negative with eStim.

If it is true that most muscle damage (and the stimulus to produce functional change) occurs during the eccentric phase of exercise, and this seems to be the consensus, then the added “agitation” of eStim during the negative phase may prove to be very conducive to maximizing gains. However, we recommend eStim users to experiment with the various settings and to cycle exercise demands by alternating sessions of eStim-only with traditional exercise and/or sporting activities to discover the best combinations.

A Closer Look at the Compex Sport System

The Compex system used in our facility is the “Sport” model (do note that Compex systems have been used by various research institutes in their study designs). This model provides four exercise settings of endurance, resistance/hypertrophy, strength, and explosive strength. All modes are influenced or can include one of five different levels or programs, with each program’s “work time” lasting as brief as 12 minutes (strength) and upward of 40 minutes (endurance). Or the reader can do as we did and ignore the duration of each program and incorporate eStim within an exercise environment. Any of these modes can range from 0 to 100 mAmp in current intensity, whereas the eStim frequency (stimulations per second) and rest between eStim contractions vary, as shown in the table below and depending on which level is chosen.

<table>
<thead>
<tr>
<th>Program</th>
<th>Contraction Frequency (Hz)</th>
<th>Contraction Time (sec.)</th>
<th>Rest Between Contractions (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endurance</td>
<td>10 to 20</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Resistance</td>
<td>50 to 70</td>
<td>7-8</td>
<td>4 to 7</td>
</tr>
<tr>
<td>Strength</td>
<td>75 to 100</td>
<td>4</td>
<td>19 to 35</td>
</tr>
<tr>
<td>Expl. Strength</td>
<td>104 to 120</td>
<td>3</td>
<td>28 to 34</td>
</tr>
</tbody>
</table>

The nature of each mode or program is relevant to the type of activity encountered and the energy system in use. For example, endurance training consists of repeated contractions followed by very short rest intervals. Consequently, a pulsating type current is delivered for 8 seconds with only 3 seconds rest between contractions. On the other end of the spectrum, sports that require explosive strength, such as sprinting or Olympic weight lifting would consist of short bursts of effort and longer recovery times to regenerate energy resources and to limit muscular fatigue and endurance adaptation characteristics. In this regard, the explosive strength program employs very short contraction times of only three seconds, a very high contraction frequency, but with plenty of rest between contractions.
Another program or mode option is the “warm-up” (potentiation). As explained in the User’s Manual: “Potentiation produces the physiological muscular phenomenon known as ‘Twitch potentiation.’ A specific system of stimulation increases the amplitude and the speed of the elementary muscle twitch response of muscle fibers, more particularly fast fibers. A potentiated muscle gains in velocity and reaches its maximum strength more easily and rapidly. This warming-up program is recommended before performing a sprint, a jump or a throw. Applied briefly just before the beginning of a competition, it offers immediate, well potentiated muscle fibers and an optional level of performance to basketball, soccer or volleyball players.” What is obvious is the value of this program prior to traditional strength training exercises, as a means of preparing the muscles to be worked without any perceived level of fatigue or loss of muscular force to lift maximal loads.

Also available on the “Sport” system is an “Active Recovery” program, whereas a low eStim frequency (1 to 9 Hz) and mAmp is chosen to increase blood flow and endorphin release, as well as to reduce spasms and increase relaxation. This mode can be used to reduce muscle soreness and lactic acid blood levels for faster recovery, while accelerating the exchanges between muscle fibers and blood for superior recovery. Although the active recovery program can be included at any time, such as the day after exercise when muscles are sore and tight, this program has a beneficial effect if included immediately after a workout as part of a cool-down.

The system is accompanied by a CD-ROM Training Planner that includes various programs and levels (over 75) for a wide variety of sports, such as football, Olympic lifting, hockey, running, wrestling, and many others. The EMS programs then can be cycled in accordance to the period of the sporting season, number of hours of training, and number of cycles for each level of eStim frequency and intensity. For example, the number of EMS sessions can be determined based on the competitive season of the athlete, an important factor since muscles have to be stimulated at different rates and to different degrees depending on whether the athlete is in a rest mode, in a maintenance mode, in a resumption of training mode, or training during competition. In regard to cyclic duration and session planning, the Training Planner helps to determine the number of weeks of EMS necessary to reach a goal, and it establishes the number of daily and/or weekly sessions to best meet this goal. The sport programs on the CD are specific in that key muscles used in a sport are those stimulated, such as quads, hamstrings and calves for hockey players. However, eStim can be implemented for other muscles outside the specific program if desired or warranted.

Features of the Compex Sport system include:

- A more “comfortable” Symmetrical BiPhasic pulse technology
- Six categories, five training levels, and 4,400 settings
- Long-lasting battery life (6-hours of continual use), with a battery level indicator and recharging adaptor
- Selected parameters “save” option
- Warm-up option prior to program implementation
- Audio and visual signal that requests an increase in current intensity to further eStim demands and a trainee’s progress (which may be disregarded)
- Electrode fault indicator to signal no electrode connected, defective or old electrode, or defective cable
- Volume and display contrast settings
- CD-Rom Training Planner
- Compact design with a carrying case
- Swiss technology
- Used and endorsed by competitive athletes, including Jerry Rice (Super Bowl Champion 1989, 1990, and 1995), Justine Henin-Hardenne (US Open & French Open Champion), Simon Lesing (5-time triathlon world champion), Hermann Maier (World Cup downhill ski champion, 1998 Olympic gold medalist, and 2003 World Cup Super G), and Patrice Cols (Mr. France and competitive bodybuilder).