Effect of Electromyostimulation Training on Muscle Strength and Sports Performance

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SUMMARY

Electromyostimulation (EMS) is a widely used methodology in applied sports science. In contrast to a typical voluntary contraction initiated by the central nervous system (e.g., in resistance training), EMS involves involuntary contractions elicited by electrical current applied to the muscle. The effectiveness of this technique has been evaluated in numerous studies examining strength and physical performance. Other reports comparing short-term (i.e., ≤3 Weeks) and long-term (i.e., ≥12 Weeks) EMS application have also reported differential results. This article will review research examining the effect of EMS on increasing strength and power, especially in sports performance.

Quick Definition and Common Use

Electromyostimulation (EMS)—electrical muscle stimulation or neuromuscular electrical stimulation—involves artificially activating the muscle with a protocol designed to minimize the discomfort associated with the stimulus. EMS has long been used to either supplement or substitute voluntary muscle activation in many rehabilitation settings, for example, for re-education of muscle action, facilitation of muscle contraction, muscle strengthening, and maintenance of muscle mass and strength during prolonged periods of immobilization (14,18,28). EMS training programs have further been used to improve muscle strength of healthy individuals (6,7), and more recently, EMS has been implemented in competitive athletes (21,33).

Typical settings of EMS exercise involve the application of electrical stimuli delivered in intermittent trains through surface electrodes positioned in proximity of the muscle motor point and preprogrammed stimulation units (Figure 1). Owing to recent advances in EMS technology, portable and relatively low-cost stimulators (300–500 U.S. dollars) can be purchased, thus are being used by a growing number of individuals. It is important to know the stimulus parameters, how contractions are triggered by EMS, and the effect of EMS on neuromuscular function to optimize its use and minimize the possible risks. After a brief overview of the methodological and physiological aspects of EMS, this article will try to answer these important questions on appropriate use of EMS in sports training:

• Does EMS improve muscle strength?
• Could EMS improve sport performance?

Recommendations and practical examples of EMS use will also be provided.

METHODOLOGICAL ASPECTS OF EMS: THE MAIN PARAMETERS

The main stimulus parameters for EMS, dictated by the physiological characteristics of nerves and muscles, include

• Frequency (number of pulses per second);
• Intensity, or current amplitude (probably the most important parameter);

Key Words:
maximal strength; jump ability; sprint ability; strength training; sport performance; neuromuscular electrical stimulation

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Pulse characteristics (shape and duration);
On/off cycle or duty cycle (to minimize the occurrence of fatigue);
Ramping (to reduce contraction abruptness and to improve comfort);
Electrode material, size, and placement.

At present, there is no general consensus on the optimal stimulus parameters, so that considerable heterogeneity exists between the different EMS studies. There is nevertheless an informal agreement on some current characteristics. For example, EMS strength training is commonly realized using biphasic symmetrical rectangular pulses lasting 100–500 microseconds and being delivered at a pulse rate of 50–100 Hz (35) to maximize the level of evoked force (muscle tension). For the same reason, current amplitude should be at the maximum level tolerated by the participants (18).

Unfortunately, a detailed and complete description of the EMS procedures (including stimulus parameters) is frequently lacking. Even if EMS parameters may facilitate the effectiveness of EMS, the practitioners agree that there is considerable subject variation in response to EMS, and optimization may relate more to the subject than to the stimulus parameters themselves (20). Similarly, Lieber and Kelly (19) suggest that the effectiveness of EMS would not depend on external controllable factors (such as electrode size or stimulation current) but rather on some intrinsic anatomic/neuromuscular characteristics.

PHYSIOLOGICAL ASPECTS OF EMS: MOTOR UNIT RECRUITMENT

During voluntary contractions, motor units are activated according to their size and threshold of recruitment, that is, small low-threshold motor units are recruited before large high-threshold ones. On the other hand, when skeletal muscles are artificially activated by EMS, the involvement of motor units is different from that underlying voluntary activation. The main argument supporting this difference is that large diameter axons are more easily excited by electrical stimuli, which would alter the activation order during EMS compared with voluntary contractions (9). However, human experiments yielded contradictory findings with some studies suggesting preferential/selective activation of fast motor units with EMS and others demonstrating minimal or no difference between the 2 contraction modalities (for an overview of these studies, see (12)).

In a recent review article, Gregory and Bickel (12) suggested that EMS-induced motor unit recruitment is nonselective/random (also see (15)), that is, muscle fibers are recruited without obvious sequencing related to their types; thus, EMS can be used to activate fast motor units (in addition to the slow ones) at relatively low force levels. The principal differences in motor unit recruitment between voluntary and stimulated contractions are summarized in Table 1.

The main consequence of such unique motor unit recruitment patterns is the exaggerated metabolic cost of an EMS contraction (36), which—compared with a voluntary action of the same intensity—provokes greater and earlier muscle fatigue (16,34). According to Vanderthommen and Duchateau (35), these differences in motor unit recruitment and thus in metabolic demand between electrically evoked and voluntary contractions constitute an argument in favor of the combination of these 2 modalities of activation in the context of sports training.

EFFECT OF EMS TRAINING ON MUSCLE STRENGTH

For unimpaired muscles, EMS training–induced strength gains are similar
A recent systematic review of EMS studies, Bax et al. (2) concluded that for impaired quadriceps (postinjury or postoperative subjects), EMS training could be more effective than voluntary training, whereas for unimpaired quadriceps (healthy subjects), the effectiveness of EMS training is generally lower compared with those of voluntary modalities. Training studies performed in the past 20 years have also demonstrated that it is possible to obtain significant improvements of muscle strength—particularly for the lower extremity muscles—in amateur and competitive athletes of all levels (Table 2).

EMS training–induced increases in muscle strength are largely mediated by neural adaptations, for example, increased muscle activation (26), particularly in the case of short-term training programs. On the other hand, EMS regimens of longer duration can elicit morphological changes in the muscle (11). In their study, Gondin et al. (11) demonstrated the time course of neuromuscular adaptations to EMS strength training. After 4 weeks of training, strength increases were accompanied by increased muscle activation, whereas the cross-sectional area of the muscle was not significantly modified. Interestingly, both neural and muscular adaptations mediated the strength improvements observed after 8 weeks of EMS, similar to the classical model proposed by Sale (30) for neuromuscular adaptations to voluntary strength training.

In summary, does EMS improve muscle strength? Yes, but results differ according to the muscle status:
- For unimpaired muscles, EMS is effective but not more than voluntary training;
- For impaired muscles, EMS can be more effective than voluntary training;
- For athletes, EMS is effective for increasing general not necessarily specific strength.

These studies are examples of the potential complementary role EMS could play in conventional strength training. The next avenue to explore is how EMS could be practically applied to various sports.

**EFFECT OF EMS TRAINING ON SPORT PERFORMANCE**

Several studies involving individual and team sport athletes have reported a significant improvement in maximal strength (as assessed using isokinetic or isometric dynamometers), and in some cases, even in anaerobic power production (vertical jump and sprint ability, as assessed using contact mats and photoelectric cells) after EMS training (Table 2). These improvements are likely to affect the field performance. However, because the stress is applied during nonspecific contractions (i.e., isometric in general), excessive use of EMS could impair motor coordination (13). Therefore, performance of complex movements requiring high levels of neuromuscular coordination can only be obtained if EMS is used in conjunction with voluntary “technical” exercise, for example, plyometrics (25).

In the study of Maffiuletti et al. (25), subelite volleyball players completed 5 sets of 10 consecutive vertical jumps immediately after EMS of the thigh and calf muscles. Jumps were completed starting from a standing position, squatting down, and then extending the knee in one continuous movement, so that the first jump of a set was a countermovement jump and the 9 others were a type of drop jump. To ensure maximal intensity, hurdles and benches (approximately 40 cm) were used.

As a practical recommendation for both individual and team sports, it is suggested that EMS training could be used to enhance muscle strength and anaerobic performance without interfering excessively with sport-specific training (4,25,27). Therefore, EMS training would be best used early in the training season (i.e., at the beginning of the preparatory training season), with 10–15 minutes of treatments, 2–3 sessions per week for 3–4 weeks (21,24,27). Electrical current intensity (in milliampere) and evoked force (as a percentage of the maximum voluntary contraction), which are strongly correlated (21), should be strictly and consistently controlled to allow EMS training intensity to be carefully quantified (22,32). It is recommended that EMS should be administered, at least for the first few training sessions (first week of a training program), by athletic trainers or strength and conditioning coaches who are familiar with the methodological and physiological aspects of EMS exercise.

The main interest of using EMS in high level sport is that this modality could be considered as a new stimulus to favor plasticity; that is, a new form of stress from a neuromuscular and metabolic point of view. EMS could be particularly useful for athletes whose performance has plateaued after several years of training and competition, but it would be supplementary to, rather than
Another interest of EMS for elite sportsmen is that a single EMS bout is usually less time consuming (12–18 minutes) than traditional volitional exercise sessions. This is extremely appealing for athletes who have a limited amount of time for conditioning (e.g., tennis players). It is not tempting to suggest that EMS could replace traditional strength training methods, but rather, EMS has to be considered as an important complement/supplement to conventional (voluntary) training programs (21).

As shown in Table 2, research in this area has examined the effect of EMS on performance enhancement of elite and subelite (noninjured) athletes in individual and team sports, such as ice hockey, basketball, volleyball, soccer, track and field, swimming, tennis, weightlifting and rugby.

As an example, Willoughby and Simpson (39) examined the effect of EMS and dynamic contractions supplemented with EMS applied during weightlifting exercises on knee extensor strength and vertical jump performance. Based on a pre- to posttraining comparison among 3 experimental groups (weight training only, EMS only, and weight training plus EMS), they suggested that supplementing dynamic contractions with EMS could be more effective than either EMS or weight training in isolation for increasing knee extensor strength and vertical jump performance. These results are compatible with previous findings by the same authors (38) who examined EMS training–induced strength gains in college basketball players.

In summary, does EMS could improve sport performance? If it is adequately combined with technical training (e.g., plyometric) and logically integrated into yearly training season, improvements could be achieved in the following capabilities:
- Jumping ability (both general and specific jumps)
- Sprinting ability (including shuttle sprints)
- Other sport performances (swimming, weightlifting, and shooting)

**Table 2**
EMS strength training in competitive sport

<table>
<thead>
<tr>
<th>Year</th>
<th>1st author</th>
<th>Sport</th>
<th>Muscle</th>
<th>Weeks (x/wk)</th>
<th>Type of EMS (settings; frequency [Hz])</th>
<th>Main findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>Delitto (8)</td>
<td>Weightlifting</td>
<td>Q</td>
<td>6 (3)</td>
<td>I-LE; 2500</td>
<td>† weightlifting</td>
</tr>
<tr>
<td>1989</td>
<td>Wolf (40)</td>
<td>Tennis</td>
<td>Q</td>
<td>3 (4)</td>
<td>C-S; 75</td>
<td>† strength, sprint, jump</td>
</tr>
<tr>
<td>1995</td>
<td>Pichon (29)</td>
<td>Swimming</td>
<td>LD</td>
<td>3 (3)</td>
<td>I-OC; 80</td>
<td>† strength, swimming</td>
</tr>
<tr>
<td>1996</td>
<td>Willoughby (38)</td>
<td>Basketball</td>
<td>BB</td>
<td>6 (3)</td>
<td>I-PC; 2500</td>
<td>† strength</td>
</tr>
<tr>
<td>1998</td>
<td>Willoughby (39)</td>
<td>Track and field</td>
<td>Q</td>
<td>6 (3)</td>
<td>C/E-LE; 2500</td>
<td>† strength, jump</td>
</tr>
<tr>
<td>2000</td>
<td>Maffiuletti (24)</td>
<td>Basketball</td>
<td>Q</td>
<td>4 (3)</td>
<td>I-LE; 100</td>
<td>† strength, jump</td>
</tr>
<tr>
<td>2002</td>
<td>Malatesta (27)</td>
<td>Volleyball</td>
<td>Q + TS</td>
<td>4 (3)</td>
<td>I-S; 105-120</td>
<td>† strength, jump</td>
</tr>
<tr>
<td>2002</td>
<td>Maffiuletti (25)</td>
<td>Volleyball</td>
<td>Q + TS</td>
<td>4 (3)</td>
<td>I-LE/SC; 120</td>
<td>† strength, jump</td>
</tr>
<tr>
<td>2005</td>
<td>Brocherie (4)</td>
<td>Ice hockey</td>
<td>Q</td>
<td>3 (3)</td>
<td>I-LE; 85</td>
<td>† strength, sprint</td>
</tr>
<tr>
<td>2007</td>
<td>Babault (1)</td>
<td>Rugby</td>
<td>Q + TS + G</td>
<td>6 (1–3)</td>
<td>I-LE/CM; 100</td>
<td>† strength, jump</td>
</tr>
<tr>
<td>2009</td>
<td>Maffiuletti (23)</td>
<td>Tennis</td>
<td>Q</td>
<td>3 (3)</td>
<td>I-LE; 85</td>
<td>† strength, sprint, jump</td>
</tr>
<tr>
<td>2010</td>
<td>Billot (3)</td>
<td>Soccer</td>
<td>Q</td>
<td>5 (3)</td>
<td>I-LE; 100</td>
<td>† strength, shoot</td>
</tr>
</tbody>
</table>

† = increased; BB = biceps brachii; C = concentric; CM = calf machine; G = gluteus; E = eccentric; I = isometric; LD = latissimus dorsi; LE = leg extension; MT = motor threshold; OC = open chain; PC = preacher curl; Q = quadriceps; S = squat; SC = standing calf; TS = triceps surae; x/wk = training sessions per week.

As shown in Table 2, research in this area has examined the effect of EMS on performance enhancement of elite and subelite (noninjured) athletes in individual and team sports, such as ice hockey, basketball, volleyball, soccer, track and field, swimming, tennis, weightlifting and rugby.

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From all the EMS studies conducted in competitive athletes, only one concentrated on long-term (12 weeks) training effects in professional rugby players (1). In this study, EMS was delivered to the knee extensor, plantar flexor, and gluteus maximus muscles of 15 experimental subjects with 10 other individuals serving as controls. After 12 weeks of carefully monitored procedures, the EMS group showed a significant increase in maximal concentric/eccentric torque, squat strength, and squat and drop jump height, compared with the controls. Based on these findings, 12 weeks of EMS training had a significant effect on muscle strength and power of elite rugby players, although their specific skills like scrumming and sprinting were not affected by EMS.

In summary, does EMS could improve sport performance? If it is adequately combined with technical training (e.g., plyometric) and logically integrated into yearly training season, improvements could be achieved in the following capabilities:
- Jumping ability (both general and specific jumps)
- Sprinting ability (including shuttle sprints)
- Other sport performances (swimming, weightlifting, and shooting)

**PROBLEM STATEMENT AND CONCLUSIONS**

Numerous studies have shown the effectiveness of EMS on healthy untrained and trained individuals including athletes. However, the significance of the observed improvements is partially compromised by factors such as...
as the pretraining status of the subjects, lack of standardization of methods, or testing protocols (31). For example, while the study by Venable et al. (37) on short-term EMS training found no effect on muscular strength, vertical jump performance, or power, a recent study by Babault et al. (1) on long-term EMS training reported significant increases in muscle strength and vertical jump ability of elite athletes. Some studies support EMS methodology and its training modalities in enhancing the contractile quality of muscle under isometric conditions (12), whereas others support EMS in combination with dynamic contractions to increase muscle strength (38). Hence, any standardization methods or testing protocol must take such factors into consideration. Such disparities in the findings warrant further systematic research that considers the possible impact of those factors on EMS effectiveness.

In conclusion, EMS has been confirmed to be an important complement to conventional strength training programs for the enhancement of athletic performance. EMS can also be applied in conjunction with sport-specific training in annual periodic training schedules (Figure 2). However, as is apparent in this brief literature review, there is heterogeneity in the magnitude of improvements between studies, depending on factors such as EMS intensity, the modality of EMS application, frequency, time course, recovery between EMS protocols, and implementation of EMS into annual periodic sports conditioning. Future research should focus on reaching a solid conclusion to ascertain its effectiveness on athletic performance.

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